Forest Ecology and Management 383 (2017) 85–98

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Environmental effects of brushwood harvesting for bioenergy ☆

Torbjörn Ebenhard [a,*], Maria Forsberg [a,b], Torgny Lind [c], Daniel Nilsson [d], Rune Andersson [e], Urban Emanuelsson [a,f], Lennart Eriksson [g], Oscar Hultåker [h], Maria Iwarsson Wide [i], Göran Ståhl [c]

[a] Swedish Biodiversity Centre, Swedish University of Agricultural Sciences, Box 7016, SE-750 07 Uppsala, Sweden
[b] Department of Law, Uppsala University, Box 512, SE-751 20 Uppsala, Sweden
[c] Department of Forest Resource Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden
[d] Department of Energy and Technology, Swedish University of Agricultural Sciences, Box 7032, SE-750 07 Uppsala, Sweden
[e] Källstigen 14, SE-757 56 Uppsala, Sweden
[f] Mobergavägen 19, SE-373 02 Ramdala, Sweden
[g] Margretelundsbacken 10, SE 18776 Täby, Uppsala, Sweden
[h] Department of Forest Products, Swedish University of Agricultural Sciences, Box 7008, SE-750 07 Uppsala, Sweden
[i] Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 Uppsala, Sweden

A R T I C L E I N F O

Article history:
Received 17 February 2016
Received in revised form 9 May 2016
Accepted 14 May 2016
Available online 3 June 2016

Keywords:
Bioenergy
Brushwood harvesting
Sustainability
Biological diversity
Climate

A B S T R A C T

Sweden aims to increase the proportion of renewable energy sources, ultimately to be able to phase out fossil fuels. To achieve this, new energy sources need to be explored. In this multi-disciplinary article, we examine the technical, economical, ecological and legal possibilities to commercially and sustainably harvest brushwood for bioenergy, while simultaneously gaining positive environmental effects, both for biological diversity, the cultural heritage, and the climate.

The Swedish open landscape is becoming covered with secondary brushwood regrowth through natural succession, except where it is kept open. Brushwood is spreading along roads, railway lines, edge zones, in power line corridors, abandoned semi-natural grasslands, nature reserves, and in marginal land in urban areas. Such brushwood consists of saplings, bushes and young trees of a range of deciduous plant species, e.g. birch, aspen, alder and goat willow, sometimes mixed with conifers, often forming dense thickets.

Such secondary brushwood regrowth could be systematically utilised as a new source of renewable bioenergy. Commercial brushwood harvesting in Sweden may contribute 26 PJ of energy annually, which may be a small but significant contribution, considering the favourable energy ratio ($E_r = 28$), indicating that large emission reductions can be achieved, if fossil fuels are replaced. Growing brushwood does not require fertilizers or pesticides, soil tillage or crop management, and it does not compete with any other potential land use. Many brushwood habitats are already being managed to clear brushwood, for other purposes, minimizing the added harvesting cost.

Apart from providing bioenergy, it has also been suggested that brushwood harvesting would benefit biological diversity. A large number of nationally redlisted species are dependent on the active management of open habitats, including semi-natural grasslands, and man-made habitats such as road verges and power line corridors.

Our literature review shows that brushwood harvesting could benefit both biological diversity and the cultural heritage, and contribute to the management of the open cultural landscape. There are however certain limitations. Brushwood harvesting would favour a certain set of species, including many redlisted, but it may also threaten another set of species, especially species associated with early successional stages of forest regeneration, as well as forest edge species, depending on how and where it is applied. Harvesting may be affected by legislation imposing limitations regarding habitats of particular importance for biodiversity. The environmental and legal constraints would probably reduce the profitability of brushwood harvesting in certain areas, as well as the annual production of bioenergy.

☆ This article is part of an special issue "Sustainability of increased forest biomass harvest from a Swedish perspective" published in the journal Forest Ecology and Management 383, 2017.

* Corresponding author.
E-mail address: Torbjorn.Ebenhard@slu.se (T. Ebenhard).

http://dx.doi.org/10.1016/j.foreco.2016.05.022
0378-1127/

1. Introduction

The growing global human population faces a number of challenges, including meeting the demand for increased supply of food, fibre and bioenergy through intensified use of arable land and productive forests. The cultivation of bioenergy plants on arable land competes with food production, and an increased forest bioenergy production may negatively affect the harvest of pulp and timber. Yet Sweden, in common with many other countries, aims to increase the proportion of renewable energy sources, ultimately to be able to phase out fossil fuels. In 2014 the total energy supply amounted to 1990 PJ (including gross energy for nuclear power), of which 460 PJ was based on bioenergy (Swedish Energy Agency, 2016).

The Swedish open landscape, outside arable and productive forest land, is increasingly covered with secondary brushwood regrowth through natural succession, unless being actively kept open. Brushwood is spreading along roads (Huisman, 2001), railway lines (Huisman, 2001), edge zones between fields and forests, in power line corridors (Svenska Kraftnät, 2010a), abandoned semi-natural grasslands, nature reserves on ancient cultural land, and in marginal land in urban areas (Johansson, 2011). Such brushwood consists of saplings, bushes and young trees of a range of deciduous plant species, e.g. birch (*Betula* spp.), aspen (*Populus tremula*), alder (*Alnus* spp.) and goat willow (*Salix caprea*), sometimes mixed with conifers such as Norway spruce (*Picea abies*) and juniper (*Juniperus communis*). The brushwood often forms dense thickets, which over time will develop into uneven-aged stands through self-thinning and regeneration, with interspersed old stems.

Very little of the brushwood regrowth is currently being utilised for bioenergy, but it is often subject to active management. Forest vegetation along roads is considered a traffic safety risk, and may undermine the road. Hence road verges are regularly cleared (Huisman, 2001). Similarly, in power line corridors (Svenska Kraftnät, 2010a,b), along railway lines (Lundh and Huisman, 2002), and in biocultural reserves, brushwood is routinely cut and often left to decompose. The cost of such management is considerable.

Secondary brushwood regrowth could be utilised as a modern source of renewable bioenergy, opening up a new field of activity for small scale entrepreneurs. The basic economic advantages would be the fact that there is no cost involved in the biomass production, no competing land use option, and the cost of harvesting could be offset by the existing management costs.

Brushwood harvesting in land use categories such as road verges and power line corridors may be performed using existing technology developed for forestry thinning and retrieval of branches and tips during clear-cutting, although technical development of more specialised equipment would increase profitability (Lindroos, 2011). Harvesting heads that can cut and bundle a large number of thin stems, or a mix of thin and heavier stems, are being developed. The harvested bundles can be brought to the nearest road by a forest forwarder, where they can be stockpiled to dry, or processed directly. A mobile chipper would process the brushwood on the road next to the stack, to minimise the volume of biomass to be transported (Brunberg, 2013).

Apart from providing bioenergy, the suggested brushwood harvesting would also contribute to the economy (the production value has been estimated to about 209–390 million €), create job opportunities (estimated to 1300–4500 yearly full-time employment positions), and contribute to the management of the cultural landscape (Andersson et al., 2016). It has also been suggested that brushwood harvesting would benefit biological diversity. A large number of nationally red-listed species are dependent on the active management of open habitats, including semi-natural grasslands, and man-made habitats such as road verges and power line corridors. There is also the possibility that other components of biodiversity would be negatively affected, especially species associated with early successional stages of forest regeneration, as well as forest edge species.

In this study we estimate the standing crop of brushwood mainly outside arable and productive forest land, and the potential for sustainable harvest. We estimate the annual biomass production, and the potential net energy gain from a commercially viable harvesting practice. We also review the possible effects on biological diversity and cultural heritage, the potential contribution to Sweden's aim to eliminate use of fossil fuels, as well as the compatibility with Swedish and European Union environmental legislation and policy goals and targets.

2. Materials and methods

2.1. Estimation of brushwood

The amount of brushwood resources was estimated for different land use categories (Table 1) and for four regions of Sweden (Fig. 1). First, the total amount of standing brushwood for each category was estimated, expressed as dry weight and energy content. Then the proportion of the total resources available for an initial harvest considering economic and other constraints was estimated, as well as the subsequent potential annual harvest. Table 1

Table 1
Definitions of and management of the land-use categories included in the study.

Land use category	Description	Management
Roads (Road)	Roads for permanent use, broader than 5 m, including areas around the road kept open	Large roads: cleared with short intervals for road safety reasons. Small roads: cleared at irregular time intervals
Railway lines (Railway)	Areas around railways kept open	Trees within 20–25 m of Swedish railway lines are routinely being cleared (Huisman, 2001; Stenmark, 2012)
Power line corridors (Power line)	Power line corridors with a width of more than 5 m	Larger power lines are managed through clearing of brushwood and trees every 8 years (Svenska Kraftnät, 2010a,b, 2013)
Agricultural land (Agric. land)	For crop production or grazing, including small patches (less than 0.25 ha) inside the agricultural land	Clearing in ditches, and thinning in the small remnant habitats
Overgrown agricultural land (Overgrown)	Abandoned agricultural land where agriculture ceased less than 20 years ago	Largely unmanaged with occasional clearing of trees, retaining some trees and shrubs important for biodiversity
Semi-natural grasslands (Grassland)	Semi-natural grasslands mainly used for grazing, which are not cultivated regularly	Regular clearing and mowing to some extent to maintain the grassland character
Urban land with brushwood (Urban)	Marginal lands in urban environment such as parks, recreational areas, and shelter zones	Managed to be kept open
Road edge zones (Edge zone road)	5 m wide edge zones on both sides of small roads, outside the area classified as road	Extra thinning in this zone is sometimes practiced to improve road conditions
Edge zones of agricultural land (Edge zone agric.)	Edge zones 10 m wide along agricultural lands	Extra thinning with whole tree harvesting is sometimes practiced to improve the agricultural production