Balancing Different Environmental Effects of Forest Residue Recovery in Sweden - A Stepwise Handling Procedure

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Abstract

An increased use of forest fuels is important in the reduction of our dependence on fossil fuels and in attempting to mitigate climate change. However, an increased use will also result in an intensified forestry. Recovery of forest residues (logging residues and stumps) results in a higher pressure on the forest ecosystems and adds environmental effects to those already existing in conventional forestry of stem-wood harvest.

The purpose of this study is to use current research on forest residue recovery and its environmental effects and suggest an approach to how these potential positive and negative effects can be balanced. For this task suitable environmental system analysis tools are identified, as well as relevant environmental quality objectives that are connected to the forestry operation.

The report suggests an environmental evaluation model in which environmental impact assessment is the fundamental part to balance local and regional effects, such as acidification, eutrophication and biodiversity. Life cycle assessment is integrated to consider global effects, such as greenhouse gas performance. Relevant environmental quality objectives are used as a measure where the compatibility between the recovery of forest residues and the development of the environmental objectives is assessed. The need for regional/local assessments is stressed as an important aspect regarding the applicability of the model, as well as improved preciseness of the environmental quality objectives utilised.

Keywords

Forest residue recovery, environmental quality objectives, environmental impact assessment, life cycle assessment, environmental evaluation model, balancing

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Avvägning mellan olika miljöeffekter kopplade till skogsbränsleuttag i Sverige

- En stegvis balanseringsmetod

Sammanfattning

En ökad användning av skogsbränsle leder till ett minskat beroende av fossila bränslen och minskade utsläpp av växthusgaser. Samtidigt innebär ett ökat uttag av avverkningsrester (grenar och toppar, grot, och stubbar) ett ökat tryck på skogsekosystemen och därmed risk för miljöeffekter utöver de som kan kopplas till det konventionella skogsbruket med enbart stamvedsuttag.

Syftet med denna studie är att utifrån befintlig forskning kring skogsbränsleuttag och dess miljöeffekter föreslå ett tillvägagångssätt om hur avvägningar mellan dessa positiva och negativa effekter kan göras. För detta ändamål identifieras lämpliga miljösystemanalytiska verktyg liksom relevanta miljökvalitetsmål som tydligt kopplar till uttag av skogsbränslen.

I rapporten föreslås en miljöbedömningsmodell där miljökonsekvensbeskrivning utgör grunden för att hantera lokala och regionala effekter som förändrad försurning, övergödning och biodiversitet. Livscykelanalys integreras för att hantera förändrade växthusgasutsläpp som ger globala effekter. Miljökvalitetsmålen används som måttstock i miljöbedömningsmodellen där avstånd till måluppfyllelse och nuvarande trend är centrala parametrar. En viktig aspekt som identifierats är behovet av ökade regionala/lokala miljöbedömningar och data/statistik för att öka den praktiska tillämpbarheten av modellen, liksom en högre detaljeringsnivå för de miljökvalitetsmål som utnyttjas i modellen och som direkt kopplar till skogsbränsleuttag.

Nyckelord

Skogsbränsleuttag, miljökvalitetsmål, miljökonsekvensbeskrivning, livscykelanalys, miljöbedömningsmodell, avvägning

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Preface

This report was conducted within the research project "Sustainability criteria for bioenergy from a system perspective", with funds from the Swedish Energy Agency, which are gratefully acknowledged.

Lund, September 2014

The authors

Contents

1 Introduction

The use of forest fuels is a further alternative to decreasing our dependence on fossil fuels which is necessary to counteract the negative development of climate change. To realize the vision of zero net emissions of greenhouse gases by the year 2050, Sweden must have a sustainable and resource-efficient energy supply. One of the stated action plans that frame the transition crucial to fulfil the vision, promotes the use of renewable energy sources. The supply of forest biomass is plentiful in Sweden where about 55 % of the total land area is productive forest land. Thus, the clear link between the use of renewable energy in society and the extensive forests in the land has led to a heightened interest in an increased recovery of forest residues. This concerns primarily logging residues (tops and branches) but recently also the use of stumps has come into play. Removal of stumps means a further intensification of forestry that already exerts an increased pressure on the forest ecosystem as a consequence of logging residue recovery. When forest fuels are taken to substitute fossil fuels, climate benefits can be expected by the reduction of greenhouse gas emissions. This affects the development of the Swedish environmental quality objective of climate change positively. However, there are also environmental quality objectives which could be affected negatively by environmental effects connected to the forestry operation. To acquire a sustainable energy supply in which forest fuel is a component, environmental impacts of the energy source must be kept low and within acceptable limits. This requires functional possibilities of handling the environmental effects that arise as a consequence of the recovery of forest residues.

1.1 Purpose and Scope

The purpose of this study is to use existing research on the environmental effects of forest residue recovery and suggest an approach to how the effects can be balanced, based on the possibilities of handling their occurrence and potential impact. The intention is to present an environmental evaluation model that can highlight the environmental effects of the recovery that should receive preferential attention. For this task suitable environmental systems analysis tools should be identified and a connection established between the environmental effects and relevant environmental quality objectives. Previous studies have linked these types of environmental effects to environmental quality objectives but information about what the objectives actually comprise that can be applied on this type of forestry operation is not fully presented. This report aims to provide this type of information and give suggestions on how the environmental quality objectives can be used in an environmental evaluation of forest residue recovery, together with environmental systems analysis tools found suitable for the purpose.

1.2 Outline of the Report

Chapter 2 presents a summary of the environmental effects of forest residue recovery based on current scientific literature. The structure of the Swedish environmental quality objectives is described and how its components might be used in an environmental evaluation of the specific forestry operation is briefly discussed. The environmental effects are connected to relevant environmental quality objectives via general environmental impact categories. Chapter 3 begins with a section about tools for environmental systems analysis. Several tools are mentioned and discussed in regard to their applicability to environmental evaluations of forest residue recovery. Properties of those tools found most suitable for the purpose are adopted and used as building blocks in a suggestion for an environmental evaluation model directed at the environmental effects of the recovery. Chapter 4 is devoted to a case study with the intention to apply the suggested environmental evaluation model and collect data to identify indicators that can be useful for the model. The case study also implies a mapping of existing information that, conversely, can be used to discuss a potential lack of information, which if it were accessible, would make the environmental evaluation model more functional. Finally, chapter 5 discusses the findings in the report with focus on the environmental evaluation model presented.

2 Environmental Effects of Forest Residue Recovery and Environmental Quality Objectives

Much of the content in this report is based on two major sources. The first is a synthesis by de Jong et al. (2012) that brings together different research results on the environmental effects of forest residue recovery (logging residues and stumps). The second main source includes assessments of the Swedish environmental quality objectives. Based on the environmental effects connected to the forestry operation, de Jong et al. (2012) relate increased recovery scenarios of different magnitude to relevant environmental quality objectives (objectives primarily affected by the recovery) to give a measure of the potential of recovery without affecting the achievements of the objectives negatively. An additional source, is a modelling study by Belyazid et al. (2010) who did something similar by evaluating the environmental effects in different scenarios of forest residue recovery in relation to relevant environmental quality objectives. The assessments of the environmental quality objectives are mainly based on the 2012 in-depth evaluation (SEPA, 2012a) and regional follow-up assessments (Miljömålsportalen, 2013). These evaluations can be found on the web page "the Environmental Objectives Portal" (miljomal.se) which gathers information on the environmental objectives. Those objectives considered most relevant for forest residue recovery are related to the specific forestry operation and summarized to convey information about their statuses and developments (see section 2.3).

2.1 Environmental Effects of Forest Residue Recovery

The definition and the use of the terms environmental effect and environmental impact differ in the literature. In this report an environmental effect means a change in a given state in the environment. For example, the removal of nutrients is an environmental effect. The reduced number of nutrients might in turn have impacts on different functions and processes in the environment, e.g. impacts on the environmental problem of acidification. In that sense the effect is the actual change, whereas the impact is the consequences the effect may lead to in the environment.

Common environmental effects of forest residue recovery which are presented by de Jong et al. (2012) are summarized in Table 1. The effects are linked to environmental impact categories and their corresponding potential geographical magnitudes are given. The environmental effect of mercury methylation, which is likely to increase due to increased soil disturbances caused by driving and stump recovery, is classed as part of biodiversity since a separate category of toxic compounds is not included in this report. A general connection is also made between the environmental impact categories and the relevant environmental quality objectives. The forest production objective is not an environmental quality objective but central in the Swedish forestry policy and has similarities to other environmental objectives e.g. *Sustainable Forests* that also cover subjects such as preserving the production ability of the forest land by a sustainable use etc.

Table 1. Overview of environmental effects that can arise as a consequence of logging residue and stump recovery (based on de Jong et al. 2012)

Logging Residue (tops and branches) and Stump Recovery							
Environmental Impact Category	Climate change		Acidification	Eutrophication	Biodiversity		Forest Productivity
Geographical Aspects	Global		Regional, Local	Regional, Local	Local	Regional, Local	Local
Environmental Effects	Alteration of the soil carbon pool	Methane and nitrous oxide emissions	Nutrient removal	Nutrient leaching	Loss of harvest residues with functions such as substrate and habitat	Hg methylation	Decreased forest growth
Description	Soil disturbances such as driving damages and compaction (likely to increase when less logging residue material and stumps have been left to serve as a protective layer and to enhance the bearing capacity of soils).	Driving damages in moisture-rich areas, where the soil bearing capacity is low, might have impacts on these types of emissions. Soil compaction can lead to poor oxygen supply and anaerobic conditions which favour the formation of these gases.	Recovery of nutrient-rich logging residues. Greatly increased by logging residues recovery compared with conventional stem wood recovery. Effect of stump recovery much less than that of logging residues.	Logging residues recovery and ash recycling should in theory not imply an increased risk of nitrogen leaching, which means that their contribution to eutrophication should in the worst case still be moderate.	The removal of logging residues and stumps that might function as substrate and provide habitats for different species. Stumps from felling activities make up a large proportion of the annual production of dead hardwood in the forests.	Soil disturbances due to driving damages and stump recovery.	Decreased growth as an impact of logging residues recovery. Observed over a few decades. No permanent impact on the production ability of the forest land.
	Stump recovery with current technology means increased disturbances.	Increased intensification of recovery might lead to an increased need for nutrient compensation of nitrogen. Nitrogen fertilization can give rise to emissions of nitrous oxides.	Areas suffering from acidification caused by air pollution belong to those areas where the acidifying risks posed by the forestry are the greatest.	Logging residues recovery can even give a relief of nitrogen in certain areas with high nitrogen loads (southern Sweden).	General conservation considerations – lack of/inadequate etc.		Repetitive forest residue recoveries at regeneration felling, clearance, and thinning, expected to restrain the forest production during parts of the rotation period in a stand.
				How ground disturbances as a consequence of stump recovery and potential damages caused by driving of forestry machines affect the leaching during the clearing phase is not clear.			Dependent on recovery intensity and nutrient content of harvested biomass.
Connection to environmental quality objectives accounted for in the report	Reduced Climate Impact		Natural Acidification Only Sustainable Forests A Rich Diversity of Plant and Animal Life	Zero Eutrophication Sustainable Forests A Rich Diversity of Plant and Animal Life	A Rich Diversity of Plant and Animal Life Sustainable Forests		Forest Production Objective

De Jong et al. (2012) assess that there is a clear potential for an increased recovery of forest residues without affecting the environmental quality objectives negatively. However, the assessment is dependent on some requirements that need to be met to make the activity sustainable from this point of view (see Table 2). The requirements comprise how and where forest residues are recovered as well as how current forestry functions. The environmental consideration needs to operate as intended, with a minimum standard according to law. In certain cases landscape values call for stricter practices, providing guide-lines that should be followed. The assessment also builds on the fact that the recovery of logging residues and stumps does not have negative impacts on the environmental consideration. The requirements are central to the work in this report and are referred to in several contexts.

Table 2. The requirements by de Jong et al. (2012) that need to be fulfilled to make a scenario of an increased recovery of forest residues compatible with the environmental quality objectives accounted for in the study

Tree Types	Ash Recycling	Environmental Consideration	Other Restrictions
• Primarily logging residues and stumps from coniferous trees are harvested. • Both residues from broad-leaved and valuable broad-leaved trees should be completely avoided in coniferous-dominated stands. • Only the dominating tree type should be recovered in broad-leaved-dominated stands (should generally be more restrictive with recovery of broad-leaved trees and it is important that regional assessments are made, for instance on species occurrence).	• Ash recycling with ash of good quality is done to compensate for nutrient losses due to the increased recovery. • Ash recycling is practiced where it is needed and adjusted to the stand type.	• The environmental consideration needs to function as intended, i.e. at least according to law and in some cases up to the advisory level (a higher level than the legal stipulation).	• Without nitrogen compensation logging residue recovery should be limited in connection to thinning, thus avoiding too many negative effects on the production. • Increased logging residue and stump recovery involves more traffic in cutting areas with risk of increased soil damage. Restrict the recovery to areas with good bearing capacities to reduce the risk of causing damage.

According to de Jong et al. (2012) the requirements are realistic even if the forestry does not fulfil all parts. Two examples are mentioned. The environmental consideration is not met everywhere according to the law and ash recycling is currently performed to a very limited extent. If Table 1 gives a first presentation of the environmental effects of forest residue recovery, the requirements in Table 2 highlight important aspects that need to be fulfilled to reduce the risk of negative environmental impact. The environmental effects and their environmental impact categories are presented in more detail in section 2.3. This section also discusses the connections between the environmental effects and the relevant environmental quality objectives. Since the environmental quality objectives have a central role in the work in this report it is necessary to give some information about the environmental objectives system which is a key player in the Swedish environmental policy.

2.2 Environmental Quality Objectives

2.2.1 The Environmental Objectives System

The Swedish environmental objectives system is currently based on one *generational goal*, 16 *environmental quality objectives* and 18 *milestone targets*. The generational goal is the overall goal of Swedish environmental policy, with the intention to hand over a society to the next generation in which the big environmental problems in Sweden are solved. This is to be achieved without exporting environmental and health problems to other countries. The goal serves as a kind of guiding light that specifies which changes must be made and their directions in order to achieve the vision within one generation i.e. by year 2020. This concerns all environmental actions at every level in society (Miljömålsportalen, 2012). The environmental quality objectives describe the conditions of the Swedish environment that should be reached by the environmental actions and met by the year 2020 (2050 for Reduced Climate Impact). The earlier interim targets have now been replaced by 18 milestone targets which are components of the strategies needed to solve the environmental problems. In that way they serve as steps on the way to achieving the ultimate goal, defined and described by the environmental quality objectives and the generational goal. The environmental quality objectives should be followed up regularly whereby the Government is supplied with annual reports and an in-depth evaluation report that is compiled once every parliamentary term. The evaluations are performed by several government agencies each responsible for their specific objectives (Miljömålsportalen, 2012; SEPA, 2012b).

2.2.2 Components of the Environmental Quality Objectives

This section introduces the components of the environmental quality objectives and discusses how they can be applied to forest residue recovery and used in an evaluation of the environmental effects that arise as a consequence of the forestry operation. The components considered as relevant are seen in Table 3, which also gives a short summary of how the components can be useful.

Table 3. An overview of the relevant components in the environmental quality objectives and how they can be used as part of an environmental assessment of forest residue recovery

Specifications	Indicators	Policy instruments
Show which parts of the environmental quality objective's meanings that are affected. Which environmental conditions that can be (negatively) impacted by the activity.	These show how the environmental effects can be covered and monitored. The indicators belonging to each of the environmental quality objectives that make the impacts of the environmental effects possible to follow up (a measure of how well the environmental effects can be covered by the objectives).	Ways of coping with the environmental effects and how these will affect the practicability of potential measures. Give prerequisites and measures to mitigate the environmental effects.

Figure 1 shows an interpretation of the environmental quality objectives system where an aggregated form of environmental effects of forest residue recovery is inserted and linked to the relevant components. The flowchart is intended to give a structural overview of the components that make up the system and how they relate internally, as well to the evaluation methodology. Note that the flowchart is an interpretation and freely developed by the authors. A more in-depth description of the components and the basis for evaluation follows below.

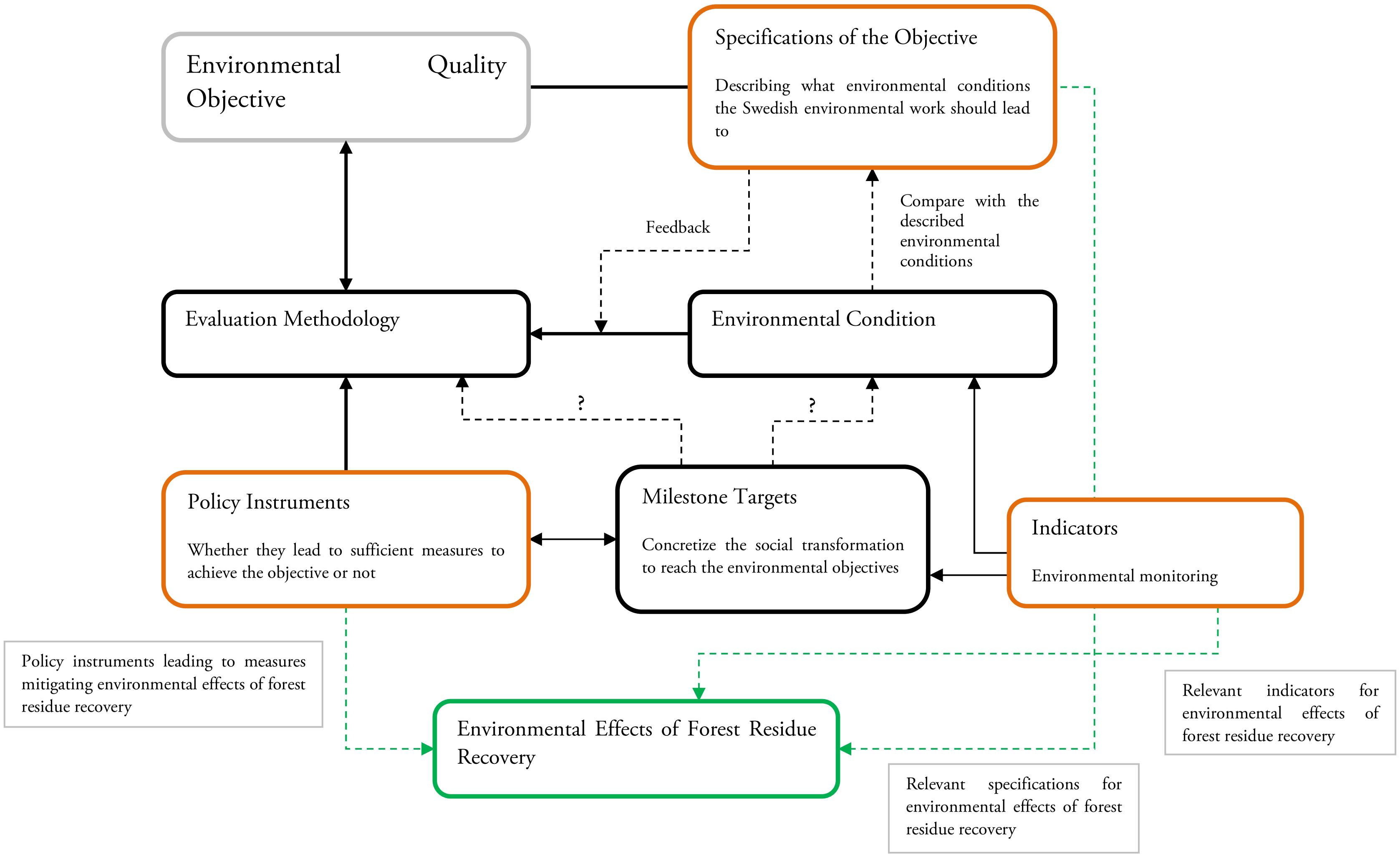

Figure 1. The flowchart shows the components of the environmental quality objectives and presents an interpretation of how they connect to the evaluation methodology. The activity of forest residue recovery is included to show how its environmental effects can be evaluated by the components of the objectives system.

Specifications

The specifications serve to clarify and describe the meanings of the environmental quality objectives and what environmental conditions the environmental work should lead to (SEPA, 2011a). In that aspect they make up the basis of how the environmental quality objectives should be interpreted. They are also criteria in the evaluation of the prospect of fulfilling the objectives and should be guiding components of the environmental work (Gov., 2012).

Those specifications in which a counteracting scenario due to forest residue recovery can be recognized might work as a general indicator of compatibility between the objectives and the activity in question. How and where the recovery of forest residues has the potential to affect the environmental conditions negatively can thus be correlated to the relevant specifications (see Figure 1). A counteracting scenario arises if environmental effects of the recovery have negative impacts on the environmental conditions which are an aspect related to the environmental conditions described by the specifications. The specifications for each of the environmental quality objectives that might be of relevance for the environmental effects of forest residue recovery give indications concerning which parts of the environmental conditions that are potentially counteracted by the specific activity. There are also situations where the environmental conditions described by specifications can be expected to be affected positively (in addition to positive climate change effects from fossil fuel replacement).

Indicators

Every environmental quality objective has a set of indicators that form the basis of the environmental monitoring of the environmental conditions that are described by the specifications. The results of the environmental conditions can then be related to the specifications, which will give an estimation of how the status of the environment is developing in relation to the intention of the environmental quality objectives.

Those indicators relevant for the environmental impacts caused by environmental effects of forest residue recovery can be used to relate the activity and its impact on the environmental conditions in accordance with the environmental quality objectives (seeFigure 1). This can give an indication of which environmental impacts comprise the current indicators (giving a range) and say something about the extent to which a certain activity is covered by the objectives' "quantitative" approach (indicators giving information in numbers). This gives an estimation of how "efficiently" the environmental impacts of forest residue recovery can be covered by the environmental monitoring as part of the environmental quality objectives. If the supply of relevant indicators is poor this might result in environmental impacts being overlooked, leading to underestimations of the activity's environmental influence as a potential consequence. This may also be a problem with indicators which are too unspecific. A supply of relevant indicators is important to give incentives to follow up the environmental effects and their environmental impacts. By identifying relevant indicators and specifications of the environmental quality objectives, a limit can be set whereby those parts of the objectives being affected by the environmental effects of forest residue recovery are highlighted.

Policy Instruments

The aim of policy instruments is that they should lead to measures which in turn will result in improvements in the environmental conditions and lead to the subsequent fulfilment of the environmental quality objectives. The policy instruments' ability to create prerequisites to achieve the objectives is an important aspect in the evaluation methodology and is further discussed below.

While the specifications and indicators relate the environmental impacts of forest residue recovery to the environmental conditions described by the environmental quality objectives, the part concerning policy instruments shows the prerequisites of handling the potential negative environmental effects. Relevant specifications and indicators that highlight those parts of the environmental quality objectives of concern for forest residue recovery also constitute an outline within which relevant policy instruments and measures can be accounted for (see Figure 1). Therefore, a mapping of the current policy instruments linked to the relevant environmental quality objectives is a relevant aspect. The aim is to find those policy instruments that cover areas to which environmental effects of forest residue recovery are applicable. Relevant policy instruments leading to significant measures are thought to have positive effects on the environmental impacts caused by forest residue recovery. Policy instruments constitute ways to cope with the environmental effects and are an important aspect when the potential of different measures is investigated. There are two inofficial categories of policy instruments concerning environmental effects of forest residue recovery. The policy instruments can be divided into those that aim at the actual environmental effects and those that are concerned with area protection, which limit the area where forestry and thus recovery of forest residues can be practiced.

Milestone Targets

Currently just a few milestone targets have been introduced and none of them is directly practicable to apply on forestry and forest residue recovery. However, there are milestone targets in the category biological diversity that do concern forestry as an industry among others, in that it utilizes ecosystem services with impacts on the forest ecosystem. The primary targets are those concerning ecosystem services and their resilience, and threatened species and nature types. Since the meanings of the two above-mentioned milestone targets are broad and do not include forest residue recovery specifically, this is a part of the structure of the environmental quality objectives left aside for the time being. The two question marks on the lines leading from the Milestone Targets box to the Evaluation Methodology and Environmental Condition boxes in Figure 1, indicate that the milestone targets are new components of the system and have not yet been used in the evaluation of the environmental quality objectives at the time of writing.

A New Basis for Evaluation

The environmental objectives system has been in a transition state and has experienced some restructuring over recent years. The changed system is now more or less established as the counties concerned have adopted the new guidelines. The changes have led to a new basis for evaluation which is used to assess the status of the environmental quality objectives. The current evaluation is based on two questions: (i) whether the conditions of the environment described by the environmental quality objective can be achieved by year 2020 (2050 for *Reduced Climate Impact*) and (ii) whether there are prerequisites making it possible to achieve the environmental quality objective in terms of decreed by national and/or international policy instruments, that will result in adequate measures being implemented before 2020/2050, to reach the described conditions at a later stage. The new version is stricter than its predecessor in the sense that what matters are the actual prerequisites to achieve the objectives by the policy instruments decided. Previously the potential of creating prerequisites was also included in the evaluation in terms of the probability that a decision on adequate policy instruments before year 2020 can be reached. The timescale has also been made more flexible, with no strictly set date by which the described environmental conditions should be achieved. This accounts for possible time lags before the effects of measures can be observed in the environment. What matters is the time of creating prerequisites via policy instruments where adequate measures are implemented before 2020, which will lead to the achievement of the environmental state described by the environmental quality objective (SEPA, 2012a).

In the new environmental objectives system the specifications have a prominent role. This is partly due to the expiration and phase-out of the interim targets. The current number of milestone targets is low compared to the number of interim targets of which the last expired in 2010. The 2011 evaluation of the environmental quality objectives was the first based on the new specifications (proposed specifications) and the basis for the evaluation. It should thus be considered as a part of the development of the new system. Hence, this evaluation differed from earlier evaluations of the environmental quality objectives and cannot be used for comparisons with previous years (SEPA, 2011a; Gov., 2010). In the in-depth and annual follow-up evaluations of 2012 the evaluation methodology was being continuingly developed, also leading to a slightly different evaluation compared to 2011. The difference was the consideration of the current prerequisites to achieve the objectives by already decided policy instruments. In 2011 also the potential for creating prerequisites was included in the evaluation in terms of the probability to come to decisions on adequate policy instruments before 2020 (SEPA, 2012a).

Background to the Changes and the Set-Up of the System

The transition in the environmental objectives system was a result of the approval of the changes by the Swedish parliament and the government in 2010. The Environmental Objectives Council (Miljömålsrådet) has been disbanded. The institution responsible for coordinating the work of following up and evaluating the environmental condition is now Naturvårdsverket (Swedish Environmental Protection Agency). The All Party Committee on Environmental Objectives (Miljömålsberedningen), an advisory group established in 2010, has been given the aasignement to present environmental strategies to the government in the form of milestone targets, policy instruments and measures etc. (SEPA, 2011a).

In the government bill *Svenska miljömål – för ett effektivare miljöarbete (prop. 2009/10:155)*, the government explained that the current specifications of the environmental quality objectives needed revision. Particularly the specifications of the objectives concerning types of environments and ecosystems were considered to be not satisfactorily functional. The Swedish Environmental Protection Agency (SEPA) was given the task to systematically review the current specifications and present a set of revised specifications. SEPA presented its proposal for new specifications in the follow-up report *Miljömålen på ny grund* (2011). Several of the specifications suggested were relatively comprehensive, which was considered necessary in order to provide satisfactory guide-lines for the environmental work towards the achievement of the environmental quality objectives and to function as criteria in the evaluation (SEPA, 2011a). When the specifications were later processed and finally formulated by the government the basic intentions were that they should describe an environmental condition and, not be action-oriented, not too comprehensive and as far as possible similarly formulated (Gov., 2012). This means that while the suggested specifications could include points aiming at social transformation and various actions, the final and now adopted specifications are not very "specific" in their formulation. Directive properties were instead to come from the milestone targets, which serve to describe the social transformation required to achieve the environmental quality objectives. This was also to highlight the need of changes within the society in order to fulfil the environmental objectives (Miljömålsberedningen, 2011). The specifications were presented in their final version in the report *Svenska miljömål – preciseringar av miljökvalitetsmålen och en första uppsättning etappmål* (2012). The government bill also suggested the fundamentals of the new basis for evaluation.

2.3 Environmental Impact Categories

The environmental impacts initiated by the environmental effects of forest residue recovery can be divided into five main impact categories, namely, forest productivity, climate change, acidification, eutrophication and biodiversity (see Figure 2). The environmental effects and their impacts on these categories are presented below. Each of the relevant environmental quality objectives is shown as part of the impact category to which it has the strongest connection. Note that the forest production objective is not an environmental quality objective and that the impact category of forest productivity is presented as part of the section on climate change (see section 2.3.1). The choice of relevant objectives is based on those described set forth presented by de Jong et al. (2012), with the exception of *A Non-Toxic Environment* which is not included in this report. Relevant specifications and indicators for forest residue recovery are presented for each of the environmental quality objectives (see Table 4 to 8). These are also summarized at the end of this chapter. Unless stated in other references, the text about environmental effects in this chapter is based on information from the synthesis by de Jong et al. (2012).

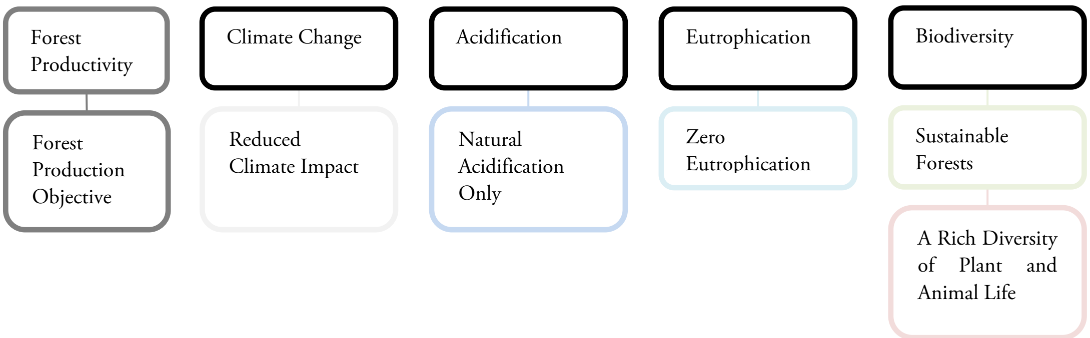

Figure 2. An overview that shows of which environmental impact category the environmental quality objectives, presented in section 2.3.1, are a part.

2.3.1 Climate Change and Forest Productivity

Climate Change

The input-output energy of forest fuels is generally very beneficial, over and above the reductions of GHG emissions when fossil fuels are replaced. Important parameters that greatly affect the climate benefits are how the carbon balance is altered, locally and over time, of different recovery practices and nutrient compensation. Emissions of nitrous oxide and methane might also have some influence as two potent GHGs. Forest production has a great influence on the long-term carbon balance. Production can be somewhat negatively affected by the recovery of logging residues, while stump recovery does not seem to give any notable effects. Increased soil disturbance due to stump recovery, in tandem with increased damage due to the transport of heavy forestry machinery, can stimulate decomposition and increase the carbon losses during the clearing phase. How the ground vegetation develops during this period is also an aspect that affects the carbon balance. An increased decomposition during the clearing phase leads to a greater liberation of nutrients, which in turn might stimulate growth, resulting in an increased litter formation and build-up of the soil carbon storage. This highlights why the forestry's GHG balance needs to be evaluated during at least one rotation period so that all relevant stages can be included. LCAs (life cycle assessment) of the GHG balance for the whole forest fuel chain at the stand level show that the time perspective has a significant impact on the total climate performance. Decomposition of stumps is slower than that of logging residues. Therefore it takes longer to compensate for the CO_2 emissions from the incineration of stumps compared to that of logging residues in relation to their respective time of natural decomposition. This is the reason why especially stumps do not give an immediate positive climate effect if the evaluation is based on a stand perspective (the trees that can take up the released CO_2 are removed in the stand by the harvest itself). The limited knowledge of indirect effects from increased soil disturbances as a consequence of stump recovery leads to uncertainties in LCA analyses. What LCA studies do show is that the energy output of logging residues and stumps is large compared with the input energy. Model simulations of carbon balances in which the stand level is scaled up to landscape level (representing all stand ages) show that increased recoveries of forest residues give a positive effect on the carbon balance already in the short-term. In the case of an intensified forest production such as the practice of fertilization adapted to stand-demand, more nutrients are added to the forest stands, especially nitrogen, which is the most growth-limiting nutrient in Swedish forests. This entails a risk of increased amounts of nitrous oxide emissions. If their magnitude turns out to be significant, it might counteract the positive climate effects that an increased forest production could give.

The number of publications and data that describe the flows of GHGs after different forest operations on different types of forest land, at different development stages, are to date limited. Thus, more knowledge is needed of the GHG balance with increased intensities of harvesting and production. This concerns all three dominant GHGs, namely, carbon dioxide, methane and nitrous oxide. If this information could be improved it would facilitate the performance of LCAs in increased detail and a more thorough comparison of different energy sources from a climate perspective. The basic data are also important when evaluations are to be performed according to sustainability criteria in standardization systems developed or under development.

Forest Production

An additional way to increase the recovery of forest residues, apart from harvesting existing logging residues and stumps, is to increase the actual forest production. Either way means an escalated practice and, with intensified forestry comes the risk of affecting some of the Swedish environmental quality objectives negatively, where the objective *Sustainable Forests* plays a salient role (de Jong, 2012). In contrast, forest-based impact assessments show that an increased future recovery is possible even when the volumes of forest residues, which should be left in the forests, due to technical, economic and environmental restrictions, are subtracted from the total volumes used in the studies. The assessments also show that the increased recoveries may be feasible without counteracting or hindering the achievement of relevant environmental quality objectives (SFA, 2008). An increased forest production could even help to fulfil other environmental objectives such as *Reduced Climate Impact* (de Jong, 2012). Climate change is considered as the topic that generally should be accounted for in all scenarios and problem descriptions of future forestry with an increased forest residue recovery.

Some studies show growth reductions after the recovery of logging residues. However, results are not uniform and in some cases no changes have been observed. The growth reductions might be compensated for by an increased plant survival, but on this point opinions vary. Some studies have shown possible compensations via vegetation control and/or fertilization as well as ash recycling. The recovery of stumps seems to reduce root rot attacks of the next forest generation. The practice might also reduce the need for soil scarification (SFA, 2009). Other beneficial outcomes are an improved plant establishment and a possible increased forest production, but this requires that smaller roots are left and that all stumps infected with root rot are removed. There are also some risks connected with stump recovery, for instance, the work of regenerating the forest may be delayed. Another aspect is the increased risk of soil compaction, damage due to traffic of forestry machines and other ground disturbances. It has been shown that ash recycling has various impacts on forest production. Thus, it is necessary to map out in which soils a risk of decreased forest production can be expected as a consequence of ash recycling, but also where one might encounter increases (de Jong, 2012).

It has been pointed out that in the continuing research process, analyses of individual studies need to be stepped up to comprise analyses of more extensive material in order to reach a uniform answer as to whether forest production is affected, and, if so, to what degree. Long-term field experiments should be continued, making it possible to study long-term effects of one or several recoveries. This is also of concern regarding ash recycling. There is also the question of whether ash recycling can be combined with nitrogen fertilization. Long-term experiments are also important in order to avoid an ultimate dependence on modelling studies. The experiments also supply modelling studies with in-data. Another aspect is the duration of growth effects in different soil types, which is important information for future production forecasts, carbon balances and LCAs.

Reduced Climate Impact

"In accordance with the UN Framework Convention on Climate Change, concentrations of greenhouse gases in the atmosphere must be stabilized at a level that will prevent dangerous anthropogenic interference with the climate system. This goal must be achieved in such a way and at such a pace that biological diversity is preserved, food production is assured and other goals of sustainable development are not jeopardized. Sweden, together with other countries, must assume responsibility for achieving this global objective."

Perhaps the most apparent relation is that biofuels can replace fossil fuels and thus reduce the emissions of fossil CO_2. Forest residue recovery might also affect GHG emissions from forest land. Primarily this concerns CO_2 emissions caused by alterations in the soil carbon balance. Growing forests bind CO_2, thus functioning as a carbon sink. Operations that reduce this binding instead turn the forest into a carbon source. Activities such as forest residue recovery, nitrogen fertilization, and ash recycling, are actions that can have impacts on the carbon balance by binding, turnover and long-term storage of carbon. The use of fertilizers and ash can give rise to emissions of nitrous oxides (de Jong, 2012). Another aspect is that forest products can be used for different purposes with different impacts on the carbon balance (Belyazid, 2010).

Table 4. Relevant specifications and indicators of Reduced Climate Impact

Relevant Specifications
Temperature
"The increase in global average temperature will be limited to no more than 2 °C above pre-industrial levels. Sweden will press internationally for global efforts to be directed towards achieving this target."
Concentration
"Sweden's climate policy will be designed to contribute to ensuring that the concentration of greenhouse gases in the atmosphere is stabilised in the long term at no more than 400 parts per million of carbon dioxide equivalent (ppmv CO2 equivalent)."
Relevant Indicators
Emissions with impact on the greenhouse effect

Forestry Production Objective

The Swedish forestry policy has two objectives that are equally important. One is a production objective and the other is an environmental objective. The latter means that the natural productive capacity of forest land should be preserved. Biological diversity and genetic variation in forests are two aspects that should be secured. Much of the content in the environmental objectives is covered by the environmental objective *Sustainable Forests*. The production objective means that forestry and forest land should produce high and sustainable yields by efficient and responsible management (Gov., 2004).

Connections between forest residue recovery and the forestry production objective concern growth reductions as an impact of the removal of nutrient-rich logging residues and other effects due to this activity. Potential growth reductions might call for compensatory measures such as nitrogen fertilization. There are differences among the various types of felling operations, and the largest production losses are assessed to occur in residue recovery in connection with thinning.

2.3.2 Acidification

Growing trees give rise to a continuous acidification process by taking up base cations (nutrients). In exchange a hydrogen ion (H^+) is released to the soil for every base cation to maintain the charge balance (Belyazid, 2010). In conventional forestry of stem-wood recovery, logging residues and stumps are left on the clear-cut ground after felling. When the residues decompose the base cations will be liberated and returned to the soil and there counteract the acidifying process that occurred during growth. However, the recovery of forest residues leads to an augmented loss of nutrients as base cations contained in the harvest residues are removed. This results in a reduced base saturation of the soil with loss in buffering capacity and consequences such as an increased soil acidification and eventually increased acidification of surface water. Compared to stem-wood, the concentration of nutrients is high in logging residues and needles. Stumps have a significantly lower nutrient content but their recovery will nevertheless increase the effect of this acidifying impact.

The scenario of nutrient removal can be counteracted by nutrient compensation in the form of ash recycling. Potential environmental risks with this procedure are the possible addition of heavy metals, of organic, environmentally toxic compounds, and of radiocesium (Chernobyl). Recycled ash composed only of incinerated forest residues should not give a net addition of heavy metals and cesium to the forest land, if it has not become contaminated. Soil damage such as track formation and water-logging caused by felling activities and other forestry operations are likely to increase the risk of transportation and methylation of mercury. Mercury in this organic form leads to a greater accessibility of the toxic metal into the food chain, especially in aquatic environments. Stump recovery is assessed as an activity which risks increasing this process. Methylation of mercury and contaminated ash are environmental effects, both relevant to the environmental quality objective *A Non-Toxic Environment*. However, this objective is not included and is treated separately in this report. Methylation of mercury is relevant for all forestry operations that give rise to soil disturbance and water-logging which may favour anaerobic conditions.

The knowledge of the effects of the recovery of logging residues and ash recycling on soil and soil water is plentiful. This knowledge comes from field experiments, modelling and regional mass balances of chemical elements. However, still lacking is an adequate knowledge of the interplay between soil and surface water due to logging residue recovery and nutrient compensation. This knowledge needs to be increased and concerns practically all substances that are transported between soil and water. The comprehensiveness of the issue makes it relevant for several environmental quality objectives. The effects that ash recycling might have on soil and water quality are not fully known and are therefore being studied. Studies are also being performed to map the "need" of nutrient compensation in quantitative terms at different locations in order to optimize the dosage. Stump recovery and fertilization adapted to stand-demand are new features in forestry and the production of fuels, and therefore an increased knowledge of their environmental effects is required. Knowledge of ash requirements in practical forestry, to make it possible to optimize the dose based on a satisfactory balance between intended effects and unwanted effects is also essential.

Natural Acidification Only

"The acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water. In addition, deposition of acidifying substances must not increase the rate of corrosion of technical materials located in the ground, water main systems, archaeological objects and rock carvings."

The increased removal of base cations as a consequence of an increased recovery of forest residues affects the achievement of the environmental quality objective negatively. The recovery of logging residues has a significant impact on this removal compared with conventional stem-wood recovery. For this reason compensatory measures should be taken when additional removals, beyond that of only stem-wood, are performed. Primary targets are the areas sensitive to acidification found in southern Sweden. Predominantly this concerns ash recycling but biomass extraction should also be adapted to the status of the acidified areas. Ash recycling makes up for the loss of base cations. As long as the recovery does not exceed the potential for recycling sufficient amounts of ash to compensate for nutrient losses the environmental quality objective is not necessarily affected negatively. Currently ash recycling is practiced to a very limited extent compared to the recovery of logging residues. In 2009 ash was spread on an area corresponding to 17 percent (11,600 hectares) of the area where logging residues were recovered (SFA, 2011). In 2010 this figure was 12 percent. The acidifying impact caused by forestry is expected to increase in the future. There are no policy instruments that regulate the practice of ash recycling today. An increased recovery of forest residues is a key player concerning measures intended to decrease the emissions of GHGs. In practice it is difficult to completely compensate for the additional acidification caused by increased recovery. It is not clear either what the acidifying effects will be from future recovery of logging residues or the effects of ash recycling. There is a risk that the positive trend of decreased acidifying deposition might be counteracted by an increased logging residue recovery, intensive cultivation and increased nitrogen fertilization (SEPA, 2012a). As a result of the significant reduction in sulphur deposition during the past two decades, forest residue recovery and nutrient compensation have gained greater significance in the attempt to achieve the environmental quality objective of *Natural Acidification Only*, especially as the recovery of forest residues is increasing.

Table 5. Relevant specifications and indicators of Natural Acidification Only

Relevant Specifications
Acidifying effects of forestry "The contribution of land use to the acidification of soil and water is counteracted by adjusting forestry to the acidification sensitivity of the site."
Acidified lakes and watercourses "Independently of liming, lakes and watercourses achieve at least good status regarding acidification in accordance with the Water Quality Management Ordinance (2004:660)."
Acidified soils "Acidification of the soil does not accelerate corrosion of technical materials and archaeological objects in the ground and does not damage the biodiversity of land and water ecosystems."
Relevant Indicators
Acidified forest land (also part of Sustainable Forests)
Acidified lakes

2.3.3 Eutrophication

The contribution to the eutrophication by forestry is not significant. Primarily it concerns nitrogen compounds. Felling and nutrient supply are activities that alter the nitrogen balance (de Jong, 2012). Even though a large proportion of Sweden's total land area is covered by forests the contribution to the eutrophication of lakes and seas, compared to that from agricultural land and sewage water, is modest. A salient area, however, is southwestern Sweden, with soils showing high nitrogen levels as a result of a long history of nitrogen deposition. Here, a significant leaching of nitrogen occurs after felling, but nevertheless, the relative contribution of nitrogen compared to other sources is low. One should be aware of the fact that if the leaching after felling increases, and intensified leaching from growing forests occurs more frequently, this could actually lead to nitrogen leaching from forest land becoming problematic in Sweden since the total area of forest land is high in this country. Nitrogen fertilization in areas with high levels of nitrogen means increased risks of nitrogen leaching (Belyazid, 2010). It is not clear how ground disturbances due to stump recovery and potential damage caused by driving forestry machines affect leaching during the clear-cut phase. Ash recycling might under certain circumstances stimulate the formation of nitrate, which increases the risk of nitrogen leaching. The Swedish Forest Agency gives recommendations on the operations for logging residue recovery and ash recycling. Experimental studies show that the impact on nitrogen leaching is very limited if these recommendations are followed (de Jong, 2012).

A positive effect is that an increased biomass recovery can give a relief in the long-term build-up of nitrogen storage in forest land caused by nitrogen deposition. The removal of excess nitrogen in high-load areas is beneficial from this point of view assuming that ash recycling is practiced. In contrast, the removal of nitrogen in areas with low levels of nitrogen increases the risk of nitrogen shortage (Belyazid, 2010). This process can be serious since nitrogen is commonly a growth-limiting factor in Swedish forests and may therefore lead to a reduction in forest productivity.

Zero Eutrophication

"Lakes and watercourses must be ecologically sustainable and their variety of habitats must be preserved. Natural productive capacity, biological diversity, cultural heritage assets and the ecological and water-conserving function of the landscape must be preserved, at the same time as recreational assets are safeguarded."

Forests take up most of the free inorganic nitrogen and phosphorus, a process which essentially counteracts the effects of nutrient leaching and eutrophication. However, a significant amount of nitrogen leaches out, but this is due to a natural leaching of organic nitrogen in which forestry is not implicated. The fraction that can be traced back to forestry occurs principally after the final felling, which is a period when nitrogen uptake is significantly reduced. Alterations of soil conditions have also an effect on the leaching since processes leading to increased amounts of mobile forms of nitrogen, such as nitrate, are favoured. Nitrogen accumulation in the soil due to deposition and fertilization are also reasons behind increased leaching. The risk of nitrogen leaching in growing forests is coupled to a long-term accumulation of nitrogen in the soil. This is seen where the nitrogen load is high due to high deposition. In these regions an increased removal of forest residues is favoured from this perspective, which is positive for the development of the environmental quality objective even if it is assumed to be of a minor degree. Forestry can affect the eutrophication in both directions and current research is being focused on how forest residue recovery, nutrient compensation and fertilization affect the nitrogen leaching to water ecosystems in the vicinity and to the Baltic Sea.

Table 6. Relevant specifications and indicators of Zero Eutrophication

Relevant Specifications
Pressure on the marine environment
"Swedish and total inputs of nitrogen and phosphorus compounds into the seas surrounding Sweden are less than the maximum loads established within the framework of international agreements."
Pressure on the terrestrial environment
"Atmospheric deposition and land use do not result in ecosystems showing any substantial long-term harmful effects of eutrophying substances in any part of Sweden."
Status of lakes, watercourses, coastal waters and groundwater
"Lakes, watercourses, coastal waters and groundwater achieve at least good status for nutrients in accordance with the Water Quality Management Ordinance (2004:660)."
Status of the marine environment
"Sea areas achieve at least good environmental status as regards eutrophication in accordance with the Marine Environment Ordinance (2010:1341)."

Relevant Indicators
Addition of nitrogen to the coasts
Addition of phosphorus to the coasts

2.3.4 Biodiversity

Logging residues contribute to forest biodiversity by providing substrates and habitats for a wide range of forest species. The relative significance of logging residues compared with other substrates present in the forest is not totally clear. If it turns out that many species are heavily dependent on logging residues, the recovery of these can have clearly negative consequences for the biodiversity. Even if this direct dependence concerned just a few species, a recovery could have an impact on populations because a lack of logging residues may reduce their chance of survival during the clearing phase (e.g. mosses and vertebrates). These are many indicates that fairly big recoveries of logging residues and soft wood from Norway spruce are possible without jeopardizing the survival of species in the landscape. In addition, logging residues from uncommon trees such as valuable broad-leaved species and aspen might have significant negative impacts. Another problem is that piles of logging residues from broad-leaved trees are attractive habitats for wood-living species such as many red-listed[1] species. The species might then be removed together with the residues, which thus function as traps for rare species. Another potential drawback of the recovery of logging residues is the risk of damage, or even causing the wood, trees and habitats that have been left for environmental considerations to be removed in the recovery. The effects of logging residue recovery on functional organisms groups seems to be of a very moderate degree. No direct changes of the ecosystem functions that are maintained by plants and soil organisms in a clear-cut area are therefore to be expected.

The consequences of stump recovery are very similar to those identified for logging residues. Few rare or red-listed species are found in habitats consisting of low stumps. When it comes to red-listed fungi, mosses and lichens, few species are found in intensely managed forests and therefore they are also absent on stumps. Concerning insects the situation is somewhat different. Stumps represent the main part (approximately 80 %) of the thick dead wood that is found in today's managed forests. It is likely that most of the beetle species living in/on wood make use of the felled stumps left in clear-cut areas. Even if just a few red-listed species take advantage of the stumps, an increased recovery could have some consequences. An impact is an increased homogenization of the clear-cut environment, which means that some habitats would disappear. This will in turn affect the life prerequisites for several different species. Stumps provide protection, micro habitat variation, and growth substrate for many species that are not strictly wood-dependent. Ground-living vertebrates (insects, spiders, etc.) and probably even mammals, use stumps as hiding places or nesting places. Birds feeding on insects search for food in stumps. Probably stumps function as refuges for drought-sensitive forest mosses during the clearing phase but can also constitute important growth substrates where mosses and lichens can avoid the competition of the vascular plants that dominate the ground vegetation in clear-cut areas. Exposed Norway spruce stumps in clear-cut areas have been shown to house species requiring light in wood habitats. As with logging residue recovery, there is the augmented risk connected to stump recovery of causing damage to the soil and spoiling areas set aside for environmental reasons, as well as causing the loss of material left for environmental considerations. Silviculture might be a way to combine forest residue recovery with a maintained or even improved biodiversity. Studies indicate that thinning under certain circumstances can increase the diversity in groups of several species. The choice of management method will also have the possibility to affect the development of different assemblages of organisms.

There is a lack of studies that examine the effects of ash recycling on species diversity. Instead, current data are focused on the effects on functional organism groups[2] such as vegetation and soil organisms. The short-term effects on vegetation and soil organisms are to a large extent dependent on the properties of the

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1 The Red list is a compilation of threatened and rare species in Sweden. The species are classified depending on their risk of extinction.

2 Collection of organisms and species based on different criteria such as carrying out the same task (function), living in the same type of environment, and feeding on the same substrate etc.

ash. In general it is clear that the higher the solubility of the ash, the faster and larger the direct effect tends to be. Easily dissolved ash can damage the vegetation, especially the surface layer of moss, while no or only minor effects are seen with hardened ash. The ground fauna seems to be fairly insensitive to the small changes in the soil chemistry that recycling of hardened ash causes. The same applies for the prevalence of mycorrhizal fungi.

Research concerning possible effects on species diversity in intensely managed forests (with limited biodiversity consideration) on a stand level, has been assessed with the conclusion that points towards the fact that only few species can live in such areas where limited biodiversity consideration is practiced. Many species are likely to disappear in favour of an increased domination of a few, less common species. This implies that this type of forest management would lead to reduced species diversity on a stand level. None of the current red-listed species are considered to be able to live in such forests. Effects on species diversity of intensely managed forests with limited biodiversity consideration on a landscape level are more difficult to evaluate. Model simulations show that the risk of species extinction is reduced if intensely managed forests are assembled adjoined in the landscape instead of being randomly separated dispersed.

Future research investigating the effects that arise due to an increased production of forest fuel have to be analysed with respect to the other aspects of forestry and the actions requiring in silviculture. The important aspect is the total effect of all forest management in the landscape over a long period (nature conservation included). It is suggested that modelling tools should be developed that can analyse wood-living species' long-term prospects of survival, both on a landscape and regional level, based on different scenarios of forest management and landscape dynamics. To give a confident evaluation of the effects on biodiversity there is a need for more data concerning the relative significance of different substrates and habitats. Examples mentioned are the importance of stumps in relation to other types of wood substrates and the significance of clear-cut habitats compared to other habitat types. The purpose of this is to map which species and groups of organisms that can be expected to be at the greatest risk of being impacted due to an increased recovery of forest residues in clear-cut areas. Better data are also needed on the effects of an increased recovery of forest residues on nature conservation. Only a few studies concerning logging residues have been published and studies on other activities are very scare. It is also important to study whether forest residue recovery can be combined with silviculture and restoration in order to achieve the objectives of biodiversity. Another obscurity is whether or not the ecological adaption in connection with felling and the restoration of the landscape have markedly positive effects on the biodiversity.

Sustainable Forests

"The value of forests and forest land for biological production must be protected, at the same time as biological diversity and cultural heritage and recreational assets are safeguarded."

Sustainable Forests is one of seven objectives that comprise whole ecosystems. This means that there is an overlap of this objective and the objectives *Natural Acidification Only*, *Zero Eutrophication* and *Reduced Climate Impact*, which all describe environmental problems. Also the objective *A Rich Diversity of Plant and Animal Life*, which can be regarded as intermediate between an environmental problem and an ecosystem-based objective, overlaps. Generally all potential impacts caused by the environmental effects of forest residue recovery can be correlated to this environmental quality objective. Hence, the development of such environmental problems in the forest ecosystem will be expressed by the well-being of *Sustainable Forests*. In that sense it acts as a general health indicator representing a wide palette of environmental problems in a great mix. The focus on *Sustainable Forests* and forest residue recovery will deal primarily with questions of biodiversity.

Table 7. Relevant specifications and indicators of Sustainable Forests

Relevant Specifications
Qualities and processes of forest land ”The physical, chemical, hydrological and biological qualities and processes of forest land are maintained.”
Ecosystem services ”Ecosystem services of forests are preserved.”
Green infrastructure ”The biodiversity of forests is preserved in all natural geographical regions and species have the opportunity to spread within their natural range as a part of a green infrastructure.”
Threatened species and restored habitats ”Threatened species have recovered and habitats have been restored in valuable forests.”
Preserved natural and cultural heritage values ”The natural and cultural heritage values of forests are preserved and the conditions for continued preservation and development of these values are in place.”
Outdoor recreation ”The value of forests for outdoor recreation is safeguarded and maintained.”
Relevant Indicators
Acidified forest land
Damages to ancient and cultural remains
Old forest
Old forest, rich in broad-leaved trees
Dead hardwood
Protection of forest land – Nature reserves
Protected area of forest land – Habitat protection area
Protected area of forest land – Nature conservation agreements

A Rich Diversity of Plant and Animal Life

“Biological diversity must be preserved and used sustainably for the benefit of present and future generations. Species habitats and ecosystems and their functions and processes must be safeguarded. Species must be able to survive in long-term viable populations with sufficient genetic variation. Finally, people must have access to a good natural and cultural environment rich in biological diversity, as a basis for health, quality of life and well-being.”

Felling and other forestry operations make up the major impacts on the forest ecosystem and lead to homogenous conditions. Results of forestry are thus, insufficient amounts of dead hardwood and a lack of stands of long continuity. Substantial areas of old forest with long continuity are still felled in Norrland[3], which is a significant threat to many species (fungi, mosses, lichens and insects living on wood). The amount of dead hardwood has increased over recent years but is still too small in total volume. Natural disturbances that are beneficial for certain species are also too few and concern fires and inundations etc. There are many policy instruments in place that serve to protect forests in different ways, thus counteracting the loss of biodiversity. However, the effects of the various measures are difficult to assess. There is also a significant need for the restoration of valuable forest types. Measures are being taken but their extent is unknown (SEPA, 2012a).

Logging residues and stumps serve as substrates and habitats for forest-living species. Acidification and eutrophication are environmental problems which also have impacts on forest biodiversity. Therefore, it is important to study how biodiversity is affected by different activities of forest residue recovery (logging residue recovery, stump recovery, intensive forest management, and nutrient compensation etc.). The impact of stump recovery on different species such as insects, fungi, lichens, and mosses has been

[3] One of three lands of Sweden. Norrland is the northern part.

investigated in various studies. To evaluate the significance of stumps and logging residues as substrates, the species diversity present in and on the substrates has been compared to other wood substrates. Since dead hardwood is a crucial substrate for many species in forest ecosystem, much research is being focussed on "correct" methods for the recovery of stumps, for example, identifying the type of stumps or forest stands which are the most valuable for biodiversity and how stump recovery should be planned (so that disturbances of the biodiversity can be kept within acceptable limits) (de Jong, 2012). Since the focus on biodiversity in this report is primarily related to its status in the forest, this implies a close link to the environmental conditions of the forest. Therefore, the indicators belonging to *Sustainable Forests* will also be a measure of the overall biodiversity status in the forest.

Table 8. Relevant specifications and indicators of A Rich Diversity of Plant and Animal Life

Relevant Specifications
Favourable conservation status and genetic variation
”Habitats and species that occur naturally in Sweden have a favourable conservation status and the status of threatened species has improved, and sufficient genetic variation is maintained within and between populations.” (Also for Sustainable Forests).
Impacts of climate change
”The increased risk of extinction indicated by climate scenarios is reduced regarding species and habitats facing the greatest risk of being affected adversely by climate change.”
Ecosystems services and resilience
”Ecosystems have the ability to cope with disturbances and adapt to change, such as a changed climate, so that they can continue to provide ecosystem services and contribute to combating climate change and its effects.”
Green infrastructure
”A functioning green infrastructure is in place and is maintained through a combination of protection, restoration and sustainable use within sectors, so that fragmentation of populations and habitats does not occur and the biodiversity of the landscape is preserved.”
Biological cultural heritage
”The biological cultural heritage is managed so that important natural and cultural values are preserved and the conditions for continued preservation and development of these values are in place.”
Nature on the urban fringe
”Natural environments near urban areas that are valuable for outdoor recreation, cultural heritage and biodiversity are safeguarded and maintained, and are accessible to the public.”
Relevant Indicators
Breeding birds in the forest

2.3.5 Compilation of Relevant Indicators and Specifications

To provide an overview of the connections between the environmental effects and environmental quality objectives, the relevant indicators and specifications presented above are summarized in tables (see Table 9 and Table 10). Connections between environmental effects and indicators and specifications are marked with an "x", which indicates weak or vague connections. All environmental effects connect to the three indicators of *Sustainable Forests* that monitor the progress of productive forest land covered by formal protection. The relation between the environmental effects and the indicators consists in this case of avoidance since the formally protected forest land is exempted from forestry. The field of the table concerned is highlighted in green of the same colour as used for *Sustainable Forests*. The environmental quality objective of *Flourishing Lakes and Streams* is not included in this report. It is a relevant objective for the forestry sector but does not have any indicators which are clearly applicable to forestry operations. The environmental quality objectives presented in this report also correlate with the research that has been carried out to date on the environmental effects of forest residue recovery. The environmental impact on lakes and streams as a consequence of relevant environmental effects connected with the recovery has not yet been sufficiently studied.

Table 9. Compilation of the relevant indicators and their correlations to the environmental effect

Environmental Quality Objectives		Reduced Climate Impact	Natural Acidification Only		Zero Eutrophication		Sustainable Forests								A Rich Diversity of Plant and Animal Life
Indicators		*Emissions with impact on the greenhouse effect*	*Acidified forest land (also part of SF)*	*Acidified lakes*	*Additions of nitrogen to the coasts*	*Addition of phosphorus to the coasts*	*Acidified forest land*	*Damage to ancient and cultural remains*	*Old forest*	*Dead hard-wood*	*Old forest, rich in broad-leaved trees*	*Protection of forest land – Nature reserves*	*Protected area of forest land – Habitat protection area*	*Protected area of forest land – Nature conservation agreements*	*Breeding birds in the forest*
Climate change	Alteration of the soil carbon pool	x													
	Methane and nitrous oxide emissions	x													
Acidification	Nutrient removal		x	x			x								
Eutrophication	Nutrient (nitrogen) leaching		x	x	x	(x)	x								
Biodiversity	Loss of substrates and habitats							x	x	x	x				x
	Soil disturbances /Driving damages														

Table 10. Compilation of the relevant specifications and their correlations to the environmental effects

		Reduced Climate Impact		Natural Acidification Only			Zero Eutrophication			
		"The increase in global average temperature will be limited to no more than 2 °C above pre-industrial levels. Sweden will press internationally for global efforts to be directed towards achieving this target."	"Sweden's climate policy will be designed to contribute to ensuring that the concentration of greenhouse gases in the atmosphere is stabilised in the long term at no more than 400 parts per million of carbon dioxide equivalent (ppm CO2 equivalent)."	"The contribution of land use to the acidification of soil and water is counteracted by adjusting forestry to the acidification sensitivity of the site."	"Independently of liming, lakes and watercourses achieve at least good status regarding acidification in accordance with the Water Quality Management Ordinance (2004:660)."	"Acidification of the soil does not accelerate corrosion of technical materials and archaeological objects in the ground and does not damage the biodiversity of land and water ecosystems."	"Swedish and total inputs of nitrogen and phosphorus compounds into the seas surrounding Sweden are less than the maximum loads established within the framework of international agreements."	"Atmospheric deposition and land use do not result in ecosystems showing any substantial long-term harmful effects of eutrophying substances in any part of Sweden."	"Lakes, watercourses, coastal waters and groundwater achieve at least good status for nutrients in accordance with the Water Quality Management Ordinance (2004:660)."	"Sea areas achieve at least good environmental status as regards eutrophication in accordance with the Marine Environment Ordinance (2010:1341)."
		Temperature	*Concentration*	*Acidifying effects of forestry*	*Acidified lakes and watercourses*	*Acidified soils*	*Pressure on the marine environment*	*Pressure on the terrestrial environment*	*Status of lakes, watercourses, coastal waters and groundwater*	*Status of the marine environment*
Climate change	Alteration of the soil carbon pool	x	x							
	Methane and nitrous oxide emissions	x	x							
Acidification	Nutrient removal			x	x	x				
Eutrophication	Nutrient (nitrogen) leaching						x	x (fertilization)	x	x (fertilization)
Biodiversity (species richness)	Loss of substrates and habitats									
	Soil disturbances/Driving damages									

		Sustainable Forests						A Rich Diversity of Plant and Animal Life					
		”The physical, chemical, hydrologi-cal and biological qualities and processes of forest land are maintained.”	”Eco-system services of forests are preserved.”	”The biodiversity of forests is preserved in all natural geographical regions and species have the opportunity to spread within their natural range as a part of a green infrastructure.	”Threate-ned species have recovered and habitats have been restored in valuable forests.”	”The natural and cultural heritage values of forests are preserved and the conditions for continued preservation and development of these values are in place.”	”The value of forests for outdoor recreation is safeguar-ded and maintained.”	”Habitats and species that occur naturally in Sweden have a favourable conserva-tion status and the status of threatened species has improved, and sufficient genetic variation is maintained within and between populations.” (Also for SF)	”The increa-sed risk of extinction indicated by climate scena-rios is reduced regar-ding species and habitats facing the greatest risk of being affected adver-sely by climate change.”	”Ecosystems have the ability to cope with disturbances and adapt to change, such as a changed climate, so that they can continue to provide ecosystem services and contribute to combating climate change and its effects.”	”A functioning green infrastructure is in place and is maintained through a combination of protection, restoration and sustainable use within sectors, so that fragmenta-tion of populations and habitats does not occur and the biodiversity of the landscape is preserved.”	”The biological cultural heritage is managed so that important natural and cultural values are preserved and the conditions for continued preservation and develop-ment of these values are in place.”	”Natural environ-ments near urban areas that are valuable for outdoor recreation, cultural heritage and biodiversity are safeguarded and maintained, and are accessible to the public.”
		Qualities and processes of the forest land	*Ecosystem services*	*Green infrastructure*	*Threatened species and restored habitats*	*Preserved natural and cultural heritage values*	*Outdoor recreation*	*Favourable conserva-tion status and genetic variation*	*Impacts of climate change*	*Ecosystem services and resilience*	*Green infrastructure*	*Biological cultural heritage*	*Nature on the urban fringe*
Climate change	Alteration of the soil carbon pool	x	x						x				
	Methane and nitrous oxide emissions								x				
Acidification	Nutrient removal	x	x							x			
Eutrophication	Nutrient (nitrogen) leaching	x											
Biodiversity (species richness)	Loss of substrates and habitats	(x)	x	x	x	x	x	x		x	x		x
	Soil disturbances/Dri-ving damages	x	x		x	x	x			x	x	x	x

2.3.6 Evaluation and Trends of Environmental Quality Objectives Based on the 2012 In-Depth Evaluation and the 2013 Follow-Up Evaluation

The current situation of the environmental quality objectives is complex. While the trends for some objectives show a slightly positive development, the general status is under the shadow of a negative development. Positive effects due to the reduction of certain emissions are difficult to observe due to the slow recovery rate of the environment. This is true concerning the conditions of, for instance, acidification and eutrophication. The global emissions of GHGs are increasing and future climate change will have negative impacts on several of the environmental quality objectives. *A Rich Diversity of Plant and Animal Life* is one of the objectives among those that show the most negative trends. Evaluation of the direction and development of the prerequisites to achieve the environmental quality objectives is considered as more difficult than the evaluation of the development of the environmental condition. The prerequisites need to be assessed by analyses of complex connections of a wide range of different factors, such as the world economy, political developments and policy instruments etc. Environmental quality objectives are also different, which makes it difficult to make a common total assessment of the prerequisites of the objectives, current situation and development. Some of the most important prerequisites are compiled to give a summary of the achievement of the objectives on a general level. Among these one finds the need for policy instruments on a national level, EU's common political agenda of, among other things, agriculture and fishing, the need for efforts within political areas other than the environmental, law enforcement, and cooperation and the provision of resources by the authorities for environmental work.

Fourteen of the 16 environmental quality objectives are found to be unachievable by year 2020. The objectives are confined by different challenges and the sizes of their distance-to-targets vary. The in-depth evaluation of 2012 was the first time-gap analysis of the objectives to be carried out since the introduction of the environmental policy system. The gap analyses are estimations of the remaining distance to go from the current state to the achievement of the aim. Hence, this type of analysis is a kind of distance-to-target approach. The analyses of the various objectives' distance-to-target situation are not based on common criteria and are qualitative. This means that they are difficult to sum-up collectively. However, from the evaluations the most apparent reasons for failing to reach the aims can be grouped as follows. These are here freely translated by the authors of this report.

- Long recovery rate of the environment gives uncertainties in the evaluation as to whether the prerequisites to fulfil the environmental quality objectives are sufficient or not.
- The majority of the environmental quality objectives cannot be solved within Sweden.
- Negative impact or competition from other areas and sectors.
- Lack of policy instruments (national and/or international).
- Insufficient implementation of policy instruments (this includes insufficient measures as a result of the policy instrument as well as insufficient resources for implementation).

The number of reasons (see Table 11) and the development trend (see Table 12) for each of the environmental quality objectives with the status of "No" are combined in the in-depth evaluation to give an estimation of the respective distance-to-target on a scale of four (see

Figure 3). An objective nearer the status of "Close" does not necessarily mean that it is easier to achieve than an objective further down the scale. This is so since the reasons that make up the distances of each objective may vary in complexity. It was mentioned that the gap analysis is a first attempt to perform this kind of evaluation in this context and is in need of further development. An example is the common reasons which were valued equally. A long recovery rate of the environment and a negative impact or competition from other objectives and sectors (e.g. forestry production objectives) are two reasons that are connected to all of the five relevant environmental quality objectives. This outcome is not unexpected since all three objectives concerning environmental conditions (environmental problems) have impacts on the objective of Sustainable Forests, which comprises a type of an environment and whole ecosystems, and the closely related A Rich Diversity of Plant and Animal Life. Their frameworks are also structured in a way that makes conflicts concerning objectives unavoidable. This also elucidates the diversity of environmental impacts within society.

Table 11. The five common reasons for achievements which failed and the relation to these of the relevant environmental quality objectives

	Long recovery rate in the environment	Major international dependence	Negative impact or competition	Lack of policy instruments	Insufficient implementation of policy instruments
Reduced Climate Impact	x	x	x	x	
Natural Acidification Only	x	x	x	x	
Zero Eutrophication	x	x	x	x	
Sustainable Forests	x		x		x
A Rich Diversity of Plant and Animal Life	x		x		x

The evaluation uses the following grades of the development trend: ↗ Positive, → Neutral, ↘ Negative.

Table 12. The statuses and trends of the most relevant environmental quality objectives from 2013 follow-up evaluation

	Reduced Climate Impact	Natural Acidification Only	Zero Eutrophication	Sustainable Forests	A Rich Plant and Animal Life
Status and trend	No ↘	No ↗	No ↗	No →	No ↘

The different reasons show a trend concerning the most relevant environmental quality objectives of forest residue recovery. *Reduced Climate Impact*, *Natural Acidification Only* and *Zero Eutrophication* all comprise the first four reasons. *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life* both comprise the first, third and fifth reasons. This concept is widened in chapter 4 where the case-study integrates regional assessments of the environmental quality objectives based on the follow-up evaluations by the counties.

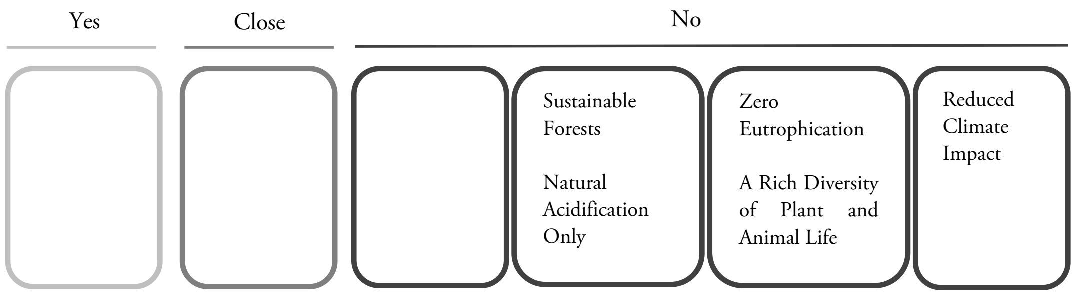

Figure 3. The figure is adapted from 2012's in-depth evaluation (SEPA, 2012a) of the environmental quality objectives. It shows the estimation of the distance-to-target analysis (the distance to the achievement of the environmental objectives based on the trend and the five common reasons for failure, see Table 11 and Table 12) of the environmental quality objectives most relevant for the recovery of forest residues. The objectives with a status of "No" are graded on a scale of four.

To present a general overall picture of how the environmental quality objectives are developing, a summary of the distance-to-target and the current situation and development of the environmental conditions that the objectives describe follows below. For statuses and development trends, see Table 12.

Reduced Climate Impact

Distance-to-target

The global emissions of greenhouse gases are increasing. To reach the global two degree climate target the global emissions have to decrease by 50-60 percent till year 2050 and almost by 100 percent till 2100 compared with the emissions of year 2000. The global emissions have increased by a higher rate since year 2000 than at the end of the 1990's. There is a trend towards increased emissions in countries with high economic growth. China is such an example which has doubled its emissions since 1990. Climate change will have an impact on biodiversity and on ecosystems. This can be observed via, for instance, alteration of species' ranges and acidification of the oceans.

Current Situation and Development of the Environmental Condition

To reach the two degree climate target global emissions have to decrease drastically in the near future. In order to meet this challenge and achieve *Reduced Climate Impact*, additional policy instruments are required. These are needed to reduce the emissions on a national level and to direct an implementation towards the most cost-effective measures from a global perspective. Measures and policy instruments to achieve the environmental quality objective have synergies and conflicts with other environmental quality objectives. Greenhouse gas emissions and air pollutants often originate from the same kind of sources and therefore the development of new policy instruments can be designed with potential synergistic effects between *Reduced Climate Impact* and *Fresh Air* in mind. Conflicts are primarily between the environmental quality objectives of *A Varied Agricultural Landscape*, *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*. A clear example is the increased demand for raw material for the production of bioenergy which might lead to an intensification of forestry and agriculture. This can result in a fragmentation of the landscape and the use of species that are not consistent with current biodiversity. Wind power parks, both on land and offshore, and an expansion of hydropower are other measures that can break up the landscape.

Sweden's work on climate change takes place at several levels. The contribution to the international work is as a member of the European Union and the implementation of the EU's climate and energy package.

This package comprises various parts, namely, development of renewable energy, energy efficiency and trade in emission permits. The Swedish government has adopted a vision which says that Sweden shall have a sustainable and resource efficient energy supply with zero net emissions of GHGs to the atmosphere by the year 2050. As part of the fulfilment of this vision some "soft" objectives have been set. By the year 2020 the use of fossil fuels for heating shall have been phased out in populated areas. The energy efficiency of the transportation system shall be successively increased and the dependence on fossil fuels eventually broken. The Swedish vehicle fleet should preferably be independent of fossil fuels by the year 2030. This should be made possible by a transition to sustainably renewable biofuels and a significant development of the electric drive technology (vehicles running on electric power). In summary, a fulfilment of the vision relies on the following three action plans that frame the transition: a vehicle fleet independent of fossil fuels; increased energy efficiency; and a promotion of renewable energy.

Natural Acidification Only

Distance-to-Target

The achievement of the environmental objective is heavily dependent on international agreements and EU directives. Preliminary calculations indicate that during the period 2005-2020 there will be a reduction of sulphur dioxide emissions of 59 percent and of nitrogen oxides of 43 percent within EU-27. The corresponding value for ammonia is estimated to reach a reduction of 6 percent. Emissions of nitrogen oxides from the shipping sector are expected to increase during the same period where the nitrogen deposition in Sweden coming from this sector is estimated to reach an increase of 10 percent. Currently the emissions of nitrogen oxides from shipping constitute about 20 percent of Europe's total nitrogen oxide emissions. Whether additional instruments are to be expected to tackle this negative trend, and what they will be, is not clear. The climate change is also a general question mark that might have an impact on the possibility of reaching satisfactory statuses.

Since the sources of the problem of acidification are largely an international concern, it is of interest to consider the development in other European countries. A preliminary presentation of the EU-27 countries and the emission ceilings they have set till the year 2010, according to the *EU National Emission Ceilings Directive*, shows the following outlooks:

- The target for sulphur dioxide emissions is reached in all countries.
- Finland and Spain are the only two countries that do not reach the target for ammonia.
- The outlook for nitrogen oxide emissions is darker. Eleven countries will not reach the target and some of these are far off the mark (Luxemburg, Austria, France and Germany). Sweden belongs to the group that will not make it.

Current Situation and Development of the Environmental Condition

There has been a substantial reduction of emissions of acidifying compounds from land-based sources in Europe during recent decades. In the period 1990-2009 emissions of sulphur dioxides decreased by 77 percent and nitrogen oxides by 42 percent. By contrast, the emissions of sulphur dioxides have increased by 6 percent and the emissions of nitrogen oxides by 20 percent from international shipping since the year 2000. The situation in Sweden follows the trend of reductions seen in Europe. During the period 1990-2010 the emissions of sulphur dioxides decreased by 67 percent and of nitrogen oxides by 40 percent. The emissions of ammonia were reduced by 20 percent between 1995 and 2010. The positive development of reduced emissions in recent decades has given a slow improvement of the acidification status of lakes and watercourses, while the conditions of forest land and groundwater have remained unchanged. Some improvement of soil water has been observed. It will take time for nature to recover. The major share of acid deposition in Sweden originates from sources in other countries and international shipping. This is the case for about 90 percent of the sulphur dioxide and the nitrogen oxide emissions and approximately 70 percent of the ammonia emissions. The deposition is highest in southwestern Sweden and the greatest problems of acidification have also been concentrated to this area. This is still the current situation. This elucidates the width of international impact but one should also remember that Swedish emissions affect other countries and surrounding seas. Hence, the environmental quality objective must rely on international measures in order to reach its objective. Additional EU directives and treaties within the *UN Convention on Long-Range Transboundary Air Pollution* are required to further limit the emissions of acidifying compounds. International agreements are also needed to constrain the emissions from international shipping. On a national (Sweden) level, instruments that restrict the emissions of nitrogen oxides are the most significant.

The acidification caused by anthropogenic activities affects primarily forest land, lakes, watercourses and groundwater. Corrosion damages to ancient remains and other objects in the ground can also be problematic. The deposition of acidifying compounds must be reduced to levels that do not cause biological damage in ecosystems, otherwise the environmental quality objective will not be reached. Particularly sensitive areas are those with thin soil layers or soils subjected to low levels of natural weathering. Emissions of sulphur dioxides have their primary origin in the combustion of fossil fuels. Nitrogen oxides arise during combustion, the major emissions coming from the transport sector. Other sources are industries with large-scale combustion activities. Forestry is also a sector that contributes, where the acidifying impacts are dependent on forest growth and the fraction of trees that are felled. Its impact is predicted to increase with an increased recovery of logging residues. To attain reductions of the acidifying impacts of forestry and an increased extraction of biomass, both strategies and more powerful instruments need to be developed. Even though the critical limit concerning acidification was exceeded less in the forest land area and the lakes' run-off area since the year 2000, calculations show that the situation will be further mitigated but still remain by the year 2020. The data on which this contention is based indicate that the limit will be exceeded by 9 percent in the forest land area and 19 percent in the lakes' run-off area, compared with 19 and 22 percent, respectively, in 2010.

Zero Eutrophication

Distance-to-Target

Currently we have a situation in which the environmental condition is either unchanged or modestly improved. The fulfilment of the environmental quality objectives is heavily dependent on international measures and on the fact that the recovery of the environment takes a long time. There is a need for additional decisions on measures within the EU, UN and international shipping. This applies also to the case of *Natural Acidification Only*. The time for recovery, as a response to different measures, might be long thus making it hard to observe positive effects in the short term. Furthermore, the implementation of all the required measures for achieving the objective will presumably also require a long time.

Current Situation and Development of the Environmental Condition

The eutrophying substances containing phosphorus and nitrogen originate as emissions to the atmosphere from shipping, automobile traffic and energy use, and as emissions to water via agriculture, sewers (municipal and individual), industries and forest land. Some slight improvements have been observed over recent years and concern primarily coastal areas. Measures taken within the agricultural sector to reduce the leaching of phosphorus and nitrogen have had some effect, and a decrease has been seen over the past twenty years. While there is a general reduction of emissions to air there is a trend of increasing emissions from shipping. The achievement of the environmental quality objective relies on an ambitious international effort. Five tools of crucial importance for achieving the objective are mentioned in the evaluation: the EU Water Framework Directive, the EU Marine Strategy Framework Directive (the Marine Directive), HELCOM (The Helsinki Commission) Baltic Sea Action Plan, the EU National Emission Ceilings Directive, and the Gothenburg Protocol within the UN Convention on Long-Range Transboundary Air Pollution. The future EU agricultural policy is also expected to play an important role. These tools and directives summarize the need for different measures on both national and international levels to reduce the pressure on the seas and the airborne deposition of the eutrophying substances.

Sustainable Forests

Distance-to-Target

According to the in-depth evaluation, achieving *Sustainable Forests* is a great challenge. The potential for improvements of the environmental condition within the structure of current policy instruments is, however, significant. In the current environmental work it is important to learn from already implemented measures in order to increase our knowledge of how ecosystems respond to different actions. That it generally takes a long time before the effects of the measures taken can be observed and that several of these are seen to be pressed for time, make the work difficult. Large and comprehensive research campaigns play an essential role to reach the targets set by the objective. Some aspects require additional political considerations. This concerns primarily the level of ambition the environmental quality objective is to attain in terms of protection and conservation of forest land, and also a possible increase of the requirements of an ecological adaption of forestry. There are also some ambiguities concerning what the responsibility of the sectors covers[4] and the extent of state commitment. These questions need to be clarified so that the actors concerned can reach a unified perspective. Other unclarified points concern the precise meaning of the ecosystem approach[5], and, furthermore, the concept of ecosystem services is not sufficiently secured for the forest sector. This also concerns the authorities both on a national and regional level. The result of this ambiguity is the various opinions and interpretations underlying the policy instruments and measures called for across the country. At present it is difficult to assess the distance to achieving the environmental quality objective. For some aspects the targets are considered as being very distant and will take a long time to reach. None of the counties assess the environmental quality objective to be achievable by 2020.

Current Situation and Development of the Environmental Condition

The Swedish forests are affected in many ways and conditions vary. Some environments are improving while others are deteriorating. Some areas face problems of eutrophication and acidification and the factor of climate change is an overall threat. The deposition of nitrogen is largest in the central and southern parts of Sweden and has been fairly constant over the past ten years. In spite of the great reduction of acid deposition in recent decades no clear recovery of the forest land can be seen. Mercury in the soil and impacts on the natural hydrology are also important complications. Processes in the forest are generally slow, a fact which makes a potential recovery difficult to assess. For this reason long series of measurements are required. There is a need for increased knowledge regarding the relations between different impact factors and the real conditions. Examples of structural problems and deficits are ecological discontinuities, fragmentation, overgrowth, and insufficient amounts of dead hardwood. The problems differ in different parts and types of landscape in the country. The reasons for the problems vary by the same measure. One reason for the problems is the results of forest management programmes in forestry. A second is that different kinds of customs and natural disturbances have ceased or been reduced as a consequence of

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4 A principle that says that forestry has a fundamental responsibility concerning how forest policy is developed. The responsibility comprises, for instance, directions of a sustainable use of natural resources and a responsible management.

5 A method of working that originates from the UN Convention on Biological Diversity with the purpose to achieve the goals set by the convention. The approach is described by twelve guiding principles (SEPA, 2008).

modern forestry. Exploitation of forest areas due to construction and infrastructural activities also contributes. The conflict of objectives between the need for an increase in renewable energy and the risks posed on forest land of an increased forest residue recovery must be treated. Connected to this conflict one finds the need for a sufficient ash recycling as a measure of nutrient compensation due to forest residue recovery. As the current use of ash is limited, a national council on ash recycling is being established to act for an increased ash recycling. At the same time there is the possibility that bio-ashes may in future be classified as hazardous waste according to the EU Hazardous Waste Directive.

Measures implemented through formal protection of forests and ecological adaption of forestry as land voluntarily set aside for nature conservation and environmental considerations are important methods to achieve the objective of *Sustainable Forests*. Environmental considerations are an obvious part of today's forestry but nevertheless there are shortfalls, and work is going on to improve the situation. A primary requirement is a well-functioning responsibility within the sector. Forest certifications such as the *Forest Steward Council (FSC)* and the *Programme for the Endorsement of Forest Certification (PEFC)*, can be considered as an integral part of this responsibility. More than 60 percent of Swedish forest land is certified. Over the past decade there has been an increase in areas of old forests (in northern Sweden > 140 years, southern > 120 years), old forests rich in broad-leaved trees and the amount of dead hardwood. The increase varies across the country, however. These are indicators that point to enhanced prerequisites regarding some aspects of biodiversity. It is likely that the positive development can be linked to measures in forestry such as ecological adaption when felling and land voluntarily set aside for nature conservation.

Just over 7 % of forested land in Sweden is formally protected. The protection is unevenly distributed, where 77 % of the protected area is located in the highlands. This region also has the largest fraction of formally protected forest land. The percentage in the remaining part of the country is significantly lower, approximately 2 % of productive forest land being formally protected. To conserve the biodiversity in forest ecosystems, so that satisfactory conservation statuses are attained for prioritized forest types and species, is a great environmental challenge. A well-functioning formal protection of nature reserves, habitat protection areas and nature conservation agreements are vital. That areas of high nature values (areas particularly valuable for the environment), e.g. key biotopes, are felled or damaged is problematic from a long-term conservation perspective. Good knowledge and easily accessible information are needed concerning the location of such valuable forest areas. As an aid to operative, strategic and political decisions. The trend of voluntary conservation areas that has been developing positively over the past decade now constitutes an important part of the work to conserve biodiversity.

Since 1999 the Swedish Forest Agency has undertaken annual follow-ups within the framework of Polytax, of the environmental consideration in connection with regeneration felling. The follow-up inventories show deficits concerning environmental considerations. A government commission report compiled by the Swedish Forest Agency (SFA, 2011) shows that forestry is capable of adapting the environmental consideration at the time of regeneration felling based on the stands' environmental values. In many cases sufficient consideration is shown but there are also negative results to be found. The losses of habitats of high value for diversity are large. Short comes are also found in conjunction with damage caused by forestry machines and a lack of consideration shown for water. Forestry causes damage to about 50 percent of the historical-cultural remains that are located in an area subjected to felling. Approximately two out of five culture environments are exposed to negative impact by regeneration felling and regeneration measures. The degree of consideration shown for these environments is closely linked to whether they are already known and can be found listed in some kind of register that is accessible to the actors concerned. Among the different operations performed during the period that elapses from the actual point of felling until the regeneration operations are finished, soil scarification seems to be the practice that affects the consideration most. Concerning damage caused by driving of forestry machines, the Polytax inventory shows a frequency of damage on one third of the regeneration felling sites. The occurrence of this type of damage has been constant over the past decade and data are insufficient to make a division between severe and less severe damage. A joint policy on damage caused by driving of forestry machines on forest land has been developed by the forestry sector which also assists with teaching and instruction. To further decrease the implications of the use of forestry machines, clarification of prescriptions and common advice concerning terrain transport and ground preparation found in the Forestry Act have been made. Nitrogen fertilization of forest land increases the risk of nitrogen leaching. 5-10 % of a normal fertilizer dose is estimated to have been leached from the soil 1-2 years after fertilization. Fertilization of forest land is primarily practiced in northern Sweden which also is the part of the country where the nitrogen deposition is the lowest. In recent years fertilization has increased from small areas to 80,000 hectares being fertilized in the year 2010, which is the largest area since 1988. The Swedish Forest Agency gives recommendations and advice regarding nitrogen fertilization to minimize its negative effects on forests, soil and water.

A Rich Diversity of Plant and Animal Life

Distance-to-Target

In summary, the measures based on existing policy instruments are insufficient. The work on preserving the ecosystems and halting the loss of biodiversity are too slow to achieve the environmental quality objective. According to the evaluation, the distance to achievement is long, even if it is difficult to assess its extent. This can be explained by a lack of sufficient knowledge regarding ecosystem services and their economic values. Furthermore, too little is known about genetic diversity, foreign species and the magnitude of the impact of climate change. It will also take time to implement all policy instruments developed for the long-term, sustainable use of resources in different sectors. Regional assessments of the environmental objective are performed by the Swedish County Administrative Boards and direct measures are taken to preserve species and sensitive habitats. However, no county assesses that the environmental objective can be achieved. Important habitats are still being destroyed. This concerns felling of key biotopes and the overgrowth of natural grazing areas as two examples. The deficiencies and the negative trend need to be tackled with increased financial support, and current measures have to be implemented to their full extent by all actors concerned on a national, as well as on a regional and local level.

Current Situation and Development of the Environmental Condition

The use of natural resources has a great influence on the ecosystems' stability and their ability to deliver these services. How the resources are used by the human society is of great importance and endangers the health of the ecosystems with risks of causing increased vulnerability. The production of commodities with a market demand may initiate a one-sided use of certain ecosystem services with the effects of an excessive use and negative impact on the materials utilized in the production itself and other functions and processes. Examples are those of monoculture practices in forestry and agriculture, use of foreign tree species and types that are not adapted to growth in the area in question. Other aspects are overfishing in the oceans and the construction of hydro power plants in waterways. Losses of ecosystem services can constitute high socio-economic costs. These services are also complex in that they often do not function in isolation, but instead co-vary. Since forests, agricultural lands, wetlands, lakes and waters often coexist they also affect each other. Thus it is crucial to include the whole landscape at the planning stage, in order to create and preserve a green infrastructure. There is also a national strategy that serves to protect those forests most in need of protection. The Swedish Forest Agency has developed and defined what is meant by a sustainable use of forests but the general conservation practiced by industries that profit from ecosystem services, such as forestry, is not yet enough. Important international prerequisites for the protection and conservation of biodiversity are the UN Convention on Biological Diversity, the strategic plan formulated at the meeting held in Nagoya 2010, and the EU Habitat Directive and Birds Directive which both constitute parts of the EU Nature Conservation Act.

3 Tools for Environmental Systems Analysis

3.1 General Description

There are several tools and methods available to describe the environmental impacts of various activities. The suitability of different tools depends on what is to be analysed. Based on earlier work, Finnveden et al. (2005) present four aspects that can be used to describe different tools in relation to different characteristics (see Table 13). These aspects can be used as a guide in the search for relevant analytical tools to be applied on a specific operation, activity, product, or what else there is to be evaluated.

Table 13. Four aspects that describe environmental systems analysis tools in relation to different characteristics

1. A procedural or analytical tool? Procedural tools (e.g. Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA)) have their focus on the procedures and the connections to the decision-making context. Analytical tools (e.g. Life Cycle Assessment (LCA), Material Flow Accounting (MFA)) are directed at technical aspects of the analysis and can be used as tools within the framework of procedural tools.
2. What types of impacts are considered? Distinctions between tools that focus on the resources used or the environmental impacts, or both, and whether economic aspects are included as part of the tool.
3. What is the object of the study? A distinction is made between five groups of objects: • Policies, plans, programmes and projects • Regions or nations • Organizations or companies • Products or services • Substances The objects relate in different ways but normally one object can be identified as the main object of the study.
4. Is the tool used in descriptive or change-oriented studies? A change-oriented study analyses the consequences of a choice and serves to present the outcome of the changes made. Descriptive studies describe systems as they are at a given time. This means that the appropriate data and system boundaries should be valid for what was actually happening in a system. This can be compared with a change-oriented study where the data and system boundaries should reflect the changes taking place.

Below, several analytical tools for environmental systems are described, and their applicability to environmental evaluations of forest residue recovery is briefly discussed. The rationale is to present a variety of tools of potential use and proceed with those considered most suitable for the purpose of the work in this report. The tools presented are: Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Cost-Benefit Analysis (CBA), Input-Output Analysis (IOA), Position Analysis (PA), Life Cycle Assessment (LCA), Substance Flow Analysis (SFA), and Ecological Risk Assessment (ERA). To give an overview of the activity of forest residue recovery and its environmental effects the reader is referred to Table 1 (see section 2.1) and Table 15 (see section 3.3.2). The aspect of environmental impact is central and the focus of the overall system of forest residue recovery in this context.

3.2 Existing Tools and Methods for Quantification of Environmental Effects

3.2.1 Environmental Impact Assessment (EIA)

Environmental Impact Assessment is a systematic process that examines the environmental consequences of plans and projects, such as exploitation of natural resources, construction of infrastructure etc in advance. In that aspect it constitutes a tool used for preventative measures. The assessment should be performed in a systematic, holistic and multidisciplinary way. The procedure involves a number of steps that should eventually result in a compiled document called Environmental Impact Statement (EIS), serving as an aid to decision-making (Glasson, 2012).

On a slightly more detailed level EIA serves to identify and describe the direct and indirect effects that a planned activity or measure might have on humans, animals, plants, soil, water, air, climate, landscape etc. This concerns the management of soil, water and the general physical environment, and also other management issues such as that of materials, commodities and energy. Based on these different aspects, the overall aim is to make possible a combined assessment of these effects on human health and on the environment (Moberg, 1999). It is a change-oriented procedural tool mainly used for assessing the environmental impacts of projects (Finnveden, 2005). The process is regulated by Swedish law and should be performed if the planned activity will (or is expected to) have impacts on the environment in any way. It is part of the Swedish Environmental Code (Miljöbalken) which also states the minimum requirements of what should be included in the EIA-document. There are no clear guidelines on how environmental impacts should be analysed and assessed in an EIA and there are no strict instructions on which environmental aspects should be included. This is decided for the specific situation.

EIA has the potential to cover a broad spectrum of prevailing environmental effects and thereby also to identify potential conflicts concerning the environmental objectives. It is a tool (or more of a process) with a methodology which makes suggestions on how measures and restoring practices can be undertaken to compensate for, and counteract environmental impact. Since the tool is site-specific (at least on a forest area level) this makes it suitable to account for environmental effects with impacts on biodiversity, acidification and eutrophication. However, it misses the environmental impact category of climate change and is not directly applicable to account for GHG balances.

3.2.2 Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment can be seen as a development of EIA and presents a way to include a "sustainable way of thinking" in the early stage of general decision-making. The method enables an approach to introduce environmental aspects in an earlier phase of the project compared with EIA (Moberg, 1999). SEA is also introduced earlier than EIA in the decision-making process where it serves as a tool by which comparisons of several different solutions are made possible before too many parameters are fixed (Johansson, 2004). Just like EIA, SEA is a change-oriented procedural tool (Finnveden, 2005). Compared to EIA, SEA is regarded as less applicable in an environmental assessment of forest residue recovery. Since it is a tool to be used in the initial stages of the planning of a project or the like, its range is broader than necessary for the recovery of forest residues.

3.2.3 Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis is an analytical economic tool that measures the total costs and benefits of a planned project (Finnveden, 2005). It is used to valuate activities from a socio-economic perspective and also attempts to include and put a monetary value on non-monetary commodities. The method is based on the market price for valuation but may require adjustment. When there is no relevant market price to be found (especially non-monetary commodities), a common way is to derive costs and benefits from individual preferences where the willingness-to-pay principle plays a salient role. Other socio-economic values found suitable can also be derived for this reason. To put a market price on something that has no monetary value may prove difficult (Moberg, 1999). The purpose of the valuation in monetary terms is to create a general sum of all costs and benefits in the analysis. In this way the CBA aggregates all positive and negative effects included to give a final sum and a unified answer (Söderbaum, 1986).

CBA contributes to the discussion with a cost perspective, an aspect that may be difficult to leave aside as it is based on neoclassicism and the economic system as we know it. The willingness-to-pay principle can be used to estimate the society's interest in fulfilling the environmental objectives in economic terms. Such an estimation may then convey the importance of the objectives as viewed by society, thus giving an additional dimension to the field. As discussed by Wenzel et al. (Wenzel, 1997) this type of estimation can be combined with political targets as a way to differentiate the importance between different objectives. Doubtlessly, there are questions of complexity due to the fact that many of the environmental objectives are linked and overlap. An example is *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life* which are both broad objectives affected by a great number of factors. *Natural Acidification Only*, *Zero Eutrophication* and *Reduced Climate Impact* all have an impact on the two above-mentioned objectives. Since economic aspects of forest residue recovery are not within the scope of the work in this report, CBA is a tool that does not find any direct use here.

3.2.4 Input-Output Analysis (IOA)

Input-Output Analysis is another analytical socio-economic tool that builds on a kind of a bookkeeping methodology. Deliveries of commodities and services between different actors in the economy are recorded in a simplified manner. The analysis can be performed for a national or regional level. Different activities, but with sufficient similarities within the industry, are summed and average values for the inputs and outputs of these are used. Also linear production connections are included. A basic assumption is that the proportion of input commodities from different industries is constant. The method can be used for long-term planning purposes in order to reach consistent forecasts for different sectors and to illuminate connections between them, for example, how changes in one industry will affect others etc. Economic and physical IOA are kept apart. An economic IOA handles flows in financial terms. In order to use this tool for environmental studies information about environmental aspects such as emissions must be coupled to the economic calculations. In a physical IOA, financial flows are substituted by material- or energy flows. A possible application of IOA from an environmental point- of-view is to see how policy instruments implemented for a certain industry affects other industries and thereby avoid a transfer of problems (Moberg, 1999).

This method may be difficult to apply on an evaluation of the actual recovery of forest residues, which is a specific activity in which the raw material is itself the product of logging residues and stumps. However, it may possibly be applicable if the extraction of forest biomass shifted towards the use of forest residues compared to the current situation where the extraction is mainly driven by the market for wood as building material and use in the pulp and paper industry. In that respect the tool could help to map potential effects from different incentives and "drivers" of forestry.

3.2.5 Position Analysis (PA)

If CBA is a method by which the effects included are aggregated to give a general sum, Position Analysis embraces the act of disaggregation where conflicts and opposing interests in the decision-making process should be emphasized. Different opinions have to be explained based on the actors' own individual stands. Versatility is a keyword and concerns the ways of regarding a problem, alternative solutions, influence, vested interests, and basis for appraisal. Institutional economy and systems theory form the basis of the method. The method is carried out in an iterative manner and readers seeking further details are referred to the several publications that describe the approach. Monetary and non-monetary terms are treated separately and viewed as positions (conditions) and flows. A certain analysis of effects that are irreversible and/or difficult to repair should be carried out as part of the methodology. These are just a few of all steps involved, on which the information is eventually put together and presented in a document for decision support (Moberg, 1999).

PA may have some procedural points that are suitable for the assessment of an increased forest residue recovery. The method includes an analytical part of irreversible effects, and effects that are difficult to repair and restore. This could constitute a basis and give ideas for ways to address the complexity regarding biodiversity, which is a major issue for the forest ecosystem and forestry that makes use of its services. However, the method as a whole is not considered applicable for the recovery of forest residues.

3.2.6 Life Cycle Assessment (LCA)

Life Cycle Assessment is a method that analyses the environmental impact of products and services. The tool is based on the whole life cycle which means that it accounts for the overall industrial system involved in the production, as well as the use and waste management phase of the product or service. Natural resource use and pollutant emissions are described in quantitative terms. LCA is also a method that describes how studies are carried out and interpreted. The requirements in the performance of LCA are rather strict (ISO, 2006). This is different from, for instance, EIA that has no fixed directives for what is to be included in a study. LCA can be used for many different applications which put different requirements on the methodology. Some fields of applications are decision-making, product development, and market communication. International standards of life cycle assessments belong to the series ISO 14040. The LCA procedure normally consists of four stages: goal and scope definition; inventory analysis; impact assessment; and interpretation and presentation of results (Baumann, 2004).

LCA is used to compile the potential environmental effects expressed in quantitative terms, and when possible, aggregated and expressed as equivalents. One example is the recalculation of greenhouse gases into carbon dioxide equivalents. Therefore, an LCA approach would be suitable to account for GHG balances, thus serving as a tool within the framework of a procedural tool such as EIA or SEA. An EIA can supply the LCA with information on possible causes of alterations in GHG balances (soil damages/disturbances, nitrogen fertilization, litter production etc.) and thereby extend its use in this field. Some parts of the methods can potentially be used or be adapted to suit the current question of the feasibility of an increased recovery of forest residues. LCA could also be suitable for modelling purposes where different scenarios can be compared (short-term, long-term, types of fuels that are substituted by forest fuels etc.).

3.2.7 Substance Flow Analysis (SFA)

Substance Flow Analysis belongs to the group Material Flow Analysis (MFA) and focuses on one substance at a time. Normally substances related to some kind of environmental impact are monitored. Both natural and anthropogenic flows are considered. The method can find use for several applications such as detection of sources, sinks and storages. A common approach is to study the total flow of a substance in a certain region. Here the regional use and consumption of a substance might be an interesting aspect. SFA might be interesting for monitoring the flows of nitrogen, as fertilization will probably play a larger role in many parts of Sweden with an increased forest residue recovery. The flows of mercury may also be a relevant aspect of forest residue recovery in some situations for which SFA may be suitable.

3.2.8 Ecological Risk Assessment (ERA)

Ecological Risk Assessment is a tool to assess the risks of a contaminant's impact on populations of plants and animals and ecological functions such as the mineralization of organic carbon and the turnover of nutrient. Assessment of contaminated land is an area for which the method is used (Jones, 2006). Its applicability in an assessment of increased forest residue recovery is considered to be low since it is an activity with an environmental impact which does not involve pollution as such and is not a source of contamination. This tool is not able to describe the magnitude of forest residue recovery when its focus is on contaminants. It could perhaps be used as part of a bigger quantification and evaluation process to include the identified risks of an increased mercury methylation and possible ash contamination.

3.2.9 Other Methods

Environmental Accounting (EA) is a method by which environmental statistics are systemized and combined with economic statistics. This is a way to include natural resources and the environment in the national accounts of resource use. There is physical and economic environmental accounting and large amounts of data are required. Perhaps certain indicators and recognized economic values from the environmental accounting system can be used within the field of forest residue recovery, while the method as such is probably too general for the task.

Ecological Footprint (EF) is a method by which the impact of humanity on the global environment is calculated to comprise acreage use (area required to meet the demand a given number of people with their specific living standards). This type of figure can then be compared with the total amount of accessible productive area on the globe. A global average of accessible productive area per person is one of many ways to present the data. The value can be used for a comparison with the actual average of inhabitants in different countries. The method does not suit the approach in this report.

A way to present physical flows is by using tools that belong to the group of Material Flow Accounting (MFA). These tools provide information about society's resource use and give an indirect valuation of the environmental impact. There are several ways to perform these kinds of analyses but the applicability for this type of biomass extraction, namely, forest residue recovery, is inadequate. Substance Flow Analysis (SFA) that belongs to the group of MFA may prove useful in connection with the recovery of forest residues and is therefore described separately above. Apart from the limitations of using these tools for the activity of forest residue recovery, is the fact that forest residues are a raw material and constitute the product in itself, which is incinerated for the generation of energy. Material flows related to the forestry operation are therefore limited. Material Intensity per Service Unit (MIPS) and Total Material Requirement (TMR) are two other methods that belong to MFA and are therefore not discussed here.

3.2.10 Suitable Tools for Forest Residue Recovery

Forest residue recovery includes both procedural and technical aspects. The operation leads to an intensification of forestry, which calls for guidelines and directions. An increased recovery may be seen as a plan needing evaluation concerning appropriate actions for the different environmental conditions under consideration. The overall tool should thus preferably be a procedural tool within the framework of which analytical tools can be used to cover relevant technical aspects. Since the focus is on the environmental effects, the environmental impact is central in the evaluation and makes up the basis of what is to be analysed. The assessment should highlight important factors which can be guidelines when the suitability of forest residue recovery on a certain stand is evaluated. Both technical and economic aspects are important parts of the recovery but outside the scope of the work of this report. Forest residues are a renewable resource and a by-product from conventional forestry of timber and pulpwood. Therefore, apart from the recovery as an object in terms of a plan, the operation also comprises products of logging residues and stumps with the function of heat generation, which makes up a second object in the evaluation. Since the forest residues are the actual products there is no direct use of natural resources but instead a utilization of ecosystem services. The latter aspect is the question formulation with its "what-if nature" due to an increased forest residue recovery. It means that according to a future scenario more of the forest residues are to be removed than the current amounts. This makes it a change-oriented study.

When the four aspects that describe the tools for environmental systems analysis are applied to the parts of forest residue recovery concerned as above, several of the tools presented can be neglected. The tools remaining are EIA, SEA and LCA, where SEA is considered as less suitable than EIA for this purpose. Besides the application of the aspects, the choice of using an EIA methodology can be motivated by its site-specificity which rhymes well with a stand's suitability for forest residue recovery, as it accounts for environmental effects with impacts on biodiversity, acidification, and eutrophication. Since there are no strict guidelines for how an EIA should be carried out and what should be included, the process can be formed to fit the specific activity. LCA is used as part of the EIA approach to account for GHG balances by which the climate performance of forest fuels can be evaluated.

3.3 Suggestion for a Stepwise Handling Procedure

The principal aim of the work in this report is to present a suggestion for an environmental evaluation model to be applied on the recovery of forest residues. It is our intention that this can answer the question as to which environmental effects of the recovery in the Swedish context should be paid particular attention. The characteristic differences of the environmental effects form the basis for deciding which approach should be used to cover the important aspects of each. This puts some constraints on the evaluation model that serves to assess the environmental effects in relation to each other. The model should be broad enough that the environmental effects all fit within its framework but not so general that important aspects are missed. The model is intended to balance the environmental effects according to the possibilities of handling their extension and their degree of compatibility with relevant environmental quality objectives. The following sections present a suggestion for an environmental evaluation model, constructed as a *Stepwise Handling Procedure*, which is also the name the model has been given.

3.3.1 Components of the Environmental Evaluation Model

The framework of the environmental evaluation model of environmental effects of forest residue recovery, or the Stepwise Handling Procedure (SHP), is inspired by the environmental parameters of the Schmitz matrix (Finnveden, 1999) to give an answer to the question of "ecological significance". An adaption of the Schmitz matrix into which the environmental impact categories connected to the environmental effects of forest residue recovery are inserted may have the following form seen in Table 14.

Table 14. The environmental parameters of the Schmitz matrix applied for the environmental impacts caused by the environmental effects of forest residue recovery

Environmental impacts	Environmental parameters				
	Ecological threat potential	Reversibility – Irreversibility	Geographical aspects	Environmental preferences of the general public	Relationship of actual and/or previous pollution to relevant environmental objectives
Climate change					
Acidification					
Eutrophication					
Biodiversity					

As motivated in section 3.2.10, the model is based on a methodology for an environmental impact assessment and constructed as a stepwise handling procedure. Based on three main sections, the environmental effects can be evaluated step by step, and therefore be handled in a stepwise manner. Inspired by the components of the Schmitz matrix, the framework is divided into two parallel tracks: an Environmental Impact Assessment Approach (EIAA) that comprises the parameters *Ecological threat potential* and *Reversibility/Irreversibility,* and an Environmental Quality Objectives Approach (EQOA) to which *Relationship to environmental quality objectives* belongs. The parameter of *Geographical aspects* is a key component for both approaches and will thus be treated as part of both. *Ecological threat potential* is also important for the Environmental quality objectives approach but will be principally handled in the EIAA. The parameter of *Environmental preferences of the population* is not included in the evaluation model. Figure 4 shows an overview of the model with its two approaches running in parallel. The dotted line between the EIA Hierarchy and the Distance-to-Target indicates that information and feedback are flowing between the two boxes. The principle is that the information from the two approaches integrated should generate a combined result of ecological significance based on critical aspects and distance-to-target evaluations.

The part Reversibility/Irreversibility highlights the importance of considering environmental effects that might lead to environmental impacts that could be irreversible. Since an irreversible environmental impact, e.g. the extinction of a species or the destruction of an ecosystem, is in principle impossible to return to its original state, this question should be given considerable attention and restrict the proceeding evaluation. This section provides the evaluation with an early warning sign which casts a shadow over the rest of the handling procedure. It also calls for the precautionary principle that might be necessary to apply in the specific situation. The EIA hierarchy approach is used to categorize the environmental effects according to the possibilities of handling their occurrences and potential impacts. The EIA hierarchy and the previous step of Reversibility/Irreversibility make up the principal part of the handling procedure of a specific environmental effect. What is concluded from these two steps should to a large extent be decisive for the actions taken in a specific situation concerning forest residue recovery. The name "Distance-to-Target" is used for the approach in which the environmental effects and their environmental impacts are referred to the statuses and development trends of the in-depth and follow-up evaluations of the relevant environmental quality objectives. This links the current situation to the general well-being on both national and regional levels, and serves as an indicator of compatibility (the significance of the specific environmental impact from forest residue recovery in relation to the overall environmental quality objective) and an indirect prioritization of the objectives. The distance-to-target approach highlights that the development and conditions of the environmental quality objectives differ in different regions and counties in Sweden. It also brings up the question of synergies and conflicts among the environmental quality objectives. The components of the environmental evaluation model are further treated for the respective approach in later chapters. Since the parameter of geographical aspects clearly influences both approaches and their components, this is a topic which will be discussed before the other parts of the model are considered more closely.

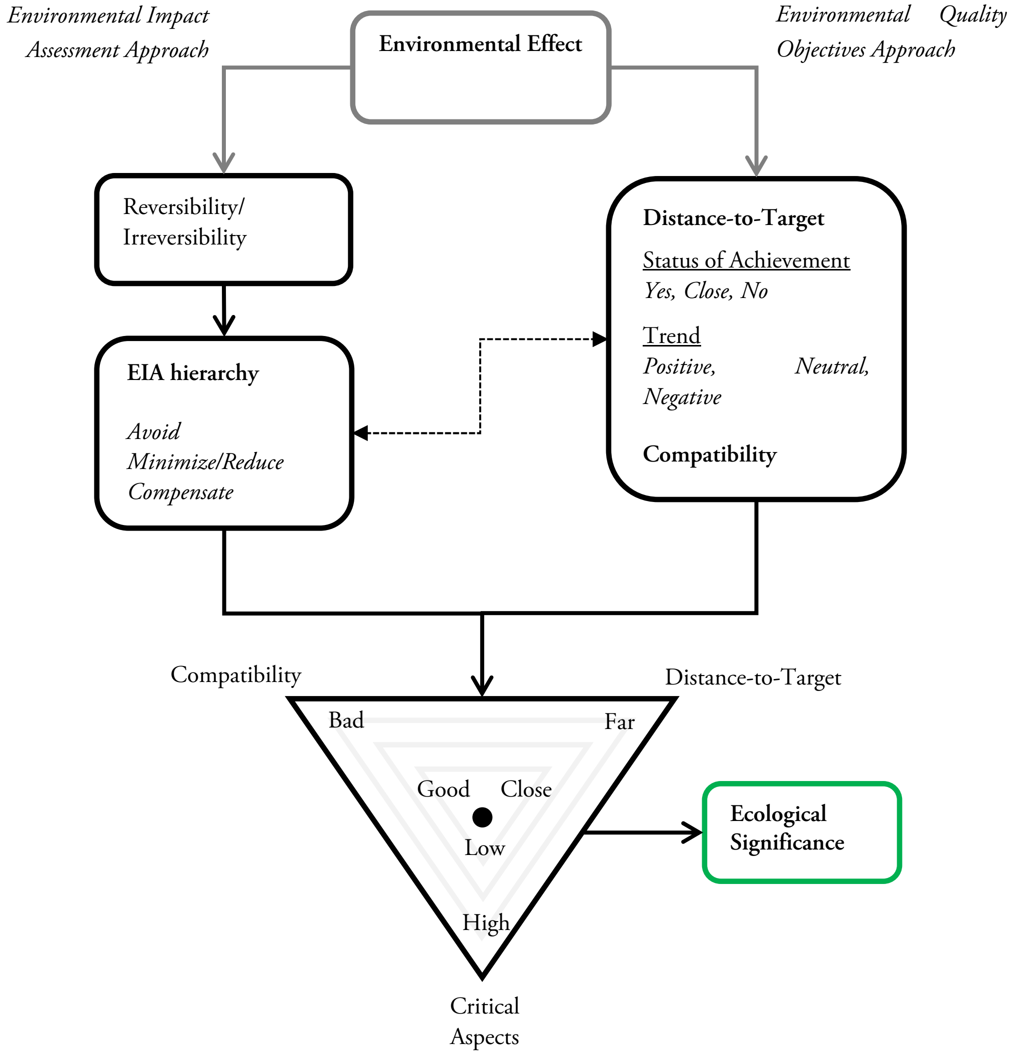

Figure 4. An overview of the environmental evaluation model which is constructed as a stepwise handling procedure and rests on two principal approaches running in parallel; an Environmental impact assessment approach (EIAA) and an Environmental quality objectives approach (EQOA).

Figure 5 shows the geographic magnitude of the environmental impact categories which may be affected by the environmental effects of forest residue recovery. The impact categories are also linked to that environmental systems analysis tool of LCA and EIA considered as most suitable for the evaluation of their potential impacts. Climate change is the only category linked to a LCA methodology. As discussed in section 3.2.10, the use of LCA to evaluate environmental effects with an impact on the climate change category can be motivated by the need for estimations of the climate performance of forest fuels. Recoveries that give rise to GHG emissions will have a negative impact on the climate performances whereas the replacement of fossil fuels will have a positive impact. For this purpose LCA is a suitable method. Climate change is also the only category with a global impact.

The connections between the environmental impact categories, on the environmental quality objectives side, and the EIA approach box, indicate flows of information. Based on the evaluations of the environmental quality objectives this information can be used to assess the environmental conditions with regard to the environmental impact categories in a specific county. These types of information can function as general indicators of how the environment and the environmental work are developing. This provides the EIA hierarchy an increased depth and the resulting categorizations can be discussed and further evaluated for specific counties on a general level. The case-study in chapter 4 was partly done to collect indicators for four counties and thereby illustrate the likelihood and the relevance of the categorization of the EIA hierarchy based on current conditions. This is a way to account for some of the prerequisites prevailing to be used in the categorization.

The environmental quality objectives side also shows a division of environmental impact categories for which Sweden has national control. Environmental effects such as GHG emissions have an impact on the climate change which is a category of global impact for which Sweden has little national control. Even though the GHG emissions occur in the counties as a consequence of forest residue recovery, it is reasonable to evaluate their contribution to climate change and the environmental quality objective *Reduced Climate Impact* on a national level. This is because reductions of GHG emissions in a certain county will not lead to positive effects specifically allocated to that county. Another reason is that the counties do not evaluate *Reduced Climate Impact*. The international dependence of achieving *Reduced Climate Impact* is substantial and GHG emissions as an environmental effect of forest residue recovery will have a global impact. This is also one reason why a distance-to-target approach of *Reduced Climate Impact* on a national level as in the 2012 in-depth evaluation is adequate. The achievements of *Natural Acidification Only* and *Zero Eutrophication* are also characterized by a significant international interdependence in which nitrogen deposition in Sweden originates mainly from sources beyond its borders. However, the environmental effects of forest residue recovery that contribute to acidification and eutrophication are occurring within the country and will have their main impacts of a geographical magnitude ranging from a stand level up to a regional level. Thus, these are parts of the environmental impact categories for which national control is strong. The same can be said for environmental effects with impacts on the biodiversity which will be even more local in their extent. The environmental quality objectives that relate to these environmental problem categories require county-based distance-to-target evaluations due to the extension of the regional environmental effects and the varying degree of dependence of the counties on international impact. An example is the acid deposition which is less in northern than southern Sweden. Therefore, the counties' prerequisites for fulfilling the environmental quality objectives are different, and this must be taken into consideration. Here the international dependence is an important factor.

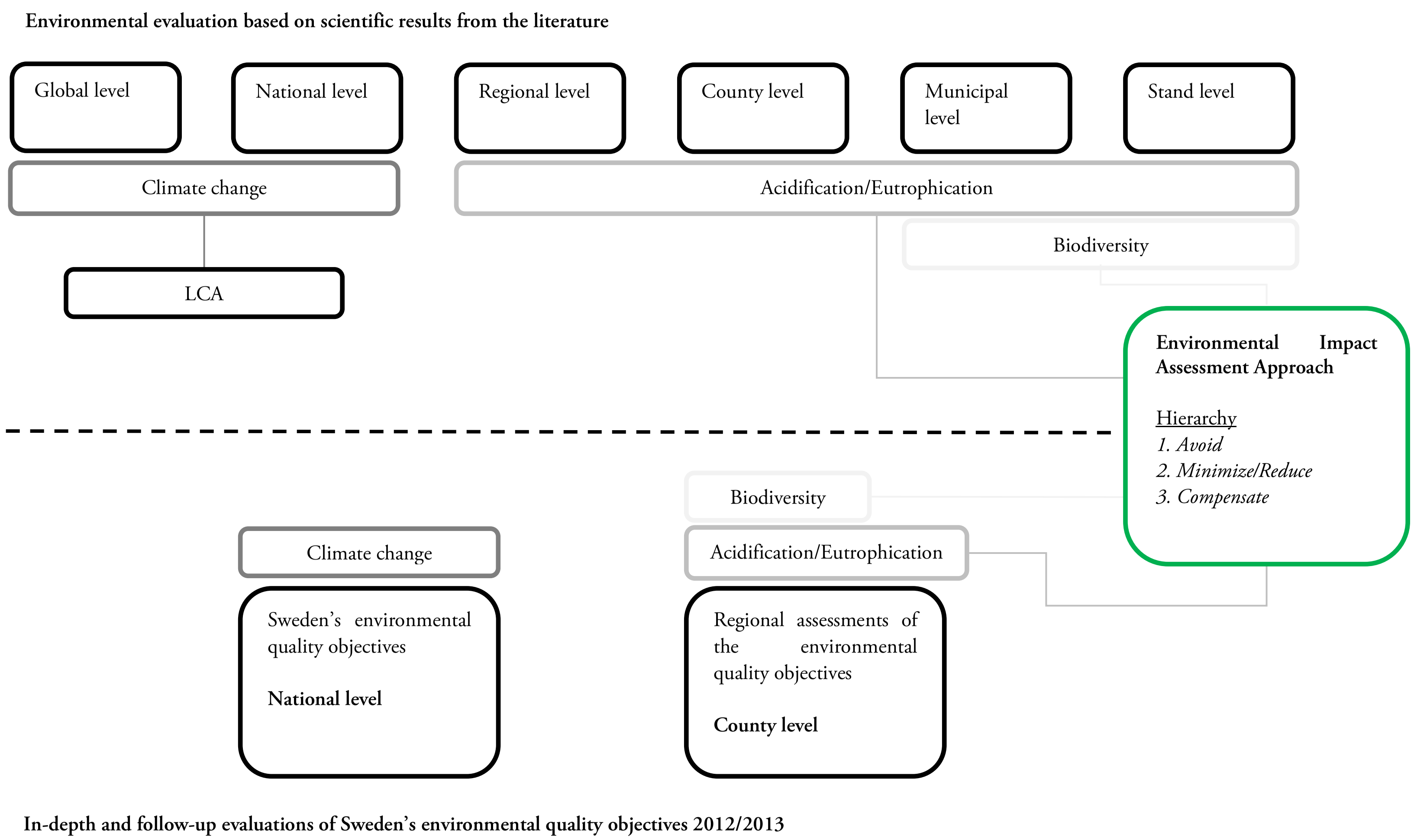

Figure 5. Overview of the geographical aspects of the environmental effects by showing the geographical magnitude of the environmental impact categories. The impact categories are linked to either LCA or EIA depending on which is most suitable to account for the specific environmental impacts.

3.3.2 Environmental Impact Assessment Approach

The requirements specified in the synthesis by de Jong et al. (2012), which need to be fulfilled to make an increased recovery of forest residues feasible without affecting the possibility of achieving the environmental quality objectives negatively, can be seen as the results of an impact prediction of what can be done to prevent and mitigate the potential impacts. The results of a modelling study by Belyazid et al. (2010) as an environmental assessment of forest residue recovery is also an example which can serve as a guide and provide information for impact prediction. The purpose of the Environmental Impact Assessment Approach is to discuss and categorize the different effects based on their likelihood of occurring and the possibilities of handling them. The Swedish Forest Agency's recommendations on logging residue recovery, stump recovery, and ash recycling, also give information about impact prediction and mitigating measures (SFA, 2008; SFA, 2009).

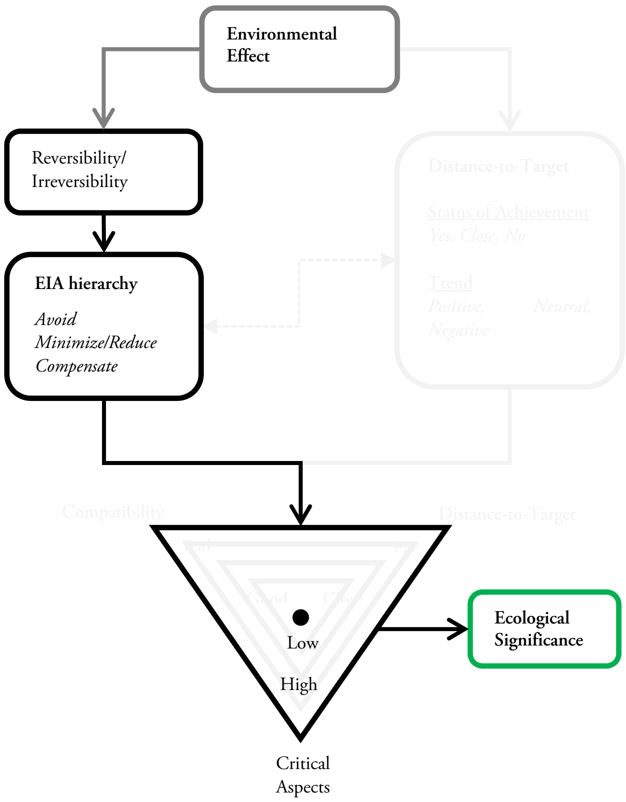

Figure 6. The Environmental Impact Assessment Approach (EIAA) of the Stepwise Handling Procedure (SHP).

Handling Based on Irreversibility – Precautionary Principle

Environmental effects with the potential to lead to irreversible environmental impacts need special attention. For this reason the environmental evaluation model contains a separate section that treats this question. Since the recovery of forest residues is directly linked to the forest ecosystem and its biodiversity, this is an aspect which clearly should be highlighted. It is a complex subject since impacts on the biodiversity might come from indirect effects due to other environmental impacts (acidification, eutrophication, climate change etc.) caused by a wide range of environmental effects. Therefore, it may be reasonable to say that the most significant impact category of forest residue recovery is on biodiversity which may result in the loss of species and valuable types of natural habitats etc. These are consequences coloured by issues of irreversibility. According to de Jong et al. (2012) there are several areas with unique species, requiring wood for their habitat, for which extinction leads to the disappearance of the species in Sweden. These areas need to be identified and completely exempted from the removal of critical substrates. This section is also a way to introduce a way of thinking in line with the Ecosystem Approach that stresses the importance of the precautionary principle (SEPA, 2008). However, an exaggerated use of the precautionary principle should be avoided, for instance in situations where social interests are important and the risks of biodiversity losses are minimal (Sandström, 2007). There are several forest-based indicators that can be used to assess the need of the precautionary principle in a specific situation. A relevant indicator is the presence of broad-leaved forest harvest residues, which is a highly valuable substrate for a broad range of species. Other indicators are the type of environment of the felling area (properties of the ecosystem such as the types of trees that have been felled and the biodiversity in the area etc.) and how the forest in the felling area has been managed historically (whether or not forestry has previously been practiced in the area) etc.

Handling Based on EIA Mitigating Hierarchy

The EIA mitigating hierarchy can be used as a method to capture the extent of environmental effects and their resultant environmental impacts. The magnitude of environmental effects depends on what the activity that gave rise to them was and the feasibility of different minimizing and compensatory measures (mitigating measures). Potential mitigating measures are also elucidated and of great importance in the assessment. The hierarchy should result in a summary of the general properties of all environmental effects which make up the groundwork of the categorization. Of course this can be performed with a high degree of detail but also a categorization based on a less detailed approach is thought to be a satisfactory guide. Table 15, which briefly describes and categorizes the environmental effects according to the EIA hierarchy, is based on the research and the corresponding results compiled by de Jong et al. (2012). The measures are built on the requirements that need to be met so as not to obstruct the possibility of achieving the environmental quality objectives of an increased forest residue recovery. The reference scenario is the current management of the existing forest.

Table 15. A summary of the impact categories and the most salient environmental effects of forest residue recovery and the measures by which they are to be mitigated and which are to be categorized according to the EIA hierarchy

Environmental impact categories	Environmental effects	Description	Measures	Overall EIA mitigating hierarchy categorization
Climate change	Alteration of the soil carbon pool	Soil disturbances such as damage and compaction caused by driving of forestry machines (likely to increase when less material of logging residues and stumps is present to serve as a protective layer and increase the bearing capacity of the soils). Stump recovery using current technology means increased disturbances.	Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Avoid, Minimize/Reduce
	Methane and nitrous oxide emissions (effect of fertilization and soil compaction/water logging)	Damage caused by driving of forestry machines in moisture-rich areas might have impacts on these types of emissions. Increased intensification of recovery leads to an increased need for nutrient compensation of nitrogen. Nitrogen fertilization can give rise to emissions of nitrous oxides.	Follow the Swedish Forest Agency's recommendations on nitrogen fertilization. Avoid fertilization where it is recommended to do so (areas with high nitrogen loads) (avoid, minimize/reduce).	Avoid, Minimize/Reduce
Acidification	Nutrient removal	Recovery of nutrient-rich logging residues. Greatly increased by logging residue recovery compared with conventional stem wood recovery. Effect from stump recovery much less than that of logging residues. Areas suffering from acidification caused by acid deposition belong to those areas where the risks of acidification originating from forestry are the greatest.	Ash recycling (compensate). Adaption of the forestry based on the acidification sensitivity (minimize/reduce).	Minimize/Reduce, Compensate
Eutrophication	Nutrient leaching	Logging residue recovery and ash recycling should in theory not imply an increased risk of nitrogen leaching, which means that their contribution to eutrophication should in the worst case still be moderate. Nitrogen leaching in connection with final felling of fertilized stands needs to be quantified. Fertilisation adjusted to stand demand can lead to an increase in nitrogen leaching. Logging residue recovery can mitigate nitrogen in certain areas with high nitrogen loads (southern Sweden). Knowledge of how ground disturbances and potential damage caused by driving of forestry machines as a consequence of stump recovery affect the leaching during the clearing phase is not adequate.	Follow the Swedish Forest Agency's recommendations on recovery, ash recycling and nitrogen fertilization. Avoid fertilization where it is recommended to do so (areas with high nitrogen loads) (avoid, minimize/reduce). Recovery of logging residues might work as a measure in itself in areas with high nitrogen loads (minimize/reduce). Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Minimize/Reduce

Environmental impact categories	Environmental effects	Description	Measures	Overall EIA mitigating hierarchy categorization
Biodiversity	Loss of forest residues which function as substrate and habitat	The removal of logging residues and stumps that might function as substrate and provide habitats for living organisms. Stumps from felling activities make up a large part of the annual production of dead hardwood in forests. Fragmentation. Environmental consideration – lack of/inadequate etc.	A functional environmental consideration at least according to law (minimize/reduce, compensate). Avoid damage to and removal of material left as part of earlier environmental considerations (avoid). Avoid recovery in close proximity to key biotopes and nature reserves (avoid). Regional assessments with regard to species occurrence (avoid, minimize/reduce). Avoid recovery of valuable broad-leaved and other broad-leaved trees completely in coniferous-dominated stands (avoid). Wildlife corridors (minimize/reduce, compensate).	Minimize/Reduce
	Damage caused by driving of forestry machines and damage to natural and cultural values.	Increased forestry machine traffic due to intensified forestry.	Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Avoid, Minimize/Reduce
Forest productivity	Decreased forest growth	Decreased growth as an impact of logging residue recovery. Observed over several decades after final felling. No permanent impact on the production capacity of forest land. Thinning seems to be more serious. Repetitive forest residue recoveries at regeneration felling, clearance, and thinning, expected to limit the forest production during parts of the rotation period in a stand. Dependent on recovery intensity and nutrient content of harvested biomass.	Nutrient compensation: ash recycling and nitrogen fertilization (compensate). Consider in connection with the type of forestry operation (weeding, thinning, felling) the recovery is done (avoid, minimize/reduce). Easier with earlier ground preparation and planting when harvest residues are recovered. This can compensate for growth reductions (compensate).	Minimize/Reduce, Compensate

Site Specificity

The evaluation according to the EIA hierarchy is dependent on the properties of the given location. One location might be more sensitive than another, which affects the magnitude and impact of a certain environmental effect. For example, an environmental effect of forest residue recovery, such as nutrient removal, might cause different degrees of environmental impact depending on the location and the prevailing environmental conditions. This is clearly shown by Belyazid et al. (2010) whose modelling study highlights the marked difference in environmental conditions between northern and southern Sweden. The environmental effects of forest residue recovery identified will thus give different prerequisites depending on the varying current environmental conditions in the country. This affects the need for measures and their potential. Even though an evaluation should be based on the conditions of a certain stand, clear environmental trends can be an incentives to carry out the evaluation at a less detailed geographical level. The current status and potential risk of acidification is probably an environmental impact category for which an evaluation in many cases can be performed at a higher level than the stand level. This would make the total evaluation less time- and labour-intensive. The biodiversity is, however, a complex subject that needs to be assessed for each location due to its explicit dependence on the prevailing environmental conditions. With an increasing need for geographical detail, the greater is the need for specific attention to the environmental effect in question. In summary, when an evaluation is performed the given location needs to be specified, but the necessity of a certain geographical level should be considered.

Potential of Measures

Based on the categorization according to the EIA hierarchy, negative environmental effects that can be avoided constitute a low or no critical aspect. Environmental effects that cannot be avoided but can be minimized or reduced constitute a higher degree of critical aspect. This category is followed by negative environmental effects that cannot be minimized or reduced but can be compensated for. The highest critical aspect will be negative environmental effects that cannot even be compensated for. If negative effects cannot be avoided, the availability of measures will play an important role in determining whether or not the effects can be minimized or compensated for. To classify an environmental effect as being possible to minimize or compensate for is not always obvious. An important aspect is also whether the EIA hierarchy is applied on environmental effects or environmental impacts caused by environmental effects, which might lead to a different categorization. An example is ash recycling that does not reduce the actual nutrient removal caused by forest residue recovery but reduces the decrease of nutrients in the forest stand. Ash recycling is thus a compensatory measure by which the negative environmental effect of nutrient removal is levelled out. In contrast, ash recycling minimizes the risk of acidification caused by nutrient removal and is therefore a minimizing measure if the environmental impact is considered. A measure to reduce nutrient removal would be to limit the recovery of forest residues by leaving a certain amount in the stand. Since the environmental impacts caused by the environmental effects are fairly well known, these will follow indirectly as part of the evaluation. Compensatory measures can also be divided into two groups, levelling measures and replacing measures. Levelling measures constitute practices carried out at the same place (e.g. forest stand), for instance, where the intervention occurs, and aim at the recreation of a lost environmental function. Replacing measures widen the concept and aim at a recreation of a lost environmental function at another place (e.g. forest area) or at the same place but with other functions than those that have been lost (Wallentinus, 2007). An advantage of focusing on the environmental effects is the higher detail and connection to certain indicators compared with the case of the more aggregated form of environmental impact.

Practicability of Different Measures

Environmental effects that can be counteracted by general compensatory measures will give these effects a "manageable status". Once again the compensatory measure of ash recycling for minimizing the risk of acidification due to nutrient removal is used as an example. Although nutrient removal is categorized as an environmental effect that can be primarily compensated for, which is the lowest grade in the EIA hierarchy, the measure of ash recycling could perhaps be seen as trivial compared with some other measures. Since ash recycling seems to be working satisfactorily when practiced, it may be appropriate to say that the operation has certain characteristics that increase its applicability as a measure. In contrast, a negative environmental effect that can be minimized according to a best-case scenario might still require measures requiring great effort in order to reach the level of "minimization". Therefore, a categorization of the environmental effects according to the EIA hierarchy should be done with care and be reviewed in an assessment. For example, the gap analysis in the 2012 in-depth evaluation, where an objective placed on the scale of four saying "No", but near the status of "Close", does not necessarily mean that it is easier to achieve than an objective further down the scale (see section 2.3.6). It is also important to consider that impacts caused by the environmental effects can be of different magnitude. An environmental effect, which is possible, in general, to avoid, might result in a significant environmental impact once it occurs. In such a case, a categorization according to "avoid" is of little value.

3.3.3 Environmental Quality Objectives Approach

To link the identified environmental effects and their potential impact, as a consequence of forest residue recovery, to relevant environmental quality objectives can be seen as quite straightforward. However, to extend the assessment and relate the environmental effects to the environmental quality objectives with the intention to attain a "compatibility indicator", by a comparison of the effects and their corresponding impact and the development of relevant environmental quality objectives, is considered to be more difficult. These issues are discussed in the sections below.

Part of an Environmental Evaluation Model

To establish the relation between the environmental quality objectives and the forest residue recovery, relevant components of the objectives which cover the environmental effects and their potential impact, need to be identified (see Figure 7). This approach is also assumed to be able to give an indication of the applicability of using the environmental quality objectives in environmental assessments of forest residue recovery. The general idea is to use the current "official" evaluation methodology and the components that form the structure of the environmental quality objectives for two closely linked purposes:

1. To discuss how the objectives can be used in an environmental assessment of forest residue recovery and their applicability. It is necessary in order to form a clear and consistent correlation of the environmental effects and their impact on the environmental quality objectives.
2. To relate the environmental effects and their impact of forest residue recovery to the objectives, in order to get an estimation of a measure of their compatibility. How do the effects affect the gap analyses of the distance-to-target approach in the 2012 in-depth evaluation?

The two purposes are closely linked in the sense that the conclusion reached on the first can be used in a subsequent evaluation of the compatibility. The basis for the first point is discussed in section 2.2. By focusing on the three aspects of specifications, indicators, and policy instruments, which are directly linked to the evaluation of the environmental quality objectives, a framework can be outlined to give the necessary "tools" for an evaluation of a specific activity. This type of evaluation is then based on the methodology that is used to evaluate the status of the environmental quality objectives. The availability of policy instruments and their functions oin creating prerequisites via measures is crucial concerning the feasibility to handle the impacts caused by the environmental effects. Well-functioning policy instruments can mitigate the extent of environmental effects and reduce their "impact significance", which leads to less severe conflicts (increased compatibility) with the environmental quality objectives. This part can be seen as an elongation of the EIA mitigating hierarchy where the potential of measures is discussed.

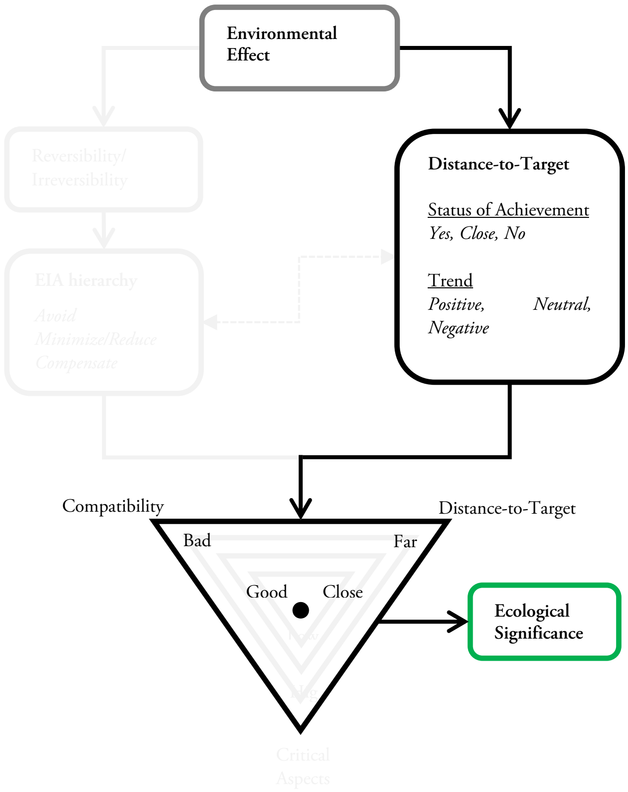

Figure 7. The Environmental quality objectives approach of the Stepwise handling procedure.

The estimation of the compatibility should preferably be performed on a county level to give a higher specificity than a national level. The in-depth evaluation is an overall result of the evaluations of the environmental quality objectives in each county. This aggregated form on a national level disguises the fact that the environmental conditions may differ significantly in different parts of the country. The general approach will be to relate the environmental effects of forest residue recovery to the environmental quality objectives and put them in a reasonable context based on the objectives' content and the information found in the in-depth and the follow-up evaluations. In this framework, the compatibility is a kind of measure that describes how the activity might affect the development of an environmental quality objective.

Meaning of Distance-to-Target in This Context

In the Environmental quality objectives approach, the section on the distance-to-target is not primarily to prioritize the environmental quality objectives based on the distance left to an achievement, but to highlight the fact that the distance of the same objectives differs from county to county. Thus, the compatibility between the environmental quality objectives and forest residue recovery differs throughout the country. In order to use a similar methodology as the gap analysis found in the in-depth evaluation, some modifications are necessary. The number of common reasons for failing achievements and the development trend of the environmental condition are parameters to which the environmental effects of forest residue recovery need to be related (see section 2.3.6). This makes it possible to integrate the environmental effects in the distance-to-target approach. Hence, the influence due to the impact of an environmental effect on the development of an environmental condition, which comprises an objective, has to be elucidated and related to an "overall" status of the objective.

The common reason of "negative impact or competition from other objectives and sectors" is an important issue for the forestry sector with its production objectives, land use, and use of ecosystem services etc., but in this case is not seen as applicable to the environmental effects. The remaining four common reasons/questions can be adapted and applied to the environmental effects to be used in a distance-to-target context (see

Table 16). These four questions are:

- Does the environmental effect have an impact on an environmental problem with a slow recovery rate in the environment? This means that positive effects of implemented measures initiated by policy instruments are likely to require a long time before they can be observed.
- What are the policy instruments directed at the environmental effect and its impact? Is there a lack of instruments or is the supply sufficient?
- If there are relevant policy instruments to hand, what are the prospects and their functionality? Do they give prerequisites that lead to sufficient measures needed to handle the environmental effect, and what about their potential implementation?
- Can the major part of the environmental objective, to which the environmental effect belongs, be solved in the county?

Table 16. Parameters adapted from the gap analysis of the 2012 in-depth evaluation to be applied on the environmental effects and be used in a distance-to-target context

	Does the environmental effect have an impact on an environmental problem with a slow rate of recovery in the environment? (National/Regional)	Is the supply of policy instruments directed at the environmental effect and its impact? (National)	Are the functionality and outlooks of the policy instruments satisfactory? (Regional)	Can the major part of the environmental quality objective, to which the environmental effect belongs, be solved in the county? (Regional)
Yes				
Neutral (in between)				
No				

The geographical level found relevant is assigned to each parameter. The development trend of the environmental quality objectives is also an important aspect which should be considered when compatibility is discussed. The distance-to-target approach is made up of two main parts. The first is to discuss how the environmental effects "behave" in relation to the four common reasons which follow below. The connections between the environmental effects and the common reasons should be highlighted. The second part is to compare the outcome of the first part with the official gap analysis of the environmental quality objectives. This is done to estimate, or rather get an idea, of which influence the environmental effects may have on the overall development of the relevant environmental quality objectives.

The generality that encumbers the gap analysis, which is based on the national evaluation of the objectives, needs to be reduced by performing county-based gap analyses. This is necessary to account for regional differences which would give the evaluation a higher specificity. However, no regional gap analyses have been performed to date, and therefore some rough estimations must to be made. This is also the reason why the case-study in chapter 4 has been undertaken. A regional gap analysis should preferably be based on the same common reasons as the national analysis in order to keep the methodology of the procedure uniform (see Table 11). Information on the development trends of the environmental conditions in each county can be found in the follow-up evaluations of the objectives compiled by the county administrative boards (see section 4.3).

Since the same policy instruments are used throughout Sweden, the identified lack of instruments concerns the whole country and not an individual county. The implementation of policy instruments may, however, differ between counties, which is an aspect that, together with the development trend, provides information for a regional gap analysis. The consequences of the fact that a significant part of the environmental quality objectives cannot be solved only within Sweden also differs among the counties and affects a regional gap analysis. One example is the significant nitrogen deposition in southwestern Sweden, which mainly originates from sources beyond the Swedish borders. This scenario with impacts on the acidification is considerably different from that in northern Sweden, which is the part of the country not exposed to the same high levels of nitrogen deposition. This implies that the distance-to-target of *Natural Acidification Only* depends much less on impact from abroad in the northern than the southern parts of Sweden. Therefore, it is obvious that also the aspect of international interdependence will have a major influence on a regional gap analysis. Once the environmental effects of forest residue recovery are evaluated and placed in a distance-to-target context they should be compared with the gap analyses of the environmental quality objectives on a county level. This comparison represents a way of estimating the compatibility between the environmental effects and the environmental quality objectives.

4 Case Study of Forest Residue Recovery in Four Swedish Counties

4.1 Introduction

The Environmental impact assessment approach in the *Stepwise handling procedure* is dependent on the possibilities of handling the environmental effects that arise due to forest residue recovery. The prospects for these possibilities vary across the country due to regional environmental conditions and different prerequisites. The purpose of the case-study performed and reported in this chapter is to bring up this type of aspects and elucidate the counties' forest land features. As part of the Environmental quality objectives approach, the follow-up evaluations of relevant objectives are summarized to show the status of the environmental conditions and their prospects of achievement in each county. This information is important since it comprises features of which the gap analysis methodology in the in-depth evaluation of 2012 is based on. The aim of the case-study is to generate general findings regarding possibilities and drawbacks of the suggested environmental evaluation model, the *Stepwise handling procedure*.

The four counties in the case-study are Västerbotten, Dalarna, Stockholm, and Skåne. Table 17 shows some basic facts on them. Their locations in Sweden and to which type of vegetation zone they belong are seen in Figure 8.

Table 17. Some general information about the four counties in the case-study (SCB, 2013)

	Västerbotten	Dalarna	Stockholm	Skåne
Vegetation zone	Boreal	North-South/South Boreal	Boreo-Nemoral	Nemoral
County land area [hectares]	5,540,100	2,819,300	649,000	1,102,700
Population	259,290	277,050	2,054,340	1,243,330

The counties of Västerbotten and Dalarna are located in northern Sweden. Both are sparsely populated and consist largely of forest land. Their land area is also substantially larger than of the other two counties in the study. Therefore, their forest fuel potential is significant. Stockholm and Skåne are two densely populated counties with a relatively small proportion of forest land and forest fuel potential, but their high population generates a greater demand for forest fuels than in the northern counties. While Västerbotten and Dalarna are counties characterized by exporting forest fuels, Stockholm and Skåne are importers.

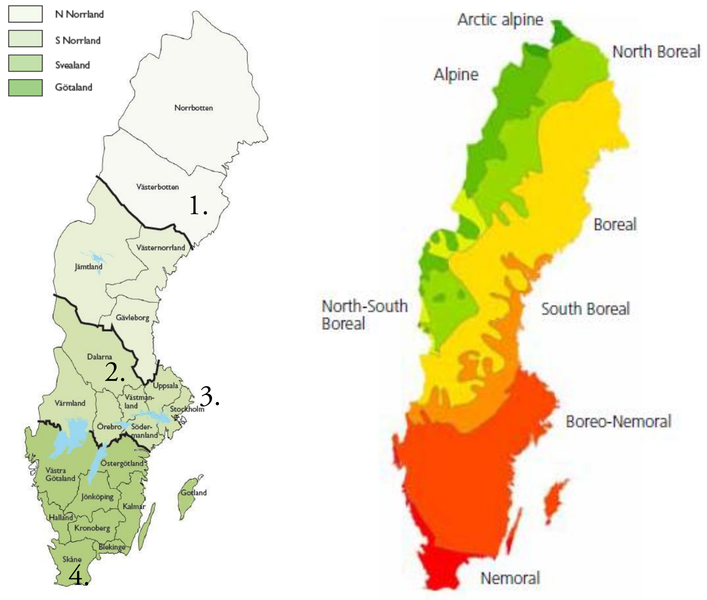

Figure 8. (**A**) Location of the four counties (SFA, 2012) and (**B**) the vegetation zones of Sweden (KSLA, 2009).

4.2 County and Regional Indicators from Forestry Statistics

The type of data presented in this case study is guided primarily by the requirements stated by de Jong et al. (2012). Table 18 can be used as a checklist and shows how the different forestry data relate to the prerequisites and specifications regarding relevant environmental quality objectives. Each section begins with a set of indicators based on the information presented. These indicators can be related to relevant specifications and discussed in that context. The indicators might imply negative as well as positive impacts on the specifications of the objectives.

Table 18. An overview of how the requirements by de Jong et al. (2012) and relevant specifications of relevant environmental quality objectives relate to the different categories of forestry statistics presented in the case-study

	Forest and Forest Land	Protected Productive Forest Land	Environmental Consideration	Felling and Wood Measurement	Recovery of Logging Residues	Ash Recycling	Large-Scale Forestry Fertilization	Urban Forests	Wood Fuel
Requirements									
Tree Types	x	x	x	x	x				
Ash Recycling	x				x	x			
Environmental Consideration	x		x						
Other Restrictions (nitrogen deficiency, driving damages)	x		x						
Specifications									
Reduced Climate Impact									
Temperature					x				x
Concentration					x				x
Natural Acidification Only									
Acidifying effects of forestry	x					x			
Acidified soils	x					x			
Zero Eutrophication									
Pressure on the marine environment							x		
Pressure on the terrestrial environment	x						x		
Sustainable Forests									
Qualities and processes of the forest land	x	x	x	x	x	x	x		
Ecosystem services	x	x	x	x	x	x	x		
Green infrastructure	x	x	x		x				
Threatened species and restored habitats	x	x							
Preserved natural and cultural heritage values	x	x	x	x	x				
Outdoor recreation	x	x	x					x	
A Rich Diversity of Plant and Animal Life									
Green infrastructure	x	x	x		x				
Biological cultural heritage	x	x	x						
Nature on the urban fringe	x		x					x	

4.2.1 Forest and Forest Land

Indicators: (i) Area of productive forest land (measure of the potential extent of forestry land use), (ii) area distribution by age class of productive forest land (measure of the proportion of old forest with comparatively long continuities of the total forest), (iii) distribution of productive forest land by site productivity (guidance for recommended ash dosage, indication of regional production differences).

A fundamental figure regarding potential forest fuel recovery is the total area of productive forest land in each county. The total figure for productive forest land area provides a base-line with which, for example, the area of formally protected forest land can be related. The proportion of productive forest land of the total land area of the county illustrates the distribution among the counties. The indicators presented have a connection to several of the specifications and all of the prerequisites of de Jong et al. (2012). The proportion of old forest is important for the biodiversity since it represents forests of relatively long continuity which are likely to have forest ecosystem properties that are lacking or rare in intensively managed forests. Long continuities of previously managed forests, imply that the forest ecosystems might be returning to a more “natural” state, which is positive for several specifications of the environmental quality objectives. Thus, the number of old forests is an important indicator for biodiversity and those objectives that are linked to this environmental impact category.

Area of Productive Forest Land

The meaning of productive forest land is forest land suitable for timber production. The land should be able to produce an average volume of timber of at least one cubic metre per hectare and year. The area of productive forest land seen in Table 19 is essential information to the possibilities of practicing forestry in these counties. The definition of old forest in Sweden depends on the region. In northern Sweden (Västerbotten and Dalarna) a forest should be more than 140 years to be defined as old, and more than 120 years in Stockholm and Skåne. The area of productive forest land is divided by age class in Figure 9 and Table 20. Note that the total area of productive forest land for the period 2006-2010 in Table 20 and Table 21 differs from that in Table 19 for the year 2011. The data for year 2011 are used as the total area of productive forest land, if not otherwise defined.

Table 19. Proportion of productive forest land of total county land area (SCB, 2011), year 2011

County	Productive forest land [1,000 hectares]	County land area [1,000 hectares]	Share of productive forest land
Västerbotten	3,125	5,519	57 %
Dalarna	1,984	2,820	70 %
Stockholm	276	652	42 %
Skåne	350	1,104	32 %

The area distribution by age class gives the area where final felling and forest residue recovery is, or is not to be advocated, based on the age of the forests.

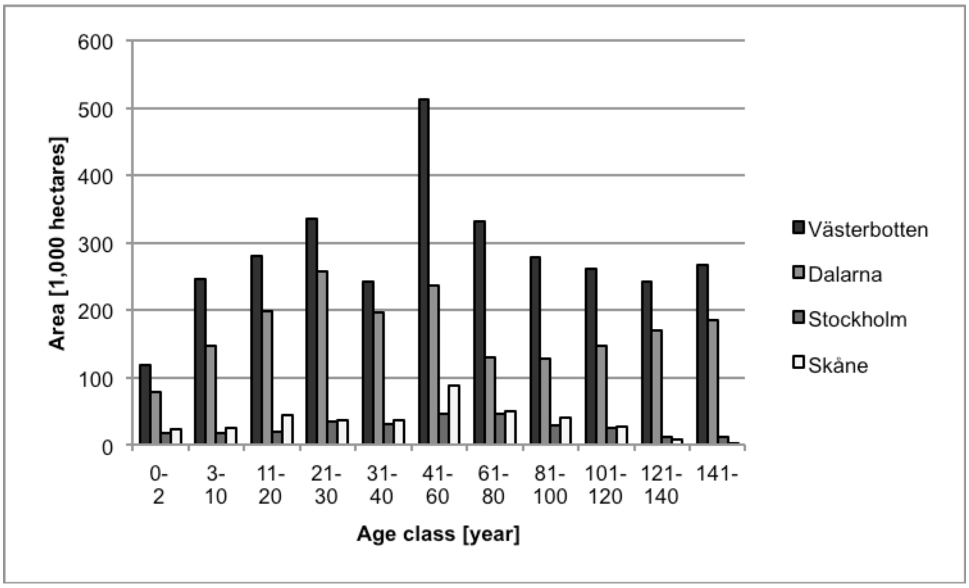

Figure 9. Area of productive forest land in each county over the period 2006-2010 (excl. protected productive forest land).

Table 20. Area of productive forest land by age class over the period 2006-2010 (excl. protected productive forest land)

County	0-2	3-10	11-20	21-30	31-40	41-60	61-80	81-100	101-120	121-140	141-	**Total**
	[1,000 hectares]											
Västerbotten	119	246	280	336	243	512	332	278	261	242	267	**3,114**
	4 %	8 %	9%	11 %	8 %	16 %	11 %	9 %	8 %	8 %	9 %	
Dalarna	78	147	198	257	196	236	130	128	147	170	186	**1,872**
	4 %	8 %	11 %	14 %	10 %	13 %	7 %	7 %	8 %	9 %	10 %	
Stockholm	17	18	19	34	32	46	47	29	25	12	13	**293**
	6 %	6 %	6 %	12 %	11 %	16 %	16 %	10 %	9 %	4 %	4 %	
Skåne	23	26	45	37	36	89	51	40	27	9	2	**387**
	6 %	7 %	12 %	10 %	9 %	23 %	13 %	10 %	7 %	2 %	1 %	

Site Productivity

Site productivity is a measure of the capacity of a forest site of producing timber under ideal conditions. It is calculated as an average timber production per hectare and year of a stand. The site productivity clearly demonstrates regional differences of forest land across Sweden. This is seen in Västerbotten and Skåne, which are two "extremes", located in the northern and southern parts of Sweden, respectively (see Table 21). The site productivity is also relevant for wood ash recirculation. The Swedish Forest Agency, for example, uses the specific soil fertility as a basis for the recommended dosage of ash. As can be seen in Table 21, Skåne has the highest soil fertility with 71 percent of its productive forest land area in the two top classes (11-12 m^3 standing volume over bark/ ha, year).

Table 21. Productive forest land area and site productivity during the period 2006-2010 (excl. protected productive forest land)

County	Forest land area [1,000 hectares]	Site quality class (by best species) [m^3 standing volume over bark/ha, year]											
		1-	2-	3-	4-	5-	6-	7-	8-	9-	10-	11-	12-
		percent of forest land area											
Västerbotten	3,114	6	33	42	16	4	0	0	0	0	0	0	0
Dalarna	1,872	3	15	19	15	23	12	9	3	1	0	0	0
Stockholm	293	0	1	4	10	19	8	17	23	6	9	3	0
Skåne	387	0	2	1	1	2	6	6	3	2	7	35	36

4.2.2 Protected Productive Forest Land

Indicators: (i) Formally protected area of productive forest land, Distribution of general forest types in national parks and nature reserves, (ii) area of productive forest land left to be protected until the end of the expired interim target on long-term protection, (iii) area of key woodland habitats on privately owned productive forest land (estimation of unprotected area of forests with high conservation values on productive forest land).

The protected area of productive forest land shows how much of the area that is exempted from forestry and thus forest residue recovery. To enlarge the concept of protection it is necessary to investigate the number of forests in the counties classified as worthy of protection. The category "protected productive forest land" generates indicators that describe conditions that are in line with many of the relevant specifications (see Table 18) and therefore have positive impacts on the environmental quality objectives to which they belong.

Formal Protection

In Sweden there are four categories of formal protection of the natural environment. A *national park* is a large area of continuous land conserved to "preserve a certain type of landscape in its natural state or in essentially unspoiled condition". The Swedish parliament and government decide on the establishment of national parks. The land must be owned by the state. *Nature reserves* are the most common type of formal protection. County Administrative Boards and municipalities have the power to decide on their establishment. According to Chapter 7, Section 4, of the Swedish Environmental Code, the purpose of nature reserves is to preserve biodiversity, conserve and maintain valuable natural habitats, satisfy needs for outdoor recreation, and/or protect, restore or create natural environments and valuable habitats for specific species. The term *habitat protection area* is used for smaller land and water areas that provide habitats for plants and animals threatened with extinction, or are worthy of protection for some other reason. Commercial activities that might damage the natural environment are not permitted to conducted on these sites. On agricultural land the County Administrative Board decides on the establishment of habitat protection areas. Concerning forest land it is usually the Swedish Forest Agency must make the decision. Also the County Administrative Board is empowered to do this. In general this type of protection is used to protect key biotopes. The last of the four is the *nature conservation agreement* which is an agreement between a landowner and the state or a municipality. This may imply that timber production is restricted to a small section of the forest for the benefit of biodiversity. The agreement is based on voluntary co-operation by the landowner and has a maximum validity period of 50 years (SFA, 2012). About 60 % of the Natura 2000 sites in Sweden are covered by forms of protection other than national parks, nature reserves, and habitat protection areas (SFA, 2013). To avoid double counting, the Natura 2000 sites are not included in the total number of protected areas (see Table 22). The information on voluntary conservation areas is given by region, not county, and is therefore not included in the table.

Table 22. Protected area of productive forest land, year 2011

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
National parks and Nature reserves (incl. montane forest) (2011)	100,610	74,207	14,758	9,693
Habitat protection areas (incl. montane forest) (2011)	1,670	1,927	894	818
Nature conservation agreements (2011)	1,892	2,954	1,056	723
Total	**104,172**	**79,088**	**16,708**	**11,234**
share of total area of productive forest land	3.7 %	4.0 %	6.1 %	3.2 %
Total area of productive forest land	3,125,000	1,984,000	276,000	350,000

The importance of substrates from valuable broad-leaved trees for many wood-living species makes it reasonable to consider the distribution of forest types in the counties' national parks and nature reserves. The figures in Table 23 can be compared with the standing volume on productive forest land based on tree species in Table 30.

Table 23. Protected productive forest land based on "forest type" in national parks and nature reserves, year 2011

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
Coniferous forest	91,470	62,251	9,675	1,237
	82.7 %	83.9 %	65.6 %	12.8 %
Mixed forest	11,889	7,180	1,862	747
	10.7 %	9.7 %	12.6 %	7.7 %
Broad-leaved forest	5,013	2,569	2,088	6,559
	4.5 %	3.5 %	14.1 %	67.7 %
Felled area and young forest	2,238	2,207	1,133	1,149
	2.0 %	3.0 %	7.7 %	11.9 %
Total	**110,610**	**74,207**	**14,758**	**9,693**
proportion of total area of productive forest land	3.5 %	3.7 %	5.3 %	2.8 %
Total area of productive forest land	3,125,000	1,984,000	276,000	350,000

Formal Protection by an Expired Interim Target

The previous interim target of the environmental quality objective *Sustainable Forests* on the long-term protection of forest land expired in 2010. The national objective of the interim target was to exempt a total of 900,000 hectares of productive forest land between the years of 1999-2010. This area was distributed and regionalized by the counties, which formed their strategies for the exemption of forest land by formal protection and voluntary conservation. The areas of voluntary conservation are not presented by county in the forestry statistics and therefore are not considered in this section of the case-study. However, areas of voluntary conservation made up a substantial part of the area covered by the strategies established.

On the national level, 500,000 hectares of the total 900,000 hectares were assumed to be protected by voluntary conservation. Table 24 shows that none of the counties fulfilled the interim target (although the target was achieved on a national level).

Table 24. The formal protection of productive forest land compared with the former interim target on the long-term protection of forest land for the period 1999-2010 (N/S – not specified)

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
Nature reserves 1999-2010	26,300	N/S	6,880	3,556
Nature reserves according to objective	34,000	32,160	12,300	5,180
Habitat protection areas and Nature conservation agreements 1999-2010	6,000	N/S	1,650	1,317
Habitat protection areas and Nature conservation agreements according to objective	3,056	8,040	4,100	2,220
Total 1999-2010	**29,356**	**21,400**	**8,530**	**4,873**
Total according to objective	40,000	40,200	16,400	7,400
Proportion of objective area	73 %	53 %	52 %	**66 %**

Key Habitats

A key habitat is an area that has great significance for the flora and fauna of the forest and it contains, or can be expected to contain, species found on the red list. Thus, key habitats are important for the conservation of biodiversity and several of the specifications that belong to *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*. The Swedish Forest Agency started to inventory key habitats on small-scale forestry holdings in 1993, an area corresponding to almost 12 million hectares. The inventory has been divided in two phases prior to the current period. The first phase continued till 1998 and the second lasted from 2001 till 2006. Today's inventory is carried out on a small scale. Owners and operators of medium-size and large-scale forestry conduct their own inventories, which are not presented as part of the forestry statistics. A control inventory in the year 2000 brought to light a large number of previously unrecorded key habitats. The investigation estimated the number and area of key habitats to be five times as many and five times as large as identified in previous inventories (SFA, 2001). The control inventory showed a significant need for ongoing inventories and still today many key habitats remain unrecorded but many are successively being identified (SFA, 2007; SFA, 2007b). According to the 2012's in-depth evaluation of the environmental quality objective *Sustainable Forests*, nearly 500 hectares forests with key habitats are felled annually. About one third of these were known previously while the rest was unidentified at the time of felling. Due to high values for biodiversity in key habitats, felling should be restricted or preferably avoided, as should also forest residue recovery.

The figures showing the geographical distribution of key habitats indicate high frequencies in Skåne and Stockholm compared with Dalarna and Västerbotten (see Table 25 and Figure 10). The data show that in relation to the other counties, the proportion of key biotopes of the total area of productive, privately owned forest land is high in Stockholm. Recovery of forest residues in these areas is likely to have extensive negative impacts on the biodiversity.

Table 25. Area of forest key habitats on privately owned land (individual forest owners), year 2011

	Västerbotten	Dalarna	Stockholm	Skåne
Privately owned productive forest land [1,000 hectares]	1,296	797	162	273
Number of key habitats	1,970	3,280	2,505	2,513
Total area of key habitats [hectares]	13,122	16,259	11,032	3,883
of which is productive forest land [hectares]	11,798	14,080	9,434	3,463
Proportion of total area of privately owned productive forest land	0.9 %	1.8 %	5.8 %	1.3 %
Total area of productive forest land [1,000 hectares]	3,125	1,984	276	350
Proportion of privately owned productive forest land of total area of productive forest land	41 %	40 %	59 %	78 %

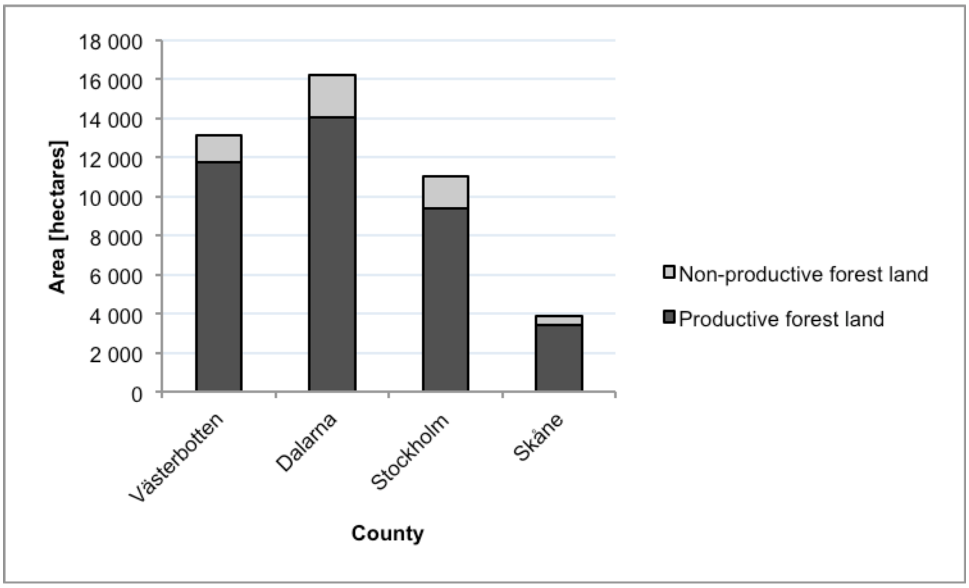

Figure 10. Area of key habitats on privately owned forest land, year 2011.

The recommendations by the Swedish Forest Agency are that forests with high values for biodiversity, such as key habitats, should be exempted from forest residue recovery. Wetland forests have a high frequency of such high values and are also found on the list of key habitats. Due to their properties this type of forest usually has soil of poor bearing capacity and therefore driving of forestry machines easily causes soil damage (SFA, 2008). The requirements by de Jong et al. (2012) also stipulate that recovery of logging residues and stumps should be avoided adjacent to key biotopes and nature reserves.

Data from Forest Companies in Sweden

Since the large forest companies conduct their own inventories of key habitats this type of information is documented elsewhere than in the forest statistics. General figures can easily be found on the biggest forest companies' webpages (see Table 26). The data presented concern primarily forest land voluntarily set aside for nature conservation, and specific information about key biotopes is usually lacking. The extent to which these areas qualify as key biotopes cannot be read from the data. However, the information can be used for comparisons between companies and give indications of their work on biodiversity conservation and protection of forest land. Statistics on the area of forest set aside for nature conservation by the company SCA Skog is lacking.

Table 26. Data on the area of forest land owned by large forest companies and the area of which is set aside for nature conservation

Svea Skog
Owns about 4.1 million hectares of forest land. 3.1 million hectares are productive forest land. 300,000 hectares are nature conservation forests of which about 75,000 hectares are key biotopes (www.sveaskog.se).
SCA Skog
The company owns in total 2.6 million hectares of forest land of which 2 million hectares are used for forestry. About 1 percent of SCA's forest land is key habitats, which is equivalent to approximately 20,000 hectares (www.sca.com).
Bergvik Skog
1.9 million hectares of productive forest land. Just over 100,000 hectares of productive forest land are voluntarily set aside for nature conservation located below the boundary of sub-montane forests (www.bergvikskog.se).
Holmen
1,032,800 hectares of productive forest land. 60,000 hectares of productive forest land voluntarily set aside for nature conservation (www.holmen.com).
Statens fastighetsverk
Northern Sweden: 870,000 hectares of productive forest land. 450,000 hectares are nature reserves. 110,000 hectares are to become nature reserves. 35,000 hectares are voluntarily set aside. 250,000 hectares are used for forestry. Southern Sweden: 11,700 hectares of productive forest land. 2,000 hectares are nature reserves. 2,000 hectares are voluntarily set aside. 8,600 hectares used for forestry (www.sfv.se).
Svenska kyrkan
Owns 396,000 hectares of productive forest land. Of these 8.6 % are voluntarily set aside for nature conservation (www.svenskakyrkan.se).

4.2.3 Urban Forests

Indicators: (i) *Urban forests of recreational importance, (ii) share of protected urban forests*

The category "Urban forests" includes two applicable specifications regarding environmental quality objectives. For *Sustainable Forests* it concerns the specification about outdoor recreation ("the value of forests for outdoor recreation is safeguarded and maintained") and for *A Rich Diversity of Plant and Animal Life* it concerns the specification about forests close to urban areas ("natural environments near urban areas that are valuable for outdoor recreation, cultural heritage and biodiversity are safeguarded and maintained, and are accessible to the public"). Currently the recovery of logging residues is high in densely populated areas due to the big demand for forest fuel in district heating plants. In contrast, logging residue recovery is lowest in the inland of Norrland, where the demand is lower and the costs of transportation are higher (SEPA, 2011b). In recreational and urban forests the recovery of logging residues is beneficial, giving easier access for visitors to the terrain (SFA, 2008). However, stump recovery may have short-term negative effects on the landscape and temporarily restrict access. Therefore, there is potentially a conflicting scenario if stump recovery is practiced in such forests (SFA, 2009).

Urban forests are defined as forests within a radius of 1 km from the border of an urban area. The data used are from Lantmäteriet (the Land Survey) and the area of forest land is based on their definition and not totally comparable with the definition of forest land in the Swedish Forestry Act (see Table 27). Areas of national recreational interest are defined by the government, according to Chapter 3, Section 6, of the Swedish Environmental Code. This is one of the Code's policy instruments directed at the management of land and water areas. The areas of urban forests belonging to the areas of national recreational interest are shown for each county in Table 27. The population and urban forest land per inhabitant give indications of the "recreational intensity" and the demand for forest fuels. The protected area in Stockholm County is almost twice as big as the area of national recreational interest.

Table 27. Urban forests of recreational importance, year 2011

	Västerbotten	Dalarna	Stockholm	Skåne
Population	259,667	276,565	2,091,473	1,252,933
Area of national recreational interest [hectares]	51,846	360,574	68,879	69,775
Urban forests				
Forest land [hectares]	36,757	88,956	83,687	56,220
Forest land per inhabitant [sqm/inhabitant]	1,416	3,216	400	449
Protected area [hectares]	407	1,310	11,107	2,760
Area of national recreational interest [hectares]	1,307	23,562	6,094	7,590
Key habitats (incl. companies' area) [hectares]	130	1,115	3,336	721

4.2.4 Environmental Consideration

Indicators: (i) Environmental consideration in connection with regeneration felling (measure of a sustainable forestry including forest residue recovery).

The environmental consideration is a broad category that comprises many components and therefore generates many indicators which can be used to "measure" the sustainability of forestry, and thereby logging residue recovery (see

Table 28 and Table 29). The definition of environmental consideration is stated in the Forestry Act (30 §) and serves to reduce the impact by forestry on forest ecosystems throughout the country. Therefore, the various indicators of this category relate to almost all prerequisites and specifications in Table 18. Environmental consideration is a way to increase the compatibility with relevant specifications and their environmental quality objectives.

Table 28. Percentage of logged area in which environmental consideration is taken in accordance with the Swedish Forestry Act, year 2007/2008-2009/2010

Factor requiring consideration	Proportion of logged area requiring consideration [%]	Degree of consideration taken [%]		
		Complete	Partial	Negligible
Sensitive habitats	61	47	25	29
Unusual trees and shrubs	89	54	31	16
Buffer zones	53	61	24	15
Red-listed unusual species	24	33	35	31
Non-productive forest land	23	85	12	3
Historical-cultural values	31	58	29	13
Land and water	98	66	26	8
Social values	15	71	16	14
Size of felling area and demarcation	46	77	16	7

Table 29. Impact on some impact categories during regeneration felling, year 2008/2009-2010/2011

	N. Norrland	S. Norrland	Svealand	Götaland	Private individual land	Other owners	Entire country
Proportion (%) of regeneration fellings requiring consideration							
Proportion of the number of […] divided into degree of impact (%)							
Sensitive habitats							
Proportion	30	76	55	41	44	58	48
None negative impact	63	65	65	63	58	72	64
Moderate negative impact	17	14	23	21	22	17	20
Strong negative impact	20	21	12	16	20	11	16
Buffer zones							
Proportion	59	50	41	29	36	51	40
None negative impact	68	79	63	60	65	69	67
Moderate negative impact	26	11	25	29	24	22	23
Strong negative impact	6	10	12	11	11	9	10
Historical-cultural values							
Proportion	7	19	40	31	28	28	28
None negative impact	60	74	52	56	57	55	56
Moderate negative impact	18	13	41	34	33	40	35
Strong negative impact	22	13	7	10	10	5	9
Stream crossings							
Proportion	13	28	20	17	17	24	19
None negative impact	74	58	50	68	56	72	61
Moderate negative impact	23	18	38	24	29	22	27
Strong negative impact	2	25	12	9	15	6	12

4.2.5 Felling and tree species

Indicators: (i) Potential supply of substrate from valuable broad-leaved trees based on the standing volume, (ii) annual gross fellings as a rough indicator of which tree species are likely to be felled.

Standing volume

According to de Jong et al. (2012), the recovery of forest residues should be limited in stands with broad-leaved tree species. It is therefore important to carry out regional assessments based on species occurrence. Oak and beech are the two tree species which are most valuable for red listed species in Sweden (SEPA, 2004). In this respect Skåne in particular has a significant percentage of oak and beech (15.5 %) of the total standing volume as a prominent feature on productive forest land (see Table 30 and Figure 11). Data on the standing volume on productive forest land according to tree species, provides information about potential substrates important for biodiversity and which might be treated as forest residues and thus be removed. Since the supply of this type of substrate is crucial for the species richness and the biodiversity of the forest as a whole, there is a relation to several specifications of *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*. However, data regarding felling of specific tree species is limited but national data on the applications for permits for final fellings of valuable broad-leaved forests under 27 § of the Swedish Forestry Act are available. This can give a rough indication of the final felling of broad-leaved tree species.

Table 30. Standing volume on productive forest land by species, year 2006-2010 (excl. protected productive forest land)

	Västerbotten	Dalarna	Stockholm	Skåne
Tree species million cubic metres standing volume (stem volume)				
Scots pine	131	122	19.4	10.4
Norway spruce	114	76.6	20.9	35.1
Other coniferous	4.1	0.9	0.2	0.1
Birch	48.4	21.9	6.0	8.1
Other broad-leaved	4.6	4.4	5.7	5.8
Oak	0.0	0.0	1.8	5.4
Beech	0.0	0.0	0.0	10.1
Other selected valuable broad-leaved	0.0	0.0	0.7	2.1
Total	**302**	**226**	**54.6**	**77.1**

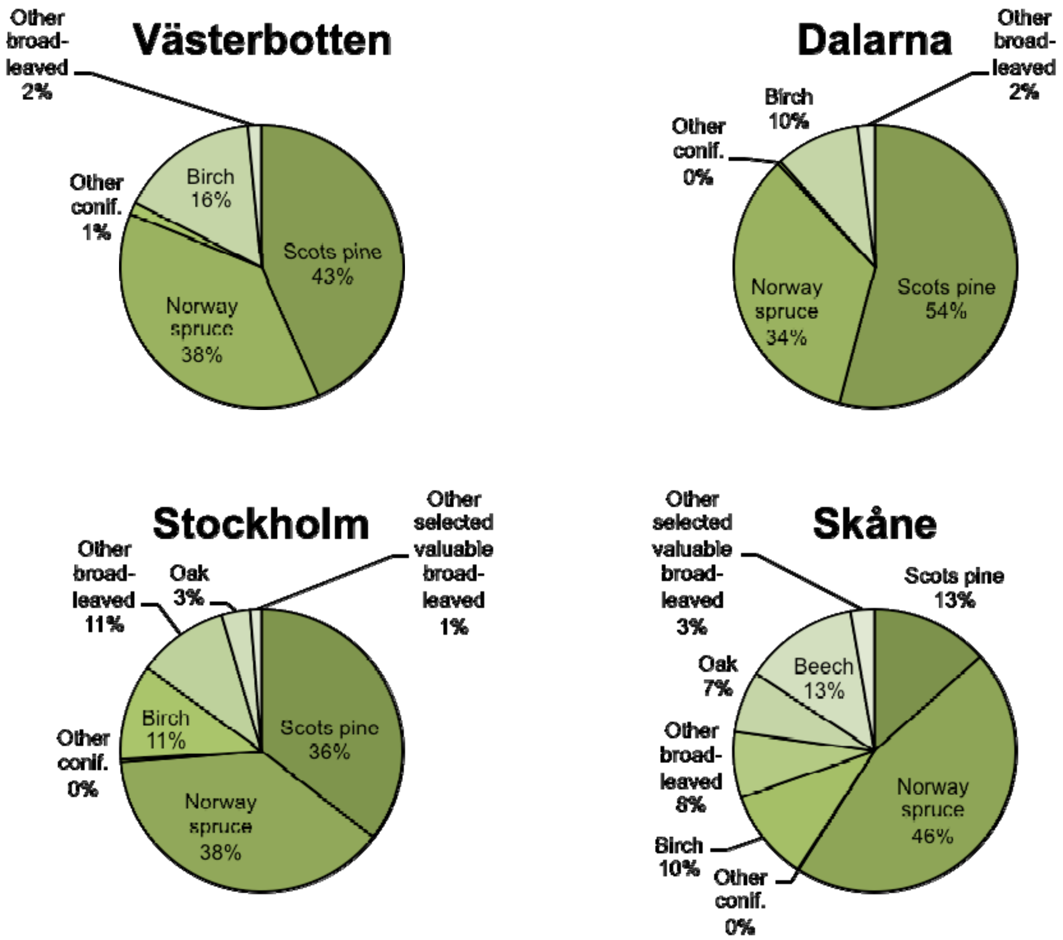

Figure 11. Proportion of tree species of the standing volume on productive forest land, year 2006-2010 (excl. protected productive forest land). Values of other coniferous trees equivalent to 0 % are rounded figures.

Coniferous trees should, from a biodiversity point-of-view, thus make up the primary type of logging residues that are recovered. The percentage of coniferous trees of the total standing volume in each county is therefore shown in Table 31.

Table 31. Proportion of coniferous trees of the total standing volume on productive forest land, year 2006-2010

County	Percentage of coniferous trees [%]
Västerbotten	82
Dalarna	88
Stockholm	74
Skåne	59

An additional indicator of relevance regarding the potential area of logging residue recovery is data on annual gross fellings per county and ownership category. This is shown in Table 32.

Table 32. Annual gross fellings per county and ownership category, year 2008-2010

	Västerbotten	Dalarna	Stockholm	Skåne
[1,000 m^3 standing volume/year]				
State and other public owners	1,138	748	106	280
Private companies and other private owners	2,998	3,942	405	728
Individual owners	1,602	1,581	673	1,791
Total	**5,738**	**6,270**	**1,183**	**2,798**

4.2.6 Recovery of Logging Residues and Ash Recycling

Indicators: Intensity of forest residue recovery, Area of ash recycling per unit area of logging residue recovery, Ash dosage (tonne DW per hectare – compared to recommendations by the Swedish Forest Agency).

Recovery of Logging Residues

The data of logging residue recovery in final felling and thinning are based on surveys of large- and small-scale forestry and are presented in volumetric units of m^3 loose volume (wood chips) per year (SFA, 2012). The proportion of forest residue recovery in thinnings is an indicator of the intensity of forest residue recovery in the counties. Recovery in connection with thinning can result in growth reductions, the removal of nitrogen probably being the main reason in northern Sweden (de Jong, 2012). Therefore, de Jong et al. (2012) recommend that logging residue recovery, without nitrogen fertilization as a compensatory measure, should be limited in connection with thinning. The damage on roots and trees, and soil compaction due to driving of forestry machines, might also be more serious in thinning than in final felling. As seen in Table 33 the recovery of forest residues in thinnings, relative the total recovery, is particularly high in Stockholm. Also in Skåne this fraction is fairly high as is total recovery, which is almost as much as in Västerbotten, where the volume of annual gross felling is more than twice that of Skåne. A conclusion to be drawn from these figures is that logging residue recovery is quite intensive in Stockholm and Skåne which are both densely populated regions with large biofuel-based plants for heat and power generation. As a result, these two counties belong to areas in Sweden that already face, or soon will face, deficits of local forest fuels relative to biomass energy demands. The deficits of local forest fuels and inflows of biofuels to district heating plants in Sweden are shown in Figure 12.

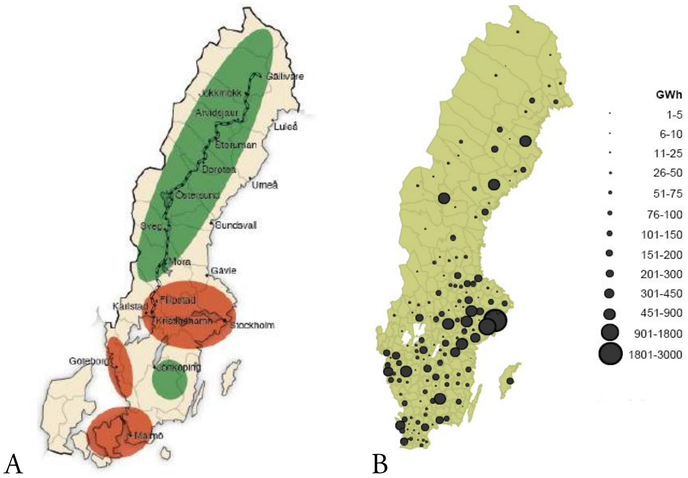

Figure 12. (**A**) Red areas indicate regions with deficits of local forest fuels or which are at risk of facing deficits relative to the demand of the energy producer, while green shows areas of surplus where the current infrastructure allows cost-efficient transports of forest fuels to red areas (de Jong et al. (2012), p. 171). (**B**) Inflows of biofuels to district heating plants given in GWh (Source: Skogsforsk.se. Picture downloaded on 2013-02-15).

Table 33. Recovery of logging residues (LR – ”tops and branches”), 3-year average, year 2008-2010 (SFA, 2012)

	Västerbotten	Dalarna	Stockholm	Skåne
[1,000 m^3 loose volume/year]				
LR - final felling	378	186	61	321
LR - thinning	15	18	20	59
Total	**393**	**203**	**81**	**380**
Thinning as proportion of total recovery	4 %	9 %	24 %	15 %

The statistics of logging residue recovery presented above are given in volumetric units. However, also additional data exist from the Swedish Forestry Agency in the report *Skogs-och miljöpolitiska mål – brister, orsaker och förslag på åtgärder* (SFA, 2011) where the recovery is shown in hectares (see Table 34).

Table 34. Recovery of logging residues (LR – ”tops and branches”), 3-year average, year 2007-2009 (SFA, 2011)

	Västerbotten	Dalarna	Stockholm	Skåne
A. [hectares/year]				
LR - final felling	4,175	3,141	793	3,716
LR - thinning	135	635	243	3,619
Total	**4,310**	**3,776**	**1,036**	**7,335**

In the forest impact assessment SKA-VB 08 (SFA, 2008) the potential recovery of forest residues (logging residues and stumps) from different forestry operations was calculated for the period 2010-2019. The calculations are based on a base-line forestry scenario called "Reference", which corresponds to the current situation in Swedish forests. The harvest of logging residues and stumps include final fellings and thinnings and also small/young trees in early thinnings. The potential was calculated based on three different restriction levels which affect the final amounts (see Table 35).

Table 35. The scenarios of forest residue recovery (year 2010-2019) in SKA-VB 08 based on three restriction levels (SFA, 2008)

Level	Restrictions	Additional information
Level 1	No restrictions at all. The amounts concerned are all forest residues that are generated by the different felling actions.	
Level 2	Ecological restrictions regarding the choice of stands and ecological restrictions within stands are taken into account. The ecological restrictions are based on the Swedish Forest Agency's recommendations on the recovery of forest residues and ash recycling.	
	Primary restrictions for the recovery in a stand.	Areas within reserves and special consideration areas.
		Areas located within 25 metres of land use categories other than productive forest.
		Areas on peat bogs, wet or damp soils with low bearing capacity.
	20 % of the logging residues and stumps are left in the stand. All stumps of broad-leaved trees are left as they are.	
Level 3	Ecological and technical/economical restrictions are taken into account.	
	Additional restrictions to those in Level 2.	20 % of the logging residues and stumps are left in the stand where recovery is performed. This means that a total of 40 % of the logging residues and stumps available are left in the stand.
		Areas with surface structures of class 4 and 5 and elevation of class 4 and 5 according to a classification of terrain types of Swedish forests.
		All stands of less than 1 hectare have been deducted due to economic considerations.

The data on the recovery of forest residues are expressed in volumetric units as m^3 loose volume in the forestry statistics. Based on the heat values *1 tonne DW = 4.9 MWh* (SFA, 2008) and *1* m^3 *(loose volume) = 0.83 MWh* (Skogforsk, 2013) the volume can be converted to dry weight. The information on the recovery of logging residues found in the Statistical Yearbook of Forestry (SFA, 2012) are average values for the period 2008-2010. The calculated amounts in SKA-VB 08 show a significant potential of increased logging residue recovery in all four counties, also at the highest restriction level (see Table 36 and Figure 13).

These results indicate a lower intensity in the logging residue harvest than discussed above (see Figure 12 and Table 33). For example, the yearly average recovery of logging residues (including both thinning and final felling) in the county of Stockholm is equivalent to about 25 % for the period 2008-2010 of the estimated logging residue potential in final felling at the highest restriction level. Since Stockholm is a densely populated county with a high demand for forest fuels (see Figure 12), and where a substantial part of the recovery is carried out in connection with thinning (see Table 33), the share was here expected to be higher. Also data for the period 2007-2009 are shown in Table 36, and in Table 37, expressed per area. A conclusion to be drawn from Table 37 is that the percentage of logging residue recovery, compared with the estimated potentials, is higher than the corresponding percentage based on weight (see Table 36). For example, the actual harvest in Skåne is calculated to be equivalent to approximately 60% of the estimated potential based on weigth, but approximately 95% based on area.

Table 36. The annual potential of logging residue recovery and the actual (real) recovery given in weight. The data on the restriction levels show only the recovery of logging residues in connection twith final felling. The actual recovery is shown for both final felling and final felling + thinning (SFA, 2008; SFA, 2011; SFA, 2012).

	Potential recovery in connection with final felling based on three restriction levels for the period 2010-2019			Real, 3-year average 2008-2010		Percentage of real recovery of Level 3	Real, 3-year average 2007-2009		Percentage of Level 3
	Level 1 - Gross	Level 2 - Ecological	Level 3 – Ecological and economical/technical	Final felling	Final felling + thinning	Final felling + thinning	Final felling	Final felling + thinning	Final felling + thinning
	[1,000 tonnes DW/year]								
Västerbotten	748	498	335	64.0	66.6	19.9 %	49.5	50.0	14.9 %
Dalarna	525	391	219	31.4	34.4	15.7 %	36.2	39.5	18.0 %
Stockholm	121	77	55	10.3	13.6	24.8 %	10.0	13.2	24.0 %
Skåne	257	181	117	54.3	64.3	55.0 %	52.5	69.8	59.6 %
Sweden	7,420	5,105	3,168	911	1,006	31.7 %	844	944	29.8 %

Table 37. The annual potential of logging residue recovery and the actual (real) recovery given in area. The data show the recovery of logging residues in connection with final felling (SFA, 2008; SFA, 2011).

	Potential recovery in connection with final felling based on three restriction levels for the period 2010-2019			Real, 3-year average 2007-2009	Percentage of level 3
	Level 1 - Gross	Level 2 - Ecological	Level 3 – Ecological and economical/technical	Final felling	Final felling
	[hectares/year]				
Västerbotten	31,254	27,053	23,666	4,175	17.6 %
Dalarna	18,382	17,151	12,748	3,141	24.6 %
Stockholm	2,931	2,234	2,103	793	37.7 %
Skåne	5,110	4,485	3,905	3,716	95.2 %
Sweden	231,994	204,017	169,204	57,178	33.8 %

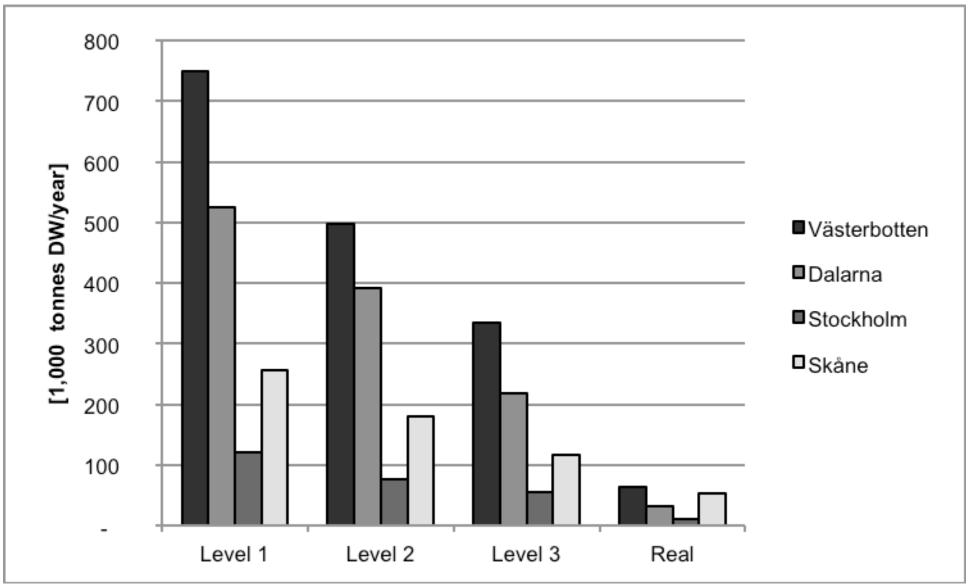

Figure 13. The potential of logging residue recovery per year (2010-2019) and the actual (real) recovery per year (2008-2010) (SFA, 2008; SFA, 2012)

Ash Recycling

The data on ash recycling are based on an annual questionnaire sent out to the companies most active in ash recycling (SFA, 2011). About five companies make up more than 95 % of the total ash recycling practiced throughout the country. Skåne is exposed to the highest levels of acid deposition and was also the county with the largest area on which ash was spread in 2010. No ash recycling was performed in the Stockholm and Västerbotten counties (see Table 38).

Table 38. Area of ash recycling, year 2010. According to data (the 2012 follow-up evaluation of Sustainable Forests in Stockholm County) no ash recycling was performed in Stockholm County (SFA, 2011).

	Area [hectares]	tonne DW	Average ash dosage [tonne DW/hectare]
Västerbotten	0	0	-
Dalarna	125	250	2.0
Stockholm	0	0	-
Skåne	1,004	4,749	4.7

The high productivity per site in Skåne (equivalent to, on average, 11.3 m^3 standing volume over bark per ha and year) (SFA, 2013) motivate the recommended higher ash dosage of 3 tonnes DW ash per hectare and ten-year period, after logging residue recovery. However, the actual dosage in Skåne is, on average, 4.7 tonnes DW per hectare (see Table 38). The recommended maximum ash dosage is 6 tonne DW per hectare during a rotation period (SFA, 2008).

The area of ash recycling, shown in Table 38, can be compared with the area of logging residue recovery, shown in Table 34. A conclusion which can be drawn from this comparison is that only a minor fraction of the harvested area is fertilized by wood ash (less than 10%). Thus, it is clear that the sector target regarding ash recycling is far from achieved (see below).

Sector Target on Ash Recycling

The sector targets in forestry aim at concretizing specific parts of the forest and environmental policy. One of the sector targets, which was stipulated by the Swedish Forest Agency in 2005, is about ash recycling and that, by the year 2010, the area of ash recycling should be equivalent to the area of logging residue recovery in final felling. This target has not been fulfilled. One reason for this, according to the Swedish Forest Agency, is that many ash producers find less costly handling alternatives, such as using the wood ash as filling materials in road constructions etc. Another reason is that ash producers do not want to bear the cost of the ash recycling in the forest. Additional implications are ash of inappropriate composition and contamination due to co-combustion with waste and fossil fuels. Recyclable ash is also generated from by-products in the forest industry (bark, sawdust etc), which are not covered by requirements for recycling wood ash from logging residues (leading to increased acidification). Furthermore, information to ash producers and forest owners about their responsibility to recirculate wood ash, and how this could be developed, from the Swedish Forest Agency and other authorities is inadequate. The debate among researchers about the acidifying impact of logging residue recovery and the need for ash recycling in the long-term perspective, but with its risk of short-term growth reduction, might have led to actors being reluctant. The possibility of spreading ash and nitrogen fertilizers in combination to avoid short-term growth reduction is poorly studied (SFA, 2011).

Large-Scale Fertilization on Mineral Soils

Indicators: Fertilized area.

In 2011, nitrogen fertilization in forests was carried out in Dalarna and Västerbotten on an area of 5,600 and 9,900 hectares, respectively. No fertilization was undertaken in Stockholm and Skåne. Regarding Skåne this is in line with the Swedish Forest Agency's recommendations that nitrogen fertilization in southwestern Sweden should be avoided. Nitrogen fertilization (in combination with ash recycling) to compensate for the removal of nitrogen in conjunction with logging residue recovery is relevant in the northern parts of Sweden where nitrogen deposition is low. Here, the risk of increased eutrophication from nitrogen fertilization is estimated to be low.

4.3 Evaluations of Environmental Quality Objectives by County

The following text about the current situation and development of the environmental quality objectives is based on the 2012 regional follow-up evaluation, found on the Environmental Objectives Webpage (Miljömålsportalen, 2013), where the county-specific information is published.

Table 39. The development and status of the environmental quality objectives in each of the four counties

	Natural Acidification Only	Zero Eutrophication	Sustainable Forests	A Rich Diversity of Plant and Animal Life
Västerbotten	No →	Close →	No ↘	No ↘
Dalarna	Close ↗	No →	No ↘	No ↘
Stockholm	Yes ↗	No ↘	No →	No ↘
Skåne	No →	No ↘	No ↘	No ↘

The conditions and developments of *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life* are similar in all four counties. In contrast, the statuses of *Natural Acidification Only* and *Zero Eutrophication* differ.

4.3.1 Reduced Climate Impact

The County Administrative Boards did not evaluate *Reduced Climate Impact,* in line with the given directions, as this is a global objective and it is impossible that evaluations could differ from the national ones (SEPA, 2013).

4.3.2 Natural Acidification Only

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No →	*Close ↗*	*Yes ↗*	*No →*

Even though there have been significant reductions of sulphur and nitrogen depositions since the mid-20th century, the long history of acidification still affects the present environmental condition and the development of the objective. As for many other environmental problems, the time needed for the environment to recover is long. The current nitrogen deposition in Skåne exceeds the critical load in the forest areas, leading to a nitrogen leaching from forest land. In the northern part of Skåne, lakes do not seem to recover even though liming is practiced.

The other three counties are all exposed to lower levels of acid deposition, both historically and currently. Several of the lakes and streams in these counties have recovered from historical acidification. In Stockholm the liming was terminated some years ago when measurements showed that not more than two percent of the county's lakes were acidified. Also the quality of the forest land is sufficient to fulfil the environmental quality objective in Stockholm, and the trend is positive. However, a prerequisite is that acid deposition will continue to be reduced.

The trend in Dalarna is also positive but slower, and the acid deposition must decrease further in order to achieve the environmental quality objective. In Västerbotten, acidification caused by soils rich in sulphur is a problem specific to the region. This is the case mainly along the coast of the Gulf of Bothnia due to the fact that these soils were historically below sea level, and on these soils liming has limited effect. Despite a significant recovery from acidification, about six percent of the lakes in the county are still acidified.

In Stockholm and Dalarna the contribution of forestry to the acidification has been calculated to amount to 50-70 percent. An intensification of logging residue recovery is estimated to increase this percentage, if compensatory measures, such as ash recirculation, are not developed. In Skåne, the two prioritized measures to reduce acidification are to minimize the negative effects of logging residue recovery and to reduce the nitrogen emissions from all types of traffic activity, as well as the sulphur emissions from coastal shipping.

4.3.3 Zero Eutrophication

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
Close →	*No* →	*No* ↘	*No* ↘

Stockholm County has a fast-growing population which increases the burden on the environment. The wastewater treatment plants have continuously improved their performance of phosphorus and nitrogen removal but since the population is increasing the reductions are not adequate. Also, increased traffic causes increased emissions of eutrophying emissions. Stockholm is the county in Sweden with the greatest problems concerning eutrophication of coasts, lakes and streams.

Skåne has the highest proportion of farm land in Sweden and the agricultural sector contributes the largest part of the nitrogen and phosphorus loads to water bodies in the county. Measures and efforts undertaken to adapt fertilization, cultivation of catch crops, construction of wetlands and other water management practices, have been implemented to reduce eutrophication, but have proved to be insufficient to meet the environmental targets. Additional policy instruments and measures are needed.

The populations in Dalarna and Västerbotten are much lower and the major parts of the counties' land areas consist of forest land. However, the eutrophication target is not met in Dalarna. Only three percent of the county area is used for agriculture but since the soil is sensitive to erosion agriculture make a significant contribution to the eutrophication. The trend is neutral in Dalarna.

With the largest fraction of Västerbotten consisting of forest and mountainous land, the problems of eutrophication are limited in this county. Three out of four specifications in the eutrophication target are achieved and the trend is positive. The nitrogen deposition on forest land falls below the critical load. However, the deposition of nitrogen has started to increase over recent years and thus additional measures are needed to fulfil the environmental target.

4.3.4 Sustainable Forests

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No ↘	*No* ↘	*No* →	*No* ↘

All counties show negative conditions and developments of *Sustainable Forests* except for Stockholm where the development is assessed to be neutral. Forestry is operated at similar intensities throughout the country and is the reason why the conditions in the counties reflect the national development. The problems and different aspects that mainly determine the development of *Sustainable Forests* are also common to all four counties. The two most important aspects are the insufficient protection of forest areas with high nature values and in general the inadequate environmental consideration in forestry operations. The indicators of old forest, old forests rich in broad-leaved trees, and dead hardwood are developing positively in all counties but the actual volumes are still too low.

Many forest types and forest-living species show unfavourable preservation statuses and the number of species on the red list is increasing. More than 850 species are connected to forests in Skåne and over 80 of these have their main existence in this county. Due to the high proportion of forest land in Dalarna and Västerbotten, a significant fraction of the threatened species is associated with forests. A major fraction of these species is developing negatively, while knowledge concerning other species is too poor to even report on their trends.

In Sweden, Stockholm has the largest area of key biotopes in relation to the area of productive forest land. An estimation is that the number of key biotops is even larger but they have not been identified due to limited resources at the Swedish Forest Agency. Current resources for protection of high value forest areas are also insufficient in all counties and these areas are continuingly subjected to fragmentation, and forests of long biological continuity are decreasing. In conventional forestry, the impact on sensitive habitats, soil and water, and historical-cultural heritages, needs to be reduced. There seems to be a trend of increased damage caused by driving of forestry machines, as a consequence of the increased recovery of logging residues. The high proportion of valuable broad-leaved trees is a prominent feature of Skåne. So as not to aggravate the situation of red-listed species even further, there is a need of incentives, policy instruments and follow-up procedures concerning larger scale recovery of broad-leaved logging residues and stumps.

4.3.5 A Rich Diversity of Plant and Animal Life

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No ↘	*No* ↘	*No* ↘	*No* ↘

The overall situation concerning the problems of biodiversity is the same for all counties. Habitats are being lost and fragmented by unsustainable forestry. The development of the environmental quality objective is negative and clearly dependent on the development of other objectives.

Skåne is the county in Sweden with most red-listed and extinct species. In Dalarna, species on the red list increased from 690 to 810 during 2005 to 2010. In 2010 the red list contained 280 nationally threatened species that could be found in Västerbotten. There are also knowledge gaps for several species for which the status is not possible to determine under current conditions. The work of protection of valuable biotops and the restoration and conservation of already protected areas, are not moving forward fast enough to create sufficient prerequisites to fulfil the objective. Increased knowledge, improved consideration, appropriate planning, and restoration of natural environments, are all important factors if the species are to survive in the ecosystems.

There is a need for strategies that focus on the landscape level, to reduce the current trend of fragmentation of valuable forests. The pressure on ecosystems is especially high in Stockholm due to the expansion of infrastructure, buildings etc. Therefore, it is important to preserve and "build in" biodiversity as part of these various constructions.

4.4 Synthesis

The information presented in the case study shows regional differences in the four counties. Basic information, such as population, county land area, and forest land area, indicates the demand for forest fuels and thereby the potential intensity in forest residue recovery. The proportion of forest land of the total land area indicates the competition from other sectors and the relative importance of forestry regarding the development of the environmental quality objectives. The proportion of productive forest land that is formally protected gives an indication of the development of preserving biodiversity. Stockholm has the highest proportion of 6.1 percent of formally protected productive forest land while Skåne has the lowest at 3.2 percent. The area and number of key habitats, not protected, show the potential risk of biodiversity losses due to final felling and forest residue recovery. The current forest statistics only present data on key biotopes linked to private land, and not on company- or state-owned forest land. Therefore, no complete figures are presented in the case study for all ownership categories in the forestry sector. The data from webpages of forest companies in Sweden give information about the area of productive forest land which they voluntarily set aside. More importantly, however, is the area of key biotopes which is not protected and could be damaged by forestry operations including forest residue recovery.

Eutrophication is a manifest problem in Stockholm and Skåne. In Stockholm this is primarily due to the dense population, while the high proportion of agricultural land is the main reason in Skåne. The high demand for forest fuels is reflected by the intensity of forest residue recovery, where 24 percent of the annual amount of recovered logging residues is removed in conjunction with thinning in Stockholm. The corresponding figure in Skåne is 15 percent. Nevertheless, the annual removal of logging residues is significantly lower than the potential calculated in SKA-VB 08, even at the highest restriction level. Logging residue recovery in thinnings in Västerbotten and Dalarna is less frequent (representing 4 and 9%, respectively). In these two counties there is an excess of forest fuels, which is in accordance with the low population and large area of forest land.

Wood ash recycling is limited in forestry practice today. The most extensive use of ash is in Skåne but the practice is still far from the sector target, namely an area equivalent to the total area of logging residue recovery after final felling. The average ash dosage in Skåne is higher than that recommended, which indicates that an adjustment is needed in a future expansion of ash recycling.

Skåne is also the county which has the highest need of ash recycling due to the current status of acidification. Its geographical location is unfavourable since the atmospheric nitrogen deposition exceeds the critical load for forests.

The negative status and development of *Sustainable Forests* in the four counties reflects the overall situation in Sweden. This is also the case for *A Rich Diversity of Plant and Animal Life* for which all counties have a status of “No” and show a negative trend. The distance to target regarding these two objectives is far and forestry practices and forest residue recovery are critical factors which need improved adaption.

5 Discussion

The Environmental Evaluation Model

This report presents an approach of how environmental effects of forest residue recovery can be balanced. The categorization step in the model is an attempt to highlight environmental effects that should be paid specific attention in this respect. The evaluation model clearly shows the importance of regional and local assessments due to the significant regional/local differences regarding several environmental effects and impacts. However, the environmental evaluation model needs further development before being put to practical use, together with the development of more locally based databases and statistics. Our intention with this report is to contribute to a new way of thinking which can inspire further work on forest residue recovery and a balancing of different environmental effects.

Balancing environmental effects is a complex task often including some subjectivity and individual interests. Our intention has been to minimize these risks by using existing and generally accepted environmental tools and the latest scientific knowledge about forest residue recovery and environmental effects compiled in scientific syntheses. The model is based on some central aspects and tools covered by two approaches running in parallel. The Environmental Impact Assessment (EIA) approach (also including Life Cycle Assessment regarding greenhouse gas balances) includes the following components: (i) the issue of irreversibility, which calls for the precautionary principle, and (ii) the mitigating hierarchy, which categorizes the environmental effects based on the possibilities of handling their occurrences and potential impacts. The environmental impacts considered are climate change, acidification, eutrophication, and biodiversity.

The parallel Environmental Quality Objectives (EQO) approach links the environmental effects of forest residue recovery to relevant environmental quality objectives. This approach has as its aim the estimation of the measure of compatibility between forest residue recovery and critical environmental issues in Sweden. Jointly, the two approaches should give the degree of *ecological significance* to be used when balancing the environmental effects.

The benefits of replacing fossil fuels by forest-based fuels should be put in relation to the environmental effects that are assessed in this report, facilitating a discussion on when a positive effect of using forest fuel can be considered as greater than a negative effect and vice versa. This type of comparison is affected by local/regional differences and the type of aspects that are taken into consideration. For instance, when can a loss in biodiversity be accepted as the price of a climate benefit? What arbitrary biodiversity loss corresponds to what degree of climate benefit? Since climate change also affects biodiversity, there is an indirect relationship which makes the balance even more complex.

Irreversibility

The environmental evaluation model presented in this report stresses the importance of thinking in terms of precaution and carefully considering aspects which may be connected to irreversibility. Examples are harvest in areas with unique wood-living species, for which extinction is imminent as well as the importance of being restrictive on the removal of valuable broad-leaved and other broad-leaved harvest residues. The question of irreversibility shows the complexity primarily of biodiversity, which is a category that generally needs more attention and knowledge based on specific local conditions etc.

EIA Mitigating Hierarchy

The categorization according to the EIA mitigating hierarchy is one approach to how the environmental effects can be structured and balanced (see Table 15). However, this approach can be made increasingly wide-ranging by increasing the number of aspects included in the categorization of the environmental effects (see e.g. the 2012 in-depth evaluation of the environmental quality objectives). Important questions are where to set the limits on the aspects to include and use as a guide in a certain categorization, which will also depend on data available and the specific conditions. Thus, good access to relevant information and data is a fundamental requirement for this aspect.

Distance-to-Target

The distance-to-target approach is a measure of the compatibility between the environmental effects and the environmental quality objectives. The approach focuses on questions such as which environmental effects that affect the environmental quality objectives the most and how to consider this based on the current status and development of the objectives. This, in turn, will raise questions such as what the "room" is for negative impact based on the overall status of the objectives in the counties etc. This report identifies relevant indicators and specifications for the environmental quality objectives connected to the environmental effects of forest residue recovery. This is a way to direct the objectives towards the specific forest activity, which gives the objectives increased practical applicability in an environmental evaluation. The relevant indicators and specifications give an estimation of how well the activity can be linked and covered by the objectives. This aspect is further discussed below.

The use of a distance-to-target approach may be seen as a controversial step since it has previously faced criticism for assuming that all targets are equally important. This is also the case in the gap analyses in the 2012 in-depth evaluation, where the authors discuss potential drawbacks regarding non-proportional relations. This may reduce the applicability of using a distance-to-target method as an indirect measure of the importance and as an approach for prioritizing the objectives. However, the Environmental Quality Objectives approach in this report is not ultimately dependent on the distance-to-target method as such, but builds on the components of the five common reasons for failure and the development trends, which are used to estimate the gaps in achieving the objectives (see Table 11 and Table 12). This makes the approach fairly flexible, which is in line with an environmental impact assessment methodology.

Applicability of Using the Environmental Quality Objectives in Environmental Evaluations

The supply of relevant indicators in the environmental quality objectives decide how well the environmental effects of forest residue recovery can be covered by the environmental monitoring in the evaluation process. The indicators also describe the basis of the specifications in the environmental quality objectives. Since the specifications are deliberately formulated in a way to avoid action-oriented contents, the indicators point out the potential measures that should be aimed for. In this way the indicators serve as clarifying components of the specifications, which in turn serve as clarifying components of the environmental quality objectives. The functionality of using the environmental quality objectives as part of environmental evaluations is largely dependent on the "relevance" of the selected indicators and specifications. If the relevance is too poor and/or the number of relevant indicators and specifications is too limited, it becomes difficult to relate an activity and its environmental effects to an environmental quality objective. The specifications are, however, generally broad, which makes their applicability flexible, while the indicators' specificity restricts their use for certain environmental effects. Among the relevant indicators in Table 9 the degree of applicability varies. Since the five selected environmental quality objectives differ in their structures, the practicability of the indicators for evaluation purposes will differ, just as the applicability of the objectives in general will differ. Three of them aim at specific environmental problems (climate change, acidification and eutrophication), whereas the objective *Sustainable Forests* describes a certain type of ecosystem. The objective *A Rich Diversity of Plant and Animal Life* is a mix of an environmental problem and a description of ecosystems. The indicators that belong to the objectives that describe environmental problems are normally expressed in quantitative terms (e.g. greenhouse gas balances, pH etc), whereas objectives that describe a type of ecosystem are much broader, also including indicators expressed in qualitative terms. Such broad indicators are more difficult to apply to specific forestry operations, such as forest residue recovery. Belyazid et al. (2010) presented their own set of indicators to better "tailor" the evaluation of different scenarios of forest residue recovery (including ash recycling and nitrogen compensation fertilization), its environmental effects and connections to relevant environmental quality objectives. To develop and use a specific set of indicators for a certain activity, instead of the more broadly defined "official" indicators of the environmental quality objectives, is an approach that increases the applicability of integrating the environmental quality objectives in an environmental evaluation. Even if the study by Belyazid et al. (2010) did not use the real components of the objectives, their structures have been adopted and the environmental quality objectives recognized in this report.

It might be difficult for an individual actor to make an estimation of the compatibility, or the significance of the specific environmental impact of forest residue recovery in relation to the overall environmental quality objective. It is therefore important to develop practical and functional measures, as suggested in this report. More focused information about the connection between environmental effects and related environmental quality objectives is crucial to describe the relation in a clear and consistent way. The sector targets for forestry convey this type of information but more directed information, for certain activities, such as forest residue recovery, is needed.

Figure 14 presents an interpretation of the applicability of using the environmental quality objectives for two different purposes, namely, as public information and parts to be included in environmental evaluation models. The applicability is based on which parts are integrated. The approachability is defined as the potential for reaching the target group, which is a general Swedish citizen, when distributed as public information. The formulation, specifications, and indicators, make up three levels of "scientific detail". It is assumed that an environmental assessment of a certain activity, in which the environmental quality objectives are integrated, requires the highest level of scientific detail as offered by the indicators and these types of components. The formulation of an environmental quality objective is the most general information and describes its overall meaning. This level is normally sufficient to be used for public information.

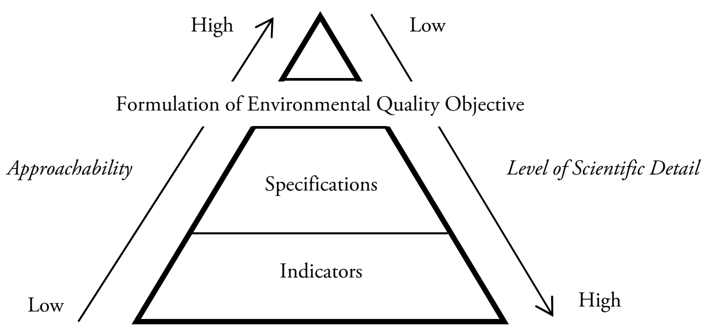

Figure 14. An interpretation of the environmental quality objectives' general applicability as public information and for use in environmental evaluation models.

Question of Allocation

When evaluating the environmental effects of forest residue recovery and their corresponding environmental impact, it is important to differentiate between the impacts that should be attributed to the stem-wood recovery and the recovery of forest residues, respectively. This might be difficult for some impact categories. Inventories that evaluate the environmental consideration that is taken during the regeneration felling include the whole operation, which means that the stem-wood recovery and forest residue recovery are aggregated. Therefore, the inventories would need to be made greater in detail, with controls also between the two recovery operations. This is, however, from a practical point-of-view, considered as unlikely. Since forest residues are by-products of stem-wood harvest it is the requirement of conventional forestry that decides which forest stands are to be felled. This means that the demands of the stem-wood harvest that should indicate potential felling of stands with high biodiversity values. Thus, the indicators of "old forest" and "old forest rich in broad-leaved trees" are directly applicable to stem-wood harvest but only indirectly to forest residue recovery. The responsibility of the recovery of forest residues begins where the activity of stem-wood harvest stops. The most salient negative environmental effects that recovery of forest residues adds to the existing stem-wood harvest are: the acidifying impact, the reduction of dead wood due to stump removal, the increased risk of damage by increased driving of forestry machines, and the removal of logging residues and stumps which decreases the bearing capacity of soils.

Reflections from the Case-Study

The case study in Chapter 4 has the aim to implement the environmental evaluation model and search for relevant information that can serve as indicators and supply the model with necessary data. Here, specific indicators were developed and connected to relevant environmental quality objectives (similar to the study by Belyazid et al., 2010). Since the forestry statistics present easily accessible information the collection of data from this source is straightforward, and it also facilitates giving greater stringency to the evaluation. The information in the regional follow-up evaluations of the environmental quality objectives concerning forestry is, however, scarce since the objectives comprise several sectors and various effects which also depend on the current condition in each county. The forestry statistics can, to some extent, be used to add information to this gap and contribute to an improved evaluation. However, there are also some important indicators of forest residue recovery which cannot be established based on forestry statistics because of the lack of data. This concerns data on the removal of valuable broad-leaved forest residues. Furthermore, data that prove a connection between the recovery of logging residues and ash recycling would have been useful with since ash is considered as an important measure to increase the compatibility between the forestry operation and relevant environmental quality objectives.

Environmental Quality Objectives for which Sweden has National Control – Prioritizing Aspect?

The 2012 in-depth evaluation presents information regarding the distribution of the environmental quality objectives according to geographical relevance (or the degree of geographical level applicable to the objective in focus) and the estimated time till the environmental objective is reached. These parameters give indications of the potential to handle the actual environmental effects on the national and regional/local scale. Except for the objective *Reduced Climate Impact*, with exclusively an international relevance, the other effects of forest residue recovery relate to environmental quality objectives with relevance ranging from an European level to a regional/local level. The objective *Natural Acidification Only* and *Zero Eutrophication* depend on reductions of nitrogen oxides and ammonia emissions abroad. Therefore, the national control of these objectives is somewhat limited. This might result in less ambitious mitigation efforts on a national level. On the other hand, if the objectives are mainly controlled within the country, this may result in more ambitious efforts. One strategy could be to focus on the environmental effects that both occur and have their impact in Sweden. One example is the acidifying effects of logging residue recovery if ash recirculation is not applied. By focusing on the national relevance and measures on a geographical level, ambitious mitigation efforts could be more clearly motivated. Biodiversity is an impact category for which the national relevance dominates and regional/local conditions are crucial. The connections between the cause and effect are clearer for environmental quality objectives with a regional/local relevance and a narrower time span. Both *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life* are objectives for which the main geographical relevance is the regional/local level but for which the time span ranges from short-term to long-term. Thus, potential measures towards achievements of the two objectives can be expected to be noticeable where practiced, which may lead to increased incentives and mitigation efforts.

6 Conclusions

The Stepwise Handling Procedure, SHP, presented in this study is an attempt to develop the first version of an environmental evaluation model directed towards a balancing of the environmental effects of forest residue recovery. Additional work is required to improve the model and increase its applicability in environmental assessments. The SHP is made up of two cornerstones, (i) an Environmental Impact Assessment (EIA) approach and (ii) an Environmental Quality Objectives (EQO) approach, which are integrated in a new and innovative way. Life Cycle Assessment is also used in the model as part of the Environmental Impact Assessment approach, calculating greenhouse gas balances.

The EIA mitigating hierarchy categorizes the environmental effects of forest residue recovery. This approach gives a good overview and compiles information on the environmental effects and different measures to counteract their impact. This categorization may be further improved, leading to increased reliability.

Since the compatibility between the environmental effects and the environmental quality objectives is dependent on local and regional conditions (also global, concerning climate change) and differs throughout Sweden, dedicated distance-to-target analyses similar to national analyses are required on a regional/local level. Developments of the distance-to-target analysis are to be expected in the forthcoming in-depth evaluation of the Environmental Quality Objectives in 2016. Based on this development, the distance-to-target approach in the environmental evaluation model presented here can be adapted accordingly.

The applicability of integrating relevant environmental quality objectives in the environmental evaluation model will differ depending on the environmental effects in focus. The specific indicators of the objectives are important and decisive regarding how well the environmental effects can be monitored and related to the objectives. The broader the environmental quality objectives are, the more difficult it is to find connected indicators that specifically target the environmental effects of concern. Therefore, it is important to have precise indicators since these are critical components in the integration between the EIA approach and the EQO approach, and thus alov in the environmental evaluation model presented.

Further development of additional indicators will improve the integration of the environmental quality objectives in the environmental evaluation model. Such indicators should be based on scientific-based statistics and knowledge found in easily accessible sources, thereby securing practical requirements. One impact category of particular importance is biodiversity since it includes the issue of irreversibility. Normally it requires site-specific indicators on a stand level, as well as on a landscape level, and is often difficult to quantify. Establishing critical limits could be one way to quantify acceptable impact levels, which is in accordance with the precautionary principle. The environmental evaluation model must provide safety margins within the forestry operations concerned with recovering forest residues, thereby securing an overall positive development of the current environmental condition in Swedish forest ecosystems.

To make the presented environmental evaluation model operational, at the same time as it makes reliable and adequate balancing of the environmental effects of forest residue recovery possible, continual judgements about the type and amount of information required are needed. Such judgements should be time efficient, thus relevant information and high-quality data have to be easily accessible in the future. Also, the required level of detail (e.g. geographical) is expected to differ depending on the situation and the environmental effects being considered. A continuous development of this environmental evaluation model should therefore include more precise prioritisations regarding the information and input data needed, and suggestions of how this information could be achieved, to make the model as efficient and useful as possible in practice.

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