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Sustainable utilisation of forest biomass for energy—Possibilities and problems: Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries

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Abstract

The substitution of biomass for fossil fuels in energy consumption is a measure to mitigate global warming, as well as having other advantages. Political action plans for increased use exist at both European and national levels. This paper briefly reviews the contents of recommendations, guidelines, and other synthesis publications on sustainable use of forest biomass for energy. Topics are listed and an overview of advantages, disadvantages, and trade-offs between them is given, from the viewpoint of society in general and the forestry and energy sectors in particular. For the Nordic and Baltic countries, the paper also identifies the extent to which wood for energy is included in forest legislation and forest certification standards under the "Programme for the Endorsement of Forest Certification" (PEFC) and the "Forest Stewardship Council" (FSC) schemes. Energy and forest policies at EU and national levels, and European PEFC forest standards are analysed. With respect to energy policies, the utilisation of wood for energy is generally supported in forest policies, but forest legislation is seldom used as a direct tool to encourage the utilisation of wood for energy. Regulations sometimes restrict use for environmental reasons. Forest certification standards include indicators directly related to the utilisation of wood for

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energy under several criteria, with most occurrences found under environmental criteria. Roles and problems in relation to policy, legislation, certification standards, recommendations and guidelines, and science are discussed.
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Keywords: Bioenergy; Certification; Environmental consequences; Forest fuel extraction; Guidelines; Legislation; Policy; Recommendations; Sustainable forest management; Wood ash

1. Introduction

The substitution of biomass for fossil fuels in energy consumption is a measure to decrease the emission of green house gases and thereby mitigate global warming. In this perspective, the use of forest biomass for energy is generally acknowledged as being in agreement with the principles for sustainable development. Carbon bound in biomass is released during combustion, but taken up by new vegetation again during photosynthesis with a corresponding build-up of carbon. There are other advantages of utilising forest biomass for energy, e.g. security of supplies and employment, but adverse effects for society, forestry, and the energy sector are also recognised. A major concern is to optimise the amount of forest biomass harvested for energy against recognised adverse effects. This balancing of trade-offs will have an impact on the amount of forest biomass produced for energy [1]. During the last 20–30 years, much research has been performed, and information has been disseminated and implemented at different levels to ensure sustainable forest fuel harvesting.

Research and review work was performed within the EU-FP5 project "Wood for Energy-a contribution to the development of sustainable forest management" (WOOD-EN-MAN), which had partners from four Nordic and three Baltic countries. The present paper was written as a part of the synthesis work within the project. Its aim is to give a brief overview and identify the status of knowledge implementation among potential end-users of the scientific knowledge created and reviewed within the project. The aim is further to contribute to discussion, development, and harmonisation, but also to recognition of a need for local adaptation of governance complexes, including legislation, certification standards, and recommendations and guidelines in relation to the sustainable use of forest biomass and wood ash recycling. Bioenergy-relevant contents of a broader range of certification standards have also been reviewed by Lewandowski and Faaij [2] with the purpose of creating a generic set of criteria for sustainable bioenergy use.

Within the framework of sustainable development, the paper more specifically

- gives an overview of recommendations, guidelines, and synthesis literature related to utilisation of forest biomass for energy and wood ash recycling,
- highlights the main incentives, advantages, disadvantages, and trade-offs between economic, environmental, and social sustainability criteria for society in general and the forestry and energy sectors,
- identifies how criteria and indicators for sustainable utilisation of forest biomass for energy are included in forest policy, forest legislation, and forest certification, and
- discusses the role of forest policy, legislation, certification, recommendations and guidelines, and research in relation to promotion of a sustainable utilisation of forest biomass for energy.

Due to the composition of the WOOD-EN-MAN project group, the main geographic scope is the Nordic and Baltic countries, but comparisons have also been made with other European countries.

2. Material and methods

The information presented and analysed in the present paper largely originates from four groups of sources:

(A) National and international recommendations, guidelines, information material, and synthesis publications on utilisation of forest biomass for energy and wood ash recycling [3–20]. Publications were included from all countries where relevant material could be found. They are very different with regard to comprehensiveness, approach, scope, and target audience, and range from scientific state-of-the-art reviews to practical user guideline summaries (Table 1). The documents were retrieved from information exchange with project partners and others, internet searches, and searches in library databases.
(B) EU and national forest policy documents from the Nordic and Baltic countries [21–29]. The documents were retrieved from the internet and project participants.
(C) EU and national forestry acts, and other legislation from the Nordic and Baltic countries related to utilisation of forest biomass for energy and wood ash recycling [30–47]. The documents were retrieved from the internet and project participants.
(D) Presently valid and newer draft forest certification standards under the Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) schemes [48,49] (Table 2). The documents were retrieved from the internet. Forest certification standards for the Nordic and Baltic

Table 1
Overview of recommendations, guidelines, information materials, and synthesis publications related to the utilisation of forest biomass for energy and wood ash recycling

Country[a]	Reference	Publication year	Responsible and type of publication	Type of publication	Comment on contents
AT	[3]	2005	Interdisciplinary project working group—Land Innovation	Background report	Literature review with emphasis on environmental consequences for the forest and research needs
DK	[4,5]	1985	The Forest Agency	Background report and official recommendations	Official national recommendations and literature review with emphasis on environmental consequences of forest fuel extraction in clear cuts and thinnings for the forest
	[6]	1996	Main actors in Danish forestry[b]	Handbook	Brief information with emphasis on production, handling, storage, and sales
	[7]	2002	Danish Energy Agency, Centre for Biomass Technology	General information	Report with equal emphasis on forestry and energy-related issues (small boilers, district heating plants, CPH, and power plants)
FI	[8]	2001	The Finnish Forestry Research Institute	General information and recommendations	Book with information and recommendations. Special emphasis on silvicultural and environmental consequences of forest fuel harvesting
	[9]	2005	Expert group and Forestry Development Centre Tapio	Recommendations	Brief and practical guidelines including a wide range of topics related to forest fuel extraction in clear cuts and thinnings
LT	[10]	2005	Ministry of Environment, Republic of Lithuania	National recommendations	Background review and practical guidelines for wood ash recycling in Lithuanian forests, including selection of sites, recycling dosage, and environmental consequences
SE	[11]	2001	National Board of Forestry	General information and recommendations	Book with information and recommendations. Special emphasis on environmental consequences and wood ash recycling
	[12]	2002	National Board of Forestry[c]	Official national recommendations	Report with official national recommendations. Special emphasis on environmental consequences and wood ash recycling
	[13]	1998	National Board of Forestry	Scientific background report	Comprehensive review of scientific literature with emphasis on environmental consequences and wood ash recycling
	[14]	2006	Swedish Energy Agency	Scientific synthesis report	Comprehensive review of scientific literature with emphasis on environmental consequences and wood ash recycling
UK	[15]	1997	Forestry Commission	Official recommendations	Related to WTH in final fellings and especially environmentally acceptable selection of sites in relation to different harvesting technology
	[16]	1999	Main actors with interests in wood energy use in the UK[d]	Good practice guidelines	Focus especially on establishment of energy production units, but with reference to many relevant subjects related to forest fuel extraction in the forest
International	[17]	2002	IEA Bioenergy Task 31	Scientific book	Comprehensive review of economic, environmental and social aspects in the production of forest fuel and wood ash recycling
	[18]	2006	BASREC Bioenergy Working Group 2003–2005 under the Nordic Council of Ministers	Manual	Manual for developing bioenergy entrepreneurships with equal emphasis on forest fuel and energy production including emissions
	[19]	2006	The RecAsh project, EU-LIFE	Handbook	Practical information on all aspects of wood ash recycling
	[20]	2007	The WOOD-EN-MAN project, EU-FP5	Scientific book	Review of economic and environmental aspects, also including policy and recommendations

[a]AT: Austria; DK: Denmark; FI: Finland; LT: Lithuania; SE: Sweden; UK: United Kingdom.
[b]Danish Forest and Nature Agency, Forest & Landscape Denmark, The Danish Forest Association, Danish Forestry Extension, and DDH.
[c]These recommendations in Swedish were available from 2001.
[d]British Biogen (now Renewable Energy Association), The Forestry Commission, Forestry Contracting Association, Wildlife and Countryside Link, the Energy Technology Support Unit (ETSU), and other stakeholders.

countries were included for both certification systems, but PEFC standards from other European countries were also included for comparison.

There might be conceptual differences between recommendations, guidelines, handbooks, and manuals, but no distinction was made between them. Primarily, documents

Table 2
Overview of national PEFC forest standards in Europe, and FSC forest standards in the Nordic and Baltic countries

Country	Reference
PEFC	
Austria	Austrian forest certification scheme, PEFC 06-1-1(endorsed 2006): Appendix 1. Criteria and indicators for assessing sustainable forest management in Austria, 2004. Appendix 2. Guidelines for sustainable forest management (PEFC) in Austria, 2004.
Belgium	Belgian Forest certification scheme (endorsed 2002): Appendix 3. Recommendations at the operational level for certification in accordance with the Belgian forest certification scheme.
Czech Republic	Czech forest certification scheme (endorsed 2006): CFCS 1002:2006 criteria and indicators for sustainable forest management, 2006.
Denmark	The Danish PEFC certification scheme for sustainable forest management, PEFC 09-1-1 (endorsed 2002, revisions endorsed 2004): Appendix 2. PEFC Denmark's forestry standard. Revision 1, 2002.
Estonia	Estonian Forest certification scheme (pursuant to the Pan-European Forest Certification Scheme, Final version, Estonian forest certification Council, 2002/2003, under assessment): Part 2. National forest standard.
Finland	Finnish Forest certification scheme, PEFC 02-1-01 (endorsed 2005): FFCS 1002-1:2003, Criteria for group certification for the area of a forestry centre. FFCS 1002-2:2003, Criteria for group certification for the area of a forest management association. FFCS 1002-3:2003, Criteria for certification of holdings of individual forest owners.
France	Revised French forest certification scheme 2006–2011, PEFC 10-1-1 (endorsed 2006): Appendix 5. Lisbon guidelines (to be taken into account when drawing up a site report and the quality policy of sustainable forest management).
Germany	Revised German Forest Certification Scheme, PEFC 04-01-01 (endorsed 2005): Appendix III. PEFC standards for Germany. Guidelines for SFM for the incorporation of forest owners into the regional framework.
Italy	The Italian PEFC certification scheme for sustainable forest management, PEFC 18-1-1 (endorsed 2004): Annex 2. Criteria and indicators for sustainable forest management on an individual and group scale.
Latvia	The Latvian PEFC certification scheme (endorsed 2001): Appendix 2. Basic requirements of the PEFC Latvia scheme for forest certification (Forest Standard). Appendix 3. Analysis and review of existing sets of Pan-European criteria and indicators versus PEFC scheme and performance standard for sustainable forest management in Latvia. Appendix 4. Analysis and review. Operational-level guidelines for sustainable forest management.
Lithuania	PEFC Lithuania certification scheme of sustainable forest management and chain of custody of forest-based products (technical document, under assessment): Annex 4. Certification standard of PEFC, Lithuania.
Luxembourg	Luxembourg certification scheme for sustainable forest management, PEFC 22-1-1 (endorsed 2005): LFCS 1002:2005 Criteria and indicators for sustainable forest management, 2005.
Norway	The Living Forests standards for sustainable forest management in Norway. Application for certification scheme re-assessment, PEFC 03-1-01, 2005 (endorsed 2006 until 2008): Appendix 2. Interpretation of the living forests standards.
Poland	Polish PEFC Forest certification system (PEFC Polska Council, Warsaw, 2005, under assessment): Document no. 4. Polish criteria and indicators for sustainable forest management for the purpose of forest certification.
Portugal	Portuguese forest certification system, PEFC 13-1-1, 2003 (endorsed 2004): Portuguese Standard 4606:2003. Sustainable forest management systems. Application of the pan-European criteria for sustainable forest management, NP 4406, 2003. Annex A (technical). Criteria and indicators of sustainable forest management. Annex B (informative). Guidelines for application of the pan-European criteria and indicators of sustainable forest management. Annex D (informative). Guidelines for the application of the pan-European criteria and indicators of sustainable forest management at the regional level.
Slovakia	Slovak forest certification system, SFCS, 1001:2004, 2004 (endorsed 2005): SFCS 1002:2004 criteria and indicators of sustainable forest management.
Slovenia	Slovenian Forest Certification Scheme, PEFC 27-1-1 (under assessment). Annex no. 2. Criteria and indicators for Sustainable forest management at the regional level, 2005. Annex no. 3. Criteria and indicators for Sustainable forest management at the group and individual level, 2005.
Sweden	Swedish Forest Certification Scheme, PEFC/05-1-1, including annexes (endorsed 2006): Revised Swedish technical document II, 2006 (Forestry, environmental and social standard).
Spain	Spanish forest certification scheme (endorsed 2002): Spanish standard. Sustainable forest management. Management unit criteria and indicators. Part 1: General criteria and indicators, 2001. Spanish Standard. Sustainable forest management. Management unit criteria and indicators. Part 2: Complementary criteria and indicators for regional assessment, 2001.
Switzerland	Swiss conference of the timber economy (HWK) and PEFC Switzerland, 2000, Swiss Q-label certification scheme (endorsed 2006): National standard "Q-LABEL WOOD" for Forestry in Switzerland.
United Kingdom	Scheme for sustainable forest management, PEFC 16-1-1 (endorsed 2002): Certification standard for the UK Woodland assurance scheme (UKWAS). Forestry commission, 2000.

Table 2 (*continued*)

Country	Reference
FSC	
Denmark	Standards for FSC Certification in Denmark, 2004 (endorsed 2005).
Finland	The Draft FSC standard for Finland. Approved by the board of the Finnish FSC association, 2005.
Estonia	SmartWood interim forest management standard for Estonia. SW-STD-EST-2005-06 (endorsed 2005).
Latvia	SmartWood interim standard for Latvia, SW-STD-LAT-2006-01, 2006 (endorsed 2006).
Lithuania	SmartWood Interim Standard for Lithuania, SW-STD-FM-LIT-09SEP05, 2005 (endorsed 2005).
Norway	No Norwegian FSC standard is endorsed or under assessment [51]. However, the development of the ''Living Forests Standards for Sustainable Forest Management'' in Norway is being followed by FSC. See Norwegian PEFC scheme.
Sweden	Swedish FSC standard for forest certification. Endorsed by the board of directors of FSC Sweden, 2005.

Source: The following documents were retrieved from the internet on 9 May 2006, if nothing else is mentioned: PEFC documents were retrieved from the international PEFC site: http://www.pefc.org (Czech Republic, 16 June 2006). FSC documents were retrieved on national FSC sites for the Nordic countries (http://www.fsc.dk, http://www.fsc-finland.org, http://www.fsc-sweden.org) and at the Nepcon site (http://www.nepcon.net/) for the Baltic countries. The Norwegian Living Forest Standard was retrieved from http://www.levendeskog.no and the Certification Standard for the UK Woodland Assurance Scheme (UKWAS) was retrieved from http://www.forestry.gov.uk/ukwas.

Table 3
Definitions of hierarchical concepts for the implementation of sustainable forest management [52–54]

Concept	Definition/example
Principle	A fundamental truth or law as the basis of reasoning or action (CIFOR) An essential rule or element (FSC) Example: Ecosystem integrity is maintained or enhanced (CIFOR)
Criterion	A principle or standard that a thing is judged by (CIFOR) A means of judging whether or not a Principle has been fulfilled (FSC) Requirement against which conformity assessment is made (PEFC) Example: Principal functions and processes of the forest ecosystem are also maintained (CIFOR)
Indicator	An indicator is any variable or component of the forest ecosystem or management system used to infer the status of a particular criterion (CIFOR) A quantitative or qualitative parameter which can be assessed in relation to a criterion. It describes objectively and unambiguously a relevant element of a criterion (PEFC) Example: Directional change in allele or genotype frequencies (CIFOR)
Verifier	Data or information that enhances the specificity or the ease of assessment of an indicator (thresholds can be defined) (CIFOR) Example: Number of alleles in the population (CIFOR)

available in English or in Scandinavian languages were used. However, documents in other national languages were included if language skills were available within the group of authors.

Several forest certification systems exist [2,50], but the analysis in this paper has been limited to FSC and PEFC forest certification schemes as they are by far the most used in Europe. When an older endorsed and a newer draft certification standard were both available for a certain country, the new draft version was preferred. As such, the PEFC standards from Estonia, Lithuania, Poland, and Slovenia have not yet been endorsed by international PEFC. The Finnish FSC draft standard and the revised Swedish FSC standard are under assessment by international FSC. Presently, no Norwegian FSC standard has been endorsed or is under assessment by international FSC, but the development of the Norwegian Living Forests standard is being followed by international FSC [51].

In both the FSC and PEFC forest certification schemes, forests are certified according to nationally adapted standards with a hierarchical structure using concepts such as ''principles'', ''criteria'', and ''indicators''. The national FSC standards are structured according to the 10 principles and 56 criteria of the international FSC standard. ''Principles'' and ''criteria'' are shortly defined as ''an essential rule or element'' and ''a means of judging whether or not a principle has been fulfilled'', respectively [52] (Table 3). The national standards also contain a third level, ''indicators'', and sometimes a fourth level, ''verifiers'' (e.g. in Denmark, Finland, and Sweden). These concepts are not explicitly explained in the international FSC standard, but the system seems to correspond well with the four-level hierarchy suggested by the Center for International Forestry Research (CIFOR) [53].

National PEFC standards operate with ''criteria'' and ''indicators'' [54]. ''Criteria'' and ''indicators'' are explained as a ''requirement against which conformity assessment is made'' and ''a quantitative or qualitative parameter which can be assessed in relation to a criterion'', respectively [55]. Inclusion of indicators prior to endorsement by the PEFC council is optional. The standards may contain variable sets of criteria, but in Europe they should be based on the "Pan-European Criteria and Indicators for Sustainable Forest Management of European Forests" (PE-C&I) with "The Pan-European Operational Level Guidelines" (PEOLG) as a reference basis [56]. Six criteria and a set of 27 quantitative and descriptive indicators can be found in these documents together with 19 and 26 operational-level guidelines for forest management planning and practice, respectively. Most of the national PEFC standards use the six PE-C&I as a first hierarchical level, but the subsequent levels appear more heterogeneous.

The topics treated by the (A) publications were grouped and listed for a brief description of the main driving forces, advantages, disadvantages, and trade-offs connected to utilisation of forest biomass for energy (Section 4). Society in general and the forestry and energy sectors were considered separately.

An identification of whether knowledge on utilisation of forest biomass for energy and wood ash recycling has been implemented in forest policy, forest legislation, and forest certification was based on the (B), (C), and (D) sources (Section 5). The documents were searched for a list of relevant terms in order to catch all contents specifically relevant to utilisation of forest biomass for energy, wood ash recycling, and coordination of policies. The relevant citations found in policy and forest certification documents were listed in tables (not shown), which were summarised in this paper.

3. Defining sustainable development

The definition underlying all international activities on sustainable development was given by the Brundtland Commission, which stated that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [57]. There is a general consensus that this includes the integration of social, economic, and environmental dimensions at international, regional, and national levels, integration across sectors and regions, and a broad participatory approach [49,58]. This general definition of sustainable development is reflected in definitions of sustainable forestry and energy.

The definition of sustainable forest management (SFM) from resolution H1 of the pan-European process of the Ministerial Conference on the Protection of Forests in Europe (MCPFE) is widely accepted in Europe. Forest management is here defined as "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic, and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" [59]. Other definitions, such as that of the Montreal process, contain more or less the same elements [60].

Definitions of sustainable energy systems are less abundant, but for example the Global Resource Action Center for the Environment [61] defines sustainable energy as "energy which, in its production or consumption, has minimal negative impacts on human health and the healthy functioning of vital ecological systems, including the global environment, and that can be supplied continuously to future generations on earth, or, alternatively, as a highly efficient energy system based on renewable resources, whose production and/or consumption processes produce adverse environmental, economic, health, and social impacts of a significantly lower order than those of fossil fuels or nuclear energy, and which ensures that the needs of the present are met without compromising the ability of future generations to meet their needs". However, EU-FP6 for example more emphasises the process, speaking of alleviating, and reversing unsustainable patterns [62].

4. Incentives, advantages, disadvantages, and trade-offs

4.1. Recommendations, guidelines, and other information materials

Economic, ecological, environmental, and social as well as technical and practical aspects are included for the whole forest fuel chain in the (A) publications (Tables 1, 4 and 5). Available and potential resources, silviculture and production in the forest, harvesting technology, processing, handling, storage, transport, logistics, fuel quality, characteristics and standardisation, combustion, gasification and plant operation, emissions from the energy plant, waste production, and wood ash recycling to the forest are treated together with institutional and participatory aspects.

Most of the publications relate to forestry, while three publications also have a substantial focus on issues related to the energy sector [7,16,18]. Books also address issues important for society such as social issues and policy [17,20,63–65]. Recommendations or guidelines have been decided for Denmark, Finland, Lithuania, Sweden, and the UK [4,5,9,10,12,15,16] with some differences as to focus, comprehensiveness, and official status (Tables 1 and 4).

4.2. The sustainable energy supply system in society

The main driving force to increase the use of forest biomass for energy in society is generally the international concern about climate change, with forest biomass being considered as a sustainable resource of energy that does not contribute to increased emissions of greenhouse gases [66,67]. In Europe, a major incentive is furthermore to improve security and diversity of the supply. A growing energy demand and an increasing dependence on import of fossil energy sources are foreseen. In the EU25, the demand is predicted to rise from about 50 EJ yr^{-1} today to more than 70 EJ yr^{-1} in 2030. Import dependency is predicted to increase from about 50% to 70% during the same period

Table 4
Overview of topics included in the publications in Table 1

Topic[a]	AT	DK			FI		LT	SE				UK		International			
	[3]	[4,5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]
Policy framework, international conventions	1			1		1	1	1					1	1	1		1
Policy, institutional framework, legislation and subsidies								1						1			1
Social issues, regional development, employment, gender														1			1
Public participation													1				
Available resources, present utilisation	1			1	1	1								1	1		1
Concepts for SFM, certification, criteria and indicators														1			1
Carbon balance											1			1			
Nutrients, organic matter, soil fertility, acidification, erosion	1	1	1	1	1	1	1	1	1	1	1	1	1[b]	1	1	1	1
Effects on wood production		1			1			1		1	1			1			
Biodiversity and wildlife	1				1	1		1	1	1	1	1	1[b]	1		1	1
Insect pests		1	1		1	1		1	1	1							1
Hydrology, water quality, streams, and lakes	1					1		1		1		1		1		1	
Landscape, archaeology, culture, and leisure					1	1				1		1					
Nature conservation, sites of conservation importance													1[c]				
Silviculture[d]		1	1		1	1						1	1	1			1
Stump harvesting		1				1		1						1			1
Production costs and economy			1			1							1	1			
Harvesting methods, harvesting technology[e]			1	1	1	1	1	1	1	1	1	1		1	1	1	
Processing, handling, storage			1	1	1	1						1	1	1	1		
Logistics, transport														1	1		
Fuel quality, characteristics, standardisation			1	1										1	1		1
Working environment, health, and safety				1		1							1	1			
Markets, sales, competitiveness			1	1										1			1
Establishing of energy plant													1		1		
Wood firing, combustion, gasification, plant operation				1									1		1		
Energy distribution													1				
Plant emissions, waste production, noise, dust, smell, etc.				1									1	1	1		
Wood ash recycling					1		1	1	1	1	1			1		1	1

[a]The topics are largely explained in the text, and otherwise assumed to be self-explanatory. AT: Austria; DK: Denmark; FI: Finland; LT: Lithuania; SE: Sweden; UK: United Kingdom.
[b]For these matters, reference is made to the UK forestry standard and associated guidelines.
[c]Recommends consultancy with forest authorities and (if in or near designated nature conservation sites) statutory conservation agencies.
[d]Selection of stand in relation to environmental constraints, integration into traditional forest management.
[e]Sometimes including damage to the remaining stand, and soil physical damage.

[68]. At the same time, Europe seeks to keep energy costs at a low level for increased economic competitiveness and social benefits such as e.g. employment. The utilisation of forest biomass for energy is also beneficial in relation to these goals, and significant domestic resources are available within Europe [1,69,70]. Wood residues directly from the forest are estimated to be able to contribute about 14–27 Mtoe yr^{-1} [1,69], depending on assumed environmental constraints, or 38–70 Mtoe yr^{-1} assuming carbon dioxide (CO_2) permit prices of 30–65 € ton^{-1} CO_2 [70]. This corresponds to 1.4–4.1% of the total energy consumption in the EU25 in 2003 [71].

Investment support, energy taxation of fossil fuels, fixed prices for energy from renewables, and subsidies to harvest forest biomass to make forest fuel more competitive cause higher energy costs for society which might reduce economic growth compared to an unregulated market [65,72]. However, such initiatives might help to overcome high transaction costs in an immature and emerging market and lead to the development of a mature market with lower transaction costs and higher competitiveness [65,73]. Presently, biofuel, including forest residuals, is becoming more competitive due to higher fossil fuel prices on the world market [67,74].

Harvesting forest biomass and subsequent production of energy may support rural and domestic development including employment [63,75–77]. However, internationalisation of the biofuel markets will create higher competition for the benefit of centralised rather than local producers [77]. The exact direct and indirect employment effects vary between regions depending on wages, fuel wood prices, availability of unutilised resources, productivity, supply and demand within the region, possibilities to supply other regions, and import from other regions.

Finally, there is concern whether conversion to bioenergy will have negative effects on emissions, air quality and human health, and conclusions are variable depending on fuel quality, type of boiler, and the environmental systems installed to remove gasses and particles [16,78,79].

Table 5
Major actual and potential advantages and disadvantages for different actors in forest fuel utilisation compared to energy production from fossil fuels. See the text for references

Advantages	Disadvantages
Society—sustainable energy system	
Biomass is generally acknowledged to be CO_2-neutral and a sustainable energy source	If not competitive on a market basis, support for targeted research and development, investment support, energy taxation of fossil fuels and fixed prices for energy from renewables, and subsidies to harvest forest biomass might lead to higher energy prices and reduced economic growth
Use of a domestic resource and a diversified supply gives higher security in supplies and stabilisation of prices	Increased emissions of gasses and particles that might be harmful to human health and ecosystems
Use of a domestic resource improves the national balance of payments	
Use of a domestic resource promotes employment and regional development	
Lower fuel contents of sulphur with subsequently lower emissions	
Forest sector—sustainable production of biomass	
Silvicultural operations such as cleanings and thinnings are being performed for the benefit of future income	Profits are usually low
Regeneration costs such as soil preparation and planting are reduced after removal of logging residues	Possibly loss of growth and site fertility due to increased nutrient removals. Increased costs for fertilisation
The risk of root rot infection of the new stand is reduced after stump harvesting if the old stand was infected	Increased leaching after stump harvesting due to increased decomposition
In some cases decreased risk of insect pests as potential breeding material is removed	In some cases loss of biodiversity due to less breeding substrate for wood-living organisms and risk of stored wood acting as trap wood. In some cases increased risk of insect pests due to storage of whole trees?
	Increased risk of soil compaction due to removal of residues and an increased number of forest operations
Energy sector—sustainable production of energy	
Lower fuel prices in economies with high energy taxes	Increased corrosion and deposition in boilers
Use of a domestic resource gives higher security in supplies	High costs of waste deposits if waste can not be recycled
Lower atmospheric emissions of SO_2 compared to fossil fuels	Possibly higher atmospheric emissions of NO_x and particles compared to fossil fuels
Waste can be recycled, i.e. wood ash recycling to the forest	High investment levels, transaction costs

4.3. Sustainable production of biomass by forestry

There are no strong driving forces in forest policy to utilise forest biomass for energy, although such utilisation is generally recognised and supported for environmental and social reasons [21–29,80]. Economic driving forces are weak, and profits are minimal [9,74,81]. A study from Sweden shows that the price paid had only minor influence on the forest owner's decision to sell or not [82]. However, when subsidies are introduced as in Finland, it can make forest fuel extraction profitable even under more demanding conditions [83]. Apart from the buyer's desire to buy forest fuels, the main incentives for forestry to extract forest residuals and pre-commercial whole trees for energy are benefits in other silvicultural operations [74,82,84–87]. These are:

- savings in regeneration operations after removal of logging residues, for example in soil preparation and planting,
- possibilities to carry out cleanings and early thinnings at diminished cost for the benefit of future income,
- conversion of inferior stands, and
- decreased level of root rot infection after stump harvesting.

A Swedish study showed that the main incentive not to sell was concerns for soil fertility [82]. The removal of biomass and nutrients is increased compared to stem harvesting, with the relative increase being larger for nutrients compared to biomass. The consequences might be a reduction in soil fertility and stand productivity, increased acidification, and adverse effects on soil water, air, and soil organic matter contents [3–9,11–14,88–91]. The removal of fresh residues after final felling in spruce and removal of whole trees in thinnings of spruce and pine has generally had negative effects on growth increment in the short term (5–30 years) in areas where growth is limited by nitrogen (N). This is usually the case on mineral soils when atmospheric N deposition is low. Relative increment losses have not been found to be larger on poor sites compared to fertile sites.

The extent to which soil organic matter is affected depends on the quantity of tree biomass removed, the amount of displacement by litterfall and dead roots, and the degree to which soil moisture and temperature are modified [88]. However, there is only a little evidence of effects on the amounts of soil organic matter, probably because the amount of organic matter removed through harvest represents only a small proportion of the total biomass produced by trees, including litterfall and root turnover [11,13,88]. For one of two sites, Vesterdal et al. [92] found significantly reduced amounts of organic matter in the forest floor after removal of logging residues. The reduction was related to decreased growth. The amount of soil base cations has also been found to decrease after removal of logging residues whereas the effect on soil N contents is less clear. The increase in pH in the forest floor after harvesting of logging residues in the final felling is generally slightly lower than for conventional harvesting [13,88].

Changes in species composition might occur due to changed nutrient status or changes in the amount of sheltering material for the benefit of insects and mammals. Most focus has been on decreased amounts of above- and below-ground breeding and feeding material for saproxylic organisms [3,12–15,81,88,93–95]. Compared to harvesting of stems only, additional nutrient-rich and finer woody material is removed when fresh logging residues or whole trees from thinnings are utilised. However, this type of fresh, finer coniferous material is usually abundant in the landscape and its removal will presumably only seldom pose a risk to saproxylic organisms. Residues after final cutting or whole trees from thinnings are sometimes stored temporarily for the shedding of nutrient-rich needles and a decrease in the moisture content. Near biodiversity hot spots or in broad-leaved stands, rare insects breeding in temporarily stored wood may be removed [94]. On the other hand, removal of fresh residues and whole trees might decrease the risk of damage to vulnerable stands due to decreased amounts of breeding material for pest insects [4,5,11,13,81,96,97]. Temporary storage of wood of especially large dimensions (>10 cm) might, under conditions with high background levels of pest insects, pose a threat as this might help breeding pest insects in reaching epidemic levels.

The removed soil organic matter in the forest can only be replaced by growth [88], and the level of organic matter might not reach former levels if intensive harvesting is continued or growth is reduced. The removal of nutrients can be compensated by fertilisation or, partly, by wood ash recycling [11–14,19,74,89,98–100]. After combustion, most nutrients, except N, are retained within the wood ash. The ash can therefore be used for soil amendment, sometimes in combination with N fertilisation. Hence, wood ash recycling can contribute to SFM, a sustainable energy system and sustainable waste management. If loose ash is spread, the most pronounced environmental effect is an increase in soil pH and an increased mineralisation rate of soil organic matter. Furthermore, changes in soil flora and fauna, damage to mosses and mycorrhiza, and increased concentrations of heavy metals in soil have also been recorded [13,99]. However, the risk of negative impacts on the forest ecosystem can be considerably diminished if the recycled ash is stabilised and hardened before spreading [19].

Substantial growth effects of wood ash addition on N-rich organic soils are known from studies performed by the Finnish Forest Research Institute already in the 1930s [19]. On mineral soils, the growth effects of wood ash addition are minimal and variable [13–14,19,99], but there are indications that the addition of wood ash increase stemwood growth on fertile sites with a low C/N ratio (<30) and cause a decrease on less fertile sites with higher C/N ratios (>30) in the forest floor [14,100]. If may be questioned if forest owners' revenues from selling forest fuels are large enough to bear the costs of wood ash recycling as a mitigation measure against the risk of growth decreases.

4.4. Sustainable energy production by the energy sector

The major driving force for the energy sector to use wood as fuel is the increased price of fossil fuels during the last 3–4 years [65,67,74,86]. The prices of forest residues and other biofuels vary substantially between countries in the emerging European market, but they are generally competitive in countries with highly taxed fossil fuels. Other advantages can be increased security in supplies and stabilised prices by drawing up long-term agreements with local suppliers, as seen for example in Denmark [7,92].

Wood is considered to be a CO_2-neutral fuel. In most other respects, environmental issues are similar for wood- and fossil fuel-fired energy plants. The atmospheric emissions of gases and particles to the atmosphere are controlled and monitored under laws, and good and appropriate pollution abatement equipment is essential [7,16]. At the European level, absolute limits for emission to the air from large combustion plants have been laid down for sulphur dioxide (SO_2), nitrogen dioxide and dust [101]. Otherwise, the limits depend on the best-available techniques (BATs) [102]. Member states are obliged to monitor technical progress, and they currently make decisions on how emission limit values may depend on the technology used, the geographical location, and the local environmental conditions. The absolute SO_2 emission limit for large new combustion plants (50–100, 100–300, and >300 MWth) is 200 mg $SO_2\,N\,m^{-3}$ (O_2 content 6%) for all solid fuels, fossil and biomass, with only one exception: for 50–100 MWth plants fired with other solid fuels than biomass the limit is 850 mg $SO_2\,N\,m^{-3}$. Regardless of fuel, the limits for NO_x emissions are 400, 200, and 200 mg $NO_x\,N\,m^{-3}$ (O_2 content 6%) for the three sizes of plants respectively, except for biomass-fired 100–300 MWth plants where the limit is 300 mg $NO_x\,N\,m^{-3}$. Emission limits for liquid fuels are similar to those for solid fuels, whereas emission limits for plants fuelled by gas, with some exceptions, are lower. For large combustion plants, the adverse effects of emissions from biomass fuels on air quality, with regard to SO_2, NO_x, and dust, should thus not be substantially different from those of fossil fuels. For smaller plants or households, the situation might be variable depending on the application and national interpretation of BAT under local circumstances [7,16].

Another economic and environmental issue for energy producers is the production of waste. Minimising waste production, environmentally sound waste reuse and recycling are the most essential components in sustainable waste management [103,104]. By European law, wood ash is regarded as waste [19]. The ash contents of wood typically range from 0.5% to 2% [7] compared to about 7–10% for coal and lignite, and minimal amounts of about 0.1% or less in fuel oils [105]. There is a long tradition of use of coal ash in concrete and cement, and frequently all ash is used [106]. Wood ash has been used for soil amendment for centuries, but much ash produced today is stored in landfills [19,107]. In Finland and Sweden, the production of peat and wood ash are about 600 000 and 800 000 tons yr^{-1}, respectively, with about 150 000 and 300 000 tons yr^{-1}, respectively being pure wood ash. Of the pure wood ash, at least 55 000 tons yr^{-1} are utilised in some way in Finland, with 27 000 tons being used for forest fertilisation in 2004. In Sweden, approximately 15 000 tons are yearly recycled to forest land. In Denmark there is likewise a considerable production of wood ash, but there are at present not many possibilities for reuse [108]. It is expected that utilisation in forest land will be an option after revision of the legislation. More strict regulation of landfills has resulted in increased costs and prices to deposit waste, which makes wood ash recycling to the forest a more economically viable alternative. As such, ash recycling services once installed have been estimated to be inexpensive: 1–2% of the fuel price in Sweden [82]. This is within the lower end of an estimated range for landfill taxes, which amount to 1.4–3.9% of the fuel price in Sweden.[1] The level of landfill taxes relative to the fuel price is similar in the UK, where both fuel and landfill taxes are lower than in Sweden. In Ireland, the level of landfill taxes ranges from 8% to 23% of the fuel price, due to low fuel prices and high landfill taxes.[1]

5. Implementation through policy, legislation, and certification

The sustainable production of forest biomass for energy is being promoted and implemented through policy, legislation, regulations, certification schemes, and recommendations and guidelines issued by authorities, membership, and other private organisations. Political intentions are expressed in action plans, legislation, and regulations as tools by governments to transform policies into practical measures. Adherence to forest certification schemes is binding, but not enforced by governments. An increasing marketing strategy is to enhance the public acceptance of forest products as environmentally friendly [109,110]. Certification schemes such as PEFC and FSC are administered by membership organisations with members from various groups of stakeholders. The forestry sector is behind the PEFC certification [48], while FSC initiatives are usually taken by environmental NGOs [49]. However, international FSC requires a broad range of members, including economic, social, and environmental stakeholders, for the formation of FSC initiatives. Recommendations and guidelines, as elaborated by government authorities with varying degrees of stakeholder involvement or independently by different groups of stakeholders, can also be a part of the governance complex, even if adherence relies on the priorities of the forest owner. However, the official Danish recommendations are enforced in state forests, while implementation in private forests is only recommended.

5.1. Policy

The increased use of renewable energy sources, including forest biomass, in energy consumption is a marked characteristic in current energy policies at both EU and national levels [87,111–118].

Forestry policies at both regional and national levels are more focused on SFM and multifunctional forestry, but the use of forest biomass for energy is explicitly supported by forestry policies at EU level and in the Nordic and Baltic countries. In the forest policy documents from the EU and the Nordic and Baltic countries [24–30], 1–11 quotes related to wood energy utilisation were found per country/EU. Commonly mentioned reasons for this focus are the contribution to sustainable energy, social welfare, and rural development, and at times forest economy. An example of the latter is the Danish policy documents, which mention that a more cost-efficient forest management can be obtained especially in regeneration and nature conservation, even if the profits of the operation are close to zero.

The most marked political support is found at EU level and in Finland. In the new EU Forest Action Plan, one of 18 key actions promotes the use of forest biomass for energy [80]. A pronounced characteristic of the Finnish forest policy is the quantified goal to increase the annual use of wood for energy by 5 million m^3. In Denmark, reference is made to the "biomass agreement" from 1993. According to this agreement, the use of straw and wood chips for energy should be increased with 1.4 million tons annually, of which wood chips would contribute with 0.2–0.4 million tons. Swedish forest policy trusts that the utilisation of wood for energy still has a potential to increase, but that the supply of wood can be a limiting factor for the energy sector in a longer perspective. Norwegian forest policy prioritises the increased use of bioenergy and the development of bioenergy markets. Estonian forest policy includes the exploration of possibilities to increase the competitiveness of wood as an energy

[1] Average fuel prices for Sweden, the UK, and Ireland, respectively: 12, 6, and 4€ $MW\,h^{-1}$ [109], ~3.3, 1.7, and 1.1€ GJ^{-1} (3.6 GJ $MW\,h^{-1}$), ~23–33, 12–17, and 8–11 € ton^{-1} (assuming energy contents from 7–10 GJ ton^{-1}, coniferous wood chips with water contents from 40% to 55% [6]). Corresponding average landfill prices are 90, 39, and 180€ ton^{-1}. Wood ash percentage is 0.5–1% [6].

resource, and the promotion of wood as an environmentally friendly source of energy. Finally, Latvian and Lithuanian forest policy supports the increased use of industrial wood scraps for energy, and in Lithuania the aim is furthermore to increase the utilisation of small-sized wood and felling residues for energy purposes.

Concern for site fertility in relation to removal of biomass is included in some forest policies. Swedish and Finnish forest policies explicitly mention wood ash recycling as a compensation measure for increased nutrient removals. In Sweden, a concrete goal is set, that no later than by year 2010 the total area being treated with fire ash shall be at least as large as the area from which harvesting residues are collected in connection with final fellings. Furthermore, guidelines for obtaining a balanced nutrient supply, including modification of forest management practices, shall be made available. In Danish forest policy, it is generally mentioned that extraction of nutrients in logging may be compensated.

A definite forest energy policy hardly exists in any country [64] or at EU level. However, the need for a coordination of forest policies with other policies, including energy policy, is recognised by the European Council [30,80]. In Finnish forest policy, it is explicitly mentioned that the forest policy has been elaborated to be in accordance with several other policies, including energy policies [25]. In Danish forest policy, it is mentioned that forest sector research should contribute not only to a knowledge-based environmental policy, but also to a knowledge-based energy policy.

5.2. Legislation

The utilisation of forest biomass for energy and wood ash recycling is usually not explicitly regulated by forest legislation [30,31,33,35,38,40,43,45], but occasionally by related regulations or by other laws including related regulations [32,34,36,37,39,41,44,46,47]. An exception is the Swedish Forestry Act, which requires a notice to the authorities when forest is regenerated in general and when logging residues are harvested (§14). In Estonia (§41(1,7–8)) and Latvia (§39(1)), notification or confirmation from authorities must generally be obtained before felling. Furthermore, the Estonian Forest Act requires that all cutting residues (cleanings excepted) are removed from the forest, and the Minister of the Environment must establish methods and procedures for this (§40(4)) [34].

In Sweden, SKSFS 1998:5 to §30 of the Forestry Act supplies prescriptions and detailed general advice not to disturb the long-term nutrient balance when tree parts other than stems are removed from the forest [47]. Needles should be left in the forest and spread as evenly as possible, and removal of tree parts other than stems should only be performed once per rotation and be avoided on acidified sites and peatland unless compensation with mineral nutrients takes place. On N-rich sites the needles can be removed if minerals are added. The contents of the regulation are also incorporated into the official national recommendations on extraction of forest fuel and compensation fertilisation [12]. In Lithuania, the ‘‘Regulations for Final Forest Fellings’’ [41] prohibit removal of logging residues on different types of nutrient-poor mineral soils and on peatlands. On affected sites classified according to the national site classification, it is recommended to chip and spread the logging residues.

SKSFS 1998:5 also gives advice concerning the possibility to compensate nutrient removals and sets the framework for wood ash recycling with regard to amount, hardening, and chemical contents. More detailed thresholds are set by the national recommendations [12], which are currently under revision. SKSFS 1991:2 is being referred to for general advice on N fertilisation. In Denmark, wood ash recycling is regulated by the ‘‘Departmental Order on Utilisation of Ash from Gasification and Combustion of Biomass and Biomass waste for Land Use Purposes’’ to the Law on Environmental Protection [32]. The departmental order, which is presently under revision, deals with thresholds for chemical contents (mainly cadmium, Cd), demands for soil quality, amounts, declaration obligations, notification of authorities, etc. In Finland, thresholds for chemical contents are presently being incorporated into the Finnish Fertilisation Law [37]. In Lithuania, Swedish thresholds for chemical contents have been incorporated into recommendations for wood ash recycling [10]. Lower thresholds are given for nutrients, and upper thresholds are given for heavy metals and other ecotoxic compounds.

In Estonia, fertilisation of forests with direct effective mineral fertilisers is prohibited by the Forest Act, except for the fertilisation of forest nurseries ((§27(3)). According to the Latvian Law on Forests, the forest owner or lawful possessor shall obtain a confirmation from the State Forest Service for use of artificial fertilisers in forest land (§39(1)), whereas in the Lithuanian Forestry Law, fertilisation must not contradict the ‘‘Law on Environmental Protection’’ and the appropriate standards (§14). In a way similar to the Swedish Forestry Act §30, the Norwegian Forestry Act gives the Ministry the possibility to issue further regulations concerning fertilisation of forests (§6). If the municipality find it necessary, they may also refuse forest owners permission to fertilise to prevent major negative effects on the environmental values (§6).

Laws or related regulations on storage of wood in the forest exist in Sweden, Finland, Norway, Estonia, Latvia, and Lithuania due to the risk for insect pests [34,36,39,42,44,46]. These regulations mostly address timber and wood of larger dimensions, but logging residues are also addressed, especially in the Swedish, Estonian, and Latvian regulations. In Sweden, it is generally not allowed to leave more than 250 m of stem length of coniferous wood with diameter over bark >7 cm, and of these, not more than 50 m must be coarser than 15 cm in diameter [44]. For spruce and pine, there are exceptions related to specific regions and specific times of harvesting during

May–September. In Estonia, it is generally not allowed to leave the logging residues spread in the forest [34]. If not used for strengthening of skid roads, they should be forwarded to piles or windrows for decomposition, burned, chopped, and spread, or be removed. In Latvia, there is a regulation for storage of harvesting residues in stacks [39]. It regulates minimum size of the heaps, coarseness of the material, storage seasons, and distance to living trees. In Finland, the Ministry can also regulate wood of smaller dimensions than timber [36], and in Norway, the forest owner is responsible for logging residues to be treated in a way that avoids creating a risk of insect damage [44]. If the forest owner is warned about a risk of swarming by pest insects, he/she should remove all coarse wood, including tops, from the forests, or otherwise make the material unsuitable for breeding by pest insects (see the regulation for further details). Lithuanian instructions on forest sanitary protection do not consider storage of logging residues or finer fractions [42].

Management actions such as forest fuel extraction and wood ash recycling are otherwise subjected to the general principles of SFM, as interpreted in the forest laws and their regulations, and general management prescriptions, e.g. on regeneration, reproduction material, tending, felling, forest protection, protection against calamities, fertilisation, and nature preservation and conservation. Apart from this, several other laws and regulations might be relevant to the sustainable utilisation of forest biomass for energy without explicit mention thereof [65]. A comprehensive list of legislation relevant to SFM in general can sometimes be found in national forest certification standards.

5.3. Certification

Certification can be performed through general certification schemes such as the International Standard on Environmental Management Systems (ISO 14000 series, ISO 14001 specifically), and the EU Eco-Management and Audit Scheme [2,119,120]. These are management tools for companies and other organisations to evaluate, report, and improve their environmental performance, and they both apply to energy producers, e.g. Dong in Denmark [108,121] and to large forest industrial companies such as Stora Enso and UPM [122,123]. Electricity producers can also be accredited as producers of green energy, e.g. under the Essent Green Gold or Eugene standards [2,124]. These certificates emphasise sustainability and traceability of the biomass throughout the entire supply chain, including production in the forest. For existing biomass-fired plants, the Eugene Standard requires an action plan to ensure that the wood used is purchased from FSC-certified sources within 4 years. For power generation stations which entered into operation after 1 January 2001, energy crops should all come from FSC-certified sources. It is suggested in a newly published report that if equivalence of other forest certification standards such as PEFC can be proven at a national basis, they shall be accepted in the course of the Eugene accreditation [111]. The report also recognises that the certification requirement would limit the supply too much in countries with only a limited area of certified forest. Therefore, a temporary ease in restrictions is proposed for countries with insufficient amounts of FSC-certified forest.

Under both the FSC and PEFC certification schemes, it is a precondition that national laws and regulations should be followed. The topic of forest biomass utilisation for energy is not explicitly included in the international FSC standard. In six PE-C&I and the PEOLG used by PEFC, the use of wood for energy is explicitly mentioned under the first criterion "Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles". In this criterion, examples of descriptive indicators are given under the concept area "Carbon Balance" [56]. These indicators relate to legal, regulatory, institutional, and economic policy frameworks for enhanced use of wood for energy. Otherwise, management actions in relation to extraction of forest fuel are subjected to more generally formulated criteria and indicators.

National certification schemes under both PEFC and FSC often include the utilisation of wood for energy explicitly. Under the first Pan-European Criterion "Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles", the Slovenian standard to be endorsed contains an analogue to the pan-European criterion. Among other things, the existence of legal, regulatory, institutional, and economic policy frameworks and financial instruments for an enhanced use of wood biomass for energy is addressed. These issues are similarly mentioned in Appendix 3 of the Latvian PEFC scheme. The regional Slovenian standard further addresses the importance of wood energy for reduction of greenhouse gas emissions and rural development.

The second pan-European criterion "Maintenance of Forest Ecosystem Health and Vitality" addresses among other things damage caused by biotic and abiotic agents (cf. also PEOLG 2.1.b), and changes in soil nutrient balance and acidity (cf. also PEOLG 2.2.d). The latter topic is often addressed in the national PEFC standards. The status of different soil parameters related to soil fertility should generally be surveyed, and in several countries the increased extraction of nutrients is explicitly addressed. As such:

- systematic removal of crown material is only allowed with a certain frequency (Austria, Sweden), or when it cannot be avoided (Italy),
- the removal should be considered in relation to soil fertility, leaching, and deposition (Denmark),
- actions diminishing the growth potential are prohibited (Slovenia),
- whole-tree harvesting should not be practiced where it is likely to have negative effects (UK),
- national guidelines should be followed in this regard (Sweden and UK).

Many standards address fertilisation, requiring omission if the purpose is increased timber increment. However, fertilisation is often accepted in specific situations such as restoring site quality, enabling regeneration or reforestation, or increasing vitality in cases of nutritional needs that have been documented by soil or foliar analyses (Austria, Denmark, Germany, Latvia, Luxembourg, Spain, and Sweden). Fertilisation might also be allowed when all aspects of environmental protection are taken into account (Czech Republic). Under the Austrian and Swedish standards, wood ash recycling is allowed when performed in agreement with national recommendations. In Latvia, sludge is similarly allowed with certain restrictions.

Under the second pan-European criterion, the Finnish standard also includes stump harvesting as a control measure to prevent spreading of fungal diseases from a regeneration area, but does not refer to the subsequent possibilities to use stumps for energy.

The third pan-European criterion "Maintenance and Encouragement of Productive Functions of Forest (wood and non-wood)" addresses the balance between growth and removals of wood under the concept area of wood production (cf. also PEOLG 3.2.c). Several countries mention intensified harvesting under this criterion:

- the usage levels of products should take proper account of the removal of nutrients (Belgium),
- the removal should not exceed a sustainable level (Czech Republic),
- whole-tree harvesting is completely or partly prohibited (Germany, Italy, Luxembourg),
- the removal of tops and branches and rotten wood for energy purposes is emphasised as a supplementary harvest with considerable environmental benefit due to replacement of fossil fuels (cf. PEOLG 3.2.a concerning a diversified output of goods and services in the long term) (Sweden),
- dead wood should be left in the forest after tending operations if there is no comprehensive danger (cf. also PEOLG 3.2.b) (Austria).

The fourth pan-European criterion "Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems" addresses among other things threatened species and biological diversity for which dead wood is one of the key habitats (cf. also PEOLG 4.2.h). Generally, it is acknowledged in the standards that larger dead wood should be left in the forest. In addition,

- removal of residues should be avoided, provided that it is legally permitted to leave them due to biotic threats such as insect pests (Austria and Luxembourg),
- branches left after harvesting should not be burned (Q-label, Switzerland),
- all deadwood should be left untouched, unless there is a documented risk of a mass propagation of insect pests. Small-size logging residue is excepted (Sweden).

The fifth pan-European Criterion "Maintenance and Appropriate Enhancement of Protective Functions in Forest Management (Notably Soil and Water)", addresses among other things soil preparation, especially in relation to erosion (cf. PEOLG 5.2.a). Some standards omit or limit the use of soil preparation (Denmark) or scarification (Germany, Luxembourg, Sweden), or state that large-scale interventions in the forest soil should be avoided (Austria). When soil preparation or intervention should be avoided, this might be an impeding factor to the use of stumps for energy in certified forests.

The sixth pan-European Criterion "Maintenance of Other Socio-Economic Functions and Conditions" addresses among other things the significance of the forest sector in Criterion 6.1 "Share of the Forest Sector from the Gross National Product". Austria explicitly includes the "Proportion of renewable resources (wood, bark, etc.) in energy supply" as an indicator. Slovenia includes a sub-criterion in the regional standard, saying that production of wood biomass for energy purposes must be based on the principles of SFM, and must be implemented in compliance with the principles of forest care. Furthermore, the use of lower-value wood for energy purposes should be promoted at the regional level.

In national FSC standards, the use of wood for energy or wood ash recycling is not explicitly mentioned in the endorsed standards for the Baltic countries or in the Norwegian Living Forest Standard. In other analysed FSC standards, the topic is explicitly mentioned under two of the ten principles. Firstly, it is mentioned under Principle 5 "Benefits from the Forest" in Finland. Secondly, it is mentioned under Principle 6 "Environmental Impacts" in Finland, Sweden and Denmark.

Criterion 5.2 concerns optimal use and local processing of the forest's diversity of products and Criterion 5.3 concerns minimisation of waste associated with harvest. Under these two criteria, the Finnish draft FSC standard encourages harvest of energy wood.

Criterion 6.3 concerns maintenance and restoration of the forest's ecological functions, including the natural ecosystem cycles that affect the productivity of the forest. Under this criterion, the Finnish draft FSC standard regards wood ash recycling in the same way as other fertilisation, with fertilisation being restricted to forests with documented nutrient imbalances observed by soil or foliage analyses. Fertilisation is also allowed as a means to prevent growth disturbances caused by nutrient imbalances in old pastures, peat fields, or other areas released from agricultural use. The Swedish FSC standard states that harvesting of small dimension wood is allowed as long as it complies with regulations, general guidelines, and recommendations of the National Board of Forestry. However, the forest owner must demonstrate, with the support of overall documentation, that this use does not conflict with sustaining the natural processes of forest ecosystems and long-term productivity, and does not have detrimental effects on other ecosystems or biodiversity values. These

Swedish requirements are also valid for actions to remediate the increased removal of nutrients such as wood ash recycling.

Criterion 6.5 demands guidelines for harvesting with regard to prevention of erosion, prevention of forest damage during harvest, road construction, all other mechanical disturbances and protection of water resources. In Finland, reference is made to the guidelines from the Forestry Development Centre Tapio on collection of harvest slash for wood energy [9].

Criterion 6.6 concerns the use of environmentally friendly non-chemical methods for pest management. The Danish standard includes a fertilisation indicator here, which states that fertilisation should generally not be used. However, the return of wood ash to prevent negative impacts of removal and burning of forest material is accepted.

6. Discussion

Wood for energy is prioritised in energy policy and supported by forest policy. Energy use of forests is furthermore favoured by employment and regional policies, which stress the importance of new job opportunities outside cities. Still, if not coordinated, different policies might work against each other. Environmental policies in Finland aim at increasing biodiversity by voluntary protection of forests, which reduces the area of forests available for wood energy supply. In Denmark, close-to-nature forestry has high priority in forest policy. The stand types from which most of the forest fuel is presently produced will to a large extent be converted to other species, other stand structures and management systems, but the overall effects on the domestic supply of wood for energy is uncertain and has not been analysed. Danish forest policy states that the production of wood chips should be considered when developing close-to-nature management systems, for example by utilising the nurse trees needed during the conversion phase and chipping of small dimension trees. However, deliberate prioritising might be necessary. If conflicts in the use of public money are to be avoided, it is important to study how different policies can co-exist in a meaningful way.

Recommendations and guidelines for sustainable forest fuel harvesting and wood ash recycling have been issued in some countries. The most up-to-date recommendations are presently found in Sweden, Finland and Lithuania, whereas recommendations from Denmark and the United Kingdom were elaborated in the 1980s. In Norway, Estonia, Latvia, and many other European countries, recommendations and guidelines have not been elaborated. With increased interest in forest fuel harvesting, nationally adapted recommendations and guidelines will be useful as non-mandatory tools for supporting and ensuring a sustainable extraction of forest biomass for energy. They can furthermore be sources for operational criteria, if mandatory or binding instruments are preferred.

Forestry legislation in the Nordic and Baltic countries is not used directly as a tool to enhance the utilisation of forest biomass for energy and wood ash recycling. In general, legislation does not prevent the practice either [64], but in some cases it might, perhaps unintentionally, restrict its use through regulations linked to the forestry laws, or through other legislation. For example, in Lithuania the "Regulations for Final Forest Fellings" can be an impeding factor for forest fuel production in districts where poor soils dominate. In Denmark, the restrictions in the present departmental order for wood ash recycling [32], e.g. thresholds for Cd concentrations in wood ash, amounts allowed to be spread in one operation, and requirements for fencing and putting up signs in the forest, have limited recycling of wood ash. On the other hand, deliberate use of such restrictions is indirectly supportive by ensuring that biomass is produced and recycled in a sustainable way.

National recommendations could be an integrated part of forest certification standards. The recommendations could be adhered to in general as is the case for legislation, or they could be adhered to under specific criteria as is the case, e.g. the Finnish FSC draft standard and the Swedish PEFC and FSC standards. Recommendations and guidelines could also be converted into criteria, indicators and thresholds. Direct reference to recommendations and guidelines could be preferable, since their complexity might not be easily contained within a hierarchical set of criteria and indicators. However, if certification bodies wish to adjust to more or less strict requirements compared to recommendations and guidelines, this could argue for conversion into criteria and indicators.

There might be other possibilities and needs for development of forest certification standards to include sustainable forest fuel harvesting. A number of basic problems with criteria and indicators systems can be listed [125,126]:

- confusion with regard to terminology and scale,
- unclearness as to the rationales behind the indicators,
- how to make indicators operational,
- lack of targets against which indicators can be referenced,
- lack of a theoretical basis for integration of ecological, social and economic indicators.

For remediation of the latter, Hoekstra et al. [127] proposed the use of "integration indicators", which consider the combination of other criteria with trade-offs between them. In relation to forest fuel harvesting, Richardson et al. [119] mentioned that the evaluation of economic criteria is incomplete in most of the current certification programs. Furthermore, it might be relevant to address best-available harvesting techniques in a way similar to techniques for pollution prevention and control [102].

The complex of restrictions in legislation, certification standards, and recommendations and guidelines are operational answers to the question of what is sustainable forest fuel extraction and wood ash recycling. Most details are given in recommendations and guidelines as compared to certification, legislation, and policy. These can be continuously improved by increasing knowledge, but the final distinction between sustainable and unsustainable utilisation of forest biomass for energy can only be made with elements of uncertainty and subjectivity. Some of the main reasons are the complexity and diversity of ecosystems and economic and socio-economic systems, changes in their corresponding environments, and the long timescales of forest ecosystem processes. The gap of uncertainty between scientific knowledge and the need for operational criteria, indicators, and thresholds can be overcome by currently available scientific opinions, as expressed by expert groups, and subsequent interpretation of such scientific opinions by authorities or certification bodies. The uncertainty allows for multiple outputs as to what is sustainable utilisation of forest biomass for energy [120], and subjectivity is introduced in the weighing of advantages and disadvantages for different actors at different scales, and in weighing trade-offs between different criteria and indicators. The final interpretation will inevitably depend on different political priorities and the balance between them in relation to technical and economic feasibility. As every restriction has economic consequences, and as a full-scale technical development of the bioenergy area must be market driven [128], the interpretation is decisive for the extent to which forest biomass will be used for energy.

7. Conclusions

The increased use of renewable energy sources, including forest biomass, in energy consumption is a marked characteristic in current EU and national energy policies. In forest policies, the use of forest biomass for energy is usually supported as a sustainable form of energy that contributes to social welfare, local development, and forest economy. Energy legislation is used directly as a tool to promote renewable energy including forest and other biomass, whereas forest legislation rather works to ensure sustainably produced forest biomass. Governments in Sweden, Denmark, and Lithuania use national recommendations and guidelines for forest fuel extraction and/or wood ash recycling to encourage the extraction of forest fuels taking place in agreement with the principles of SFM. In Finland and the United Kingdom, similar recommendations have been elaborated by other actors. In national PEFC and FSC forest certification standards, issues related to wood for energy are included under several criteria. Recommendations elaborated by governments or other groups of stakeholders could possibly be used for further development of legislation and certification standards in relation to the sustainable utilisation of forest biomass for energy. Recommendations vary according to subject, but as a whole, economic, ecological, and social questions are treated for the whole forest fuel chain, from removal of biomass from the forest to recycling of wood ash to the forest. Uncertainty is high when scientific results are interpreted and transferred to operational criteria, indicators, recommendations, and guidelines, with the final thresholds being set by politicians, certification bodies, or other stakeholders. This interpretation is decisive for future utilisation of forest biomass for energy and recycling of wood ash.

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