BIOFUELS AND ECOSYSTEM SERVICES

Karin Hansen & Julia Hansson, IVL Swedish Environmental Research Institute

Danielle Maia de Souza, Swedish University of Agricultural Sciences (SLU)

Gabriela Russo Lopes, Stockholm University (SU)

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Background and aim

Biomass for the production of biofuels may be grown on agricultural and forest land 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 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.

Ecosystem services are the benefits people obtain from ecosystems. There is evidence that biofuels offer ecosystem services but also compromise other services (e.g. SCOPE, 2009; Fischer et al., 2009). However, there is limited knowledge about how the production of biofuels affect ecosystem services and related synergies and trade-offs. 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 synthesizes and 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 for different biofuel production schemes. We account for impacts of biofuel production on ecosystem services in a Swedish perspective. Forest biomass based biofuels (HVO from tall oil and methane from forest residues) and agricultural based biofuels (wheat-based ethanol and rapeseed biodiesel) are included. For comparison, the ecosystem services linked to the production of crude oil are described.

The specific targets of the project are to:

- identify and describe the ecosystem services that affect and are affected by an intensified Swedish biofuel production compared to current 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.

The CICES classification (Common International Classification of Ecosystem Services) and the Ecosystem Service Cascade Model are used to place biofuels in the ecosystem services scheme for forest and arable 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. A synoptic comparison to ecosystem services linked to the production of fossil diesel is included.

Results

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). 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. 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 been indicated to diminish natural habitat and biodiversity as well as increase 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 served 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). 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.

An intensified agricultural production of biofuels from agricultural crops such as wheat based ethanol and biodiesel from rapeseed thus has certain positive impact on some ecosystem services such as bioenergy and negative or neutral impact on others such as soil quality and control of pests (Table A presenting ecosystem services in the agricultural biomass production).

Table A. 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	Habitats	Area of nursery habitats [ha]; Area of fallow and untilled land	Reproduction success [n/yr]; Indicator species [n/yr]	Shelter and nutrition	Willingness to pay to protect threatened species; Avoided cost of management

	and bio-logical conditions		[ha]; Area of or-ganic farming [ha]			measures; Intrinsic value
		Pollination	Vegetation area supporting polli-nation [ha]; Polli-nator nesting and foraging habitats [ha]	Abundance of polli-nators [n]	Improved crop production and in-creased yield [kg/ha]; Increased availability of food [kg/ha]; Additional nutrition	Reduction in food costs; Influence on gardening; Intrin-sic value
		Soil quality	Functional diver-sity of soil organ-isms	Content of soil organic C [Mg/ha]; Availability of nutrients; pH; Den-sity [g/cm3] and macro-pore porosity [%]; Weathering [mekv/m2/yr]	Improved soil quality; Higher availability of nu-trients; Higher production and harvest	Avoided costs of fertilizer use; Value of improved income
		Decomposit-ion and fixing processes	Areas of N fixing crops [ha]	Nitrogen fixation rates [kg/ha/yr]; Decomposit-ion 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 capac-ity; pH of topsoil; Soil organic matter content [%]	Improved soil quality; Increased agricultural pro-duction	Avoided costs of soil improvement; Value of improved income
		Biological pest control	Area not needing pesticide treat-ment [ha]; Area of organic farm-ing [ha];	The density of hedges and shrubs [no/ha]	Less pest damage in crops; Higher production	Avoided costs of pest damage
		Climate regu-lation and C sequestra-tion	C-storing habitats [ha]	C sequestration rate [t/ha/yr]; C balance	Climate regula-tion; C stocks (in vegetation and soils) [Mg/ha] and C sequestration [Mg/ha/yr].	Avoided costs for mitigation of cli-mate impacts; Market value for C emission trading; Avoided costs with impacts on human health; Avoided costs of climate re-lated impacts
Cultural services	**Physical and intellectual interaction with biota, ecosystems and land-scapes**	Recreation and training	Preferred recrea-tion farmland ar-eas [ha]; Area of croplands for hunting [ha]; Walking and bik-ing 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 competi-tions associated with agriculture [n/yr]	Increased oppor-tunities for recrea-tional activities; Bird population control	The willingness to pay for a visit; The willingness to pay for hunting licens-es; The willingness to pay for hiking and walking; Avoided health costs
		Tourism	Preferred farm-land areas for tourism [ha]	Tourists in agricultural areas [n/yr]; Number of rural enterprises offer-ing tourism services [n]; Sleep-over-nights [n/yr]	Jobs in the tourist sector	The willingness to pay for tourism ac-tivities; Value for tourist visits
		Mental and physical health	Areas offering varied and inter-esting agricul-tural land-scapes[ha]	Number of ticks carry-ing meningitis [n]	Improved or im-poverished health	Health value - avoided as well as increased costs
		Knowledge and inform-ation	Areas of croplands used for scientific studies [ha]	Visitors in agricultural areas [n/yr]; Number of didactic farms; Number of scientific studies [n/yr]; Number of publi-cations [n/yr]	Increased aware-ness of sustaina-ble farming prac-tices; Source of knowledge	The willingness to pay for a visit; Value for science and education; Funding for re-search activities
		Heritage, cul-tural	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

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 and grassland. The changes are described qualitatively as well as semi-quantitatively using a scale (-/--/---/0/+/++/+++) (Table B).

Table B. Potential changes in ecosystem services as an effect of intensified forest management. The reference situation is today's forest biomass production. Possible actions to mitigate the potential changes are furthermore suggested in the table. Intensified forest harvest and fertilization 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 to 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 +.

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 prabably 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
	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 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 sugests 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/-

The same considerations are made for increased use of existing forest residues and intensified forest fellings and fertilization in order to produce higher amounts of forest biomass which in turn might lead to an increased production of biofuels such as HVO (Hydrotreated Vegetable Oils) from crude tall oil and methane from forest residues (not shown here).

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.

Conclusions

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. 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.

We consider the approach including qualitative and semi-quantitative valuation of ecosystem services useful to understand the importance of several additional impacts of biofuel production. It 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.

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

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