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Article

Perspectives on the Potential Contribution of Swedish Forests to Renewable Energy Targets in Europe

Gustaf Egnell [1,*], Hjalmar Laudon [1] and Ola Rosvall [2]

[1] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden; E-Mail: Hjalmar.Laudon@slu.se

[2] The Forestry Research Institute of Sweden, P.O. Box 3, SE-918 21 Sävar, Sweden; E-Mail: Ola.Rosvall@skogforsk.se

* Author to whom correspondence should be addressed; E-Mail: Gustaf.Egnell@slu.se; Tel.: +46-90-786-8455; Fax: +46-90-786-8163.

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Abstract: Forest biomass is an important energy source in Sweden and some other European countries. In this paper we estimate the physically available (*i.e.*, total potential) forest biomass for energy from annual forest harvesting (1970–2008) or in the total standing stock (2008) in Sweden. To place Sweden's forest resources into perspective we relate this to an estimated need for renewable energy sources in Europe. As Swedish forests supply a range of goods and ecosystem services, and as forest biomass is often bulky and expensive to procure, we also discuss issues that affect the amount of forest biomass that is actually available for energy production. We conclude that forests will contribute to Sweden's renewable energy potential, but to a limited extent and expectations must be realistic and take techno-economical and environmental issues into consideration. To meet future energy needs in Sweden and Europe, a full suite of renewable energy resources will be needed, along with efficient conversion systems. A long-term sustainable supply of forest resources for energy and other uses can be obtained if future harvest levels are increased until they are equal to the annual growth increment. Delivering more than this would require increasing forest productivity through more intensive management. The new management regimes would have to begin now because it takes a long time to change annual production in temperate and boreal forests.

Keywords: whole-tree harvest; renewable energy; wood fuel; forest fuel; sustainable forestry

1. Introduction

Wood has been used as an energy source ever since humans discovered fire, with varying levels of utilization, depending on the availability, price and quality of alternatives. For instance, charcoal was intensively used in the Swedish mining and metal industries until the mid-19th century, when coal became a competitive alternative. Since then, fossil fuels have dominated the energy market. To use locally produced wood instead of imported fossil fuels has been suggested from time to time in Sweden. As early as 1918, Professor Gustaf Lundberg stated "*that it is strange that a forest-rich country like Sweden should be dependent on foreign fuels*" [1]. The use of wood fuel increased during and after the First and Second World Wars, and during the oil crises in 1970s, but decreased once cheaper fossil fuels became available again.

The oil crises during the 1970s led to changes in energy policies in many countries, e.g., in Sweden the government decided to increase the use of nuclear power to decrease the dependence on fossil fuels for electricity production. At the same time, the forest industry responded to the high oil prices by using their residues as an energy source—primarily to generate heat and electricity. Concurrently, biomass for energy production became a competitive option for district heating. District heating is currently the fastest growing bioenergy sector in Sweden, with heat usually being cogenerated with electricity in combined heat and power plants (Figure 1). Bioenergy is also used for residential heating (firewood, wood pellets), and a small, but growing proportion is used as liquid biofuels (predominantly ethanol) by the transport sector. Swedish forest industry uses biomass that almost exclusively comes from forests; and forest biomass is also the dominant feedstock for district heating, even if other sources such as solid waste, peat, and biomass from agriculture are used as well (Figure 2).

Figure 1. Total bioenergy supply (1980–2008) in Sweden (including peat and solid waste) and the amounts used in industry, district heating, individual houses, and transportation (biofuels) [2]. (1 petajoule (PJ) = 10^{15} joule).

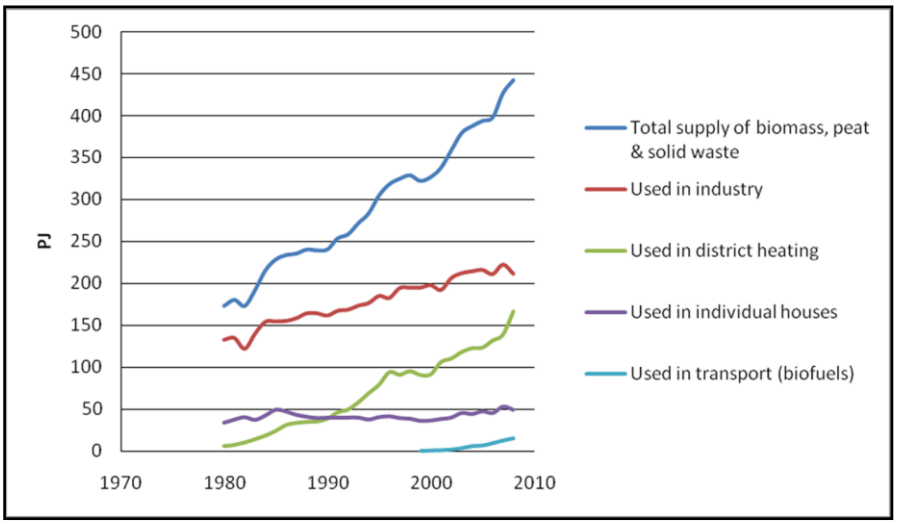
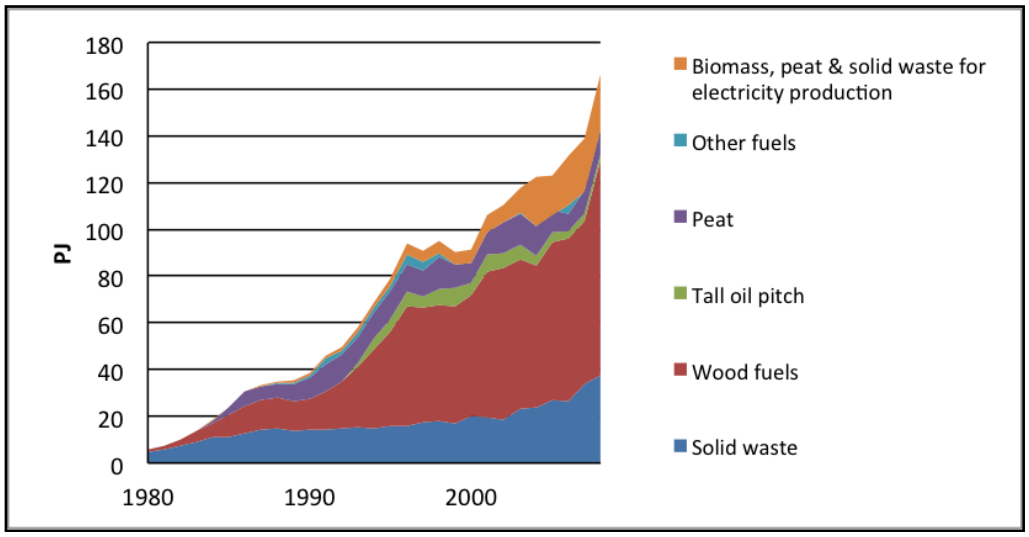
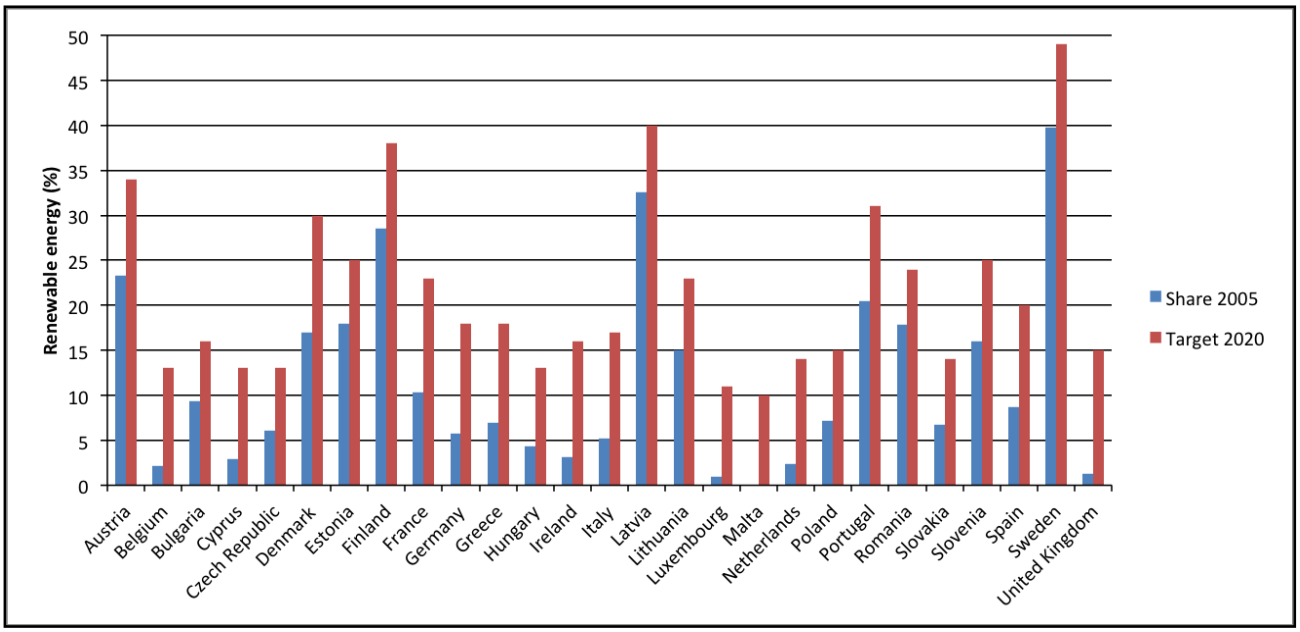


Figure 2. Production of energy (petajoule) from biomass, peat, and solid waste in district heating (predominantly combined heat and power plants) in Sweden (1980–2008) [2].



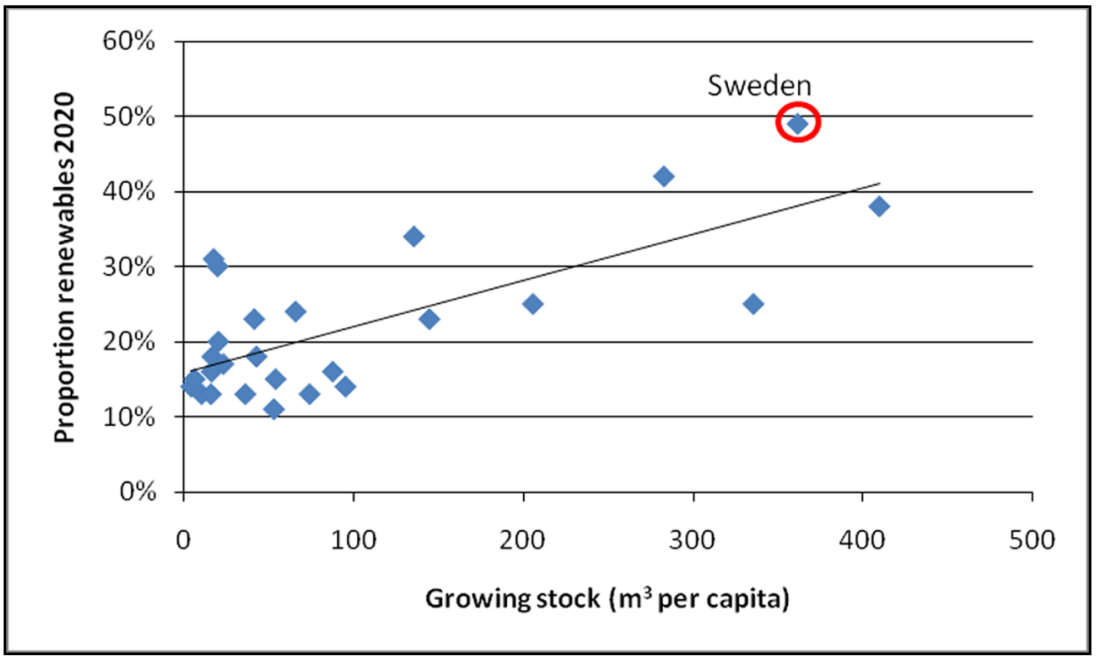
During the last decades the concern about human-induced global warming has emerged as an important issue both among the general public and the politicians. The awareness of the problem is based on a large number of scientific reports (e.g., [3,4]) and extensive coverage in the media. The Earth Summit in Rio de Janeiro (1992) led to the United Nations Framework Convention on Climate Change (1994) and the Kyoto Protocol (1997), which was ratified in 2005. These agreements have led to policies that generally view the increased use of bioenergy as a primary way to reduce greenhouse gas (GHG) emissions. As a Kyoto signatory, Sweden agreed to reduce the average GHG emissions during the period 2008–2012 by 8%, compared to the emissions in 1990.

Figure 3. National proportion (%) of energy from renewable sources in gross final energy consumption in 2005 and targets (%) for the proportion in 2020 agreed upon within the European Union [5].



Both the concerns about climate change and dependence on imported fossil fuels lie behind the 2020 targets for reduced CO_2 emissions and increased use of renewable energy agreed upon by the European Union [5]. These targets will most likely result in a greater use of forest resources in forest-rich countries like Sweden. In addition, bioenergy markets outside of Sweden may grow, especially in European countries with limited forest resources per capita that are striving to meet their EU-2020 targets for reductions of CO_2 emission (Figure 3). This growing market is likely to place additional pressure on forest resources in Sweden and other forest-rich countries. This is supported by the dependence placed on forests for meeting 2020 targets (see Figure 4).

Figure 4. Relation between the growing forest stock per capita [6] and the targeted share of renewable energy sources in gross final energy consumption in 2020 for countries within the European Union [5] ($R^2 = 0.52$; $p < 0.001$).



At present, almost all residues from the Swedish forest industry (*i.e.*, sawdust, shavings, bark, black liquor, *etc.*) are used as a bioenergy source. The residues from logging operations (*i.e.*, slash and stumps) therefore have to meet the new demands from the Swedish bioenergy market in the short term (0–30 years). This market is already growing by approximately 11 PJ (petajoule = 10^{15} joule) annually, corresponding to 1.5 million m^3 of solid wood [2]. In addition, a new market for bioenergy is emerging in Europe and globally.

The objective of this paper is to generate realistic expectations of the energy potential of Sweden's forest resource in relation to the need for increased renewable energy sources, reduced GHG emissions, and reduced dependence on imported energy in Sweden and Europe. Estimates of the total energy potential in tree biomass in the annual harvest and in the total forest growing stock in Sweden is compared with energy consumption in Sweden and Europe. Important factors that make the market-available forest biomass for energy substantially smaller than the physically available forest biomass are discussed.

2. Materials and methods

Data from the Swedish National Forest Inventory was used to estimate the total tree biomass in annual harvests from 1970 to 2008, and biomass in the total forest growing stock in 2008. It was assumed that annual stemwood harvest multiplied by a biomass expansion factor of 1.7 [7-9] and an average wood density of 0.4 [10] gave an estimate of the potentially available dry forest biomass in stemwood, slash, and stumps for each year and for the total standing stock in 2008.

Equation (1) was used to estimate the energy potential in the whole forest biomass (stemwood, slash, and stumps) that was potentially available following annual forest harvest in Sweden from 1970 to 2008 and in the total growing stock in 2008. Equation 1 uses an effective heating value of dry biomass (W_{ea}) of 19.6 GJ (1 gigajoule = 10^9 joule) per Mg (1 megagram = 1 metric ton) dry forest biomass [10] and an average moisture content (MC) in harvested biomass of 40% [11,12] to give an effective heating value (W_{em}) for the biomass of approximately 18 GJ per Mg dry forest biomass:

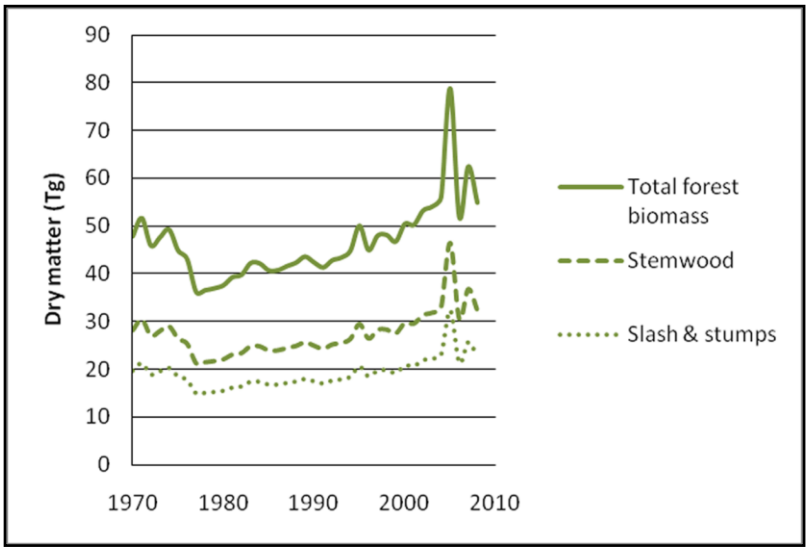
$$W_{\mathrm{em}} = W_{\mathrm{ea}} - 2.45 \times \frac{MC}{(100 - MC)} \quad (1)$$

where: W_{em} = effective heating value of biomass with moisture (GJ Mg^{-1} dry mass), W_{ea} = effective heating value of oven-dried biomass (GJ Mg^{-1} dry mass), MC = moisture content of biomass on a fresh-mass basis (%), and 2.45 is the amount of energy (GJ Mg^{-1}) required for vaporizing water at 20 ^{o}C.

3. Results

The estimated total tree biomass (including stemwood, slash, and stumps) in the annual forest harvests (1970–2008) in Sweden varied between 40 and 60 Tg a^{-1} (1 terra gram = 1 million metric tons) (Figure 5). The peak in 2005 is the result of salvage logging after the hurricane "Gudrun", which caused major windthrow in southern Sweden [13].

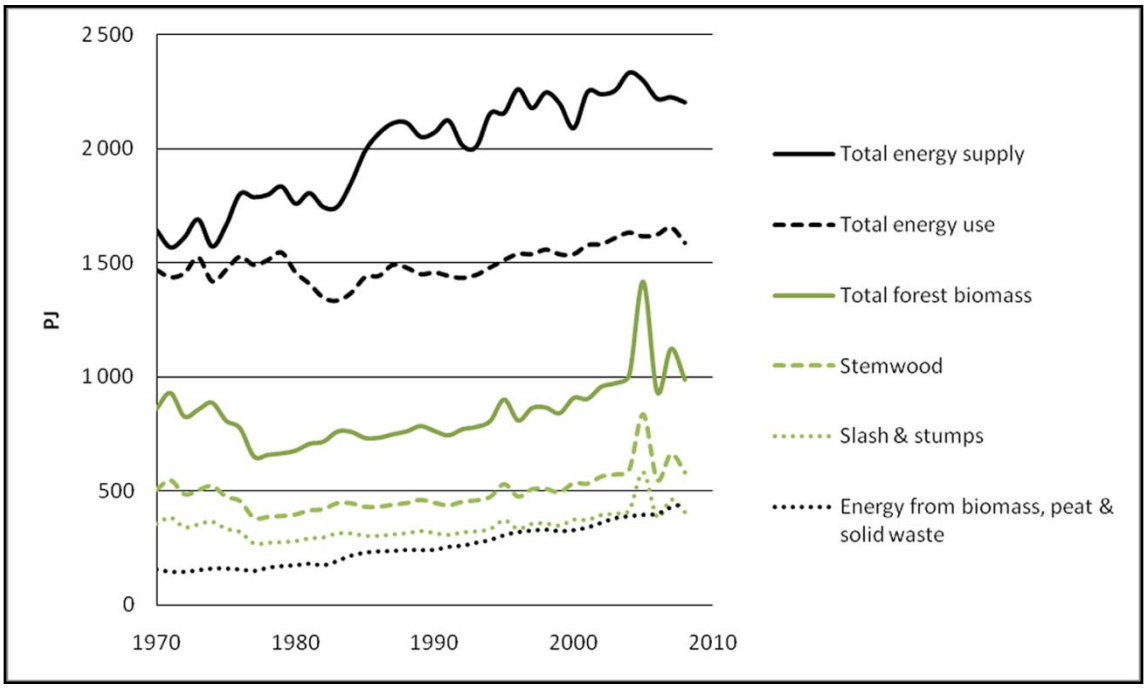
Figure 5. Estimated annual potentially available biomass in stemwood, slash, and stumps; and the total tree biomass in thinnings and final fellings in Sweden (1970–2008), based on stemwood harvest statistics [14].



If all available forest biomass in stemwood, slash, and stumps had been harvested, then the average annual energy potential in biomass would have been 840 PJ, ranging from 650 PJ (1977) to 1,400 PJ (2005). From 1970 to 2008, the total energy supply in Sweden varied between 1600 and 2,300 PJ, and the total energy use varied between 1,300 and 1,700 PJ (Figure 6). Thus, even with the unrealistic assumption that all potentially available tree biomass had been harvested and used for energy, forest biomass could not have met the energy demands in Sweden during those years.

In 2008, the total Swedish forest growing stock was 3,441 million m^3 [15], corresponding to 1,376 Tg dry matter in stemwood; adding slash and stumps would increase the total to 2,340 Tg of dry matter. This amount of biomass has an energy potential of approximately 42,000 PJ. If this resource was mined to satisfy the total energy consumption in Sweden, with a consumption rate equivalent to 2008 (1,587 PJ), it would last for 26 years (not accounting for annual forest growth, changes in energy consumption over time, and energy conversion losses).

Figure 6. Estimated total bioenergy potential (PJ) in Sweden's annual forest harvest (1970–2008) in comparison with the total energy supply and use (conversion and distribution losses and losses in nuclear power stations excluded) and the amount of biomass, peat, and solid waste used for energy during the period [2,14].



The United Kingdom, with an energy consumption of 9,744 PJ in 2005, of which 1.3% came from renewable energy sources, has set a target of 15% renewable energy to be used in 2020 (cf. Figure 3). To reach this target, assuming the same energy consumption in 2020 as in 2005, another 1,335 PJ of renewable energy will be needed annually. If the total growing forest stock in Sweden was used to meet the U.K.'s demand, it would last for 30 years. Using the same assumptions for the total European demand to reach the set targets for renewable energy, the Swedish forest resource would last for only five years.

4. Discussion

The estimates above are based on the unrealistic assumption that the total forest biomass resource would be available for energy. However, the largest proportion of forest biomass is stemwood, which is the feedstock for the pulp and sawmill industries. Another competitor for wood is the building industry, which at an increasing rate is substituting high fossil energy-demanding construction materials (e.g., steel, aluminum, and concrete) with forest products, thereby contributing a reduction in CO_2 emissions [16,17]. It is also predicted that, within a new bio-based economy, bio-refineries will eventually produce high-value advanced materials and chemicals using forest biomass instead of fossil fuel feedstock [18]. Within the Swedish forest industry, today approximately 40% of the biomass, in terms of timber and pulpwood, is directly converted to energy [19]; and most end products have an energy potential that could be utilized at the end of their life. Thus, traditional as well as a new forest bio-industry will make a significant contribution to the mitigation of global warming while continuing to be a strong competitor in the renewable biomass market.

Although estimates of biomass availability in Sweden are large, there are two main conclusions to be drawn: (*i*) from a European perspective is the potential contribution of biomass from Swedish forests for energy production moderate compared to demand, and (*ii*) if significantly more forest biomass is to be used for energy production then there would have to be increases in either the harvest level (*i.e.*, increased percentage of the standing volume) or the harvest intensity (*i.e.*, more biomass from each tree)—or both.

However, substantially increased harvest levels are not sustainable and will only solve market supply issues in the short-term. Annual volume increment in Swedish forests has increased over time and has during the last half-century exceeded gross fellings (Figure 7), resulting in an almost two-fold increase in growing stock since the National Forest Inventory statistics began in the early 1920s (Figure 8). This trend will be reversed if gross felling exceeds annual increment and will then decrease the standing stock, annual volume increment, and hence available biomass. Apart from not being able to sustain long-term (>30 years) supplies of raw material, this strategy will also lead to decreased carbon storage in forests.

Figure 7. Annual increment and gross felling in Sweden from 1956 to 2006. Data are five-year annual averages (*i.e.*, data for 2006 are the means for 2004–2008) [15].

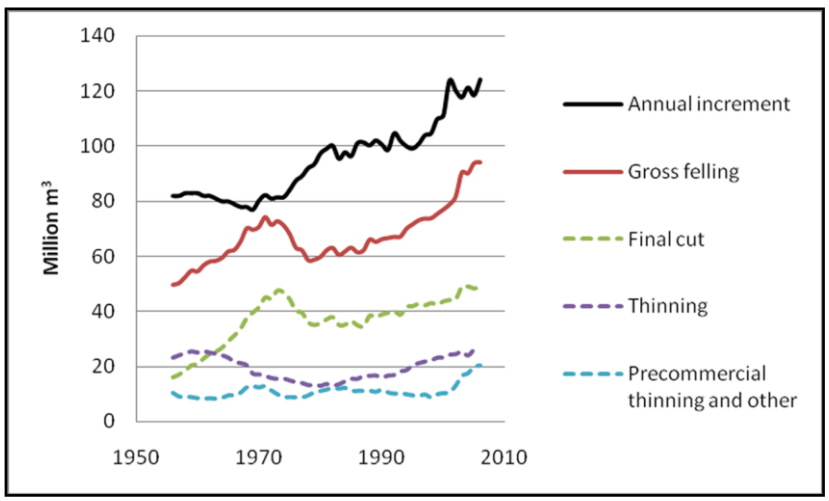
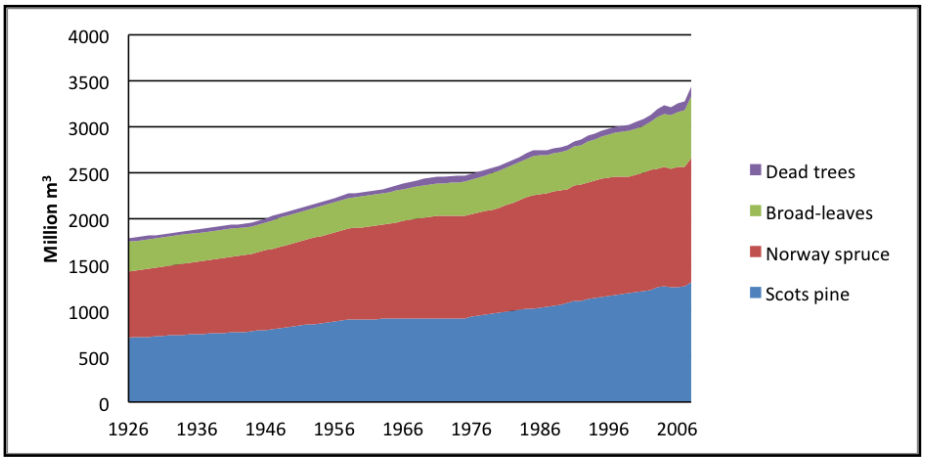


Figure 8. Total standing stock (stem volume) in Swedish forests 1926–2008 [15].



If forest bioenergy is to be sustainable and fully renewable in the long-term, annual harvests must be less than or equal to the annual growth increment. Once harvesting equals annual increment, the only way to increase harvest levels is by increasing annual increment through improved silviculture and/or expansion of forested land. However, growth-enhancing treatments will only have an impact in the long-term because of the slow growth rates and long rotation periods in temperate and boreal forests. Furthermore, there is an upper limit to the size of growing stock and annual increment, determined by factors such as site fertility, area of forest land, and the biological potential to increase growth rates by means of silvicultural treatments.

In the short-term, more intense harvesting (including slash and stumps) is the only option for meeting the growing demand for both traditional forest products and biomass for energy. In the estimates above, it is assumed that almost all biomass in slash and stumps will be harvested for energy markets. In reality, however, there are a number of factors that will considerably limit the amount of available forest biomass that can be used for energy production.

4.1. Other Constraints Limiting the Potential of Forest Energy

The profitability of using logging residues for energy is low because it is a bulky, low-value commodity that is expensive to collect and transport. Even if more sophisticated harvesting technologies are developed the basic conditions with small amounts of biomass distributed over large remote areas will limit the areas harvested. In addition, where logging residues are harvested, recovery rates with today's technology are well below 100% leaving a considerable amount of logging residues behind [20].

A number of environmental values and services can be affected by increased harvest intensity [21]. Removal of logging residues substantially increases the amount of nutrients exported from sites [22-25]. This may have an impact on the growth of the next generation of trees [26-28], or on the remaining stand in the case of thinning, unless the removal of nutrients is compensated by fertilizer application [29,30].

Increased export of nutrients in logging residues can also change the buffering capacity of the soil that, in turn, may alter the soil fertility, as well as the chemistry of soil water, which may have negative

downstream effects on ground and surface waters [31-34]. Water amounts and quality could also be affected by increased soil physical damage (*i.e.*, rutting and soil compaction) that may arise if skid roads are not bedded with slash, or through current technologies for stump harvesting [35,36].

Leaving a considerable amount of dead wood in the managed forest landscape is important for maintaining biodiversity [37,38]. As slash and stumps are dead wood, some of it should be retained to maintain biodiversity in managed forests [39].

Concerns about land-use change may decrease the availability of biomass from forests. For example, Sweden forestry and traditional reindeer husbandry compete because of overlapping land-use practices, and the impact of biomass harvesting for energy on winter grazing resources for reindeer is a critical issue [40].

These above mentioned factors will in combination determine the final amount of forest biomass that will be available for energy purposes during the coming decades. Thus, the physically available biomass in forests cannot be used as an estimate of the renewable energy potential. No attempt to estimate the available proportion is made in this study, but in an EU report it was estimated that when taking soil productivity, soil moisture, and restrictions by slope and elevation into account, it would result in a 40% reduction in slash availability [41].

There is no question that forest biomass can contribute to the energy supply system—but the resource must be utilized wisely, and forest bioenergy is not the ultimate solution. Some of the short-fall in feedstock needed to meet energy targets could be met using biomass from agriculture [42]. However, the energy potential in total biomass production in Swedish agriculture in 2005 was estimated to be only 280 PJ, with approximately 100 PJ in residues such as straw [43].

World demand for food is continuously increasing making arable land a limited resource and residues are often needed to maintain soil quality in agriculture. Thus, other renewable energy resources than those using biomass are also needed, as well as technologies for increasing energy use efficiency. If future Swedish policies require that more biomass be produced from forests for renewable energy production then forest management practices and silvicultural treatments for increasing forest growth must be initiated without delay (cf. Figures 7 and 8).

5. Conclusions

The growing bioenergy markets in Sweden and Europe will likely increase the use of Swedish forest resources, and Swedish forests will contribute to the transition of energy supply systems in Sweden and Europe—from dependence on fossil fuels towards renewable sources of energy. Forest bioenergy is, however, only one form of renewable energy, and other renewable resources and technologies for increasing energy use efficiency are also needed if GHG and energy targets are to be met. Expectations of the amount of biomass that forests can produce must be realistic and take into account both environmental issues and the current techno-economical context. When these are accounted for, the potential is far less than the physically available forest biomass. A long-term sustainable supply of forest biomass for energy and other uses requires annual harvest levels that do not exceed the annual increment. If decided to meet the rapidly increasing demand for forest biomass new management practices have to be implemented without delay.

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