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BIOFUELS AND ECOSYSTEM SERVICES

Report from a project within the collaborative research program *Renewable transportation fuels and systems*

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(Photo source: IVL)

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This project has been carried out within the collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system), Project no. 40770-1. The project has been financed by the Swedish Energy Agency and f3 – Swedish Knowledge Centre for Renewable Transportation Fuels.

f3 Swedish Knowledge Centre for Renewable Transportation Fuels is a networking organization which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities
- Carries through system oriented research related to the entire renewable fuels value chain
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

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SUMMARY

Ecosystem services are the benefits people obtain from ecosystems. The production of biofuels may influence important ecosystem services, such as for example bioenergy for different purposes, soil quality, carbon sequestration and recreation. This study assesses the current knowledge and state-of-the art on the potential impact of the intensification of biomass production for biofuel production on ecosystem services and their indicators in Swedish forest and agricultural ecosystems.

We map a large number of forest and agricultural ecosystem services linked to biomass production and describe a range of indicators for the services by the use of CICES (Common International Classification of Ecosystem Services). A synoptic comparison to ecosystem services linked to the production of fossil diesel is included.

An intensified agricultural production in Sweden may lead to an increased production of biofuels from agricultural crops such as wheat based ethanol and biodiesel from rapeseed. This has positive impact on some ecosystem services such as bioenergy and neutral or potentially negative impact on others such as soil quality and control of pests. In the case of biofuels based on forest biomass it is the general expected increased demand for forest biomass that might result in an increased use of existing forest residues and intensified forest fellings and fertilization which in turn might lead to an increased production of biofuels such as HVO from crude tall oil and methane from forest residues. Linked to this development there are also positive effects on some ecosystem services and neutral or potential negative impacts on other. We do not allocate the potential impact between different products. Thus, we do not indicate to what extent the related impact on ecosystem services should be carried by biofuels.

Increased production of biofuels influence ecosystem services in a different way compared to increased fossil fuel production and thus fossil fuel production mainly impacts other habitats than biofuel production. Fossil diesel originates from a non-renewable source from underground while biofuels are produced above ground. How the impact on ecosystem services from different fuel alternatives may be compared needs to be further discussed.

We find that a valuation of ecosystem services may be considered a useful point of departure in visualizing and bringing attention to more aspects of sustainability linked to biofuels which are not fully discussed or included in decision making tools as LCA and policy instruments today. For example, a value such as recreation might receive larger interest from stakeholders than today if we regard the biomass production from an anthropocentric point of view.

As of now, we consider the approach including qualitative and semi-quantitative valuation of ecosystem services, as applied in this report, useful to understand the importance of several additional impacts of biofuel production. It therefore represents an important first step towards assuring sustainable biofuel production and making wise and more conscious decisions. However, still work needs to be done before we may quantify and monetarily value all ecosystem services impacted by biofuel production.

To operationalize a sustainability scheme based on ecosystem service indicators is however challenging due to considerable knowledge gaps. Future work should lead to larger useful databases and work towards acceptance of the concept which would further facilitate the possibility to consider ecosystem services in certification schemes and in other decision-making.

SAMMANFATTNING

De nyttor som människan får från ekosystemen kallas ekosystemtjänster. Produktion av biodrivmedel kan påverka viktiga ekosystemtjänster till exempel biobränslen av olika slag, markkvalitet, kolinlagring och rekreation. Med utgångspunkt i befintlig litteratur kartlägger och beskriver vi påverkan på ekosystemtjänster och tillhörande indikatorer vid en eventuell ökad svensk biodrivmedelsproduktion från skog och jordbruk.

Vi kartlägger ett stort antal skogliga ekosystemtjänster och ekosystemtjänster kopplade till jordbruket och beskriver ett stort antal indikatorer för dessa ekosystemtjänster med hjälp av klassificeringssystemet CICES (Common International Classification of Ecosystem Services). En översiktlig jämförelse med ekosystemtjänster kopplat till produktionen av fossil diesel ingår.

En ökad jordbruksproduktion i Sverige kan leda till en ökad produktion av biodrivmedel från jordbruksgrödor i form av vetebaserad etanol eller biodiesel från raps. Detta har positiv påverkan på vissa ekosystemtjänster som till exempel bioenergi men negativ eller neutral påverkan på flera som till exempel markkvalitet och reglering av skadedjur. Detsamma gäller ett bättre utnyttjande av existerande grenar och toppar från skogsbruket och ett intensifierat skogsbruk med gödsling för att öka mängden skogsbiomassa, i en framtid med generellt ökad efterfråga av skogsbiomassa, som därmed även skulle kunna öka produktionen av biodrivmedel till exempel hydrerade vegetabiliska oljor från tallolja och metan från skogsrester. I denna studie sker ingen allokering av den möjliga påverkan mellan olika produkter varpå den andel av påverkan som biodrivmedel skulle kunna bedömas stå för.

Ökad biodrivmedelsproduktion påverkar ekosystemtjänster på helt annat sätt än ökad produktion av fossil diesel. Fossil diesel belastar till stor del andra livsmiljöer än de som påverkas av produktionen av biodrivmedel. Fossil diesel framställs av en icke förnybar oljeresurs från underjorden vilket gör att de ekosystemtjänster som påverkas är radikalt olika från de som påverkas vid biodrivmedelsproduktion. Hur påverkan på ekosystemtjänster från olika drivmedel ska kunna jämföras behöver diskuteras vidare.

Vi bedömer att värdering av ekosystemtjänster är en användbar utgångspunkt för att visualisera och öka uppmärksamheten kring aspekter av hållbarhet kopplat till biodrivmedel som i dagsläget inte i tillräcklig utsträckning diskuteras eller inkluderas i beslutsfattande, till exempel i livscykelanalyser och styrmedel. Värden som till exempel rekreation kan uppnå större intresse från intressenter än i dag om vi ser på produktionen med människan i centrum.

I dagsläget framstår ansatsen att använda beskrivande och kvantifierande värdering av ekosystemtjänster som viktig för att förstå betydelsen av påverkan från biodrivmedelsproduktion. En ekosystemtjänstvärdering är därför ett viktigt första steg mot att säkra hållbar biodrivmedelsproduktion och mot att definiera vilka områden som ska ingå i hållbarhetssystem för att ta mer medvetna och välunderbyggda beslut. Det är dock fortfarande mycket arbete kvar innan vi kan kvantifiera och ekonomiskt värdera ekosystemtjänster som påverkas av en ökad biodrivmedelsproduktion.

Det är en utmaning att operationalisera ett hållbarhetssystem baserat på indikatorer för ekosystemtjänster på grund av befintliga kunskapsluckor. Framtida forskning bör leda till större dataunderlag och acceptans av begreppet som underlättar möjligheten att beakta ekosystemtjänster i beslutsfattande och styrmedel.

CONTENTS

ABBREVIATIONS

CICES	Common International Classification of Ecosystem Services
CO_2	Carbon dioxide
DME	Dimethyl ether
FAME	Fatty acid methyl ester
FAO	Food and Agriculture Organization of the United Nations
FEGS-CS	Final Ecosystem Goods and Services Classification System
GHG	Greenhouse gases
HVO	Hydrotreated Vegetable Oils
LCA	Life Cycle Assessment
MA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment of Ecosystems and their Services
RED	Renewable Energy Directive
TEEB	The Economics of Ecosystems and Biodiversity

1 INTRODUCTION

A transition from fossil based fuels in the transport sector to more renewable energy sources and biofuels is prioritized by governments both in Sweden and internationally in order to move towards a sustainable bioeconomy and reach global climate change mitigation targets. Motives for producing and using larger amounts of biofuels include: i) reduced greenhouse gas (GHG) emissions, ii) the need to secure energy supplies, and iii) a more cost-effective energy use (Chum et al., 2011; UNECE and FAO, 2011; BP, 2016; EC, 2015; Johnson et al., 2012).

Sweden has ambitious long-term goals to reduce the GHG emissions and mitigate climate change, *i.e.* no net GHG emissions to the atmosphere by 2050, likely to be changed to 2045 (Regeringskansliet, 2008; Wjikman, 2016), and aim for a vehicle fleet independent of fossil fuels by 2030. The introduction of sustainable biofuels is part of the measures to achieve these targets (SOU, 2013b). Sweden already has a relatively high renewable transport fuels share within the European Union (19.2% in 2014) (Government Offices of Sweden, 2015). At present, the Swedish energy demand for road-based transportation is 84 TWh_{fuel}. A significant share of the biofuels or the raw material is imported at present, however there is a considerable potential for increased domestic biofuels production (SOU, 2013b; Grahn and Hansson, 2015; Börjesson, 2016).

Biomass for the production of biofuels may be grown on agricultural land, be based on forest resources or be derived from the sea. The largest share of the liquid biofuels currently produced in Sweden is based on biomass produced on farmland e.g., wheat-based ethanol (Swedish Energy Agency, 2015b; Ulmanen et al., 2009). However, also liquid biofuels based on forest products, primarily Hydrotreated Vegetable Oils (HVO) are being produced based on crude tall oil, a side product to pulp production (Swedish Energy Agency, 2015b). Cellulosic based processes are considered to open up for increased volumes of biofuels. There is a growing trend towards a use of feedstock requiring less agricultural land, such as forest biomass and sea-based biofuels based on aquatic biomass (e.g. microalgae and seaweeds). Sea-based biofuels are still at an early development stage but have prospective to supply further biomass (Alvarado-Morales et al., 2013; Menetrez, 2012; Demirbas, 2010; Demirbas & Faith Demirbas, 2011).

An increased production of some biomass types has been found to lead to disturbance and fragmentation of habitats as well as to reduced levels of species richness (Fargione et al., 2010; Gasparatos et al., 2012; Hellmann & Verburg, 2010; Koh, 2007; Scharlemann & Laurance, 2008; Wiens et al., 2011). The production of biomass for biofuel production may thus influence important ecosystem services, such as provisioning (e.g. food supply), supporting (e.g. habitat provision), regulating (e.g. carbon sequestration, biological control, freshwater regulation) and cultural services (e.g. recreation, aesthetics, health) (Gasparatos et al., 2011; Holland et al., 2015). Aspects such as geographic location, management practices and land use intensity, related to the production of biomass, may affect different ecosystem services differently. For example, the yield of woody biomass depends on harvesting practices (e.g. extracting only stems or also stumps and branches). Extracting stumps and branches may considerably increase harvested quantities, but depending on the considerations taken it may impact soil structure and biological life, nutrient management and carbon sequestration (de Jong et al., 2012; de Jong et al., 2014; Hansen et al., 2014; Hansen & Malmaeus, 2016). Harvesting practices may imply on important environmental impacts and drastically modify landscape aesthetics and recreational value (de Jong et al., 2012; de Jong et al., 2014). The extent to which biofuels may impact these services is currently unknown. We need to understand the impacts of different biofuel feedstock on the ecosystem and the services it provides. A more all-inclusive discussion of the existing trade-offs and synergies is needed and a broad assessment is necessary to draw more in-depth conclusions about the sustainable profile of biofuels (Bringezu et al., 2009).

The EU Renewable Energy Directive (RED) requires the EU member states to report estimated effects of the domestic production of biofuels on water resources, water quality, soil quality as well as biodiversity in the mandatory national progress reports on the development of renewable energy (EU, 2009). These are not stated as ecosystem services in the Directive but they comply with ecosystem services. The ecosystem service concept is, however, well recognised within other EU policies, such as the EU forest strategy (EC, 2013).

The Millennium Ecosystem Assessment (MA, 2005), the Economics of Ecosystems and Biodiversity (TEEB, 2009), the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013) and the Final Ecosystem Goods and Services Classification System (FEGS-CS) (Landers and Nahlik, 2013) developed conceptual classification schemes providing the foundation for understanding interactions between ecosystems and human well-being, *i.e.*, to describe and understand the variety of effects that projects will have on nature and people's well-being. The European Commission, as part of the EU Biodiversity Strategy to 2020, has performed an extensive work to hamper biodiversity loss and the degradation of a range of ecosystem services (EC, 2011), reviewing indicators for describing and mapping ecosystem services (Egoh et al., 2012) and recommending a systematic framework for ecosystem assessments (Maes et al., 2013).

As part of the national environmental goals, the Swedish Government has established a milestone target to considerably improve the knowledge about ecosystem services and promote their integration in political and economic decisions by 2018 (SOU, 2013). As a result of the increased political interest the Government commissioned the Stockholm Resilience Centre to investigate how ecosystem services should be valued and integrated in economic resolutions as well as political and societal decisions (SOU, 2013). This further led to a Governmental proposition 2014 (Regeringen, 2014), where a strategy for strengthening biodiversity and ecosystem services is presented. The increasing relevance of ecosystem services in Sweden, and more broadly in the EU, will likely have a strong impact on the biofuel sector (as well as other biomass related sectors) in the future. It is, therefore, of paramount importance for the biofuel sector to reach an improved understanding of the link between biofuel production and ecosystem services, in order to work in line with future challenges and move to an efficient and sustainable production and use of biomass.

There is evidence that biofuels offer ecosystem services but also compromise other services (e.g. SCOPE, 2009; Fischer et al., 2009). However, little is known about how the production of biofuels affect ecosystem services and the knowledge on these synergies and trade-offs is sparse. An all-embracing assessment set to evaluate which services are mainly affected during the production of biofuels is needed. So far, we are only aware of two publications by Gasparatos et al. (2011) and Holland et al (2015) specifically dealing with this matter. Kettunen et al. (2012) and Fitter el al. (2010) identified ecosystem services in general in the Nordic countries and in Europe. Hansen et al. (2014) and Hansen & Malmaeus (2016) has described and, to a certain degree, quantified different ecosystem services in Swedish forests, while the environmental impacts of forest and agricultural based biofuels have been shortly described in the f3 project "Biofuels and land use in Sweden – An overview of land use change effects" (Höglund et al., 2013). The findings of these projects serve as the starting point for this study.

2 AIMS AND TARGETS

The overall aim of this project is to synthesize and assess the current knowledge about the potential impact of the intensification of biofuel production on ecosystem services for different biofuel production schemes. We concentrate on forest biomass based biofuels (HVO from tall oil and methane from forest residues) and agricultural based biofuels (wheat-based ethanol and rapeseed biodiesel). For comparison, the ecosystem services linked to the production of diesel are described.

The specific targets of the project are to:

- identify and describe the ecosystem services that potentially affect and are affected by an intensified Swedish biofuel production compared to today's production;
- identify appropriate indicators to assess changes in ecosystem services;
- propose a conceptual framework to include ecosystem services in decision-making, specific to the biofuel sector, based on already existing recommendations;
- identify knowledge gaps and recommend future scientific development;

This report aims to present the approach and outcome of the project. An analysis aiming at proposing a conceptual framework to include ecosystem services in decision-making for biofuels is presented in a separate manuscript for publication in a scientific journal.

We account for impacts of biofuel production on ecosystem services in a Swedish perspective. If an expected increased bioeconomy will cause an increased forest based biomass production in Sweden there will be a foundation for an increased production of HVO and methane from the intensified forestry through higher use of treetops and branches (in Swedish called GROT) as well as higher fellings. In this report, for simplification we hypothesize such higher use and production without reflecting on the economics behind such incentive. In the future forest crops grown for energy purposes on arable land such as willow could be used for biofuel production. This is not considered in this study.

As in the case of all environmental impact (and in particular in Life Cycle Assessments, LCA), a detailed quantification of the impact on ecosystem services should consider the potential need to allocate the impact between different products. However, we do not consider to what extent the intensified forestry would be driven by biofuel production and to what extent the related impact on ecosystem services should be carried by biofuels. Allocation principles lie outside the scope of this project whose main focus is qualitative and semi-quantitative valuation of ecosystem services.

3 APPROACH

In order to identify and describe the ecosystem services that potentially affect and are affected by an intensified Swedish biofuel production and appropriate indicators (the first two targets in Section 2) the following tasks are performed:

- A literature review is carried out in order to gain knowledge on ecosystem services in general and connected to biofuel production. Literature from both Sweden and abroad is included.
- Appropriate ecosystem services associated with production of biofuels for transport are listed for two land covers (forest and agriculture) (Chapters 5 and 6). We include four case studies. From forest biomass we analyse the production of HVO from crude tall oil and methane from forest residues whereas wheat-based ethanol and biodiesel from rapeseed produced from agricultural biomass. The ecosystem services identified in each case are described and appropriate indicators capable of showing change in the ecosystem services are identified (Chapters 5 and 6). Potential changes in ecosystem services as an effect of intensified use of agricultural and forest biomass are described with reference to today's production. Possible actions to mitigate the potential changes are suggested. To what extent the intensified forestry assumed in this study would be driven by biofuel production and to what extent the related impact on ecosystem services should be carried by biofuels is not assessed. We discuss whether or not enough data exist to describe changes in indicators - and as such in ecosystem services (Chapter 9.2).
- Needed data and future possible measurements are outlined in order to secure a possible evaluation of changes in ecosystem services as a result of intensified production of biofuels (Chapter 9.2).
- Possible synergies and trade-offs between ecosystem services resulting from intensified biofuel production in Sweden are outlined, recognizing that different intensities of biomass production for biofuels impact the associated ecosystem services differently (Chapters 5 and 6).
- For comparison, ecosystem services linked to the production of crude oil are described (Chapter 7).

In order to propose a conceptual framework to include ecosystem services in decision-making, and to describe knowledge gaps (the third and fourth target in Section 2) the following tasks are performed.

- Relevant existing frameworks for classifying ecosystem services are analyzed to understand possibilities for the integration of ecosystem services in planning and management (e.g. MA, 2005; TEEB, 2009; CICES by Haines-Young and Potschin, 2013; FEGS-CS by Landers and Nahlik, 2013) (Appendix 2).
- A conceptual framework to evaluate biofuel production systems with regard to different ecosystem services is suggested. The requirements needed for information on ecosystem services for the concept to be useful in planning and decision-making and future development of sustainability criteria for biofuels are discussed (Chapter 8).

- The current state-of-the art of the integration of ecosystem services in decision-support tools, such as Life Cycle Assessment (LCA) and national environmental objectives is evaluated (Chapter 8.2). A separate article on integration of ecosystem services into LCA is written (Maia de Souza et al., 2018).
- Based on the identified and described ecosystem services (Task 1) and the current consideration of ecosystem services in decision-making and future policy developments it is discussed to what extent the ecosystem services concept may contribute to evaluations of the sustainability of different biofuels (Chapter 9.1).
- Gaps in knowledge in order to enhance the future use of ecosystem services in planning and management and recommendations are given (Chapter 9.2 and 9.3).

4 ECOSYSTEM SERVICES

Based on an extensive literature review of scientific literature available and usable knowledge on ecosystem services is summarized. We included both reports and scientific peer-reviewed articles. Our search for literature was performed querying science direct, google, and google scholar mentioning keywords such as “ecosystem services”, “ecosystem service valuation”, “ecosystem service concept” as well as “ecosystem service framework” both in combination with and without the search words “forest”, “forestry”, “agriculture”, “biofuels”, “HVO”, “methane”, “ethanol”, and “biodiesel”. Background knowledge on ecosystem services is summarized in this chapter.

4.1 BACKGROUND AND DEFINITION

The term ecosystem services is increasingly used in environmental sciences. It is becoming a common concept used to describe all goods and services provided by nature. In the Millennium Ecosystem Assessment report “Ecosystems and human well-being” (MA, 2005) the term is described as “the benefits people obtain from ecosystems”. Before then, Daily (1997) outlined the concept in more detail as “conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life”. Other authors define the concept differently as outlined in Patterson and Coelho (2009) (Table 1). Several definitions are aimed at raising awareness for a continuously decrease in biological diversity while others aim at a further valuation of ecosystem services.

Table 1. Diverse definitions of ecosystem services used by different authors. The table is based on Patterson and Coelho (2009).

Citation	Definition	Principal uses
Daily et al., 1997	The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life	Awareness
MA, 2005	The benefits people obtain from ecosystems	Awareness
Collins and Larry, 2007	Natural assets that support human health and well-being	Awareness
Costanza et al., 1997	Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions	Awareness, valuation (est. of replacement costs) modeling
US EPA, 2006	Outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some outputs may be bought or sold, but most are not marketed.	Valuation (ecological benefits assessment)
Boyd and Banzhaf, 2007	The ecological components directly consumed or enjoyed	Valuation (green accounting)

After having conducted a literature review on a range of publications which all used the concept of ecosystem services it became obvious that the term is used in many different, unconfined, and at times contradicting ways. Conclusively, it is a concept that is not consistently defined with one specific agreed definition (Nahlik et al., 2012). Through our work, we have therefore chosen to work with the definition described by MA (2005) (Table 1) since the Swedish Environmental Protection Agency uses this definition.

The idea that ecosystems deliver many different services to humans was first described in 1935 (Willis, 1997) and at this point Willis only talked about the environmental services. The first time the term ecosystem services appeared in a peer-reviewed paper was 1983 (Ehrlich and Mooney, 1983). Hereafter, more than 10 years went by before the concept was brought up in scientific papers again, this time by Costanza et al. (1997) and Daily et al. (1997) in order to stress the importance of all services we receive from different ecosystems and which human mankind often takes for granted. These papers started the discussion on ecosystem services and after 1997 the number of scientific peer-reviewed articles slowly increased. The publication of the MA (2005) managed to raise even more awareness on ecosystem services through a review of the status of the ecosystems of the world and the showing of how changes do influence human life. Hereafter, a large, almost exponentially increase in publications on ecosystem services came about (Vihervaara et al., 2010; Dick et al., 2011; Potschin and Haines-Young, 2011; Tuvendal, 2012). The ecosystem services concept in research is therefore a relatively new area and the experience about how to quantify the services, analyse synergies and trade-offs between services as well as economically price ecosystem services is rather limited.

4.2 CLASSIFICATION OF ECOSYSTEM SERVICES IN FRAMEWORKS

Different systems, so-called frameworks, are used to sort ecosystem services into classes. Such systems help to identify and classify services in a logical way. A widespread interest and considerable efforts have arisen in order to classify ecosystem services at different scales (Yang et al., 2013; Nelson et al., 2009; Power, 2010). Mixed opinions exist on how ecosystem services are best classified. Four main efforts of classification have in recent years contributed to advance the assessment of multiple ecosystem services at the global scale: the MA (2005), the TEEB (2009), the CICES (Haines-Young and Potschin, 2013) and the FEGS-CS (Landers and Nahlik, 2013). Basically, they build on to each other and are not widely different. All include provisioning, regulating and cultural ecosystem services. The systems differ on how they define supporting services. There are more frameworks described in literature, some of which Nahlik et al. (2012) reviews asking the question “Where is the consensus?” In their paper they indicate that most frameworks reviewed are based on a poor definition of the concept and this might prevent further work on practical implementation.

We have reviewed the four major frameworks (Appendix 2) in order to identify a best suitable one to address the impacts of biofuel production on ecosystem services.

4.2.1 Selecting a framework

A clear, well-functioning and well described classification system is a prerequisite for measuring and quantifying, mapping and economically valuing ecosystem services. A standardized framework will help to generate the possibilities to compare the impact of production of biofuels on different ecosystem services. In this report, we decided to work with the CICES (v. 4.3) classification scheme incorporating the Cascade model since its hierarchical structure permits us to specify details of the chain from ecosystem structure to benefits and value to human beings using more indicators for each level to specify impacts of biofuel production. Secondly, this classification scheme is currently the most used framework in Europe and we find it important to be able to compare to other initiatives.

4.3 HABITATS AND INDICATORS FOR ECOSYSTEM SERVICES

We adopted the classification of ecosystems by Maes et al. (2013) which again is based on the European Nature Information System (EUNIS, 2013) into broad classes of habitats. Our case studies on forest biomass for biofuel is using and impacting woodland and forest habitats while cases studies on agricultural biomass for biofuel is using and impacting cropland as well as grassland and pastureland. Even onshore crude oil production impacts terrestrial ecosystems. On the other hand, offshore crude oil production has effects in coastal areas and marine ecosystems.

A good indicator should be a quantitative variable which is measurable and may lead to the collection of useful and relevant data supplying information on the status of a given ecosystem service as well as information on possible changes in a service for example as an effect of management and climate change (e.g. Efroymson et al., 2013; Dale et al., 2013; Dale et al., 2015a). In the next chapters we analyse and identify ecosystem services for forest and agricultural ecosystems along with suitable indicators through a qualitative description of each of these services.

5 BIOFUEL AND FOREST ECOSYSTEM SERVICES

Forestry in Sweden has by tradition a large economic importance with a total production value of 214 billion SEK (year 2010). Approximately 23 million hectare of productive forest area (Swedish Forest Agency, 2013) corresponds to 56.6% of the total Swedish land area. It is estimated that the total wood stock was circa 3 000 million m^3 during the period 2008-2012 (Swedish Forest Agency, 2013). The forest grows approximately 100-120 million m^3 per year (Swedish Forest Agency, 2013). Today, about 90% of the growth is felled. Since the annual gross fellings currently are smaller than the increment the standing stock increases continuously. An intensified removal of forest biomass will be possible and we hypothesize increased outtake without knowing if the market will allow it. On the other hand, such an increased removal will influence other ecosystem services and biodiversity.

Forests in Sweden are significantly producing wooden biofuels (firewood, wood chips, sawdust, pellets and briquettes) and biofuels, including forest fuels, accounts for approximately 26% of the total Swedish energy consumption (Swedish Energy Agency, 2017). As such, Swedish forest biomass is already an important part of the conversion of the energy system depending less on fossil fuels. A further conversion of the transport system as well as other sectors to less reliance on fossil fuels will cause forest biomass to have an even more important role in the future.

5.1 FOREST ECOSYSTEM SERVICES AND INDICATORS

The Swedish forests are rich in biodiversity, timber and pulpwood, berries and mushrooms. They sequester and store carbon and supply the population with pure water and recreational opportunities (Hansen and Malmaeus, 2016) as well as with renewable biomass for substitution of non-renewable fuels and materials. Thus, the Swedish forests are a central and crucial provider of ecosystem services with large values for the population which makes the sustainability of these services an important issue for the society in general.

For the forest ecosystem, we based our analysis on the list of main ecosystem services identified in Swedish forests from a recent work by Hansen and Malmaeus (2016). This list was built adapting the CICES classification separating them into provisioning, regulating and maintenance as well as cultural services (Haines-Young & Potschin, 2010). Hansen and Malmaeus (2016) added two more classes from the MA (2005) classification namely mental and physical health as well as biogeochemical cycles. Furthermore, they omitted some CICES classes which were not eligible for Swedish conditions. Hansen and Malmaeus (2016) identified 22 forest ecosystem services (Table 2) and developed indicators for each of the four cascade-levels for all services. We modified the table according to new information (e.g. Holland et al., 2015; Cederberg et al., 2016) and this comprehensive matrix of services and indicators for forest environmental state and human well-being is usable for our work of relating the production of biofuels to ecosystem services.

5.1.1 Provisioning services

Provisioning services in the Swedish forests comprises nutrition through things we can consume, materials that we convert to valuable use as well as energy with low climate impact. From a nutritional aspect the forests provide us with berries mainly blueberries and lingonberries, but also cloudberries, cranberries and raspberries are produced with a large health potential (Knekt et al., 2002; Karjalainen et al., 2010). Picking berries furthermore serves as a cultural service. Also, a large amount of edible mushrooms are picked in the forest, mainly chanterelle, funnel chanterelle and porcini mushrooms. Sweden have approximately 280 000 active hunters supplying game meat providing approximately 4% of all meat eaten in Sweden (Mattsson et. al., 2008a,b). Primarily, moose, red deer, roe deer, wild boar, rabbit, birds and fox are hunted. On the other hand traffic accidents with game involved, mainly moose, makes up for a large, expensive disservice. Another kind of meat comes from reindeer husbandry by the Saami people where approximately 260 000 reindeers nourish partly in the northern forests (Sametinget, 2013). Finally, the Swedish forests provide drinking water in good quality. The materials mostly provided by the forest are timber and pulpwood. Approximately 45% of the felled roundwood is transported to the sawmill where sawn wood products are produced (Staffas et al., 2015). Almost one third of the sawmill timber becomes sawdust and chips when sawn planks are produced. Most of the chips are transported to the paper and pulp industry. Sawdust becomes particle boards and pellets or are transformed to energy at the sawmill or in district heating. The bark is burnt for energy. Another 45% of the felled roundwood is used by the paper and pulp industry (Staffas et al., 2015). Eight percent is burnt in domestic houses. Lastly, a fraction of the treetops and branches are chipped and burnt for energy but a lot is left in the forest after thinnings and loggings. The main biofuels produced are firewood, wood chips, sawdust, pellets and briquettes. We harvest less than the forest grow and therefore the standing stock increases in the forest leaving us with future possibilities for larger outtake (Swedish Forest Agency, 2013). Further goods produced are Christmas trees, spruce spray, mosses and lichens normally used at Christmas time in Sweden (Hansen et al., 2014). Lichens are moreover used as winter fodder for reindeers. Finally, different kinds of forests preserve different genetic resources.

5.1.2 Regulating and maintenance services

The regulating and maintenance services in Swedish forests mediate flow and thus prevent for example damage from movement and loss of soil through erosion, storm damage and flood damages which are often preventing changes in other ecosystem services such as timber production and associated carbon sequestration as well as recreation. Regulating and maintenance services also see to it that physical, chemical and biological conditions are maintained in the forest in an optimal way for flora and fauna, for example habitats for different species are available, and pollination, biogeochemical cycling and soil quality is kept ideal for the benefit of provisioning services. Lastly, Swedish forests foster an important service regulating precipitation and temperature for the benefit of the climate worldwide. When trees sequester carbon dioxide (CO_2) and build biomass through the photosynthesis they counteract the build-up of CO_2 in the atmosphere. The annual net uptake of C in Swedish forests are estimated to be 38 million ton CO_2 year 2010 (Swedish Environmental Protection Agency, 2012) while the total area with forest has a stock of approximately 1000 million ton in aboveground biomass and circa two times more C in the soil.

5.1.3 Cultural services

The Swedish forests further provide cultural services where many Swedish inhabitants and active in nature and use it for training and recreation (Fredman et.al., 2008a,b; 2013). We are active in nature and enjoy and value the forest as a positive and aesthetic place to walk, run, bike, ride and ski. Recreation in the wild may further involve reindeer and moose safari, hunting and fishing, bird watching, paddling, rafting, picnicking, berry and mushroom picking, and camping. Furthermore, tourists come to Sweden to experience the wilderness in our forests. Our visits to the forest also comprise a health aspect since such nature encounter seems to improve human health considerably for example through prevention of depression and anxiety, the lowering of blood pressure and increased stress tolerance. Also, quality of sleep seems to be improved after time spent in the forest. On the other hand, the forest trip might lead to first encounter with ticks and tick diseases as a disservice.

Table 2. Ecosystem services in Swedish forests and related indicators categorised using CICES v4.3 and the Cascade model. The table is mainly based on Hansen and Malmaeus (2016) but has been slightly modified by information from Holland et al. (2015) and Cederberg et al. (2016).

CICES			CASCADE indicators			
Class	Division	Ecosystem service	Structure (spatial)	Function (temporal)	Benefit	Value [SEK]
Provisioning services	Nutrition	Berries	Area of berry habitats [ha or %]	Annual production of berries [t/yr]	Harvest of berries [t/yr]	Sales and total value of berries; Picking income; Health value
		Mushrooms	Area of mushroom habitats [ha or %]	Annual production of mushrooms [t/yr]	Harvest of mushrooms [t/yr]	Sales and total value of mushrooms; Picking income; Health value
		Game	Area of game habitats [ha]	Game population [n/yr]; Population of predators [bear, wolf, wolverine] [n/yr]; Birthrate [%]; Number of hunters [n/yr]	Harvested game [t/yr]; Game meat consumption [t/yr]; Improved health eating meat without antibiotics	Market value of game meat; Sales of game meet; Health value
		Reindeer and forage	Area of reindeer habitats [ha]	Reindeer entreprises [n/yr]; Reindeer population [n/yr]; Birthrate [%]	Harvested reindeer [n/yr]; Consumption of reindeer meat [t/yr]; Employment in reindeer production [n]	Market value of reindeer meat; Sales of reindeer meat; Value of employment in reindeer production
		Drinking water	Forest area dedicated to preserve drinking water [ha]	Total supply of water per forest area [m^3/ha/yr]; State of surface water and groundwater	Provision of clean drinking water [m3]	Avoided costs for cleaning water
	Materials[1]	Timber and pulpwood	Productive forest area [ha]; The total biomass stock [m^3]	Growing stock increment [m3/yr]; Annual increment [m^3/yr]	Annual fellings [m_3/yr]; Employment hours in industry [n]	Gross value of timber; Value of employment in industry; Climate benefit of substitution
		Decorative materials	Area of Christmas tree production [ha]	Production of Christmas trees [n/yr]; Collected lichens [t/yr]	Sold Christmas trees [n/yr]; Sold lichens [t/yr]	Market value of Christmas trees; Market value of lichens
		Genetic resources	Area of gene reserve habitats [ha]	Amount of red-listed species [n/yr]; Variety in species [n/yr]	Genetic variance; Breeding; Fellings [m^3/yr]	Value of genetic variance
	Energy	Bioenergy	Area of bioenergy production [ha]	Biomass available for bioenergy [m^3/yr]; Wood fuel consumption [m^3/inhabitant]; Pellets production [t/yr]	Bioenergy from forest biomass [TWh/yr];	Market value for forest fuels and pellets; Total value of the annual outtake from forests; Climate benefit of substitution
Regulating and maintenance services	Mediation of flows	Prevention of erosion	Area with eroded forest soil [ha]	Amounts of lost soil [t]; Sediments transported and settling in streams and lakes [t]; Sediment retention rate [t/yr]	Avoided erosion [t soil/yr]; Improved nutrient retention and water quality	Avoided costs for quality in surface waters
		Prevention of storm damage	Area with storm damaged forest [ha]	Fellings by storm [m^3/yr]; Dead and hurt persons [n/yr]	Avoided storm damage	Avoided cost of storm damaged forest

		Prevention of floods	Undrained forest area [ha]	Number of floods[n]	Flood control through higher retention time	Avoided costs for flooding; Avoided cost of damaged trees in the forest
	Maintenance of physical, chemical and biological conditions	Maintenance of habitats	Area of special habitats [ha]: old forest, older deciduous forest, selection harvesting, habitat protection [e.g. Natura2000]	Tree species distribution [n of species]; Volume of deadwood [m^3/ha/yr]; Indicator species [n/yr]	Access to a wide variety of species; Shelter and nutrition	Willingness to pay to protect threatened species; Intrinsic value through contribution to a greener society; Willingness to pay for healthy habitats; Avoided costs of management
		Pollination	Areas supporting pollination [ha]; Pollinator nesting and foraging habitats [ha]	Abundance of pollinators [n]; Pollinator species [n]; Forest edges [%]	Improved yield of provisioning services [t/ha]	Value of improved production caused by pollinators
		Soil quality	Areas with good functional and structural diversity [ha]	Content of soil organic C [Mg/ha]; Availability of nutrients; pH; Density [g/cm^3] and macropore porosity [%]; Weathering [mekv/m^2/yr] and decomposition	Improved soil quality; Higher availability of nutrients; Higher production and fellings	Avoided costs of soil improvement; Avoided costs of loss of production
		Climate regulation and C sequestration	C storing forest habitats [ha]	Net uptake of C [t CO2/yr]; C sequestration rate [t/ha/yr]; C balance	Climate regulation; C stocks (in vegetation and soils) [Mg/ha]	Avoided costs for mitigation of climate impacts; Market value for C emission trading; Climate benefit of substitution; Avoided costs with impacts on human health; Avoided costs of climate related impacts
		Biogeochemical cycling	Production forest soils [ha]	Mass balances – removal rates slower than supply rates [N, C, P, Na, K, Mg and Ca]; Amount of acidified forest soils [ha]	Optimal pools and fluxes of nutrients to supply final ecosystem services; Increased harvest	Avoided costs of exhausted soils, acidified and eutrophied soils and waters
Cultural services	Physical and intellectual interaction with biota, ecosystems and landscapes	Recreation and training	Area of forest accessible for recreation [ha]	Visitors [n/yr]; Number of hunting licenses [n/yr]; Hunting activities [n/yr];	Opportunities for recreational activities [n/yr]; Number of walks [n/yr]	The willingness to pay for a visit; The willingness to pay for hunting licenses; Value of visits to forests; Health value – avoided costs
		Tourism	Preferred natural areas [ha]	Sleep-over nights [n/yr]; Number of enterprises offering tourism services [n]; Number of ecotourism operators [n]	Number of jobs within the tourist sector [n];	Total turnover in the tourist sector; The willingness to pay for tourist activities
		Mental and physical health	Areas of interest [ha]	Sickness caused by tick and snake bites [n/yr]; Dead and retired because of sedentary life style [n/yr]	Healthy inhabitants; Pulse and blood pressure decrease; Stress hormone decrease in blood	Health value - avoided as well as increased costs
		Environment and aesthetics	Preferred forest landscapes [n, ha]	Change in preference	Aesthetic experiences	Willingness to pay for trips to aesthetic landscapes

		Knowledge and information	Areas of interest [ha]	School forests [n]; Nature schools [n]; Forest research infrastructures [n]; Number of scientific studies [n/yr]; Number of publications [n/yr]	Knowledge available	Value of knowledge

[1] New areas of use will probably appear and advance in the future e.g. dissolving substances for textile production and various chemicals due to new technical solutions.

5.2 HVO FROM TALL OIL (CASE STUDY I)

The production of biofuels based on Swedish forest products is dominated by Hydrotreated Vegetable Oils (HVO), produced based on crude tall oil. Crude tall oil is a product from the Kraft (sulphate) process of wood pulp manufacture when pulping mainly coniferous trees. In Sweden today, 7 600 kton sulphate wood pulp is estimated available (from own biomass as well as imported), producing approximately 266 kton tall oil (Staffas et al., 2015). The amount of produced crude tall oil is proportional to how much pulp is cooked. Thus, an extended production of crude tall oil is depending on sales opportunities at sawmills and pulp industry. In other words, it is not economically feasible today to clearcut forest for tall oil production only but the available amount of tall oil may increase by modified Kraft processes.

The HVO is produced in two steps in Sweden. First the intermediate product crude tall diesel is separated from the crude tall oil in the Sunpine facility in Piteå. Then the crude tall diesel is processed further to HVO diesel by an integrated process in a petroleum refinery whereafter it is blended into conventional fossil-based diesel. The use of HVO in Sweden in 2014 based on crude tall oil corresponds to 22% of the total HVO use and was based mainly on domestic biomass resources. HVO is also produced from slaughter waste (35%), vegetable and animal waste oil (23%), palm oil (15%), and animal fat (5%) (Swedish Energy Agency, 2015b). In total, 19% of the total Swedish HVO use was based on Swedish resources (Swedish Energy Agency, 2015b). However, only the HVO from crude tall oil is included in the analysis in this report.

5.3 METHANE FROM FOREST RESIDUES (CASE STUDY II)

Several biofuels can be produced from syngas from gasification of biomass, e.g., methane, methanol, DME (dimethyl ether), and Fischer-Tropsch fuels, with forest residues being the expected long-term raw material. Lately, there has been an interest in facilities for methane production through gasification in Sweden, which was realized by the Biomass Gasification Project, GoBiGas project in Gothenburg (Grahn & Hansson, 2015). Initially, the GoBiGas plant has used pellets but plans to start to use wood chips during 2016 and the future plan is to base the production on Swedish forest residues (Göteborg Energi, 2016), most possibly using tops and branches (GROT) available from thinnings and final fellings.

5.4 IMPACT OF BIOFUEL PRODUCTION ON FOREST ECOSYSTEM SERVICES

A sustainable biobased economy is relying on forest biomass being used for industrial production alongside with ecosystem services coupled to the forest ecosystem being sustained or improved. A larger production of HVO for the Swedish market based on Swedish forest biomass is possible if an intensification of removal of timber, mainly coniferous forest, is made, as a reply to an increased general demand for biomass, leading to the production of additional crude tall oil in the wood pulp manufacture. Assuming that the Swedish forests will supply even higher amounts of raw wood material in coming years, felling a larger share of the available increment, will increase the potential outtake. The estimated potential increase in sustainable supply of forest biomass (including forest residues from final fellings and thinnings that is not conflicting with the Swedish environmental quality objectives) based on current conditions, amounts to approximately 20 TWh per year (de Jong et al., 2017; Börjesson et al., 2017). Biomass production may also be intensified through a higher frequency of fertilization in the forests and a shorter rotation time (Scenario 1).

A production of methane may be based on forest residues (Scenario 2) but we can here distinguish between two cases: a) a substantial share of all GROT (tops and branches) available from current thinnings and loggings left in the forest may be used, a rather large resource of GROT is today left in the forest since there is no demand for it and it is not economically feasible today to extract and use it; b) extra thinnings and fellings due to increased forest biomass demand will provide additional GROT biomass for an increased methane production. In practice, the maximal outtake of GROT is influenced by environmental considerations such as recommendations by the Swedish Forest Agency.

The main aim of this study is to scientifically test the effects of an increased removal of biomass for biofuels production on ecosystem services in the two scenarios. The scenarios are thought to be theoretical and therefore do not take into account the economic plausibility and judgements on whether such removals are sustainable. The results are thus not to be understood as the truth of how production of such biofuels may influence ecosystem services, but rather an academic estimation of potential effects on ecosystem services in scenarios with high production and use.

5.4.1 Qualitative and semi-quantitative valuation of change in indicators

The Swedish Environmental Protection Agency (2015) has published instructions to valuation of ecosystem services. In this guide, the valuation of ecosystem services and their indicators are described in four different succeeding levels; i) description in qualitative terms through words, ii) semi-quantitative description based on a scale (e.g. 1-5, +/-, yes/no), iii) quantitative description of indicators through the use of biophysical units or/and iv) in monetary terms. The guide specifies that all four ways of valuation is not always necessary in ecosystem services analysis.

We describe the effect that an intensification will have on forest ecosystem services through a qualitative description of changes as well as a semi-quantitative description (scale: -/--/---/0/+/++/+++) (Table 3). When the effects of removal of forest residues on different ecosystem services (Scenario 2a and 2b) differ from the removal of whole trees for HVO production (Scenario 1), this is noted using bold text in Table 3.

Table 3. Potential theoretical changes in ecosystem services as an effect of intensified forest management. The reference situation is today's forest biomass production. Allocation of impacts between different outputs from the forest is not considered. Possible actions to mitigate the potential changes are furthermore suggested in the table. Intensified forest harvest is assumed needed in order to produce higher amounts of tall oil from forest resources leading to a higher production potential of HVO (Scenario 1). For methane the production might primarily rely on GROT from current thinnings and loggings (Scenario 2a) but may even rely on extra thinnings and fellings in case of larger forest demand which provide additional GROT biomass (Scenario 2b). Whenever Scenario 2 differs from Scenario 1 in the influence on ecosystem services, these special aspects are marked with bold in the table. The CICES framework is used to structure the ecosystem services. The colors show either negative impact (red) or positive impact (green). The stronger the color the more impact is expected. Three +++ means a larger impact than one or two +. To what extent the impacts should be carried by biofuels remains to be analysed.

Class	Division	Ecosystem service	Description of changes in ecosystem services as an effect of intensified forest management	Relative importance of change 0/+/-
Provisioning services	**Nutrition**	Berries	Blue berries are not favored by clear-felling and only reestablishing approximately 10 years after. Lingonberries are more robust and only decrease insignificantly after harvest appearing in the area again one to two summers after clear-felling. A shorter rotation time reduces the time when the forest is attractive for berry picking.	-
		Mushrooms	Presumably mushrooms disappear after final fellings and appear only when the appropriate combination of light (canopy closure) and moisture return.	-
		Game	Game is important in Sweden both for meat (36%) and for recreative purposes (64%). Intensification of forestry will lead to more use of heavy machinery in harvest procedures that might scare game away in harvest areas during the actual operation. After any forest operation game probably return to the area, where rejuvenation sites host emerging young trees as a perfect food resource to game.	0
		Reindeer and fodder	Fodder for reindeer is mostly lichens in older forest stands; if forest stands being important fodder areas for reindeer are used more intensively and ultimately harvested this might impact the availability for fodder, especially during harsh winters. Intensified use of machinery also scares reindeer.	--
		Drinking water	Intensified forestry does not necessarily have effects on drinking water unless the intensification includes a larger use of fertilizers. Fertilizing might lead to nitrogen leaching to surface waters.	0/-
	Materials	Timber and pulpwood	A larger removal of biomass naturally leads to increased availability of resources of timber and pulpwood, and hereby also crude tall oil for the production of HVO. **A larger removal of biomass for timber may lead to a possible larger removal of GROT for methane production.**	+++
		Decorative materials	Extra removal of biomass for pulpwood or GROT does not influence the production of decorative materials being another forest resource.	0
		Genetic resources	No knowledge.	nd
	Energy	Bioenergy	Intensified harvesting leads to more bioenergy from forests, both through regular harvest (HVO) **and through tops and branches, GROT (Methane).**	+++
Regulating and maintenance services	**Mediation of flows**	Prevention of erosion	Growing trees have root systems that hold on to soil and prevent erosion. In intensified harvest trees are cut and fields left open. Clear-felling as well as stump removal lead to possibilities for larger erosion. **Even GROT staying on top of the soil decreases soil erosion (Methane).**	-
		Prevention of storm damage	Forest stands next to clearfelled areas are more susceptible to storms.	-
		Prevention of floods	Clear-felled trees/stands are no longer there to dampen the peaks of water run-off and take up part of the circulated water flows.	-
	Maintenance of physical, chemical and biological conditions	Habitats	If coarse woody debris (snags and logs), which provide breeding and foraging for a wide range of organisms, and old trees are increasingly removed from the forest, habitats are disturbed and diminished. However, management can be undertaken to avoid this for example decreasing harvesting in nesting periods.	-
		Pollination	Intensified harvest will not necessarily affect the pollination of vegetation and berries.	0

		Soil quality	Increased use of heavy machinery in thinned or clear-felled stands will have effects on compaction which will appear more often. Compaction is a clear threat to soil quality. **Removal of forest residues such as GROT and even needles will remove a considerable amount of nutrients leading to possibilities for lower soil quality, deficiency and acidification as well as eutrophication (Methane). However, this may be compensated by bringing back ashes to the forest stands and leaving GROT to dry in the forest for needles to fall off before removal. Fertilization may also compensate the removal and further lead to increased carbon sequestration but on the other hand, it may lead to more acidification or/and eutrophication.**	--
		Climate regulation and C sequestration	Biofuels produced from forest biomass substitute for fossil fuels and thereby contribute to mitigating climate change. Biofuels from forest biomass may lead to sequestration of less C as well as less C stored.	++
		Biogeochemical cycling	Where biomass is removed the soil is acidified. The more biomass removed, the larger the acidifying effect. The removal of these parts leads to changes in the biogeochemical cycles, acidification of soil and possibly water courses and finally may affect future primary production. However, this may be partly compensated by bringing back ashes to the forest stands.	--
Cultural services	**Physical and intellectual interaction with biota, ecosystems and landscapes**	Recreation and training	Visitors to forests enjoy the quietness and wild animals they may see on their trip. A more intensified forest management may lead to shorter rotation time with 10-20 years compared to today. Final fellings will be more frequent and sounds may disturb the quietness and temporarily scare off game; however, most probably this temporary effect will not be significantly different from present forest management. Visitors have indicated that they find GROT and deadwood laying in the forest messy and untidy which suggests that a higher removal of GROT will be positive for visitors. Shorter rotation times would however shorten the period that visitors find the forest to be most beautiful.	0/-
		Tourism	Tourists are looking for the Nordic wilderness comprising older forests, interesting (different from home) habitats, game and quietness. Shorter rotation times and intensification in the form of fertilization may disturb these services.	-
		Mental and physical health	Pulse and blood pressure as well as stress hormones in blood decrease when visiting the forest. Intensification might temporarily disturb the quietness in the forest; however, most probably this temporary effect will not be significantly different from present forest management.	0/-
		Environment and aesthetics	Visitors do not want to see or hear large forest machines on forest trips. Anything which disturbs the order is disliked. However, the number of machine days will only increase insignificantly within the rotation time.	0/-
		Knowledge and information	No knowledge.	nd

5.4.2 *Quantitative and monetary valuation of change in indicators*

Provisioning ecosystem services in forest ecosystems relating to timber, pulpwood, decorative materials, berries, mushrooms and game are often well described and many quantitative data can be gathered often from the national forest inventory performed annually. These services are also sold on a market and may therefore easier be economically valued (Hansen and Malmaeus, 2016). Indicators for water provision is however more rare and often we depend on modelling exercises to estimate changes in water supply (Maes et al., 2016). Indicators for regulating and maintenance services are scarce but some studies have been performed on the willingness to pay to protect threatened species, avoided cost of storm damage and production caused by pollinators. Also, the role of forests in climate regulation may be quite well determined. Indicators for cultural services are at times possible to deliver often based on visitor statistics and the willingness to pay for a visit; however, the amount of data available, especially for monetary valuation, is still restricted. Hansen and Malmaeus (2016) document further specifics on the possibility to physically quantify and economically value forest ecosystem services and their indicators.

5.5 SYNERGIES AND TRADE-OFFS

Forest resources need to serve many different purposes. The different ecosystem services interact with each other and this may lead to oppositions between them. Some services interact synergistically, where the provision of one service may provide the concurrent supply of another service. Other services may react combatively (Bennett et al., 2009), where the provision of one service may negatively impact the supply of another service. Different services are thus related to each other (Meyerson et al. 2005; Bennett et al. 2009) in often complex ways. A number of trade-offs and synergies between services becomes apparent when we assume a larger production of forest biomass for biofuels in the future.

The annual gross fellings in Swedish forests are currently less than the annual increment, which indicates that the stock continuously increases. This extra stock biomass may be partly used for biofuel production, depending on the actual competition between product lines. However, the roundwood production today is by far the most economically important product line and the most plausible scenario is that intensification leads to increased roundwood production and as a result we are able to produce more material suitable for biofuel production. When the removal of forest biomass is intensified possibly through a shortened rotation time, a higher removal of nutrients is started and this may lead to an altered biogeochemical cycling, lower soil quality and an acidification of soil and downstream water courses. Removing yet extra biomass through e.g. all GROT and some stumps may potentially cause decreased or increased leaching of nitrate to downstream waters and lead to deficiency of nutrients. On the other hand, this outtake may be compensated by a return of ashes and by fertilization. Forest management operations such as thinning, logging and possible removal of stumps are often performed using sizeable machinery. When heavy machines harvest biomass, compaction may follow, deep tracks may lead to leaching of mercury to ground and surface waters but further assessments are needed. Use of such machines, in what people expect to be a quiet forest, is considered undesirable for outdoor recreation and access for visitors, leaving them with a negative experience of their visit. However, most probably the number of machine days will not be significantly different from present in a shortened rotation time by 10-20 years. Intensified forest management will furthermore have a negative impact on the habitat for wildlife and the possibilities for hunting. Furthermore, less carbon will be sequestered and stored in biomass and soils if more biomass is removed. However, if biomass for bioenergy as expected may substitute fossil fuels, it will cause less emission of carbon dioxide and a decreased impact on climate. An increased removal of biomass will reduce the amount of deadwood and old trees present in the forest, which may have a negative impact on biodiversity. However, existing regulations and certifications secure that old trees and deadwood are left after clear-felling.

6 BIOFUEL AND AGRICULTURAL ECOSYSTEM SERVICES

A conversion of the energy system to less reliance on fossil fuels will cause crop biomass to have a more important role in the future. In Sweden, a little less than 3 million ha land is occupied by agriculture (year 2013, Swedish Board of Agriculture, 2016) which corresponds to circa 7.5% of the total available land; however, agricultural land is often left aside for economic reasons. Today, 67 000 farms are covering this area, which is about half as many as in 1970. A decrease in the number of active farms and farmers has been observed. Despite this, Sweden still produces well since the farms each have become larger and more productive covering approximately 41 ha each as respective to about half the area 40 years ago. Every ha of land and every animal is nowadays producing more, for example one ha of a wheat field produces 4-5 t in comparison to a production of 3 t in 1970 (Swedish Board of Agriculture, 2016). In 2007, the value of the Swedish production was approximately 47 billion SEK.

6.1 AGRICULTURAL ECOSYSTEM SERVICES AND INDICATORS

Agriculture is utterly important for the production of food, feed and energy, all of which are provisioning services of positive value to human beings (Gasparatos et al., 2011; Joly et al., 2015). Thus, Swedish agriculture is a central and crucial provider of ecosystem services with large values for the population which makes the sustainability of these services an important issue for the society in general. Despite our northern location the soils are productive and will by possible future climate changes gain higher importance.

Different means have been introduced in Swedish agriculture in order to optimize the production of provisioning services per area. For example, an increase in field size and the introduction of larger machinery along with simplified rotations of genetically yield-optimised crops have through the years led to a less complex landscape with loss of edges, roads and natural islands of vegetation which have diminished natural habitat and biodiversity as well as increased the possibilities for pest damage (Björklund et al., 1999; Power, 2010; Dänhardt et al., 2013). Also, the use of fertilizers and plant protection products has increased to serve the purpose of enlarged production.

Conventional agricultural activities may cause a wide range of environmental impacts, or trade-offs on other services (Gasparatos et al., 2011; Dänhardt et al., 2013), among which for example degradation of soil structure and compaction, destruction of natural habitats and promotion of invasive species and biological hazards through an often adapted monoculture of annual crops, along with contamination of water bodies by pesticides and a surplus of nutrients (through fertilization) caused by intensive resource inputs. Agricultural activities are thus responsible for both use of resources (e.g. in biological pest control and soil fertilization) and provision of different ecosystem services (e.g. fuel, food and feed) (Power, 2010) as well as having certain environmental impacts. This creates a tight connection between provisioning and other ecosystem services, where sometimes services are turned into dis-services (Zhang et al., 2007).

Some of the most important ecosystem services and dis-services provided by agriculture are listed using the CICES framework (version 4.3) and the Cascade model in Table 4. While reviewing literature (in particular Björklund et al., 1999; Zhang et al., 2007; Power 2010; Gasparatos et al., 2011; Dänhardt et al., 2013; Cederberg et al., 2016), we identified 23 agricultural ecosystem services and suggested indicators for each of the four cascade-levels for all services. The comprehensive matrix of services and indicators for agricultural environmental state and human well-being is usable for our work of relating the production of biofuels to ecosystem services.

6.1.1 Provisioning services

Provisioning services provided by Swedish agriculture comprise consumables, materials and energy. The production of food from crops mainly consists of wheat, rye, barley and oat as well as oils, while the livestock production generates meat (pork, goat meat and mutton, chicken, beef), products such as egg, milk and other dairy products) as well as byproducts and wastes. Also, horticultural products such as potatoes, green vegetables, onions, fruits and berries are produced. Agricultural areas host a large amount of game, providing valuable meat as well. Agricultural products may further be used for bioenergy directly through farming of energy crops (e.g. willow, poplar and elephant grass) for production of electricity or heat or through the use of for example grain for production of bioethanol or indirectly when rest products such as straw and animal manure is used for biogases (Cederberg et al., 2016). Furthermore, plant fibers along with raw-material for plant-based pharmaceuticals and cosmetics are agricultural products produced; however, in rather negligible amounts. The agricultural food production is depending on valuable genetic resources through a large range of species used; however, the largest part of our crop food is produced by crops where the variation in genetic material is decreasing since agriculture strive to find more and more high producing crops and animal species. Inadequate maintenance of sufficient genetic diversity in crops may cause high expenses (Zhang et al., 2007). Lastly, the provisioning of clean drinking water is affected by agricultural production. The capacity of agricultural crops to deliver these important provisioning services depends on spatial and temporal scales, on-farm management practices and natural environmental conditions. Changes in local and regional climate, such as oscillations in temperatures and precipitation rates, may alter the overall ecosystem structure and lead to a reduction in production and in the ability of providing a specific service. For instance, increases in global temperature and changes in precipitation patterns may reduce crop production yields and the provision of materials from plants.

6.1.2 Regulating and maintenance services

Regulating and maintenance services in agriculture mediate flow in the agricultural landscape. For example, crops secure that erosion is avoided and prevented. On the other hand, soil preparation between new rotations might cause erosion. Crops retain nutrients leading to better water quality and increased production. On the other hand, the use of fertilizers may lead to eutrophication through leaching of nutrients in excess to downstream waters (wetlands, lakes, rivers and seas). Regulating and maintenance services also make sure that physical, chemical and biological conditions are maintained supplying e.g. suitable habitats for flora and fauna. It is projected that nearly half of all vascular plant and mammal species existing in Sweden are found in arable landscapes. However, conventional farming in many parts of Europe suggests that the diversity of beneficial soil organisms continues to decline (Hedlund et al., 2012). Especially, bacteria, fungi, nematodes, microarthropods and protozoa, and their complex interactions are essential in delivering good soil quality for a beneficial production. The type of crop also influences the soil quality; e.g., perennial crops have larger root biomass growth compared to annual crops leading to higher soil organic matter and larger soil C storage (Brady and Weil, 2008). The content of C depends on the use of the soil; soil preparation, inputs of inorganic fertilizers and length and type of crop rotation may influence the soil content of organic C (Hedlund et al., 2012; Dänhardt et al., 2013). Agricultural soils worldwide are found to be depleted in C (Lal, 2011). While the soil C content decreases the crop output decreases (Brady et al., 2015a, b). Higher inputs of fertilizers are then needed to reach similar product output (Hedlund et al., 2012) leading to adverse effects on water quality (Björklund et al., 1999). Decreases in soil organic matter leads to decreased amounts of substrate for different insects and earthworms, fungi and microorganisms leading to a decline in decomposition of litter which is important in soil structure and making the nutrients available for plants (Mulder et al., 2011). Also, N fixation by soil bacteria has a large influence on the nutrient balance (Jetten, 2008). Both decomposition and N fixation help in improving the soil quality and secure the provisioning services through maintenance of soil productivity and harvest of crops. The agricultural crops are to different degrees dependent on pollination and the amount of different pollinators is essential to a long-term sustainable service. However, the diversity of pollinators has decreased through many years caused by intensified arable production leading to fragmentation of suitable pollinator habitats (Bommarco et al., 2012). Future appropriate considerations need to be taken to improve pollinator habitats as a supporting service to provisioning services. Crops sequester carbon dioxide and build biomass through the photosynthesis. With the exception of perennial crops, the sequestration of C in growing arable biomass is merely temporary since most C returns to the atmosphere when the biomass is decomposed. The Swedish agricultural soils are estimated to be a source rather than a sink of C (Swedish Environmental Protection Agency, 2014).

6.1.3 Cultural services

Agricultural landscapes provide cultural services when people use it for training and recreation. We are active in nature and relax, enjoy and value the open landscape as a positive and aesthetic place to walk, run, bike, ride and ski. Recreation involves hunting, bird watching, picnicking, and camping. Our visit in nature may be valued on the cultural heritage of the landscape (e.g. settlements, land use, roads, cairns, ancient monuments and remains), the possibilities for entering arable areas, e.g. walking paths, and the aesthetics of what we see on our trip (animals and birds, flowers, colors) etc. (Cederberg et al., 2016). Even tourists come to Sweden to experience the unique mixing of wilderness and farmed landscapes and the tourist industry is one of the fastest growing branches in Sweden (Business Sweden, 2016). Our visits outdoor result in comfort and well-being and has been shown to have healing influences. On the other hand, the visit to areas with high grass might lead to tick and snake bites as a dis-service.

Table 4. Ecosystem services in Swedish agricultural ecosystems and relevant indicators categorized using CICES v4.3 and the Cascade model.

CICES			CASCADE Indicators			
Class	**Division**	**Ecosystem service**	**Structure (spatial)**	**Function (temporal)**	**Benefit**	**Value [SEK]**
Provisioning services	**Nutrition**	Cultivated crops – food and forage	Area under cultivation [ha]	Annual production of crop and feedstock [t/yr]; Use of pesticides [t/yr]; Nutrient dynamics	Crop harvest [m^3]; Yields of food or feed crops [t/ha]; Employment in crop production [n]	Income; Health value; Value of employment in crop production
		Livestock	Area of pastureland [ha]	Number of animals [n/km^2]; Annual production of livestock [t/yr]; No of livestock farms [n]; Use of antibiotics [t/yr]	Harvested livestock [t/yr]; Meat consumption [t/yr]; Employment in livestock production [n]	Income; Health value – avoided costs; Value of employment in livestock production
		Game	Area of game habitats [ha]; Area of fallow and untilled land [ha]	Game population [n/yr]; Species richness [n/yr]	Harvested game [t/yr]; Game meat consumption [t/yr]	Market value of game meat; Sales of game meet; Health value for meat without antibiotics
		Drinking water	Area dedicated to preserve drinking water [ha]	Total supply of water per agricultural area [m3/ha/yr]; State of surface water and groundwater	Provision of clean drinking water [m3]	Avoided costs for cleaning water
	Materials	Plant fibers	Fiber crop area [ha]	Manure [t/yr]	Yields of fiber crops [t/ha]	Market value of fiber crops
		Materials from plants	Crop area used for pharmaceutical and cosmetic raw-material production [ha]; Variety in species [n]	Breeding [n/yr]	Yield of crops used for pharmaceuticals [t/ha];	Market value of plant-based pharmaceuticals and cosmetics
		Genetic resources	Area of agricultural gene reserve habitat [ha]	Amount of red-listed species [n/yr]; Variety in species [n/yr]; Breeding [n/yr]	Breeding; Discovery potential; Genetic variance for future agricultural use	Market value for resources
	Energy	Bioenergy	Crop area for bioenergy production [ha]	Annual growth of biomass [t/ha/yr]	Harvest [m^3]; Yields of energy crops [t/ha or MJ/ha]; Employment in bioenergy sectors [n];	Value of employment in bioenergy sectors; Health value – avoided costs of air quality improvement; Intrinsic value through contribution to a greener society
Regulating and maintenance services	**Mediation of flows**	Filtration of pollutants	Concentration of pollutants in soil in agricultural areas [mg/m^3]	Decomposition of waste by biological and biophysical processes	Improved water and soil quality, more contaminant-free	Avoided costs of contamination remediation
		Nutrient retention	Area of more sustainable crop areas (decrease in nutrient loss)	Nutrient retention in the soil	Improved water quality; Improved nutrient retention	Market value for nutrient rich soil; Market value for clean water
		Prevention of erosion	Percentage of soil cover [%]; Undisturbed soils [ha]	Particle retention rate/potential (stability of soil aggregates)	Avoided erosion [t soil/yr]; Improved soil quality in marginal lands; High quality surface water	Avoided costs of fertilizer use; Avoided costs of erosion control

	Maintenance of physical, chemical and biological conditions	Habitats	Area of nursery habitats [ha]; Area of fallow and untilled land [ha]; Area of organic farming [ha]	Reproduction success [n/yr]; Indicator species [n/yr]	Shelter and nutrition	Willingness to pay to protect threatened species; Avoided cost of management measures; Intrinsic value
		Pollination	Vegetation area supporting pollination [ha]; Pollinator nesting and foraging habitats [ha]	Abundance of pollinators [n]	Improved crop production and increased yield [kg/ha]; Increased availability of food [kg/ha]; Additional nutrition	Reduction in food costs; Influence on gardening; Intrinsic value
		Soil quality	Functional diversity of soil organisms	Content of soil organic C [Mg/ha]; Availability of nutrients; pH; Density [g/cm3] and macropore porosity [%]; Weathering [mekv/m2/yr]	Improved soil quality; Higher availability of nutrients; Higher production and harvest	Avoided costs of fertilizer use; Value of improved income
		Decomposition and fixing processes	Areas of N fixing crops [ha]	Nitrogen fixation rates [kg/ha/yr]; Decomposition rates [mekv/m2/yr]	Improved nutrient balance; Improved soil quality; Higher production and harvest	Avoided costs of N fertilizer use
		Weathering processes	Area of organic farming [ha];	Cation exchange capacity; pH of topsoil; Soil organic matter content [%]	Improved soil quality; Increased agricultural production	Avoided costs of soil improvement; Value of improved income
		Biological pest control	Area not needing pesticide treatment [ha]; Area of organic farming [ha];	The density of hedges and shrubs [no/ha]	Less pest damage in crops; Higher production	Avoided costs of pest damage
		Climate regulation and C sequestration	C-storing habitats [ha]	C sequestration rate [t/ha/yr]; C balance	Climate regulation; C stocks (in vegetation and soils) [Mg/ha] and C sequestration [Mg/ha/yr].	Avoided costs for mitigation of climate impacts; Market value for C emission trading; Avoided costs with impacts on human health; Avoided costs of climate related impacts
Cultural services	**Physical and intellectual interaction with biota, ecosystems and landscapes**	Recreation and training	Preferred recreation farmland areas [ha]; Area of croplands for hunting [ha]; Walking and biking trails [km]; Area of croplands for training [ha];	Visitors in agricultural areas [n/yr]; Number of hunting licenses [n/yr]; Hunting activities [n/yr]; Number of competitions associated with agriculture [n/yr]	Increased opportunities for recreational activities; Bird population control	The willingness to pay for a visit; The willingness to pay for hunting licenses; The willingness to pay for hiking and walking; Avoided health costs
		Tourism	Preferred farmland areas for tourism [ha]	Tourists in agricultural areas [n/yr]; Number of rural enterprises offering tourism services [n]; Sleep-over-nights [n/yr]	Jobs in the tourist sector	The willingness to pay for tourism activities; Value for tourist visits
		Mental and physical health	Areas offering varied and interesting agricultural landscapes [ha]	Number of ticks carrying meningitis [n]	Improved or impoverished health	Health value – avoided as well as increased costs
		Knowledge and information	Areas of croplands used	Visitors in agricultural areas [n/yr]; Number of didactic	Increased awareness of sustaina-	The willingness to pay for a visit; Value for science

			for scientific studies [ha]	farms; Number of scientific studies [n/yr]; Number of publications [n/yr]	ble farming practices; Source of knowledge	and education; Funding for research activities
		Heritage, cultural	Farmland area [ha]	Number of monuments in agricultural areas [n/ha]; Interaction and preservation of areas	Cultural continuity on sustainable farming	Story tradition; The willingness to pay for a visit

6.2 WHEAT-BASED ETHANOL (CASE STUDY III)

Wheat-based ethanol represents a large fraction of biofuels in the European Union, being particularly produced in Northwest Europe, where wheat is abundantly available (de Vries et al., 2010). In Sweden, wheat is grown on approximately 460 000 ha of agricultural land. Bioethanol is produced through a reduction of wheat rich in sugar polymers with enzymes to single glucose molecules which are then fermented with microorganisms to ethanol (Erdei, 2013). Approximately 2 TWh of ethanol was used for transport in Sweden in 2014 (Swedish Energy Agency, 2015a). 56% of the reported ethanol for transportation in Sweden in 2014 was based on wheat and 19% of the ethanol was based on domestic resources (Swedish Energy Agency, 2015b). In Sweden, Agroetanol in Norrköping produces 230 000 m^3 grain-based ethanol and 180 000 tons of fermented protein feed per year. Their product, Agro Cleanpower 95, is mainly used in public busses and by trucking companies.

6.3 BIODIESEL FROM RAPESEED (CASE STUDY IV)

The European Union is the world's largest producer and consumer of biodiesel, and rapeseed accounts for 80% of its biodiesel feedstock (Malça et al, 2014). In 2011 biodiesel was responsible for 78% of the total biofuels used for road transportation in the EU and corresponded to 3.9% of the total transportation demand in 2012 (Ibidem). In Sweden, rapeseed is grown on 94 500 ha of agricultural land. The entire reported amount of fatty acid methyl ester (FAME) in 2014 is produced from rapeseed (Swedish Energy Agency, 2015b). 7% of the rapeseed originated from Sweden (Swedish Energy Agency, 2015b), but the national production is also based on imported feedstock. There are and have been several producers of FAME in Sweden, Perstorps BioProducts AB in Stenungsund and Energigårdarna Eslöv/Ecobränsle in Karlshamn being the largest (Grahn and Hansson, 2015).

6.4 IMPACT OF BIOFUEL PRODUCTION ON AGRICULTURAL ECOSYSTEM SERVICES – VALUATION

A sustainable biomass based economy in Sweden has to, apart from forest biomass, also rely on agricultural biomass. It is discussed whether or not growth in the production of biofuels might compete spatially with the food and fiber production and in several countries it probably is likely to do so, as for example in the US (Howarth et al., 2009; Gasparatos et al., 2011); on the other hand, Kline et al. (2009), FAO (2007) and Parish et al. (2013) conclude that this is unlikely to happen. A larger biomass production of wheat and rapeseed may be farmed on underutilized land already available for production at low cost (Gasparatos et al., 2011); bringing land in marginalized areas with poorer quality back into production (Fargione et al., 2010; Valentine et al., 2012; Milner et al., 2016). The potential for biofuel production on arable land in Sweden, without jeopardizing the current food and feed production, is discussed by Börjesson (2016). He projects that Sweden has large areas with abandoned arable land, fallow land and to certain extent even grassland farming that is more likely to be used for an extra intensified crop production for biofuel than food production areas. Approximately 88 000 ha of former arable land is abandoned (Olofsson and Börjesson, 2015) and probably more will become abandoned, potentially including 900 000 ha that are existent arable fallow land (Börjesson, 2016), and approximately 250 000 ha that are existent grassland (Börjesson, 2016), in total 1 238 000 ha. This uncultivated land could potentially be available for intensified biofuel production (Swedish Board of Agriculture, 2016) on top of the biofuel production already existing today without impacting food and feed supplies. Pasture land is not included in this estimation since it is considered a more species-rich biotope having higher nature values than arable land and therefore better to preserve (Björklund et al., 1999; Börjesson, 2016). New research looks into other ways of increasing the agricultural biomass production for biofuel production through for example new and more productive genetic material. Alongside, climate change is expected to move the border for cultivation of crops up further north in Sweden, again making more land available for cultivation.

On-farm management practices associated with agricultural crops may affect the services provided by the ecosystem (Castanheira and Freire, 2013; Montoya and Raffaelli, 2010), by altering key ecosystem services. In general, the increased production of agricultural products, altogether with intensified agricultural management, results in the degradation of other ecosystem services, however, indicating if it will cause a positive or a negative effect in practice is at times difficult. In fact, how intensive or extensive agriculture impacts ecosystem services is poorly understood and further research is needed (Zhang et al., 2007). For instance, sustainable crop production intensification is based on increased levels of crop productivity, but without leading to adverse impacts on natural resources.

6.4.1 Qualitative and semi-quantitative valuation of change in indicators

We describe the effect that an intensified production of wheat and rapeseed might have on agricultural ecosystem services, when produced on formerly abandoned arable land as well as on fallow land or grassland. The changes are described qualitatively as well as semi-quantitatively using the same principles and scale as for the forest ecosystem services (Table 5). The relative importance of change will depend on how the intensification occurs and possible actions to mitigate the potential changes are also indicated in the table.

Table 5. Potential changes in ecosystem services as an effect of intensified use of already existing agricultural land such as abandoned arable land, fallow land and grassland. The reference situation is today's crop production. Possible actions to mitigate the potential changes are suggested in the table. Intensified agricultural production is here assumed needed in order to produce higher amounts of ethanol from wheat and biodiesel from rapeseed. The CICES framework is used to structure the ecosystem services. The colors show either negative impact (red) or positive impact (green). The stronger the color the more impact is expected. Three +++ means a larger impact than one or two +.

Class	Division	Ecosystem service	Description of changes in ecosystem services as an effect of intensified agricultural production	Relative importance of change 0/+/-
Provisioning services	**Nutrition**	Cultivated crops – food and forage	A larger production of wheat or rapeseed leads to a larger availability of biomass and as such possibilities for a larger production of biodiesel and ethanol.	+++
		Livestock	If the intensified crop production is performed on abandoned and fallow cropland, there is no effect on the possibilities to keep livestock. However, in case the new cropland competes with livestock there is a potential trade-off between intensified crop production for biofuels and livestock production. An increased biofuel production may however improve the livestock production because of the associated possible improved access to sustainable produced high-protein feed.	0/-
		Game	Game is important in Sweden both for meat and for recreational purposes. Intensification of crop production for biofuels will lead to more use of heavy machinery in soil preparation and harvest procedures that might potentially scare game away (even if the effect is uncertain). Also, larger fields provide less shelter and habitat supporting wild animals. However, the development towards larger fields is also happening because of potentiation.	-
		Drinking water	Intensified agricultural production does not necessarily have effects on drinking water unless the intensification includes a larger use of fertilizers. Fertilizing and the use of pesticides might lead to reactive nitrogen and phosphorus leaching to surface waters and a build-up of harmful chemicals. Smart handling and extra precision of fertilization may however partly diminish the problem.	-/--
	Materials	Plant fibers	When the increased crop production for biofuels is mainly produced on abandoned and fallow agricultural land no competition between the production of plant fibers and biofuels exist; however in areas earlier used for fiber crop production, a trade-off between the two productions will occur.	0/-
		Materials from plants	When the increased crop production for biofuels is mainly produced on abandoned and fallow agricultural land no competition between the production of e.g. pharmaceuticals and biofuels exist; however in areas earlier used for such production, a trade-off between the two productions is apparent.	0/-
		Genetic resources	Intensified agricultural crop production for biofuel production does not necessarily have an impact on the genetic resources; however, if the production causes the variation in genetic material to decrease because more and more high producing crops, genetic resources will be influenced negatively.	-/--
	Energy	Bioenergy	Intensified crop production and harvesting leads to more possibilities for bioenergy/biofuel production. During the process high-value protein forage (distiller's grains and solubles) is produced as a co-product reducing the need for other feeds. A possible increase in employment might follow.	+++
Regulating and maintenance services	**Mediation of flows**	Filtration of pollutants	Intensified crop production may lead to a certain pollution of soil and water bodies (e.g. by heavy metals) through the extra use of sludge, fertilizers and pesticides.	--
		Nutrient retention	Crops hold nutrients in soil and biomass. Intensified crop production uses more fertilizers and there is a risk for overdosing leading to higher nutrient leaching. However, smart handling and extra precision as well as optimized fertilization may diminish the problem.	-
		Prevention of erosion	Growing crops have root systems that hold on to soil and prevent erosion. An intensified harvest of wheat and rapeseed for biofuels on abandoned and fallow land will lead to annual crops before perennial crops (shortening the management cycle) on land such as pastureland or grassland which will cause fields to be annually har-	-

			vested and tilled and possibilities for larger erosion than for perennial crops (with year round soil cover). However, the development towards new methods of reduced soil preparation and direct seeding will counteract somewhat.	
	Maintenance of physical, chemical and biological conditions	Habitats	Abandoned and fallow land as well as grassland farming have longer rotations and less management than annual croplands do and as such better breeding and foraging possibilities for a wide and different range of organisms. Biodiversity will diminish as landscape complexity decreases. However, management may to a certain extent be undertaken to avoid this. For example, harvesting might be avoided in nesting periods and variation in the landscape should be endorsed through rotation and creation of “islands” in the agricultural landscape, such as edges, uncultured corridors, uncultured spots, stone fences, ditches etc. providing vital refugia.	--
		Pollination	Intensified arable production has caused a decreased diversity of pollinators through the alteration of the structure of the landscape (larger fields and less uncultivated islands). Further intensification and harvest will fragment suitable pollinator habitats further. Also, direct effects of insecticides on pollinators have been observed. However, arrangements such as flowering edge zones may counteract.	--
		Soil quality	Increased use of heavy machinery in annual crops will have effects on compaction which will appear more frequent posing a clear threat to soil porosity and bulk density. Since perennial crops often leads to higher soil organic matter (deep root systems and high litter input) and larger soil C storage, a conversion to more intense biofuel production based on annual crops like wheat and rapeseed will decrease soil quality. However, a well-planned crop rotation and having crops longer periods of the year may help to avoid compaction.	--
		Decomposition and fixing processes	Decomposition is important in soil structure and in making the nutrients available for the plants again. Decreases in soil organic matter leads to decreased amounts of substrate for different decomposers further leading to a decline in decomposition of litter.	-
		Weathering processes	Soil formation is a slow process where weathering forms new minerals which are important for the continued soil quality. No knowledge is available on whether intensified agricultural production will cause any changes in weathering processes.	nd
		Biological pest control	Pests may cause large reductions in yield. Further intensification of biofuel production may cause larger outbreaks of pests and impact the possibilities for natural biological pest control negatively. Variation in crop rotation and the existence of fallow land and grassland nearby will however increase the availability of natural enemies.	--
		Climate regulation and C sequestration	Biofuels produced from agricultural biomass substitute for fossil fuels and thereby contribute to mitigating climate change. Today, the Swedish agricultural soils are estimated to be a source rather than a sink of C. Biofuels produced from annual crops may reduce soil C and increase emissions of CO_2.	++
Cultural services	**Physical and intellectual interaction with biota, ecosystems and landscapes**	Recreation and training	Visitors enjoy quietness and wild animals they meet in nature. Anything which disturbs the order is disliked. When a more intensified agricultural management is adapted animals may be scared off and harvesting disturbs the quietness. Visitors have indicated that they like variation in the landscape which a rotation of different crops, pasture and grassland will provide. However, if fallow fields are again being cultivated, a vivid countryside creates positive effects for recreation.	-/0
		Tourism	There is not much knowledge on what tourists prefer when visiting Swedish arable landscapes. An increased crop production will probably create more noise since more heavy machinery will be used.	-/0
		Mental and physical health	Pulse and blood pressure as well as stress hormones in blood decrease when visiting quiet areas with scenic beauty. Intensification might disturb the quietness. No knowledge on health issues.	-
		Heritage, cultural	New possibilities for income and support to farmers.	nd
		Knowledge and information	Knowledge on biomass production for biofuels.	nd

6.4.2 Quantitative and monetary valuation of change in indicators

The provisioning ecosystem services food, feed, fiber and energy from agricultural ecosystems are well quantified through a range of indicators in Sweden as well as at EU scale. Data for these services are monitored through the Common Agricultural Policy (CAP). As for forest provisioning services are sold on a market and may therefore easier be economically valued. Indicators for regulating and maintenance services are scarce but some are nonetheless available, for example indicators for erosion regulation and pollination. In Sweden, Brady et al. (2015b) estimated the value of the supporting services in farming to be the summed up decrease in the profit in case the ecosystem services are lost. The authors observed that the value of supporting services is higher for society at large than it is for the individual farmer. Indicators for cultural services are on the other hand less well monitored; only a few indicators are obtainable (Maes et al., 2016). Studies on the impact of changed management and variations in the agricultural landscape on the whole range of ecosystem services and biodiversity is needed in order to increase the possibilities to value them monetarily and hereby gain knowledge on which decisions need to be made to enhance a positive development in agricultural ecosystem services.

6.5 SYNERGIES AND TRADE-OFFS

The services interrelate among each other, magnifying or reducing one another's effects, i.e. trade-offs and synergies exist on the provision of different services from agriculture, especially in provisioning and regulating services (Elmquist et al., 2011). The magnitude of the benefits and trade-offs are dependent on natural conditions and agricultural management practices. In general, biofuel production encompasses trade-offs between the economic benefits to society and the changes in landscape configuration.

Management aspects, such as rotation periods may play a significant role on how ecosystem services impact biological diversity and ecosystem services. Moreover, the production of biofuels in short-rotation periods may require an augmented application of fertilizers (nutrient cycling), which may make crops grow faster and better but also cause a surplus of nutrients in the soil, lead to negative effects such as biodiversity loss, decreased decomposition, increased soil erosion rates, possible leaching to water bodies and decrease in water quality and quantity (Björklund et al., 1999). It also may entail an intensified use of pesticides (biological pest control), which protects crops against pests but a possible overuse may turn into a disservice for biodiversity affecting soil fauna directly and reducing habitats for flora and fauna, reducing pollination and ultimately proceeding to surface waters, groundwater, municipal drinking water supplies and potentially being detrimental to aquatic organisms as well as raising concern for human health (Björklund et al., 1999). As a consequence, ecosystem services such as nutrient cycling, soil quality, C sequestration and water regulation are altered. Also, the tillage regime may affect soil properties and functions, such as soil evaporation and C sequestration, and, as a consequence, water filtration capacity and microbial biomass (Power, 2010; Islam and Reeder, 2014; Lal, 2004). Mechanical ploughing, cultivation and harvesting directly affect soil structure, possibly leading to soil erosion, compaction and reduced water filtration capacity. Improvement of soil structure usually leads to positive impacts on water availability for agricultural plant communities.

A general loss in other than provisioning ecosystem services, especially the regulating and maintenance services, caused by an intensified biofuel production is apparent (Table 5). This line of direction could lead to difficulties in producing in the future as well as in loss of natural values (Björklund et al., 1999; Dänhardt et al., 2013; Cederberg et al., 2016). To protect and possibly improve these services and make the production of provisioning services more sustainable in a longer perspective a range of measures and actions might need to be taken. For example, it is imperative to trust and invest more in these services instead of increasing yield by external inputs. Management actions could be taken in order to invest in higher humus and C content in soils and in this way slowly increase the soil quality and the ability to produce (Dänhardt et al., 2013). Such management actions might consist of i) increasing the use of perennial crops, N-fixing crops and undersown catch crops in varied rotations in order to build both organic matter and nitrogen levels to improve the soil and prevent soil erosion and N leaching, ii) decreasing the use of deep soil preparation methods such as plowing or apply it stages when leaching is less (Aronsson and Torstensson, 2003), iii) applying fertilizers only in needed amounts to reduce the N amounts which are leached. Higher C and N sequestration in the soil might even lead to less C emission. Likewise, other management actions might be taken to improve for example the pollination service and the pest control service.

As indicated the production of different biofuels impact ecosystems differently. Uncertainties in the impact assessment of agricultural crops on ecosystem services are associated with natural and management conditions. For instance, Peltonen-Sainio et al. (2011) noted that oilseed rape crops are strongly controlled by genotype, growing conditions and crop management. In order to grasp the magnitude of contribution of fuel production to different ecosystem services, it is necessary to allocate impacts among different crop production end products (e.g. fuel, feed, food).

7 FOSSIL-BASED DIESEL AS A REFERENCE CASE

The Swedish transport sector is dominated by fossil fuels mainly petrol and diesel (Swedish Energy Agency, 2015a). Since some of the biofuels described in the former chapters (HVO and biodiesel from rapeseed) are supposed to replace fossil diesel (produced from crude oil) we intend to identify the ecosystem services linked to the production of crude oil based on available information. We here describe the way crude oil is produced in order to understand the background for how this production impacts different ecosystem services. We have however not been able to find any literature specifically addressing the effects of oil extractions on ecosystem services. On the other hand, a great deal of literature exists on how oil extraction influences the environment.

7.1 EXTRACTION OF CRUDE OIL

Fossil diesel is distilled from unprocessed crude oil in a process called refining where the crude oil is separated into a range of components where one is fossil diesel. The dark flammable liquid oil is formed from dead organic vegetable parts which are fossilized in the deep ground under heat and pressure. Oil mainly consists of different hydrocarbons and a small content of other substances such as for example sulphur. The formation is a natural but extremely long process of many million years and it cannot be restocked in a human lifetime. This is in contrast to biofuels where agricultural crops can be replanted and regrown within a short timeframe and forest biomass becomes available in frequent thinnings and final harvest. The timescales for biofuels and fossil diesel are thus severely different.

The crude oil is stored in natural reservoirs across the world but concentrates to some areas more than to others, for example in the Middle Eastern OPEC (Organization of the Petroleum Exporting Countries) countries such as Kuwait, Saudi Arabia, Iran and Oman a lot of oil has been extracted during several years (Figure 1). Also, Russia, the United States and China have abundant oil resources and produce large amounts. Apart from Norway no oil reservoirs are used in Scandinavia and as such the oil is mostly produced spatially far away from Sweden, which is in contrast to the present and possible future national production of biofuels based on local and regional agriculture and forestry resources.

Figure 1. The world-wide areas from where crude oil originates (from EIA, 2013).

Crude oil is extracted from underground deposits which happened to be formed when the oil was hindered from passing to the surface by for example solid layers of different materials such as salt and clay. Such reservoirs are common both onshore and offshore (EIA, 2013) where offshore extraction today accounts for 37% of the worldwide production (World Ocean Review, 2014). Offshore floating oil extraction platforms has increased with the rising ability to extract from deeper waters (marine areas with a depth larger than 500 m) and the running out of suitable onshore extraction possibilities.

Oil extraction is mostly performed by drilling which implicates a mechanical penetration through rock formations to reach the reservoirs. The same procedure is used both onshore below the bedrock and offshore below the seabed, but the offshore drilling is often more expensive since it is frequently remote and displaced from normal logistics and requires on-sea floating platforms and instrumentation (World Ocean Review, 2014).

The production of oil worldwide was 1700 thousand million barrels at the end of 2014 (BP Statistical Review of World Energy, 2016). The demand for energy worldwide is projected to increase by 53% from 2008 to 2035 and the demand for fossil oil for utilization has been estimated to increase by approximately 27 barrels per day between 2008 and 2035 (Institute for Energy Research, 2011). These increases in demand will likely drive fossil oil extraction to be performed in even more remote and beforehand undisturbed areas (Butt et al., 2013; Dale et al., 2015b).

7.2 IMPACTS OF OIL PRODUCTION ON ECOSYSTEM SERVICES

Most of the classifications of ecosystem services described in Chapter 4 focus on biotic elements and living organisms. Minerals and resources such as crude oil are not considered ecosystem services in themselves according to the MA and CICES frameworks of services (MA, 2005; Haines-Young and Potschin, 2010). The search for, the launching and the extraction of crude oil logically impacts a series of other ecosystem services. We here describe, in general terms, how the change from a nature area to an oil exploration area will influence different ecosystem services. As crude oil is produced both onshore and offshore this means that different environmental risks are in force and different ecosystems are affected implying that different ecosystem services will be impacted.

7.2.1 Onshore crude oil production – effect on ecosystem services

For onshore production a soil-vegetation system is affected. A significant number of ecosystem services may be affected by the initial seismic surveys searching for sub-surface oil reserves and suitable extraction areas (Parish et al., 2013). Extensive surveys clear large corridors through natural vegetation, generally called seismic lines, measuring between 6-9 m and extending for several km. A seismic study would usually clear several parallel seismic lines 100-400 m apart creating a large network of clear-felled paths. This off course causes large fellings of often mature forest and alteration of forest structure leading to fragmentation of the forest and the landscape (Finer and Orta-Martinez, 2010; Parish et al., 2013; Dale et al., 2015b) with large edge effects and disturbance and loss of flora and fauna. Following the seismic surveys, the establishing of well sites causes more clearing of land. In the US, each borehole and surroundings disturb an area of about 3.6 ha (Parish et al., 2013) and several boreholes are often capturing a larger area, each estimated to produce for an average of 30 years (Miskimins, 2009). After extraction of oil from the wells, the crude oil needs to be transported to a refinery by either truck or train or in established pipelines which further will impact the environment.

For the provisioning ecosystem services, soil which was beforehand used for active production (forest, agriculture, grassland etc.) or was in a natural state, and possibly created a range of provisioning services, is transformed into a drilling area. Provisioning of for example timber and pulpwood, grain, game, grazing animals, berries and mushrooms as well as drinking water will stop when the area of exploitation is established and extraction of crude oil starts. However, oil production is often performed in dry areas where these services are less of an issue. Previously remote areas become accessible through oil industry developed roads since all well-sites requires transportation access and this enables further deforestation along with logging and hunting in areas of high biodiversity (Butt et al., 2013).

The regulating and maintenance services such as photosynthesis and primary production, habitats as well as genetic resources, water regulation and risk of soil and groundwater contamination will be suffering in the extraction area. For example, drilling fluids are used in the boreholes and these frequently hold chromium, barium and chlorides likely to contaminate wastewater (Parish et al., 2013). Also, drilling through rocks which often contain uranium and thorium will cause contamination by decay products and lead to radioactive waste. Furthermore, drilling leads to changes in pressures underground which might alter the flow of groundwater and potentially lead to seismic waves and mild earthquakes (Parish et al., 2013). Risks may also potentially result in leaks and spills and in fires (accidental or deliberate) which emit particles, sulphur dioxide and nitrogen oxides to the atmosphere, hereby leading to a distinct decrease in air quality (e.g. Khordagui and Al-Ajmi, 1993) but gases such as GHG and potentially sulphur dioxide may also migrate to the surface and emit from the extraction. Also, the different methods used are energy intensive resulting in enlarged GHG emissions. Naturally, the exploration excludes all former vegetation and fauna with a loss of natural value (Butt et al., 2013), wildlife avoids exploration infrastructures because of visual and noise disturbances and habitats are thus diminished. Further, oil spills create difficulties for both flora and fauna.

The exploration area is closed for the public and cultural services are restricted on and around the area. The influence on recreation and outdoor life is probably moderate in the vicinity of the area. Cultural services such as experiencing wilderness and activities related to sporting, tourism, environment and aesthetics will be lost. For example, hunting possibilities will be changed in the near area since wild animals may leave due to noise. The scenery will be significantly changed near the exploitation area and considerably affect the experience for tourism. The extraction activities as well as transports of oil to refineries will generate noise that may disturb and cause people and animals to avoid this and adjacent areas. Neighbors may also be affected visually as well as by vibrations.

7.2.2 Offshore crude oil production – effect on ecosystem services

For offshore production an aquatic ecosystem is affected often in remote marine areas. A significant number of ecosystem services may be affected by the launching of an extraction platform at sea. However, these are in nature different from ecosystem services impacted by terrestrial-based oil extraction. Decreased catches of fish is expected during both the construction period and when operating the platform. Increased turbidity and high amount of suspended material may disturb fish and other sea animals during both the exploration, construction and extraction period. A reef effect from the fundamentals may possibly act as artificial hard bottoms which favorize shellfish, create new substrate for macro algae and thus promote recruitment of some species before others.

Species might be sensitive to high under water noise under construction and drilling far exceeding the standard safety levels (Parish et al., 2013) and thus spawning grounds in the area may be threatened. Sounds travel efficiently under water and acoustic threats will affect the habitat for several vulnerable and protected species, such as demonstrated for the bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea (Schick and Urban, 2000). Also, important bird migration routes may be disturbed and seabirds are at risk around offshore oil platforms (Wiese et al., 2001) and in oil field wastewater disposal facilities (Ramirez, 2010). The same environmental risks for air quality exist as in the case of onshore extraction. A specific environmental risk connected to extraction of oil in marine environments connects to the possibilities for significant leakage and spills to the water body. When oil distributes in water it forms a coating on the surface of the water which after some days becomes thick and viscous. Such oil layers are likely to cover especially seabirds and other animals and stick to feathers and skin, exposing them to sudden drops in temperature eventually leading to death (Worlds Ocean Review, 2014). In the case of oil spills, cold marine environments, for example in Alaska, will be more difficult to restore and the recovery time will be long. It has been estimated by Epstein and Selber (2002) that approximately 120-290 billion liters of crude oil is accidentally lost through spills both on- and offshore worldwide every year.

As to cultural services, small scale recreational fishing will probably not be affected. Noise from an extraction platform is significant but will possibly not be heard on land. The platform is visible and to some extent recreation and tourism in the area may be negatively affected but this is less of an issue out on the sea.

7.3 DIFFERENCES BETWEEN IMPACTS OF FOSSIL FUEL AND BIOFUEL PRODUCTION

Our case studies dealing with production of biofuels are potentially impacting forest and cultivated agricultural habitats often being areas already affected by anthropological actions. Onshore crude oil production also impacts terrestrial ecosystems but more often these are more remotely located. On the other hand, offshore crude oil production is mainly affecting marine and coastal habitats. To a large extent, biofuels and fossil fuels are thus impacting different habitats. The impact of crude oil production on ecosystem services is radically different from the production of biofuels, since fossil diesel builds on extraction of non-renewable resources from underground as opposed to production of for example HVO where forest biomass is constantly regenerating (over a much shorter timespan) though the growth of new trees. For example onshore crude oil extraction, completely changes the exploitation area in the used ecosystem by removing existing vegetation and fauna while a current forest used for intensive outtake of forest biomass will, although harder utilized than other forests, still look and act like a forest ecosystem, and a row-crop on agricultural soils will continue to regenerate in rotations of new crops. The use of biofuels as compared to fossil fuels will result in reduced levels of GHG emissions.

If it wasn't for fossil fuel production the remote areas hosting some of the most fragile habitats and biodiversity in the world would remain relatively uninterrupted. There is a need for avoiding to position future extractions of fossil petroleum in fragile biodiversity areas in order to evaluate the best possible locations. In a recent work, Dale et al. (2015b) overlaid maps of potential crude oil production locations with maps of high and important species richness as well as threatened species. In the study, they mapped these in all possible former pasturelands. In comparison, the authors also overlaid maps depicting the distribution of biofuel production on pastureland. The likely areas for extraction of crude oil covered over 5.8 billion ha while biofuel production on pastureland would potentially cover approximately 2 billion ha (Dale et al., 2015b). Thus, there seem to be a greater number of locations where oil may be produced compared to the area of pastureland where biomass for biofuels may be grown; however, it should be considered that further fallow land and abandoned arable land also might be available. Dale et al. (2015b) concluded that crude oil production areas potentially have higher impacts than biofuel production areas on fragile areas such as coastal and marine areas and tundra and that the biofuel production is likely to show effects smaller in magnitude and duration. On the other hand, it is not nearly half as efficient to convert biomass to liquid biofuel (30-40%) than it is to convert crude oil to fossil diesel (93%) (Howarth et al., 2009). To sufficiently well compare crude oil production to biofuel production more information is needed on the size of areas used for each, the degree of negative and positive influences and the amount of energy produced.

8 ECOSYSTEM SERVICES IN DECISION MAKING

As presented in former chapters, Sweden has the potential for an intensified production of biofuels through a larger outtake in forests, an improved use of existing forest residues (Chapter 5) and on available former arable land and fallow land (Chapter 6). Further outtake and change in production have to be sustainable. The question is if and how we may use the concept of ecosystem services, including their suggested indicators, to guide us towards a sustainable production and use of biomass for biofuels. As pointed out by the national Swedish inquiry on biodiversity and ecosystem services (SOU, 2013) there is a general need to further take ecosystem services into consideration in policy instruments and decision making.

8.1 RELATED POLICY INSTRUMENTS AND DECISION-MAKING

Sweden is working towards improving the knowledge about ecosystem services and incorporating them into political and economic decisions by 2018 (SOU, 2013). The inquiry thus suggested a range of measures in order to work towards integration of biodiversity and the value of ecosystem services in developments of decision-making. A range of instruments are available which may influence the provisioning of services, for example environmental support, taxes, laws and legislation as well as information and counselling about possible advantages/disadvantages of ecosystem services. In the field of ecosystem services the possibility for paying for ecosystem services (PES) is an emerging instrument that perhaps will create incentive for the producer (farmer or forester) to invest in ecosystem services (Wunder, 2005; Robertson et al., 2014). In PES, forest owners or farmers will manage their resources to provision services other than yield and in return get paid by consumers and beneficiaries, including at times governments benefitting their residents.

There are several existing policies that relate to ecosystem services in agricultural and forest landscapes. The **EU Common Agricultural Policy (CAP)** and related national regulations and support systems, such as for example farm support and the rural development programme, regulate the agriculture in Sweden and thus impact related ecosystem services. **The Swedish Forestry Act** and associated regulations aim to regulate forest management in Sweden including wood production levels that must be attained and considerations for conservation of nature and the cultural heritage (Swedish Forest Agency, 2016). Some further environmental policies and decision-making processes are discussed below.

8.1.1 Swedish policy instruments and decision-making tools

The Swedish system of **national environmental objectives** today comprises one generational objective which is the overall goal of the Swedish environmental policy, sixteen environmental quality objectives that describe the state of the Swedish environment and are to be met within one generation, i.e. by 2020, and twenty-four milestone targets, which form steps on the route to achieving the environmental quality objectives and the generational goal (Swedish Environmental Protection Agency, 2016). The environmental objectives which are important for arable and forest landscapes are Good-Quality Groundwater, Zero Eutrophication, Natural Acidification Only, Sustainable Forests, A Non-Toxic Environment, Reduced Climate Impact, A Rich Diversity of Plant and Animal Life, A Varied Agricultural Landscape, and Clean Air. The follow-up on the status of the environmental objectives is performed by the use of a sequence of indicators. These are monitored in time to see the changes (Swedish Environmental Protection Agency, 2016).

The concept of ecosystem services has at times been integrated into the national environmental objectives. For instance it is mentioned in two of twenty-four milestone targets under biodiversity, saying that “Important ecosystem services and factors impacting their maintaining are identified and classified by year 2013” and “by 2018 the importance of biodiversity and the value of ecosystem services should be known and integrated in economic standpoint, political decisions and other decisions in society where relevant”. Only one environmental objective (Sustainable forests) has a clarification that ecosystem services need to be maintained, but no indicator is assigned to monitor it. While the indicators might be the same for several environmental objectives, indicators are often unique for the follow-up of certain ecosystem services. The current indicators for environmental objectives often describe a change in for example the inflow from atmosphere to ecosystem (e.g. deposition of N and S), a state in the ecosystem (e.g. cloride in groundwater, acidification of soil and water, breeding birds) or external factors (e.g. ozone in air, emissions of N and S) while the indicators for ecosystem services are following the structure, function, benefit and value scheme as shown in Chapter 5 and 6.

The two kinds of indicators are thus quite different in manner. There are a few examples of equal indicators between the two systems such as area of old forest, volume of deadwood, area of special habitats, area of pastureland and area of cropland. If the environmental objectives are fulfilled it contributes to provide better and more goods and services from nature. On the other hand, ecosystem services may impact the possibilities to fulfill the environmental objectives. The regulating and maintenance services are the backbone for many environmental objectives as well as ecosystem services. The other way around environmental objectives, such as Sustainable Forests and A Rich Diversity of Plant and Animal Life, may remind a bit about the regulating and maintenance services. We find that it is not easy to translate ecosystem services into environmental objectives or the other way around but we are however convinced that the visibility and preserving of ecosystem services is positive in the work with the environmental objectives. An effort of determining possible common indicators for the two systems may help to couple the two systems in future.

Environmental Impact Assessments (EIA) are prepared around the world guided by the European directive on Environmental Impact Assessments (85/337/EEC). EIA’s generally provide information on the environmental impacts of a proposed future action and they provide environmental considerations to the planning of projects and plans. EIA’s are required in Sweden for all actions impacting the environment according to the chapter 6 of the Swedish Environmental Code along with complementing rules in the constitution (1998:905) on Environmental Impact Assessments. The outlining of EIA’s is thought to strengthen the quality of decisions and certify qualified implementation of these actions.

The SOU (2013) inquiry suggested that ecosystem services are accounted for in EIA and strategic environmental assessment (SEA). A national project funded by the Swedish Environmental Protection Agency addressed the problem of how to work with ecosystem services in such decision making circumstances and specifically analysed the possibilities for integration of ecosystem services into EIA and Socio-Economic Impact Assessments (SEIA) (Malmaeus et al., 2016; Hansen et al., 2016; Hasselström et al., 2016). Assessments like these are imperative for decision-making in relation to projects, plans and programs where ecosystems are impacted. The case studies in Malmaeus et al. (2016) and Hansen et al. (2016) indicate that issues which the general public find important to include in an EIA are often not described well enough and the report state that possibly these questions of interest would be handled better and earlier in the process if an ecosystem services perspective is adapted. The conclusion from the project was that an ecosystem service perspective provides good background for solid support which might lead to a different outcome of decisions. Other international papers argue about pros and cons of a possible integration of ecosystem services in EIA (Landsberg et al., 2011; Baker et al., 2013; Partidario and Gomes, 2013; Landsberg et al., 2014).

8.1.2 European and international policy instruments and decision-making tools

The **EU Renewable Energy Directive** (EU-RED) specifies the sustainability criteria that biofuels for transport and other bio-liquids must meet in order to count towards the national renewable energy targets. In practice, it means that a given level of GHG emissions reduction must be met compared to fossil fuels (initially set to 35%, increasing to 50% in January 2017 and from 2018 saved emission of at least 60% should be presented for biofuels and bio-liquids produced in installations in which production started on or after 1 January 2017) (EU, 2009). These criteria also stipulates that biofuels and bio-liquids shall not be made from raw material from (i) land with high carbon stock for example wetlands, (ii) peatlands and (iii) land with high biodiversity value, for example, areas designated for nature protection purposes, primary forest and highly biodiverse grassland (EU, 2009). The concept of ecosystem service is acknowledged in RED, but further guidelines or sustainability criteria on how to assess these services are not given.

Several voluntary national or international sustainability schemes related to biofuels are today used to certify that the biofuel comply with the sustainability criteria in the EU-RED. The certification schemes, such as the RSB EU RED (Roundtable of Sustainable Biofuels EU RED), RSPO RED (Roundtable on Sustainable Palm Oil RED) and Bonsucro EU, have all been assessed and validated by the EU Commission to be approved as a certificate to demonstrate compliance with EU RED. Many of the existing certification schemes have added special amendments to existing criteria documents in order to comply with the demands set in the EU RED framework and include several additional criteria not found in the EU RED. Meyer and Priess (2014) have tested whether different certification schemes, linked to bioenergy, agriculture and forestry (including some of the schemes recognized by the EC), are able to show trade-offs between biomass use and other ecosystem services. It is indicated that assessed certification systems do not seem to adequately consider impacts on ecosystem services.

Besides the sustainability criteria, the EU-RED requires EU member states to report estimated domestic impact of the production of biofuels on biodiversity, water resources, water quality and soil quality in their progress reports, to be submitted every two years (EU, 2009). In the associated reporting from the EU Commission (summarizing the input from the member states renewable energy progress reports) it is indicated that the use of biofuels for transport in the EU for example may affect biodiversity due to e.g., the potential use of sensitive or threatened ecosystems, may warrant considerations in areas with water scarcity and that the related use of agrochemicals may reduce water quality in some areas (EC, 2015).

The Swedish Government and Parliament ratified **the International Convention on Biological Diversity** in 1994. Sweden therefore conforms to **the EU Biodiversity Strategy** to 2020, with the goal to stop the loss of biodiversity and in the EU by the year 2020. The strategy comprises six targets to be fulfilled by member states. Each target comprises a range of actions and measures. Ecosystem services are addressed by the strategy in for example target two: “Maintain and restore ecosystems and their services”. Action 5 instructs the Member States to “map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020". Other actions in the strategy describe possibilities for measures that will enhance biodiversity as well as the value of ecosystem services (as for example genetic resources, habitat and soil quality) in arable and forest landscapes:

- Action 8b: The Commission will propose that CAP direct payments will reward the delivery of environmental public goods that go beyond cross-compliance (e.g. permanent pasture, green cover, crop rotation, ecological set-aside, Natura 2000).
- Action 9b: The Commission and Member States will establish mechanisms to facilitate collaboration among farmers and foresters to achieve continuity of landscape features, protection of genetic resources and other cooperation mechanisms to protect biodiversity.
- Action 11b: Member States and the Commission will foster innovative mechanisms (e.g. Payments for Ecosystem Services) to finance the maintenance and restoration of ecosystem services provided by multifunctional forests.

Life Cycle Assessment is an approach to assess potential environmental impacts in the life cycle of products and services, often used in decision-making. For example, the life cycle perspective is an important part of the RED (EU, 2009). For biofuels, LCA studies generally focus on accounting GHG emissions, which depends on the related policy development (Dunn, 2012; Gnansounou et al., 2009). At present, impacts on ecosystem services and biodiversity are to a limited extent addressed in LCA (Arbault et al., 2014; Bringezu et al., 2009; Zhang et al., 2010). Challenges still exist in an integration of LCA and the concept of ecosystem services. In the scientific world, an increased interest in including other impacts of biofuel production on ecosystem services in an LCA is investigated, especially to include additional impact categories to represent ecosystem services (Arbault et al., 2014; Cao et al., 2015; Koellner et al., 2013; Maes et al., 2009; Saad et al., 2013; Zhang et al., 2010a; Zhang et al., 2010b). The possibility to include the assessment of impacts on ecosystem services in LCA would facilitate the link to policy making. For a more elaborated synthesis and discussion on the main gaps for linking LCA and ecosystem services see the separate manuscript developed as part of the project (Maia de Souza et al., 2016).

8.2 A FRAMEWORK TO INCLUDE ECOSYSTEM SERVICES IN DECISION-MAKING

By the help of an ecosystem perspective and analysis, new relationships may be discovered between production of biomass and the impacts on the environment as well as the impact on human well-being. A basic framework describing a possible connection between an activity influencing the environment, potentially causing environmental problems and possible solutions, including an analysis of ecosystem services, may contribute with a systematic overview and communication about which values are impacted. Thus, this creates a basis for better and transparent decisions and larger acceptance by concerned stakeholders.

Dale et al. (2014) presents a framework for selecting indicators of bioenergy sustainability. The Swedish Environmental Protection Agency (2016) produced a guidebook with advice on how to perform an ecosystem service assessment. Based on these publications, we formulated a conceptual framework for incorporating ecosystem services in decision-making, with reference to the biofuel sector (Figure 2). Note, that besides this section, the analysis aiming at proposing a conceptual framework to include ecosystem services in decision-making is also presented in a separate manuscript focusing on LCA (Maia de Souza et al., 2018).

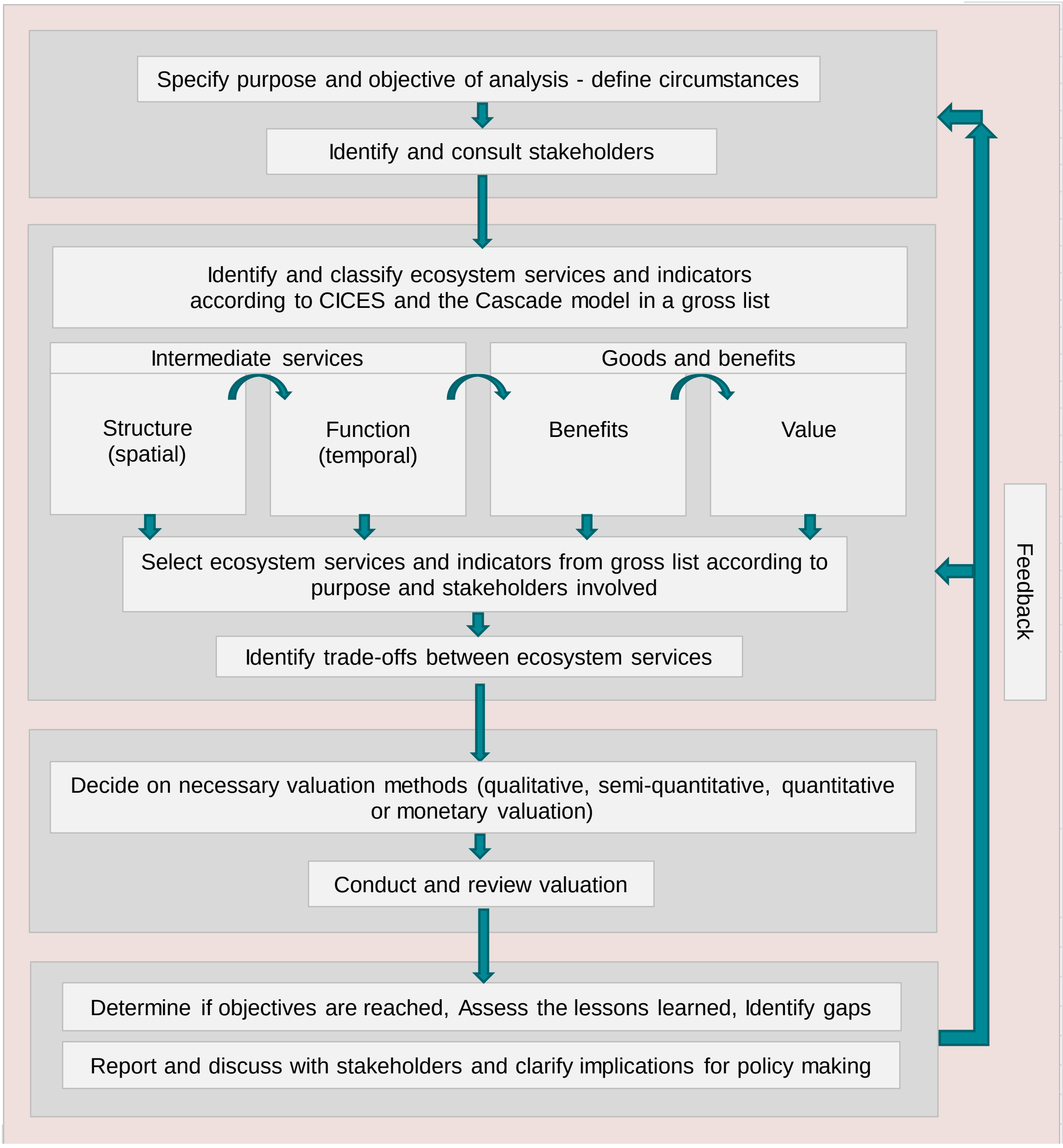

Figure 2. A conceptual framework to include ecosystem services in decision-making. The framework is developed based on Swedish Environmental Protection Agency (2016) and Dale et al. (2014).

8.2.1 Purpose, objective and stakeholders

A range of questions on the implications and sustainability of biofuel production becomes motivated when we want to increase the production of biofuels through for example the intensified growing of either arable or forest biomass. The questions guide the specific purpose and objective of the analysis. The circumstances for the analysis are likely to be influenced by the objectives, and both will need discussions with identified stakeholder groups which typically are challenging since stakeholders often have different interests and understandings of objectives. However, the early discussions with stakeholders should preferably increase the relevance to them and facilitate the possibilities for beneficial debates (Dale et al., 2014). A formal conceptual framework like the presented might help stakeholders to understand the process which is often considered too academic and difficult to comprehend. Ideally, all key stakeholders should be included in a participatory process. Stakeholders interested in decision making and policy instruments for governance and guidance in the biofuel sustainability area may range from individual decision makers such as farmland and forest owners and practitioners, fuel companies and organisations, administrative authorities, policy makers and society in general representing e.g., the use of biofuels (Efroymson et al., 2013; SOU, 2013).

In Sweden, it is possible as a first assessment to relate the environmental impact of bioenergy to the environmental quality objectives. However, not all ecosystem services are covered by these objectives and thus additional analyses are required.

8.2.2 Identify and select ecosystem services and indicators

The purpose and objective of the analysis might be to account for the impacts on ecosystem services that different fuel types may bring about (compare two or more) or alternatively to assess impacts of an intensification of one specific biofuel might cause compared to a reference scenario. Perhaps the analysis should be restricted to specific ecosystem services ruling out others from the analysis. However, we suggest as a first step of the analysis to identify and classify all relevant ecosystem services and indicators according to the CICES and the Cascade model (Haines-Young and Potschin, 2013), *i.e.*, to produce a gross list of possible ecosystem services available in forest and agricultural landscapes (or other ecosystems investigated). The list of ecosystem services and indicators outlined in Chapter 5 and 6 (Table 2 andTable 4) illustrates this step.

The next step is to select the most relevant ecosystem services from the gross list of services. Likewise, the most interesting indicators are also selected from the total list of indicators. All in all, this step in the analysis is performed to narrow down the list (if wanted) of ecosystems and the number of indicators to analyse to those that are most interesting for the specific goal and the stakeholders involved.

The identification of trade-offs among different services represents a further challenge, which additionally will influence the valuation procedure. Therefore these trade-offs should be described, preferably also to avoid any double counting of services.

8.2.3 Valuation methods

A decision has to be made on how the value of indicators should be described: i) in qualitative terms through words, ii) semi-quantitatively based on a scale, iii) quantitatively through the use of biophysical units and/or iv) monetary terms. These methods are described in the Swedish Environmental Protection Agency (2016). The purpose of the analysis affects the type of value created and thus the suitability of methods to use in the valuation. Also, the choice of method may be affected by which analysis resources that are available and by the existing data supply.

8.2.4 Fulfillment of objectives and feedback

When the valuation is finalized feedback is needed. The goal of the feedback is to put the results in a context. Questions to discuss are whether or not the indicators are effective, if the valuation of ecosystem services/indicators provides an answer to questions asked and if the answers and results provide a good enough background for decisions to be made. If not, probably new studies are needed and/or a revision of purpose and objective as well as revisiting the indicator selection process in cooperation with the stakeholders. Finally, the lessons learned should be assessed and the gaps in knowledge still present should be identified.

The described framework is a way of simplifying and structuring the assessment of sustainability impacts of a change linked to biofuel production. The intention of the framework is that the analysis and valuation processes become easier to understand, supply an overview and moreover remove some of the burden associated with impact assessments of biofuel production which stakeholders are often faced with

9 DISCUSSION AND CONCLUSION

This report contains a synthesis of the current knowledge and state-of-the art on the potential theoretical impact of the intensification of biomass production for biofuel production (linked to a general increase in biomass demand) on ecosystem services in Sweden. It is based on a literature review covering the rest of the world as well. It is meant to provide research-based knowledge and foundation for policymakers, industrial sectors and other stakeholders as a step towards deciding on sound and sustainable choices linked to agricultural and forest based biofuel production.

A holistic approach is needed to evaluate the overall system effects (environmental, social and economic) of an intensified biofuel production based on biomass from agricultural and forest ecosystems. The use of the ecosystem services concept involves a perspective where the relation between mankind and nature is in focus leading to an apparent and efficient visualization of the value of a certain ecosystem for human well-being.

In this report, based on existing literature, we identify and describe ecosystem services that affect and are potentially affected by an intensified Swedish biofuel production in the case of forest and agricultural ecosystems and we identify appropriate indicators to assess changes in ecosystem services. Perennial energy crops such as willow and poplar has not been considered and would result in other impacts than the included agricultural crops. We use the CICES classification and the Ecosystem Service Cascade Model (Chapter 4) to place biofuels in the ecosystem services scheme for forest and arable ecosystems (Table 2 Table 4). The actual impact of increased biofuel production on ecosystem services crucially depends on the assumptions made regarding the feedstock and allocation principles for the impact, considering that tall oil constitute ca 1% of the tree biomass. Is for example intensified biomass production assumed needed or not, which depends on the national biomass supply potential and in case several products are linked to the intensified biomass production to what extent should the impact on ecosystem services be carried by biofuels. This study focuses on the biomass production phase and associated ecosystem services, and for simplicity, all forest ecosystem effects have been allocated entirely to the tall oil or felling residues used for biofuel production. However, similar assessment can be made for the other phases of the biofuel value chain e.g., transports and biofuel production processes.

Our judgment is that ecosystem services help in visualizing and bringing attention to more aspects of sustainability linked to biofuels which are not discussed to a full degree today in the biofuel debate as well as pinpointing suitable questions to be answered. Although difficulties exist in how to quantitatively and economically value ecosystem services and allocate the impact we advocate that even the first steps in a valuation of ecosystem services (qualitative and semi-quantitative valuation, Chapter 8) may provide an interesting view on and increased integrated understanding of the possible impacts of an intensified biofuel production in Sweden (summarized in Table 6).

We find that intensified agricultural production in Sweden – here assumed needed in order to produce higher amounts of biofuels from agricultural crops – has positive impact on some ecosystem services and negative or neutral impact on others. The same is true for increased use of existing forest residues and intensified forest fellings and fertilization in order to produce higher amounts of biofuels in Sweden.

This assessment may contribute to enlighten several aspects which are not specifically discussed in for example current LCA analyses and biofuel policy instruments. For instance, values linked to recreation appear to be of larger interest to individual stakeholders when we adopt an anthropocentric viewpoint.

Table 6. Summary of potential changes in ecosystem services as an effect of intensified forest management and intensified crop production for a scenario not constrained by sustainability considerations or market driving forces. All possible impacts have for simplicity been allocated to the biofuels. Please, also note that some impacts are only valid for certain regions/areas. Possible solutions for limiting the impacts are not included. The colors show either potential negative impact (red) or potential positive impact (green). The stronger the color the more impact is expected. Three +++ means a larger impact than one or two +.

Class	Forest ecosystem service	Potential changes of intensified forest biomass use	Class	Agricultural Ecosystem service	Potential changes of intensified crop biomass use
Provisioning services	Berries	-	Provisioning services	Cultivated crops – food and forage	+++
	Mushrooms	-		Livestock	0/-
	Game	0		Game	-
	Reindeer and fodder	--		Materials from plants	0/-
	Drinking water	0/-		Drinking water	-/--
	Timber and pulpwood	+++		Plant fibers	0/-
	Genetic resources	nd		Genetic resources	-/--
	Bioenergy	+++		Bioenergy	+++
	Decorative materials	0	Regulating and maintenance services	Nutrient retention	-
Regulating and maintenance services	Prevention of erosion	-		Prevention of erosion	-
	Prevention of storm damage	-		Weathering processes	nd
	Prevention of floods	-		Filtration of pollutants	--
	Habitats	-		Habitats	--
	Pollination	0		Pollination	--
	Soil quality	--		Soil quality	--
	Climate regulation and C sequestration	++		Climate regulation and C sequestration	++
	Biogeochemical cycling	--		Biological pest control	--
				Decomposition and fixing processes	-
Cultural services	Recreation and training	0/-	Cultural services	Recreation and training	-/0
	Tourism	-		Tourism	-/0
	Mental and physical health	0/-		Mental and physical health	-
	Environment and aesthetics	0/-		Heritage, cultural	nd
	Knowledge and information	nd		Knowledge and information	nd

The ecosystem services concept therefore potentially gives a good background to discuss the value of the goods and services that is provided through the ecosystems around us. The human perspective may motivate larger public participation and greater involvement in decision-making. Also, it may contribute to earlier identification of crucial concerns which should be tackled in decision-making processes. Therefore, the use of an ecosystem services framework may be helping to pinpoint human mankind's dependence on ecosystems and provide larger motivation for a sustainable use.

The mapping of ecosystem services linked to the production of fossil based diesel show that to a large extent, biofuels and fossil fuels impact different habitats. Since fossil diesel builds on extraction of non-renewable resources from underground the impact of crude oil production on ecosystem services is also radically different compared to the production of biofuels. How to more clearly compare the impact on ecosystem services for different biofuels as well as other transport fuels also need to be further discussed. In this case system boundaries and allocation principles are important.

We have proposed a first version of a conceptual framework to include ecosystem services in decision-making with the aim to highlight services affected and related trade-offs, and to identify the necessary valuation methods. The framework needs to be tested by stakeholders and further developed in order for the ecosystem concept to be successfully implemented in policy making.

As indicated in the beginning of the report, a more detailed quantification of the impact on ecosystem services should consider the potential need to allocate the impact between different products. For example, to what extent should impact on ecosystem services related to intensified forestry that enables an increased production of HVO and methane but that is mainly driven by outtake of forest biomass for other products, such as timber and pulp, be carried by biofuels? The literature review indicate that principles for allocating the impact on ecosystem services between different products (of which biofuels is one) is not specifically addressed in existing studies.

Within LCA there are three main ways of handling allocation. Avoided allocation means allocating all identified environmental impacts to the main product of interest. This is the first choice according to ISO 14040 (ISO, 2006). The second choice is allocation on the basis of physical relations, often the mass of the co-products. The third alternative is allocation based on other relationships, often economic value. Allocation based on physical relations will not be applicable in the case of ecosystem services since not all ecosystem services can be expressed in this way. Avoided allocation and allocation based on economic value might be possible in the case of ecosystem services, the latter at least in the future since there is ongoing research linked to economic valuation of ecosystem services. The policy development might also impact the choice of allocation rules. For example, the current handling of waste, residues and by-products in the RED treats crude tall oil and forest residues differently where tall oil needs to fulfil demands related to keeping trace of origin and reduction of GHG emissions while forest residues also need to fulfil criteria related to protection of land areas (EU, 2009).

The concept of ecosystem services is acknowledged in the RED, but further guidelines or sustainability criteria on how to assess these services are not given. Building certification schemes will have to target the different components of a sound and thriving ecosystem. The concept of ecosystem services is a useful point of departure in defining what areas needs to be covered in a sustainability scheme. To operationalize a sustainability scheme based on ecosystem service indicators is however challenging as existing practice on quantifying and monetarizing impacts is still naturally limited because the investigation and consideration of ecosystem services in the field of biofuel production is quite a young science with few studies being conducted, leaving yet many unanswered questions and lack of data. It has, however, interest for both scientists and policy makers and there is a continuous development in how to quantify, value, allocate and follow up impacts on ecosystem services and how different stakeholders can present their concerns to manage and support long-term functional and resilient ecosystem services which their operations are relying on. Further work could thus very well bring new insights and standards that would more directly cover ecosystem services and would be possible to include in certification schemes and in better informed decisions.

Certification schemes and appropriate policy instruments are important to further promote the development of effective and environmental systems and to allow the biofuel industry to take risks in investments. In general, there is a need to identify and assess which policies that could be used to guide in this area, i.e. be used to consider ecosystem services. Among possible policy tools are methodologies to pay for ecosystem services (PES) to farmers and foresters exploring if society and consumers are willing to pay for services such as natural habitats for conservation, recreation or aesthetics (Robertson et al., 2014).

Biophysical and monetary indicators are important tools for describing the effects of certain actions, for example management, on the ecosystem services, as well as communicating the value of ecosystem services to stakeholders. Based on our review, we suggest a large amount of generic indicators for agricultural and forest ecosystem services (Gross lists, Table 2 andTable 4) as reference indicators to follow up on changes in the agricultural and forest ecosystems. The costs and technical problems of monitoring and measuring changes in a large variety of sustainability indicators may be large and at times overwhelming (Lee et al., 2011; Efroymson et al., 2013). The gross set of indicators might be prioritized according to the analyzed project or action leading to a selection of a special range of assigned appropriate indicators specific to each particular situation (Turnhout et al., 2007). Such selection procedures should be assessed and discussed in greater detail.

Generally, plenty of data are available in order to quantify and value the provisioning ecosystem services for both agricultural and forest ecosystems while the quantification and the monetary valuation of other ecosystem services is more inadequate such as for example the cultural services. Often lack of relevant historical data on suitable spatial and temporal scales limits our ability to follow-up on indicators for these services. Here, more studies on the willingness to pay for certain services as well as on avoided costs are needed to visualize these services equally. As of now the approach including qualitative and semi-quantitative valuation (as applied in this report) is useful to understand and argue for the importance of several additional impacts of biofuel production. It seems to add importance as a first step towards assuring sustainable biofuel production and making wise and more conscious decisions.

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APPENDIX 1. OUTREACH OF THE PROJECT

WEB PAGES AND SOCIAL MEDIA

We published information about the project on LinkedIn on Danielle Maia de Souzas space. The project has furthermore been presented at IVL's and SLU's web sites at the following links:

- http://www.ivl.se/sidor/aktuell-forskning/forskningsprojekt/ekosystemtjanster/biodrivmedel-och-ekosystemtjanster.html
- http://www.slu.se/danielle-maia-de-souza

Information on the project has been sent to and distributed by the Swedish Life Cycle Center Network, working group of Biodiversity and LCA.

INTERNAL PROJECT MEETINGS

Through the project time the group had a series of project meetings to advance the project. Throughout the project time we had in total 12 meetings, where 6 where physical meetings and the rest were Skype meetings.

REFERENCE GROUP

The reference group constituted of representatives of the following (with contact persons):

Stakeholder	Person	E-mail
Göteborg Energi	Karin Björkman	karin.bjorkman@goteborgenergi.se
Preem	Mattias Backmark	mattias.backmark@preem.se
Lantmännen	Andreas Gundberg	andreas.gundberg@lantmannen.com
Energimyndigheten	Linda Kaneryd	linda.kaneryd@energimyndigheten.se
Sveaskog	Jessica Nordin	jessica.nordin@sveaskog.se

The stakeholders assisted us in reviewing project progress and deliverables through one physical meeting held June 2nd, 2016 at IVL in Stockholm. Furthermore, the stakeholders reviewed the final report and the international manuscript.

PRESENTATIONS

- The project was presented at the program conference for the Swedish Energy Agency and f3 collaborative research program Renewable transportation fuels and systems (Förnybara drivmedel och system) in Gothenburg on February 4th, 2016 by Julia Hansson. An oral presentation was produced.
- A poster was presented at the 24th European Biomass Conference and Exhibition in Amsterdam, June 6-9, 2016 by Julia Hansson (also by a short oral presentation). The produced poster is attached as Appendix 3.
- The project was presented by Julia Hansson and Karin Hansen at the reference group meeting at IVL in Stockholm on June 2nd, 2016. An oral presentation was produced.
- The project was presented by Karin Hansen at a meeting with the IVL advisory council "Verksamhetsrådet Naturresurser, klimat och miljö" in Stockholm September 9th, 2016. An oral presentation was produced.

- The project was presented by Julia Hansson and Karin Hansen at a meeting with the Swedish Life Cycle Center Network, working group of Biodiversity and LCA in Gothenburg September 15th, 2016. An oral presentation was produced.

APPENDIX 2. CLASSIFICATION OF ECOSYSTEM SERVICES IN FRAMEWORKS

We have reviewed the four major frameworks in order to identify a best suitable one to address the impacts of biofuel production on ecosystem services.

MA

The MA (2005) solidly introduced ecosystem services (Maes et al., 2016), while aiming at identifying and understanding the connections between human health and comfort and the services provided by ecosystems (Dick et al., 2011). The extensive work of the MA overview (MA, 2005) was initiated by scientists and politicians who found that knowledge about the status of ecosystems and biodiversity was insufficient and therefore requested an extensive global analysis. The work pointed towards negative ecosystem changes at large scale such as a common degradation of ecosystems and a depletion of biodiversity largely as consequences of various anthropogenic activities. The MA further concentrated on possibilities and ways to improve sustainability for the benefit of both ecosystems and humans as part of them. The MA framework classifies ecosystem services into four categories: i) provisioning services (e.g. food and fuel supply), ii) regulating services (e.g. climate and freshwater regulation), iii) supporting services (primary production), and iv) cultural services (e.g. recreation) (Figure A1).

The MA is the most widely used classification framework. However, the MA has some drawbacks (Burkhard et al., 2012; Fisher et al., 2009; Seppelt et al., 2011). First, dis-services, i.e. ecosystem services that are damaging to human welfare (von Döhren and Haase, 2015), are not well distinguished. The consideration of these dis-services (e.g. water consumption by other plants may reduce the availability of water for agricultural production) is meaningful, as negative ecological effects may cause harmful effects to ecosystems, such as biodiversity loss (Chapin et al., 2000). In addition, the MA is not appropriate for economic valuation of ecosystem services (Fisher et al., 2009). Lastly, intermediate and final services are not clearly differentiated in MA, which leads to the risk of double-counting ecosystem services (Wallace, 2007). According to Wallace (2007) the foremost problem with the MA classification, is that it mixes up ends with means; that is the benefit and value that people actually experience and the functioning of the ecosystem needed to produce the specific ecosystem service. This is particularly true for supporting services, which are associated with the functioning of ecological processes and whose value is reflected in other services (Hein et al., 2006). The supporting services differ from the other three types of services since they do not directly benefit people, but rather form the basis for generation of other services.

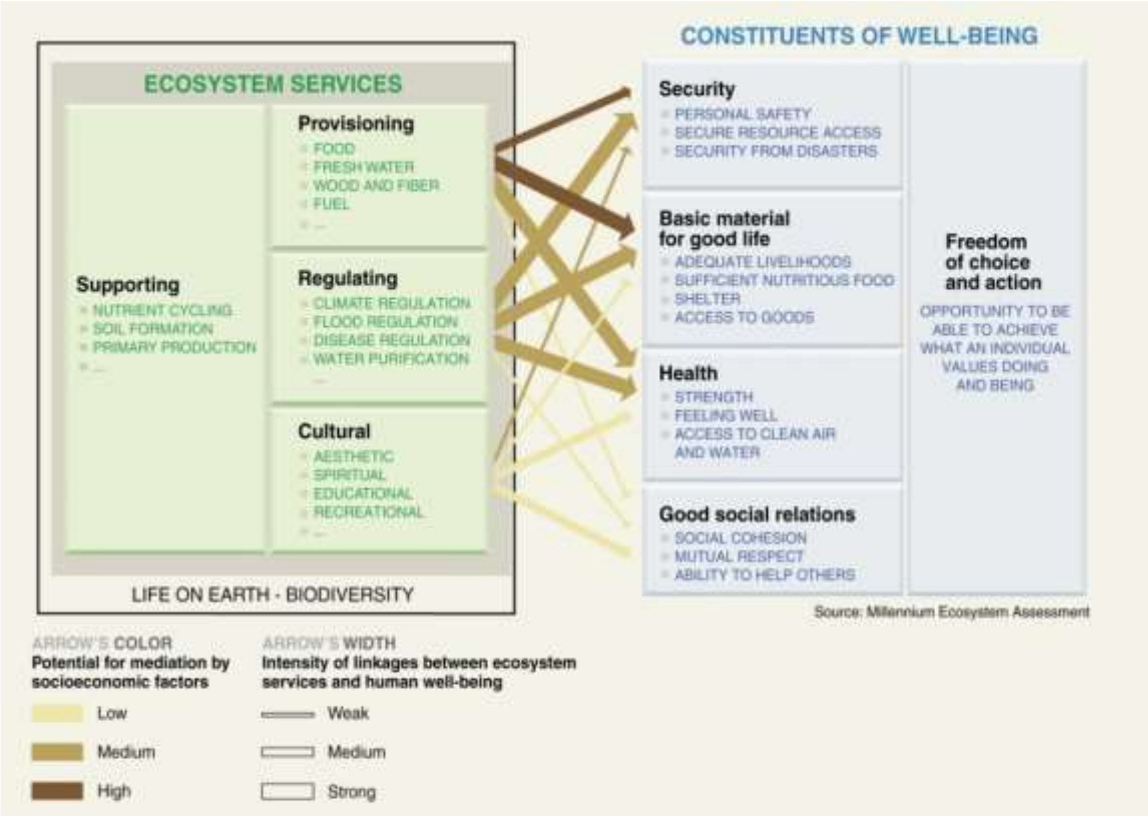

Figure A1. The MA framework (MA, 2005) with different categories of ecosystem services (provisioning, regulating, supporting and cultural) and components of human well-being.

TEEB

The TEEB study followed five years after the MA (TEEB, 2009) and it is an important initiative to create awareness to the economic value of biodiversity and point out that biodiversity loss and deprivation of ecosystem functions cost the society a great amount of money. Scientists and politicians were this time working in close cooperation with influential economists to demonstrate the ability of economics in safeguarding biodiversity and pointing out possible actions and solutions in order to stop further loss and degradation. The TEEB describe 22 ecosystem services and divide these further into four classifications (provisioning, regulating, habitat maintenance and cultural services), which is to a large degree respecting the MA classification. However, the supporting services in MA are exchanged (Figure A2) by habitat services in TEEB. This new classification highlights the importance of providing suitable habitat for many different species and of safeguarding genetic resources.

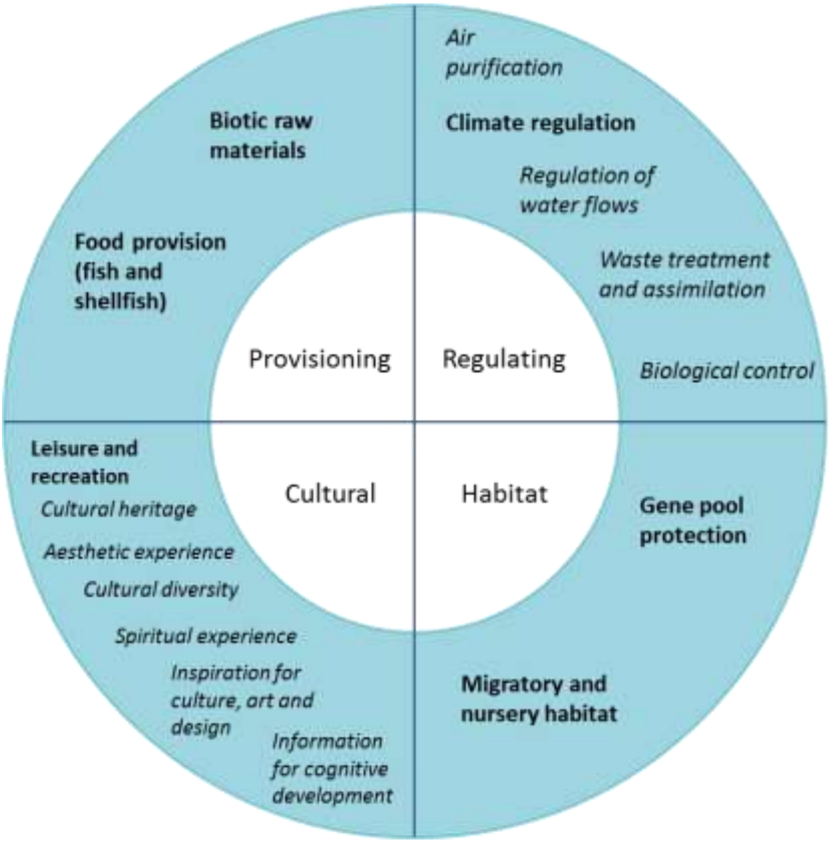

Figure A2. The TEEB framework of ecosystem services including provisioning, regulating, habitat and cultural services (TEEB, 2009).

CICES

The CICES classification was developed in close cooperation with the European Environment Agency. The last version of the CICES (v.4.3) classification is described by Haines-Young and Potschin (2013). CICES has been adopted at the EU level by the Mapping and Assessment of Ecosystems and their Services (MAES) which forms part of the European Union's Biodiversity 2020 Strategy (Maes et al., 2013).

The CICES framework was developed 2009 to 2011 alongside and shortly after the TEEB classification was published. As far as possible, CICES strives to use the same nomenclature as in MA and TEEB. As a difference from the other two classifications CICES has a hierarchical structure (Figure A3) that provides a more comprehensive description of ecosystem services in several levels and scales. In comparison to the MA, it differentiates services that are directly used (final services) from those that merely support production of services (intermediate services) and here CICES focuses mainly on the final services. It is argued that this accordingly secures less double accounting of services. The CICES groups services into three sections: provisioning, regulating and maintenance, and cultural services in a ranked typology retaining eight divisions and 20 groups (Table A1). Case studies described by Maes et al. (2016) show that the grouping of services is valuable where the data availability is poor and attainable only at group or division level.

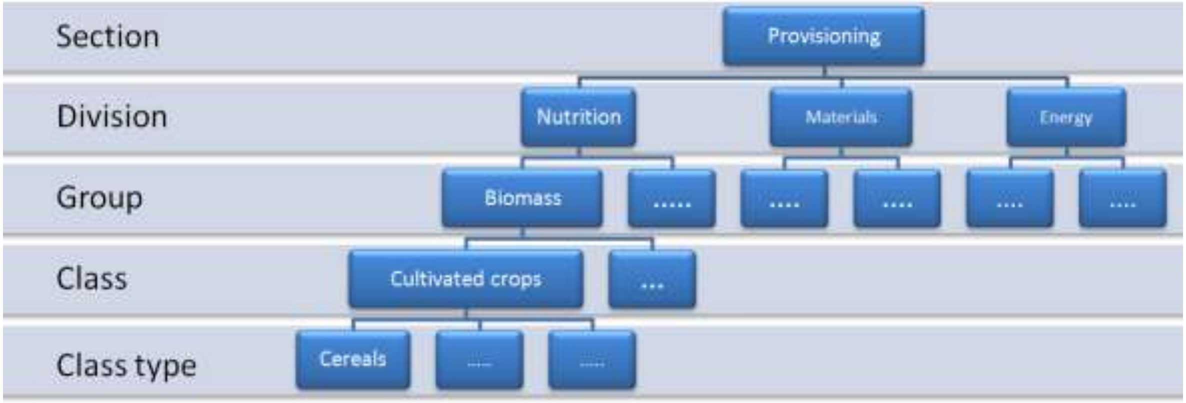

Figure A3. The hierarchical structure of the CICES version 4.3 (from Haines-Young and Potschin, 2013).

Table A1. The structure of the CICES version 4.3 classification of ecosystem services (after Haines-Young and Potschin, 2013).

Section	Division	Group
Provisioning	Nutrition	Biomass
		Water
	Materials	Biomass, Fibre
		Water
	Energy	Biomass-based energy sources
		Mechanical energy
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota
		Mediation by ecosystems
	Mediation of flows	Mass flows
		Liquid flows
		Gaseous / air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
		Pest and disease control
		Soil formation and composition
		Water conditions
		Atmospheric composition and climate regulation
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings]	Physical and experiential interactions
		Intellectual and representational interactions
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes [environmental settings]	Spiritual and/or emblematic
		Other cultural outputs

THE ECOSYSTEM SERVICE CASCADE MODEL

Haines-Young and Potschin (2011, 2013) represent the ecosystem services in a logical scheme of chains called the Ecosystem Service Cascade Model, or short for the Cascade model (Figure A4). The sequence is described as a running red cord from biophysical structures (and processes) produced by organisms in ecosystems, which create possibilities for the ecosystems to function in a way that generate concrete services, which again leads to advantages (benefits) that beneficiaries obtain and the values that these benefits might have to people. The major feature of this model is that there is a flow between the two end points. For example, the structure for producing berries is that we have forest berry habitats suitable for production (function). It is a benefit for humans that we annually have possibilities for harvesting berries and it has value for our health and as an income.

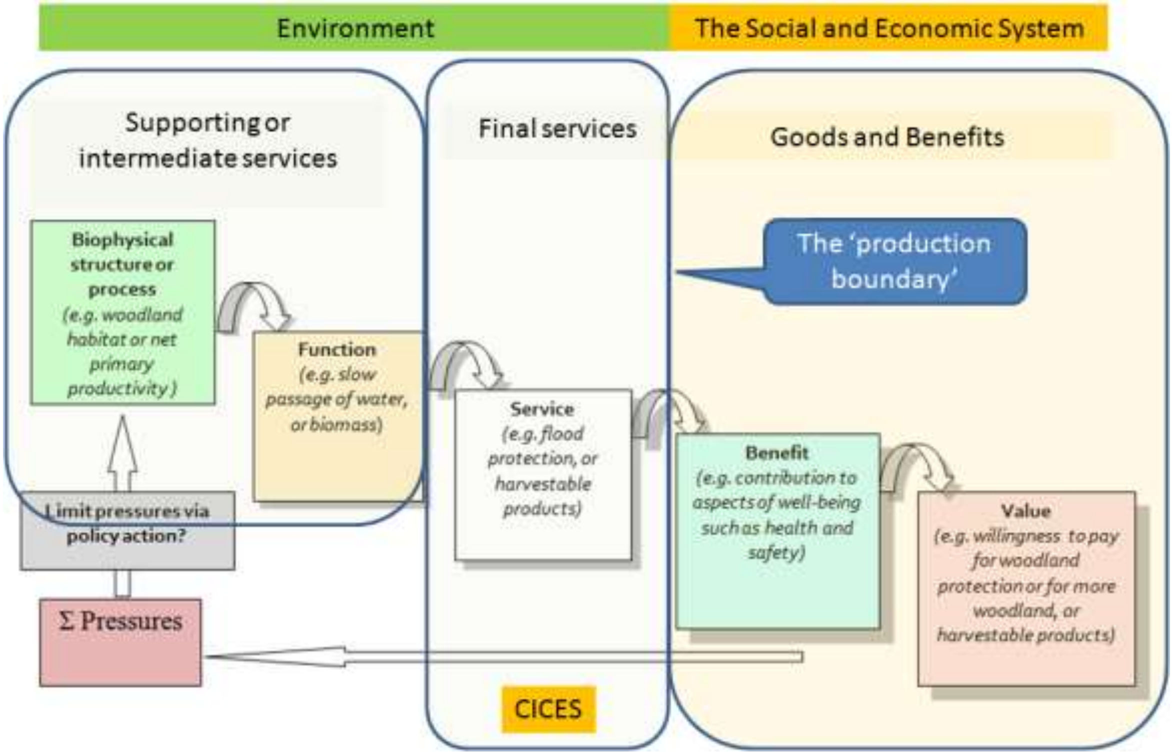

Figure A4. The connection between biodiversity, ecosystem function and human well-being in the Ecosystem Service Cascade model used in CICES (Haines-Young and Potschin, 2013).

Figure A5. The Cascade model demonstrated for the service of berries to be picked from forest ecosystems (Adopted from Haines-Young and Potschin, 2011).

FEGS-CS

The FEGS-CS (Landers and Nahlik, 2013) is an American initiative funded by the United States Environmental Protection Agency in order to classify final ecosystem services in an organised way. FEGS-CS defines final ecosystem services as Boyd and Banzhaf (2007) did before them from an economic point of view as "components of nature directly enjoyed, consumed or used to yield human well-being". Opposed to this, the intermediate ecosystem services are rather defined to be services that are necessary and important to produce the final services but not directly yielding human use and consumption. Taking the berry example once again, for a recreational berry picker forest berry habitats are an intermediate service necessary to produce berries, which are the final service. Johnston and Russell (2011) have described a scheme to clarify how one may distinguish final from intermediate services. In the FEGS-CS, a set of principles was further developed to help classify services as either final or intermediate. FEGS-CS incorporates three environmental classes (aquatic, terrestrial and atmospheric) and 15 sub-classes (e.g. forests, agroecosystems, grasslands etc.) with ten beneficiary categories (e.g. agricultural, recreational, humanity etc.) and 38 sub-categories (e.g. foresters, farmers, weavers etc.). FEGS-CS describes the many recipient groups to possible benefits and it further discusses the significance of the final services to these people.

APPENDIX 3. POSTER PRESENTED IN AMSTERDAM, JUNE 2016

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

SVENSKA MILJÖINSTITUTET

Biofuel impacts on ecosystem services

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PROJECT AIMS

- to strengthen the knowledge base on biofuel production and its impacts on ecosystem services;
- to identify the impact of selected biofuel production schemes based on forest biomass and agricultural crops (Hydrotreated Vegetable Oils (HVO) from tall oil and methane from forest residues as well as wheat-based ethanol and rapeseed biodiesel) on ecosystem services in Sweden;
- to draw recommendations on how to holistically assess ecosystem services, associated with the biofuel sector, using life cycle assessment (LCA).

ECOSYSTEM SERVICES

Ecosystem services are the benefits (goods and services) human beings directly and indirectly obtain from ecosystems. Understanding how ecosystem services are affected by biofuel production is entwined with different context specific aspects, such as supply chain and farming management practices; spatial and temporal variability of impacts; and natural environmental conditions. In Figure 1 the main ecosystem services associated with forest-based biofuels is listed.

Table 1. Examples of changes in ecosystem services as an effect of intensified removal of forest biomass for biofuel production. - denotes expected negative change and (+) expected positive change.

Class	Division	Ecosystem service	Potential changes in ecosystem services
Provisioning services	Materials	Timber and pulpwood	A larger removal of biomass leads to incresed availability of resources of timber and pulpwood, and hereby also HVO (+)
	Energy	Bioenergy	Intensified harvesting leads to more bioenergy from forests, both through regular harvest (HVO) and forest residues like tops and branches (Methane) (+)
Regulating and maintenance services	Mediation of flows	Prevention of erosion	In intensified harvest trees are cut and fields left open which might lead to larger erosion (-)
	Maintenance of physical, chemical and biological conditions	Climate regulation and carbon sequestration	Biofuels produced from forest biomass substitute for fossil fuels and thereby contribute to mitigating climate change (+). Biofuels from forest biomass may reduce soil carbon (-)
Cultural services	Physical interaction with biota, ecosystems and landscapes	Recreation and training	Visitors to forests enjoy the quietness. With a more intensified forest management harvesting sounds may disturb the quietness and the view (-).

Figure 1. Ecosystem services provided by forests: provisioning services (e.g. food and fuel supply), regulating services (e.g. climate regulation and freshwater regulation), supporting services (e.g., primary production), and cultural services (e.g. recreation). Source: Swedish Ministry of the Environment and Energy

INITIAL FINDINGS

In Table 1 we assess potential changes in ecosystem services as a result of intensified removal of forest biomass.

Ecosystem services interrelate in complex ways, across space and time, and synergies and trade-offs among different services may occur. These trade-offs are difficult to quantify and specific services may lead to improvement or reduction of other services.

Biofuel production induced changes in ecosystem flows may be both positive (e.g. enlargement in forest area) and negative (e.g. decrease in soil fertility and water availability), depending on context-specific aspects.

Our approach demonstrates that although some challenges remain unsolved, due to the existing LCA structure, existing ecosystem frameworks are helpful tools to better include ecosystem services into LCA of different biofuels.

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