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SHORT COMMUNICATION

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Selected aspects of the impact of energy wood harvesting on the forest environment

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Abstract

Global demand for energy, including renewable energy, continues to rise. As a result, the proportion of woody biomass used for energy purposes is also increasing. The article focuses on a literature review of selected natural consequences of forest biomass utilisation for the forest environment. The impacts of harvesting forest biomass for energy purposes consider three harvesting systems: conventional harvesting (CH), whole-tree harvesting (WTH) and whole-tree harvesting with stump removal (WTH + S). The results of the literature review show that harvesting for energy affects the forest environment, including soil productivity, forest water and biodiversity. The impacts are mostly negative and largely depend on the harvesting system. This literature review shows that the more intensive the timber harvesting system (WTH, WTH + S) is, the greater the impact on the natural environment. Of all systems, conventional timber harvesting (CH) has the best impact on the natural environment.

Key words

biodiversity, carbon, forest environment, renewable energy, soil, timber harvesting, water

Introduction

The development of renewable energy sources (RESs) has become one of the main objectives of European countries' energy policies. To promote renewable energy, the European Union (EU) has adopted a number of policy and legislative packages to support the energy transition, reduce greenhouse gas emissions and increase the share of clean energy in the European energy mix. One of these packages is the European Green Deal, which aims to achieve climate neutrality in the EU by 2050 (The European Green Deal 2019).

In contrast to fossil fuels, biomass from forestry has many advantages. First of all, wood is a renewable resource and the energy produced is not dependent on weather conditions as is the case with solar or wind energy (Nicholls et al. 2008). Moving away from coal towards the use of RESs, including biomass, brings economic and social benefits as well as environmental ones. From an economic point of view, forest biomass is an alternative to fossil fuels, enables the diversification of forestry production, creates a market for low-value wood and increases the income of forest owners. From a social point of view, forest biomass improves rural development and increases employment.

However, the production of forest energy wood can conflict with social aspects by reducing the attractiveness of forests and, above all, it can run counter to the

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objectives of protecting forest biodiversity and nature conservation, as it leads to a reduction in the biodiversity of habitats and their degradation. From the point of view of forest production efficiency and environmental protection, choosing the right timber harvesting system is very important. Due to the increasing demand for post-harvest wood residues in Europe, whole-tree harvesting (WTH) is becoming more common (De Vries et al. 2021). As a result, biomass harvesting is increasing by 30% compared to conventional harvesting (CH) (Pels 2011; Aherne et al. 2012; De Vries et al. 2021).

The main objective of the article is to review the scientific literature on selected consequences of the energy use of woody biomass for forest management and forest ecosystems. The literature review is related to the impact of forest biomass harvesting on the forest ecosystem, taking into account the harvesting practices.

Methods

To achieve the main objective of the thesis, the method of quantitative systematic literature review was applied. In particular, the Web of Science – ISI Web of Knowledge database, the Scopus database and the Google Scholar search engine were used. To obtain a broad, preliminary list of articles, a set of keywords was used, taking into account the general thematic background (biodiversity, forest environment, renewable energy) and specific issues related to the impact of timber harvesting on the environment and, in particular, the impact of post-harvest residue removal (timber harvesting, soil, forest biomass, water, carbon). The search was narrowed down to articles published in the years 2001–2021. In the next phase, the abstracts were reviewed and their content analysed to identify the most relevant topics.

The effects of energy wood harvesting (EWH) of forest biomass on the forest ecosystem are often presented in the literature under consideration of the harvesting systems. In this context, a distinction can be made between CH), WTH and whole-tree harvesting with stump (WTH + S) removal. In the CH system, the above-ground part of the tree is harvested, whereby the trunk is uprooted and removed from the forest, while the remaining parts (branches and crown) remain at the harvesting site, where they decompose. In WTH, the entire tree is harvested and hauled out of the forest, including the tops and branches, which can later be chipped and sold as fuel (e.g. to an energy company). The third system (WTH + S) combines the assumptions of the second system with the additional harvesting of stumps for energy purposes. The paper focuses primarily on biodiversity, soil productivity (organic carbon and nutrient stocks) and water in forests.

The paper focuses primarily on issues related to biodiversity, soil productivity (organic carbon and nutrient resources) and water in forests. These are very sensitive elements of the forest environment, the disruption of which can have serious consequences for the functioning of forest ecosystems.

Results

Soil productivity

Forest ecosystems play a key role in the carbon cycle as they absorb large amounts of carbon dioxide and thus represent a huge reservoir of carbon. Some of this carbon is in living biomass, but most of it is stored in the soil (Fahey et al. 2010; Achat et al. 2015). The carbon stored in the soil is not only important for carbon sequestration, but also for maintaining the productivity of forests. It is one of the main components of soil organic matter (SOM), which is an important source of energy and nutrients for soil microorganisms, buffers the pH value in the soil and helps to stabilise the soil structure (Harrison et al. 2017; Buchholz et al. 2014; Zanchi et al. 2012). Along with nitrogen and phosphorus, SOM is considered an indicator of soil health and quality (Harrison et al. 2017). The harvesting of wood and crop residues influences the availability of organic carbon and nutrients in the soil and its structural (functional) diversity (Dahlberg et al. 2011). Since much of the organic carbon and nutrients in trees is found in the trunks, leaves and small branches, the removal of these components results in less nutrient release to the soil, which may increase the risks associated with nutrient imbalance and lower forest production in the long term (Clarke et al. 2021; Helmisaari et al. 2011; Tveite and Hanssen 2013).

The initial impact of timber harvesting on soil carbon stocks varies and leads to a small short-term decrease in carbon (Johnson and Curtis 2001; Nave et al. 2010). According to Nave et al. (2010), a large part of this decline is due to the mixing of litter and mineral soil. This process is dependent on climate, soil type and vegetation (Hoover 2011).

Studies from Scandinavian countries and the UK show that intensive biomass utilisation with the WTH system leads to a greater loss of organic carbon and soil nutrients in forest ecosystems in conifer stands than conventional (CH) utilisation (Johnson and Curtis 2011; Achat et al. 2015; Clarke et al. 2021). In addition, the analyses by Achat et al. (2015) showed that harvesting with the WTH system led to organic carbon losses in all soil horizons investigated (humus horizon, mineral soil above and below 20 cm). In addition, the authors' research results prove that the removal of post-harvest residues reduces the availability of nutrients, which can contribute to a decline in site fertility and tree productivity. At the same time, the authors' research results proved that harvesting with residues left behind does not cause organic carbon losses, as the small loss of organic carbon in the forest soil was compensated by the accumulation of SOC in deeper soil layers (Achat 2015 et al.).

However, if stump removal (WTH + S) is added to harvesting with the WTH system, the organic carbon stocks in the soil may be even lower (Persson 2017). This is confirmed by the studies of Clarke et al. (2021), which show that intensive timber harvesting with the WTH + S system depletes the soil even more in terms of organic carbon and nutrients than with WTH alone. Clarke et al. (2021) show that of all soil layers, the greatest reduction in organic carbon and total nitrogen was observed in the understorey compared to the topsoil in the WTH + S harvesting system. According to Clarke et al. (2021), this is a surprising result as the mineral soil is mixed with material from the forest floor during stump removal.

The impact of timber harvesting on the carbon content of the soil depends on the type of soil and its organic matter content. Studies have shown that the removal of forest biomass can have little impact on soil carbon content (Thiffault et al. 2015; Brandtberg and Olsson 2012; Klockow et al. 2013), except in sandy and coarse-grained soils with low organic matter (Thiffault et al. 2011). According to Page-Dumroese et al. (2010), this soil type is considered very sensitive to forest biomass harvesting.

Timber harvesting will also affect the stock of base cations in the mineral composition of soils (Ca, Mg, K). Poor soils with a low base cation content are particularly susceptible. The use of high-intensity timber harvesting systems (WTH, WTH + S) will further reduce the content of base cations in the soils. Trees growing on such soils may have growth problems and, in particular, be more susceptible to drought or frost stress (Thiffault et al. 2015; McLaughlin and Wimmer 1999; De Hayes et al. 1999; Schaberg et al. 2001).

Soil productivity is also influenced by nitrogen. However, studies by some researchers have found no correlation between soil nitrogen levels and forest biomass yield (Brandtberg and Olsson 2012; Klockow et al. 2013). However, according to Thiffault et al. (2010), the removal of logging residues can affect the mechanisms of the nitrogen cycle between soil and vegetation, thereby worsening the nitrogen supply to trees and the ability of forests to fix atmospheric nitrogen.

The availability of phosphorus in the soil is one of the key factors influencing the functioning of forest ecosystems. The basic natural source of phosphorus in the soil is the parent rock and the phosphorus minerals it contains (Sapek 2014). Studies show that harvesting forest biomass can significantly affect phosphorus stocks in the soil. Harvesting of woody debris in pine stands in the southern USA has been associated with reduced soil phosphorus levels and reduced tree growth (Scott et al. 2004; Scott and Dean 2006). However, this risk is likely limited to geographical regions where soils have particularly low phosphorus concentrations (e.g. the southern USA) or to specific locations such as former agricultural lands (Thiffault et al. 2015).

Forest biomass harvesting also leads to degradation of soil physical properties (texture, slope, moisture content and depth) through erosion, displacement, compaction and rutting (Kosenius and Ollikainen 2013). Compaction of soil by heavy equipment can increase the volume density of soil and affect other soil properties (such as porosity), which can reduce its permeability to roots, air and water. Heavy machinery can also cause deep ruts which, together with an increased water table in the deforested area, can alter the hydrology of the site (Titus et al. 2021).

Water in the forest

Forest ecosystems supply streams with high-quality water, regulate their hydrology and provide a variety of aquatic habitats (Neary et al. 2009; Vance et al. 2018).

Due to the close relationship between soil and surface water, technological processes associated with forest biomass harvesting can have a negative impact on the quality of streams in the forest ecosystem (Laudon et al. 2011). Among other things, they can have a negative impact on water quality and expose forest ecosystems and aquatic organisms to toxic substances (Neary et al. 2009). Four types of potential impacts of forest biomass use on water resources have been identified in the literature, including sedimentation, nutrient concentration, temperature and water availability (Stewart et al. 2010).

Forest biomass harvesting can lead to compaction of forest soils, which increases the export of nutrients and dissolved organic carbon to surface waters (Binkley and Brown 1993). According to Kreutzweiser et al. (2008), this can lead to eutrophication and nitrification of these waters. An important note is that sawing wood into piles in riparian areas can lead to an increase in nutrient concentrations and, together with machine traffic, increases erosion and the movement of nutrients and sediments into watercourses, leading to acidification of water bodies (Helmisaari et al. 2011). The extent of nutrient leaching into watercourses is higher with CH than with WTH. The reason for this is that leftover logging residues contain a rich source of nutrients that can lead to fungal growth and deoxygenation of local watercourses (Nisbet et al. 1997). To slow surface runoff and thus reduce mineral soil erosion (reducing sediment transport from slopes to streams), biomass would need to be processed as close to the harvest site as possible (Buttle and Murray 2011).

Biodiversity

Assessing the impact of forest biomass harvesting on the overall health of ecosystems and on biodiversity, in particular, is complicated by the trade-offs that exist between biomass production and biodiversity. At the global level, climate change itself is an important factor in biodiversity loss. At the local level, more intensive forest management for biomass production can increase the pressure on forest ecosystems. Similarly, the land-use change associated with afforestation can have a positive or negative impact on local biodiversity (Abreu et al. 2017).

The literature shows that timber harvesting for energy purposes, especially in a conventional system where the wood residues decay, affects the biodiversity of forest ecosystems. In most cases, the impact depends on both the location and the species (Roxby et al. 2015).

The harvesting of biomass in the WTH and WTH + S systems by removing stumps and felling residues has a negative effect on the biodiversity of the soil flora and fauna as well as on the occurrence of saproxylic species (Dahlberg et al. 2011). At the stand level, the harvesting of dead snags has been found to reduce the number of beetle species living in them (Victorsson and Jonsell 2013) and reduce the abundance of ground-dwelling invertebrates (Taylor and Victorsson 2016). Caruso et al. (2008) found that for some lichen species, the colonisation rate depends on the number of stumps, which are the source of lichen dispersal. The authors assume that there are threshold values for the number of stumps remaining after timber harvesting that must be adhered to in order to prevent the extinction of species in the stand (Caruso et al. 2008). Studies by some researchers suggest that leaving logging residues can have a positive effect on invertebrates such as runners and spiders and contribute to the diversity of their habitats (Nittérus et al. 2004; Skłodowski 2017; Castro and Wise 2009).

The harvesting of forest biomass causes a number of short- and long-term changes in forest structure. One of these changes is the enlargement of gaps in the stands, leading to improved light penetration to the forest floor, which has a positive effect on the development of vegetation in the understory and thus increases species diversity and abundance (Homyack et al. 2005; Harrod et al. 2009; Vance 2018). Therefore, stand gaps created by harvesting forest biomass have a positive or neutral effect on biodiversity and species richness in the forest ecosystem. Gaps contribute to nutrient availability and storage. As the size of the gaps increases, so does the potential for exporting components to neighbouring forests.

Conclusion

The results of the study show that the harvesting of wood for energy purposes is not without impact on the functioning of forest ecosystems and entails pressures that are difficult for them to assess. This impact will depend, among other things, on the type of harvesting. The most important conclusions include the following:

- In coniferous stands, biomass harvesting under the WTH system results in a greater loss of organic carbon and soil nutrients compared to harvesting under the conventional system.
- The greatest impact of forest biomass harvesting on soil organic carbon content will be on sandy and coarse-grained soils with low organic matter.
- The use of high-intensity harvesting systems (WTH, WTH + S) depletes the alkali cation content of soils more than a conventional system (CH), and trees growing on such soils are more susceptible to drought and frost.
- Soil compaction due to the use of heavy forest biomass harvesters increases the volumetric density of the soil, leading to a reduction in soil permeability.
- Harvesting in CH systems can contribute to eutrophication and nitrification of watercourses.
- High-intensity timber harvesting has a negative impact on the diversity of ground flora and fauna, especially when stumps are harvested using the WTH + S system.
- To protect against the environmental consequences of harvesting forest biomass, it is important to implement sustainable forest practices, monitor the impact of activities on ecosystems and protect valuable habitats,
- This literature review can help to increase the knowledge of scientists and stakeholders on the aspects of harvesting wood for energy purposes.

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