Ecological Indicators 89 (2018) 411–421

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Integrating impacts on climate change and biodiversity from forest harvest in Norway

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ARTICLE INFO

Keywords:
LCA
Climate change
Biodiversity loss
Forestry management
Albedo

ABSTRACT

Forest ecosystems provide a variety of services, from climate regulation to biodiversity conservation. Temporary land cover variations such as those related to forest management can contribute to climate change through both biogeochemical (carbon, warming) and biophysical (albedo, cooling) mechanisms. As global rising demand for biomass for energy and materials can contribute to biodiversity losses, there is an evident need for integrated assessments of climate and biodiversity impacts to investigate possible trade-offs and synergies. We explore the integration of impacts on climate change and biodiversity from forest harvest for three case studies based on forest plantations in Norway. We focus on impacts from land disturbance after clear-cutting using three plots of one ha each of homogeneous forest in two ecoregions in Norway involving three different tree species: spruce, pine and birch. We use existing ecoregion specific characterization factors (CFs) to quantify occupation, short-term and long-term transformation impacts of land use on biodiversity loss for five taxonomic groups: mammals, birds, amphibians, reptiles and plants at regional and global level. For climate change impacts, we quantify the contributions of CO_2 fluxes and changes in albedo. We estimate CFs for two complementary climate metrics, namely global warming potential (GWP) and global temperature change potential (GTP) for time horizons of 20 and 100 years and quantify impacts in CO_2 equivalents. We pursue the integration of impacts on climate and biodiversity from a time perspective: very short (GWP20 and land occupation), medium (GWP100 and land transformation within 100 years) and long (GTP100 and land transformation after 100 years). We find CFs from −0.21 to 1.6 kg CO_2-eq./kg CO_2 for carbon emissions, and from −0.03 to −1.4 kg CO_2-eq./kg CO_2 for albedo changes, while net characterized impacts range from −44.8 t CO_2-eq./ha (GTP100, spruce) to 93.25 t CO_2-eq./ha (GWP20, spruce). Damages to biodiversity range from $4.76 * 10^{-13}$ to $6.24 * 10^{-8}$ global species eq. lost per ton of carbon harvested. Our results reinforce the notion that spatially and temporally explicit analyses are vital when assessing life-cycle impacts from land derived products. We show that the existing set of multiple and complementary indicators for climate change and biodiversity impacts can be integrated into a common framework to better inform about the complex heterogeneities of the forest ecosystem response to disturbances. We argue for a more frequent consideration of integrated impacts on biodiversity and climate change from forestry operations to better highlight possible co-benefits or adverse side-effects of forest management strategies.

1. Introduction

Anthropogenic greenhouse gas (GHG) emissions are driving increasing trends in annual average surface temperature that are threatening species and ecosystems (Stocker et al., 2013). The energy sector accounts for the majority of these GHG emissions (35%), mainly due to consumption of fossil fuels (Bruckner et al., 2014). Limiting global warming thus requires a large transformation of the energy sector, and the latest assessment report of the United Nation's Intergovernmental Panel on Climate Change (IPCC) identifies bioenergy as part of the solution for climate change mitigation (IPCC, 2014). Nevertheless, there are growing concerns that an increased demand for biomass from forests for energy production can have adverse effects on a variety of ecosystem services (e.g., water chemistry, soil stability), and especially biodiversity where some species living in forests could decline (Cornwall, 2017).

Life cycle assessment (LCA) is a commonly used methodology for evaluating the total environmental impacts of products or systems during their entire lifecycle (Hellweg and i Canals, 2014). LCA is frequently used to assess bioenergy production systems, but there are methodological challenges related to the complexity of climate and ecosystem services involved in land-derived products. Terrestrial

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https://doi.org/10.1016/j.ecolind.2018.02.034
Received 19 April 2017; Received in revised form 8 February 2018; Accepted 15 February 2018

ecosystems interact with the climate in many different ways (Bonan, 2008). Land use and land cover changes, like those from forestry operations, directly alter the global radiation balance through two mechanisms: biogeochemical effects (the release and absorption of GHGs like CO_2) and biophysical effects (such as those from changes in the surface energy budget) (Liu et al., 2011; Myhre et al., 2013a; Schimel et al., 2001; Zhao et al., 2009). Among the biophysical effects, changes in surface albedo are dominating at high latitude or in areas affected by seasonal snow cover (Davin and de Noblet-Ducoudré, 2010). Albedo, which indicates the reflectivity of a surface, varies with the type of land cover and local climate. For instance, in forests it is lower than in open land, especially when covered with snow (Jackson et al., 2008). The biogeochemical and biophysical contributions to the global radiative forcing (RF) from historical land use changes have similar magnitudes but opposite signs (Cherubini et al., 2017; Myhre et al., 2013a). Deforestation causes warming through release of CO_2 emissions stocked in the biomass and cooling from increased surface albedo (Bala et al., 2007; Davin and de Noblet-Ducoudré, 2010). On the other hand, afforestation leads to cooling effects on climate due to CO_2 sequestration during biomass growth while masking the ground with forest canopy progressively reduces albedo and hence leads to a warming effect (Arora and Montenegro, 2011; Lohila et al., 2010). Land cover changes can have a significant impact on climate also when they are temporary, such as in the case of stand-replacement disturbances in forest management (Cherubini et al., 2012; Luyssaert et al., 2014). Changes in land cover have a third direct effect on the global radiation balance by altering emissions of biogenic organic compounds that rapidly oxidize in the atmosphere generating multiple warming and cooling climate pollutants like ozone and secondary organic aerosols, whose impact can be of the same order of magnitude of surface albedo or carbon fluxes (Arneth et al., 2010; Unger, 2014). These compounds also affect cloud formation patterns and properties, thereby indirectly influencing climate through changes in cloud albedo, but these contributions are still subject to large uncertainties and under continuous refinement (Carslaw et al., 2013).

Many articles argue for the importance to go beyond a simple carbon accounting framework when assessing the impacts of land activities on climate (Cherubini et al., 2016; Jackson et al., 2008; Zhao and Jackson, 2014). Over the recent years, an increasing number of studies attempted to include biophysical effects in LCA (Caiazzo et al., 2014; Cherubini et al., 2012, 2016; Guest et al., 2013a,c; Muñoz et al., 2010). These studies generally conclude that quantification of biophysical and biogeochemical impacts from land cover changes can have large influence on the results, and are highly dependent on local specific factors. Some studies directly compute the response of the global carbon cycle and climate systems and derive emission metrics for forest bioenergy explicitly taking into account carbon and albedo dynamics, thus facilitating a consistent assessment of biogenic and fossil CO_2 emissions in LCA (Bright et al., 2012; Cherubini et al., 2012, 2016). The latest IPCC Assessment Report applies this approach to quantify climate impacts from forest bioenergy (Bruckner et al., 2014; Smith et al., 2014).

Whereas GWP100 is the most common option, impacts on climate can be assessed through a variety of indicators, including GTP and the use of multiple time horizons (TH). GWP is the radiative forcing (RF) from a pulse emission at time zero integrated until a chosen TH and divided by the result of an equivalent integration for CO_2. GTP represents the impact of an emission pulse on global temperature at the chosen TH, again relative to that of CO_2 (Myhre et al., 2013a; Shine et al., 2005). Given the complementary essence of these metrics, the recent guidelines from the Global Warming Task Force of the UNEP/SETAC life-cycle initiative recommends the use in LCA of GWP100 to target shorter-term impacts (using GWP20 in a sensitivity analysis) and GTP100 to assess long-term impacts (Levasseur et al., 2017).

Land use and land use change are identified as the main global drivers for terrestrial biodiversity loss (Millennium Ecosystem Assessment, 2005). Biodiversity stabilizes ecosystem productivity over time (Hautier et al., 2015; Isbell et al., 2015; Naeem and Li, 1997) and has an intrinsic value for humans. In 2005, 28% of the word's land surface registered a 20% net reduction in local species richness (Newbold et al., 2016). Productive forest in Norway represents an abundant resource, respectively one quarter of the country's land area (Statistics Norway, 2016), and it is the main habitat for most species (Henriksen and Hilmo, 2015). At the same time, the pressure from forestry operations accounts for 41% of threatened species in Norway while land-use change is considered to be a serious pressure on 90% of the species classified as threatened (Henriksen and Hilmo, 2015). In addition, almost half of the species (48%) on the Norwegian Red List are forest species (Henriksen and Hilmo, 2015) and 50% of all species in Norway depending on dead wood are on this list (Michelsen, 2008). The recent study from Liang et al. (2016) shows that a 10% loss in tree biodiversity also leads to a 3% loss in forest productivity. In general, previous studies indicate that intensive forest management leads to a reduction in habitat quality for many species (Berg et al., 1994; Paillet et al., 2010) beyond vascular plants. Clear-cut boreal forests have been pointed out as bottlenecks for the survival of biodiversity (Rudolphi and Gustafsson, 2011; Stenbacka et al., 2010; Widenfalk and Weslien, 2009). The largest number of threatened species in forest are specialist species, usually found on dead wood, mainly from large deciduous broad-leaved trees. Most of the Norwegian red-listed species are associated with rich broad-leaved forest (Henriksen and Hilmo, 2015). Fauna has been pointed in previous studies to be sensitive to logging intensity (Bicknell and Peres, 2010; Burivalova et al., 2015).

Although land use has an essential impact on biodiversity loss, there is no clear consensus on how to assess this in LCA (De Baan et al., 2013; Koellner et al., 2013; Michelsen et al., 2012). During the last years, several studies proposed methodological improvements and computed different biodiversity loss indicators (Chaudhary et al., 2015; Michelsen, 2008; Teixeira et al., 2016). Recently, the UNEP/SETAC life cycle initiative has made preliminary recommendations for a biodiversity loss indicator for terrestrial ecosystems (Milà i Canals et al., 2016), which is based on the method of Chaudhary et al. (2015). The impact from land use on biodiversity depends on the ecoregion and site-specific assessments should always be conducted due to the differences in local species richness and species vulnerability.

Joint consideration of impacts from land use and land use change such as biodiversity loss, changes in surface albedo and biogenic CO_2 fluxes are rare (Jørgensen et al., 2014; Michelsen et al., 2012). Some of the challenges to combine both climate change and biodiversity impacts in a common framework arise from the complex interplay between the different effects and their temporal distribution. For instance, uncurbed biodiversity loss can threaten long-term climate change mitigation efforts due to alterations of ecosystem functions and services, among which biomass production (Cardinale et al., 2012; Newbold et al., 2016) and a loss of intrinsic values. In this study, we select three case studies of bioenergy production from forest biomass in Norway where we simultaneously estimate post-harvest carbon flows, changes in albedo and biodiversity loss impacts. We chose the three main local species of trees, Norwegian spruce, pine and birch. Our aim is to provide an integrated platform to assess in a common framework impacts on climate and biodiversity from land cover disturbances. We apply the recent UNEP/SETAC guidelines (Frischknecht et al., 2016; Frischknecht and Jolliet, 2017) to compute three alternative climate indicators (GWP20, GWP100 and GTP100) and Potential Disappeared Fractions of Global Species (PDF) to quantify impacts on biodiversity for five taxonomic groups (mammals, birds, amphibians, reptiles and plants). We use empirical site-specific data for forest dynamics and integrate the characterized results from the different metrics under a time perspective based on short-, medium, or long-term impacts.