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Implementation of voluntary verification of sustainability for solid biomass—a case study from Denmark



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Abstract

Background: Renewable energy and biomass are becoming increasingly important energy sources to help mitigate climate change and meet national renewable energy targets. This will lead to a substantial growth in solid biomass consumption for heat and electricity, but questions about its sustainability have been raised. Danish energy companies have addressed these issues with sustainability criteria in a voluntary industry agreement since 2016. The aim of this study was to synthesise and evaluate biomass sourcing in the Danish energy sector and its compliance with voluntary sustainability criteria.

Methods: We collected energy companies' public industry agreement sustainability reports and compiled the included information into a dataset that allowed us to compare and analyse the Danish energy sector's biomass sourcing, compliance and implementation of sustainability criteria in 2016 and 2017. Furthermore, we analysed the supply chains and feedstock use of Danish energy companies.

Results: In Denmark, medium to large energy companies documented that 57% and 70% of their biomass sourcing was in compliance with the sustainability criteria in 2016 and 2017, respectively. To show compliance with the sustainability criteria, sustainable forest management certification was most common in 2016 while risk-based certification prevailed in 2017. Most biomass is sourced and reported sustainability compliance by a few large companies. Wood pellets are sustainability reported and sourced in significantly larger volumes than wood chips. Danish energy companies source solid biomass from local to global scales, but especially from countries around the Baltic Sea.

Conclusions: The Danish approach to sustainable sourcing with voluntary sustainability criteria has been successfully implemented for most of the wood sourced for energy by medium to large energy companies in Denmark. The implementation of this approach shows that it has been possible within a couple of years to implement sustainability governance with risk-based criteria for multiple energy companies that source solid wood biomass at the megaton scale. A risk-based approach to implementation of sustainability criteria for forest biomass has also been chosen by the European Union (EU) and will be implemented through the EU Renewable Energy Directive from 2021.

Keywords: Solid biomass, Sustainability criteria, Bioenergy governance, Denmark, Forest certification, Case study, Renewable energy directive, Sustainable forest management, Energy policy

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Background

The Danish energy system

Renewable energy is important as a means to reduce countries' dependence on fossil fuels and their related greenhouse gas (GHG) emissions. Solid biomass plays a key role in this development, and it is currently the largest source of renewable energy in the EU28 as well as in Denmark [38]. For this study, biomass is defined as solid biomass, i.e. wood in the form of wood pellets and wood chips unless otherwise mentioned. Biomass is expected to contribute substantially to the renewable energy targets of 2020 [4] and 2030, despite large uncertainties about future biomass supplies and demands. At present, most of the biomass used in the European energy systems originates from Europe, but imports from countries outside the EU are expected to increase [13, 38].

The gross energy consumption in Denmark was 772 PJ in 2017, showing only a slightly declining trend since 1990. In the last decades, the energy sector has experienced an increasing diversification in fuel inputs driven mainly by reduced coal consumption and increased biomass, wind and solar resources [38]. Of the gross energy consumption in 2017, approximately 30% came from renewable energy, with biomass alone, including biological waste, contributing 21.5%, compared to 6.7% in 2000. Solid biomass, including straw but excluding biological waste, contributed 16.4% in 2017, thus constituting 50% of the renewable energy supply. By 2017, the total Danish energy sector consumption of solid biomass was 2.5 Mt of wood chips, 2.3 Mt of wood pellets and 0.2 Mt of wood waste (Fig. 1a, Table 1). An increasing part of the demand is met by imported wood pellets and wood chips (Fig. 1b). A significant part of these resources are also used outside the energy sector (Table 1), in

households (firewood, wood pellets) (Table 1). For the purpose of this paper, we define the “energy sector” as the heating plants and combined heat and power plants (CHPs), which are connected to district heating networks and which have public, semi-public or cooperative ownership. Outside the “energy sector” is a diverse group of primarily private dwellings and vacation homes with wood and pellet stoves, process heat for industries, public service institutions, agriculture, forestry and horticulture [38].

Various forms of public ownership is predominant in the Danish energy sector, which consists of few centralised CHP plants and a large number of decentralised CHP and district heating plants. The centralised CHP plants are mostly located close to ports to allow for fuel deliveries by ship and enable sea water cooling. The heat supply is characterised by a comparably high penetration of district heating [103], with the dominating fuels being biomass, natural gas, waste and coal [38]. District heating supplied heat to 64% of all Danish households in 2017 [42]. A thorough statistical description of the Danish energy system is available in English for 2016 [16]. Descriptions of the district heating network and regulatory framework are also available from Danish Energy Agency [15] and Danish Energy Agency et al. [17].

Policy incentives and biomass use

The use of biomass in the energy sector in Denmark has been on the political agenda since the mid 1980s [5]. Significant political agreements driving the development were the Biomass Agreement from 1993 [80], which included a mandate on straw and wood biomass use. An agreement from 2008 liberated the fuel choice on centralised CHP plants and allowed for consumption of an additional 0.7 Mt of solid biomass (both straw and

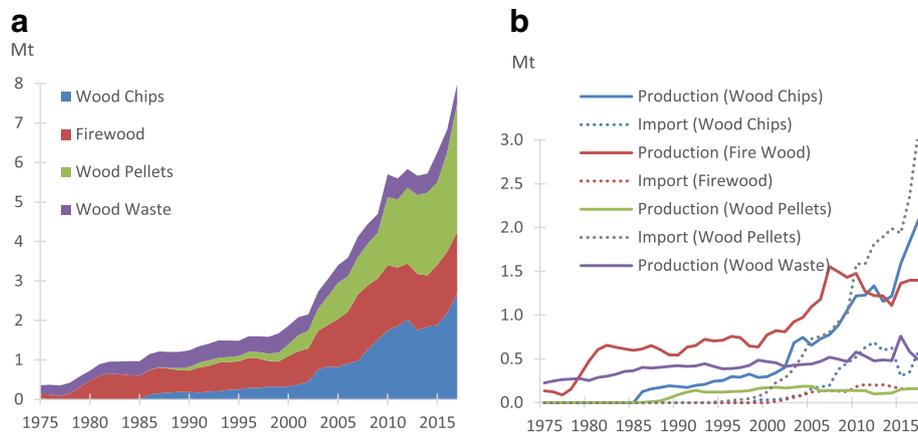


Fig. 1 Consumption of solid biomass (wood chips, wood pellets and wood waste) in the energy sector in Denmark 1975–2017 (a), and domestic production and import of solid biomass (wood chips, wood pellets, wood waste and firewood) in Denmark 1975–2017 (b). Adapted from Energistyrelsen [38]

Table 1 Consumption of solid wood biomass in and outside the energy sector in Denmark in 2017 and the proportion of this consumption liable to the Danish “Industry Agreement to ensure sustainable biomass (wood pellets and wood chips)”(IA) [18] relative to both energy sector and total consumption, respectively. The IA is described in following paragraphs. Based on data from Energistyrelsen [38] and “Additional file 1”. Wood waste is not part of the IA and firewood is not used in the energy sector [38]

	Wood Chips	Firewood	Wood Pellets	Wood waste	Total
Total consumption (Mt)	2.68	1.56	3.26	0.49	7.99
Energy sector consumption (Mt; % of total)	2.50 (94%)	0 (0%)	2.28 (70%)	0.20 (40%)	4.98 (62%)
Consumption outside energy sector (Mt; % of total)	0.17 (6%)	1.56 (100%)	0.98 (30%)	0.29 (60%)	3.01 (38%)
Percentage of energy sector consumption liable to the IA (%)	53%	0%	91%	n.a.	71%
Percentage of total consumption liable to the IA (total)	49%	0%	63%	n.a.	57%

n.a. not available

wood) on two of the largest plants [36]. EU strategies and legislation also shaped the solid biomass use in the Danish energy sector. The 2001 Directive (2001/77/EC) [94] on promotion of electricity production on renewable resources recognised biomass as renewable, and the EU Biomass Action Plan from 2005 identified a number of initiatives to boost bioenergy [74]. In order to meet the national targets for renewable energy as set by the Renewable Energy Directive (Directive 2009/28/EC (REDI)) [46], the Danish National Renewable Energy Action Plan (NREAP) stipulated an increased consumption of wood chips of 32 PJ by 2020 relative to 2005 [65]. Finally, the national commitments under the Kyoto Protocol [67] of 1997, which entered into force in February 2005, have provided a policy incentive for countries to increase the amount renewables in the energy system. Denmark committed itself to GHG emissions reduction of 21% during the commitment period 2008–12 relative to 1990 [36].

In 2012, all political parties in the Danish parliament and the government agreed upon the energy policy for 2012–2020 [87]. As a part of this agreement, an analysis was conducted to explore the potential role of biomass in the Danish energy system. The analysis was published in 2014, and it concluded that there are current and future sustainability challenges connected to the Danish consumption of solid biomass in the heating and CHP sector [35]. At about the same time, the policy frameworks for biomass fuelled by CHPs were changed to favour increased use of biomass [64]. In 2018, the Danish government, with support from all parties in the Parliament, agreed to continue these favourable conditions until 2030 [100].

Various policy instruments are being employed to support the deployment of renewable energy. Exemptions from fuel and CO₂ taxes and different forms of feed-in tariffs and feed-in premiums (FIP) on renewable electricity have been the main incentives in Denmark since 1993 [63, 71]. For biomass for electricity production, different FIPs have been in place since the early 2000s [39, 84]. The value of this

subsidy is for most plants about 2 EUR kWh⁻¹. From April 2019 and onwards, this subsidy is available for 15 to 20 years depending on whether the CHP is converted from coal to wood pellets or if it is a new power plant. Solid biomass CHPs built after April 2019 are eligible for FIPs similar to other renewable energy projects [34, 39]. A complete overview of subsidies for renewable energy including biomass in Denmark is available from the Danish Energy Agency Energistyrelsen [39].

Biomass sustainability frameworks

As the use of biomass for energy has been growing over recent decades, sustainability concerns have been expressed by several NGOs, researchers and other stakeholders. Concerns are for example that the use of biomass does not lead to real GHG emission savings [10, 47, 82]; that biomass is not a truly renewable energy source [40]; that ecologically sensitive areas and habitats will be harmed [19]; and that undesirable indirect land-use changes (iLUC) will take place [10]. These discussions are still ongoing and are a topic Danish Energy companies, and organizations are addressing as part of their corporate social responsibility, sustainability or strategy programmes, e.g. HOFOR [61]; Ørsted [79].

The rise of such concerns led to the introduction of sustainability criteria for bioliquids in RED I, which was adopted in 2009 [46]. It was questioned, however, if sustainability criteria for solid and gaseous biomass used for heat and electricity could lead to market distortions [74]. In 2010, the EU issued recommendations which encouraged Member States to establish national sustainability criteria for solid and gaseous biomass [43]. The recommendations build on the RED I requirements for bioliquids [74].

Belgium had already introduced criteria for GHG emission reductions in 2001, but the United Kingdom (UK) was first to introduce such national requirements in 2009, with adoption of national legislation in 2013, which took effect in October 2015 (Table 2) [73, 74]. In 2012, The Danish government suggested

Table 2 Indicative comparison of sustainability issues for forest biomass as included in Denmark, the Netherlands, the United Kingdom, Belgium and the newly adopted EU RED II [44, 45, 66, 73]. The displayed issues are not necessarily named in the same manner in the individual frameworks

Sustainability criteria	Belgium	United Kingdom	Denmark	The Netherlands	EU RED II
Legality ^a	No	Yes	Yes	Yes	Yes
Sustainable forest management ^b	No	Yes	Yes	Yes	Yes
GHG emission savings from bioenergy value chains ^c	Yes	Yes	Yes	Yes	Yes
Carbon stocks and sequestration	No	No	No	Yes (carbon debt)	Yes (LULUCF accounting)
Indirect effects	No	No	No	Yes (iLUC)	No
Governmental control	Yes	Yes	No	Yes	Yes
Start time	2001	2015	2016	2016	2021
Implementation	Implemented	2015-	2016-2019	2018-2022	2021-

LULUCF land use and land-use change and forestry

^aCovered by the EU Timber Regulation 995/2010 [95]

^bThere are differences in the included sustainable forest management criteria, but it is outside the scope of this paper to further analyse these

^cThresholds differ among countries

that the two Danish industry associations, Danish Energy and the Danish District Heating Association, and their member companies establish an industry-initiated voluntary sustainability framework for wood chips and wood pellets. This resulted in the “Industry agreement to ensure sustainable biomass (wood pellets and wood chips)” (IA) being concluded and approved by the government in 2014 [18, 68]. The implementation of the IA started on 1 August 2016. The agreement is expected to be fully phased in by the end of 2019 (Table 2). In 2017, an agreement was also concluded in the Netherlands, with implementation taking place from 2018 to 2022 [77].

At EU level, the European Commission proposed revisions to the Renewable Energy Directive in 2016, which included the introduction of risk-based sustainability criteria for solid and gaseous biomass used for heat and electricity in the EU [44]. These sustainability criteria were developed for transport biofuels based on the RED I, but new sets of sustainability criteria were suggested for the Directive to additionally cover solid and gaseous biomass used for heat and power generation. After a legislative process in 2016–18, the new Renewable Energy Directive (Directive (EU) 2018/2001, RED II) was finally adopted in 2018, becoming statutory from January 2021 [45, 96]. RED II introduces risk-based sustainability criteria for solid and gaseous biomass used for heat and power in the EU. Some of the criteria are specific to solid biomass from forests, while others are specific to other types of biomass.

The sustainability criteria of solid biomass from forests differ to some extent among EU Member States (Table 2), with the main differences being the approach to effects on the carbon cycle and carbon sequestration [66, 73]. All countries and the EU RED

II establish criteria for GHG emissions savings in the bioenergy value chains, even if thresholds are not similar. The overall regulatory approaches also differ. In Belgium, the UK and the Netherlands, sustainability criteria are linked to governmental subsidies. They have been implemented through laws and compliance is subject to governmental control. In Denmark, compliance with national sustainability criteria is voluntary and not linked to subsidies. Currently, there is to our knowledge little mutual learning taking place between national systems in different countries, and publication and communication of experiences from these systems are not yet taking place in public debates.

Parallel processes have taken place in the private sector. In order to avoid trade barriers for solid biomass fuels due to existing differences in company policies and emerging differences in national systems [73], the larger European energy companies started a collaboration in 2010, to develop common sustainability criteria for solid biomass [74]. This collaboration resulted in the launch of a new certification system, Sustainable Biomass Program (SBP), in the autumn of 2015 [74]. Multiple other national-, regional-, and international initiatives exist, which have relevance to biomass sustainability, with some of the most important being certification systems for sustainable forest management (SFM) [50, 70, 81]. Two major systems exist, the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). The SBP system accepts FSC and PEFC certification as verification of their SFM criteria [91].

Energy company policies

Two of the largest Danish energy companies, Ørsted and HOFOR, have actively participated in the

collaboration to develop SBP, and address biomass sustainability as part of their corporate social responsibility, or in specific sustainability strategies and programmes, see HOFOR [61]; Ørsted [79].

In 2007, the largest Danish energy company, DONG Energy (named Ørsted from 2017) had a code of conduct for responsible wood sourcing, which required that the solid biomass they consume is certified [22]. Early attempts to address sustainability also include a report on solid biomass resources, markets and sustainability commissioned by several larger Danish district heating companies in 2010. The report recommends that governance of biomass sustainability including certification should be handled by the EU or the Danish government through binding criteria. Furthermore, it suggests that energy companies should require certificates of origin for their biomass sourcing and that solid biomass should meet the criteria recommended by the EU in the same year [12, 43]. Focus on sustainability governance of solid biomass within Danish energy companies thus gradually emerges around 2007–2014. In 2013, the Danish Energy and the Danish District Heating Association, which most Danish energy producers are members of, published a booklet on sustainability of solid biomass for energy [20], and in late 2014, the IA, described below, was agreed upon.

The Danish Industry Agreement

The Danish IA has eight sustainability criteria with several quantitative and qualitative indicators under each criterion (Table 3). The sustainability criteria were developed with the requirements of the UK Procurement Policy as a starting point, the so-called Central Point of Expertise on Timber criteria [11]. These criteria had already formed the basis for the Danish public procurement policy for wood and wood products, before the IA [90]. Various certification systems, such as the SBP, the FSC and PEFC, are approved as eligible to verify compliance with the SFM criteria of the IA. Also, other forms of documentation are accepted, on a case by case basis involving third-party auditing. SBP certification also covers collection of all relevant data for calculations of value chain GHG emission savings, while the calculations are done by energy companies, to show that the biomass meets the thresholds set by the IA.

Compliance with the IA is documented through yearly reporting by each energy company. Reports can be developed or written by third-party auditors, and they are made public on each energy company's website and on the websites of Danish Energy and the Danish District Heating Association, depending on energy company memberships [18].

Aims

At present, there is little specific knowledge available on the documentation of sustainable wood sourcing of energy companies operating under national level sustainability frameworks in European Union Member States. There are a few exceptions such as the reporting by the British energy company DRAX [24]. In Denmark, the IA requires that energy companies publish annual reports with information on how they document the sustainability of the biomass, according to the sustainability criteria of the IA. However, the information from these reports has not yet been presented in a synthesized form. As experiences gained in such processes should form a basis for continued learning and improvements, this study aims to synthesise the information about Danish energy companies' reporting, as a basis for analysing their solid biomass sourcing, and evaluate the degree to which it is in compliance with the requirements of the IA. The study analyses the development during the first 2 years of the IA implementation, 2016–2017. We believe that the results will benefit the further implementation of the IA and solid biomass sustainability governance in general.

Methods

Sustainability reports

Our analysis was based on all IA reporting by Danish energy companies in 2016 and 2017. These reports are published by energy companies as part of their obligations in relation to the IA (Table 3). The reports of 2016 are published in 2017 and reports of 2017 are published in 2018 (Table 4).

Template for data compilation

We have designed a template for synthesis of the information from the submitted reports of the 17 energy companies (Table 5). The compiled information includes 16 variables. During data compilation, we have translated data from the reports into English. All data from the reports is included in the Additional file 1 as an MS Excel Spreadsheet.

The reports do not always present data in a consistent form, e.g. some companies report biomass sourcing as a percentage of total sourcing and other report everything in volumes. This has led to small rounding errors in the dataset. Similarly, missing data in the Additional file 1 indicates that data was not published or available from the reports.

Supply chains

The sustainability report's information about country of origin was used to classify supply chains into different, but somewhat, overlapping categories: global, European, regional and local. We use the term "supply chain levels"

Table 3 Overview of sustainability criteria and other requirements in the Danish Industry agreement to ensure sustainable biomass (wood pellets and wood chips) (IA). The content of this table is condensed and adapted from the agreement published by Danish Energy and Danish District Heating Association [18]

Criteria	Indicator
Sustainability criteria	
1. Legality	<ul style="list-style-type: none"> • Logging only from legally designated areas • Payment of relevant taxes and duties • Logging in compliance with forest and environmental legislation • Indigenous people's rights must be respected • Compliance with customs and trade legislation
2. Protection of forest's ecosystems	<ul style="list-style-type: none"> • Forest management must ensure the preservation of the forest ecosystem • Assessment of the environmental impact related to logging • Impact assessment of forest management on ecosystems and biodiversity • Scheme to minimise negative impact on ecosystems and biodiversity
3. Forest productivity and carbon cycle	<ul style="list-style-type: none"> • Management of forest ecosystems must ensure the least negative impact on forest productivity and carbon sequestration
4. Healthy and well-functioning forests	<ul style="list-style-type: none"> • Forest management must ensure healthy and well-functioning forests
5. Protection of biodiversity, sensitive areas and areas worthy of preservation	<ul style="list-style-type: none"> • Forest management must ensure protection of biodiversity, sensitive areas and areas worthy of preservation • Identification of particularly vulnerable areas • Protection of designated areas, e.g. soil erosion, high biodiversity, water resources
6. Social and work-related rights	<ul style="list-style-type: none"> • Forest management must protect social and work-related rights • Identification, documentation respect of original inhabitants' rights • Establishing complaint mechanisms • Employees have the right to organise • Child labour, forced labour and discrimination is not allowed
7. CO ₂ emission limits for biomass value chains	<ul style="list-style-type: none"> • Only biomass with specific value chain emissions is allowed • Biograce II is chosen as calculation method
8. Additional requirements: carbon cycle, forest carbon stock, indirect land-use change and indirect wood-use change	<ul style="list-style-type: none"> • The industry aims to not use biomass that leads to deforestation, iLUC, iWUC nor that negatively impacts quality and quantity of forest resources in the medium and long term • This criterion is not yet implemented and is not yet documented. If standardised methods are developed, the industry must accept these methods before incorporation into IA
Other requirements	
Compliance and publication	<ul style="list-style-type: none"> • Compliance with IA is documented by yearly third-party audited, public reports that are published on company websites • There are no legal consequences for non-compliance
Documentation	<ul style="list-style-type: none"> • Compliance with criteria 1-6 can be documented through the certification system developed by Sustainable Biomass Partnership (SBP) • Certification by Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) is also recognised • Other appropriate forms other than certification are also recognised ("Alternative documentation")—must be third-party audited
Timeframe	<ul style="list-style-type: none"> • Energy companies shall document on an annual basis the following proportion (by weight) of wood pellets and wood chips are in compliance with the IA: 2016 (from August 1st): 40 %, 2017: 60 %, 2018: 75 %, 2019: Fully phased in, but 10 % can be in compliance with only criterion 1 (legality).
Plants included	<ul style="list-style-type: none"> • All CHP and heating plants in Denmark generating heat and/or power from wood chips and wood pellets are covered by the IA • Only plants > 20 MWth are subject to documentation requirements
Types of biomass	<ul style="list-style-type: none"> • IA applies only to wood pellets and wood chips from forest areas

to refer to these different geographical scales. Global level is sourcing from outside Europe, while European level covers countries in continental Europe. Regional level covers countries around the Baltic Sea, and local is the area around the CHP or heating plant, typically within a radius of about 50–100 km from the plant.

Unit conversions

In some instances, we have converted between energy and mass units for biomass. This was done based on conversion values used by official Danish Statistics for energy content (wood chips: 9.3 GJ metric tonne⁻¹, wood pellets: 17.5 GJ metric tonne⁻¹, wood waste: 14.7

Table 4 Company names, websites and references to annual reports for energy companies submitting sustainability reports to demonstrate compliance with the IA. Presence or absence of an “x” indicates whether a company published a report for that year’s solid biomass sourcing

Company name	Report 2016	Report 2017	Company website	Reference 2016 report	Reference 2017 report
Aabenraa-Rødekro Fjernvarme	x		https://www.aabenraa-fjernvarme.dk/	[1]	
Assens Fjernvarme	x	x	http://www.assensfjernvarme.dk/	[2]	[3]
Biomassefyret Kraftvarmeværk		x	https://bkvv.dk/		[7]
Bornholms Energi og Forsyning	x	x	https://beof.dk/	[8]	[9]
Ebeltoft Fjernvarmeværk	x	x	http://www.ebeltoftfjernvarme.dk/	[32]	[33]
Fjernvarme Fyn	x	x	https://www.fjernvarmefyn.dk/	[48]	[49]
Haderslev Fjernvarme	x	x	https://www.haderslev-fjernvarme.dk/	[52]	[53]
Halsnæs Varmer		x	https://hnf.dk/		[54]
Hillerød Forsyning	x	x	http://hillerodforsyning.dk/	[55]	[56]
Hjørring Varmeforsyning	x	x	https://www.hjvarme.dk/	[57]	[58]
HOFOR	x	x	https://www.hofor.dk/english/	[59]	[60]
Dong Energy/Ørsted	x	x	https://orsted.com/en	[23]	[78]
Skanderborg-Hørning Fjernvarme	x	x	https://www.skfj.dk/	[86]	[85]
Sønderborg Fjernvarme	x	x	http://www.sonderborg-fjernvarme.dk/	[88]	[89]
Tarm Varmeværk	x	x	https://www.tarmvarm.dk/	[92]	[93]
VEKS	x	x	https://www.veks.dk/en	[98]	[99]
Verdo Grenaa Kraftvarmeværk		x	https://verdo.dk/en/visitor-type-selector		[51]
Verdo Randers Kraftvarmeværk	x	x	https://verdo.dk/en/visitor-type-selector	[101]	[102]

GJ metric tonne⁻¹ and firewood: 16.1 GJ metric tonnes⁻¹ [28–31].

Results

Total biomass sourcing

The total sourcing of forest biomass in the Danish energy sector (plants > 20 MWth), as reported to the IA, was about 1.2 Mt in 2016 (August–December) and 3.4 Mt in 2017 (January–December) (Fig. 2). Most of the biomass consumption is concentrated in only a few energy companies. Ørsted, VEKS and HOFOR were the largest consumers in both 2016 and 2017 with 78 % and 79 % of total sourcing, respectively. Ørsted alone accounted for 2.1 Mt of the total 3.4 Mt sourced in 2017.

Biomass sourcing at different supply chain levels

Most companies did not report sourcing details such as country of origin and species quantitatively. However, the information available suggested that Danish energy companies source biomass from all supply chain levels, including global, European, regional and local. Large CHPs with seaports can source wood chips and wood pellets transported to the plant on freight ships. These energy companies include Ørsted, HOFOR, Verdo and BEOF. They sourced most of their imported biomass from countries

around the Baltic Sea, including Latvia, Estonia, Lithuania, Russia, Poland, Norway and Sweden (the regional supply chain level), some in Portugal, France, Germany (European supply chain level), and some from further away, e.g. the U.S.A., Swaziland, Australia (the global supply chain level), see also Additional file 1.

Smaller CHPs and heating plants without seaports used biomass, mostly wood chips, transported to the site on trucks (local supply chain level), or in some cases, biomass unloaded at a seaport and shipped by road to the CHP or heating plants. Examples include Halsnæs Varmer, Skanderborg-Hørning, Sønderborg Fjernvarme, and Hjørring Varmeforsyning (see Additional file 1). When reporting on compliance with the EU Timber Regulation (EUTR), most companies reported that either they source no biomass outside EU or they did not disclose the EUTR status of biomass sourcing. Only few companies published details about their EUTR compliance.

Feedstock types

Wood pellets accounted for 65% and 61% of the wood sourcing in 2016 and 2017, respectively, and wood chips correspondingly for 35% and 39%. Some wood was delivered at the plant as whole logs and chipped on site (Additional file 1). The use of wood from outside forests was reported by about 10 companies each year, but

Table 5 Information categories, variables and their units or the value they can take

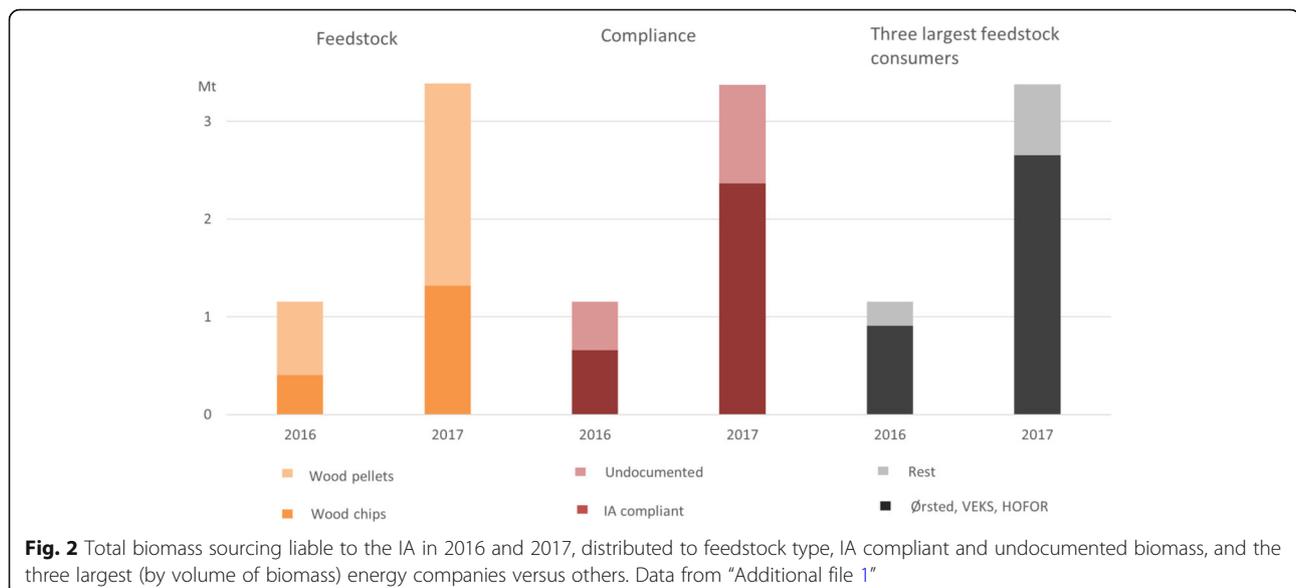
Information category	Variable	Unit/values
Feedstock amounts	Wood chips	Mg (adding up to "Total from forests")
	Wood pellets	% (adding up to 100%)
	Total from forests	Mg
	From outside forests	Mg
	Total from forest and outside forest	Mg
IA-SFM compliance for forest biomass	SFM certification	%, adding up to 100%
	Alternative SFM documentation	
	Undocumented	
Verification systems	FSC	%, not necessarily adding up to 100%
	PEFC	One shipment of biomass can be certified through more than one certification body and thus count towards two or more verification systems
	SBP	Some energy companies do not report certification body
	Alternative documentation	
Other information	Country of origin	List of countries, sometimes with percentage distribution
	Species	Species names or categories, or "Non-disclosed", which can both mean that the company does not publish tree species composition or that the company was not informed by their suppliers
	EUTR DDS	"No non-EU biomass", "Non-disclosed", "SFM Compliant biomass: No non-EU biomass". "insignificant risk of illegality for non-EU biomass"
Auditing and reporting service	Company	Name of the auditing company and reporting service company (in all cases NepCon)

Mg: mega gram, 10⁶ gram, 1 metric tonne

compared to the total sourcing it was a very small fraction (approximately 0.03 Mt in 2016 and approximately 0.04 Mt in 2017). However, for some small companies, it can constitute a substantial part of their total wood sourcing (approximately 20 %). Because solid biomass from outside forests is not covered by the IA, there is little information about it in the sustainability reports.

However, some companies mention in the reports that it is for instance SRC willow [3], horticultural wood waste [89, 93], hedgerows and fruit tree plantations [99].

Some companies provided tree species information for their feedstock, often in very general terms such as "mixed conifer and mixed broadleaves". Only the two companies with the largest sourcing, Ørsted and HOFOR, provide



more precise information for their global and European level certified supply chains. For 2016 and 2017, Ørsted reported that biomass from the southeastern USA was made from mixed hardwoods and three different pine species (in 2017, 19% broadleaves and 81 % conifers), while biomass from Australia was mixed conifers. Biomass from Portugal was from eucalypt and maritime pine (*Pinus pinaster*), and biomass from France was mixed broadleaves. HOFOR reported that their IA-SFM compliant biomass included alder (*Alnus* spp.), birch (*Betula* spp), Norway spruce (*Picea Abies*), Scots pine (*Pinus sylvestris*), and poplar (*Populus* spp). Non-IA-SFM compliant biomass from the Baltic states additionally included larch (*Larix* spp), while species information was not available for biomass from the U.S.A.

Industry Agreement and compliance

In 2016, 57% of the reported wood volume was documented to be compliant with IA requirements, and in 2017, this was 70% (Fig. 2). The IA requirements for the phase-in period were a minimum of 40% compliant biomass in 2016 and 60% in 2017, indicating that the implementation has been successful so far.

Compliance was ensured by SFM certification (FSC or PEFC) for 75% and 44% of the IA compliant biomass in 2016 and 2017, respectively. The corresponding risk-based SBP certified biomass covered 13% and 54%, respectively (Fig. 3). Various types of alternative documentation were also used, but this fraction was reduced from 2016 to 2017 (Fig. 3).

Industry Agreement non-compliance

In 2016 and 2017, three energy companies did not reach the targeted share of IA compliant biomass, and by April 2019, two other companies have not published a sustainability report for one of those 2 years. Additionally, six energy companies were supposed to report according to the IA because they are larger than 20 MWth, but they have not published reports for either 2016 or 2017. These six companies each used less than 0.5 Mt of wood chips and/or wood pellets in 2016, which amounts to a total of approximately 0.15 Mt for all of them together [37], see also Additional file 1. Thus, there is no third-party audited documentation of sustainability for this

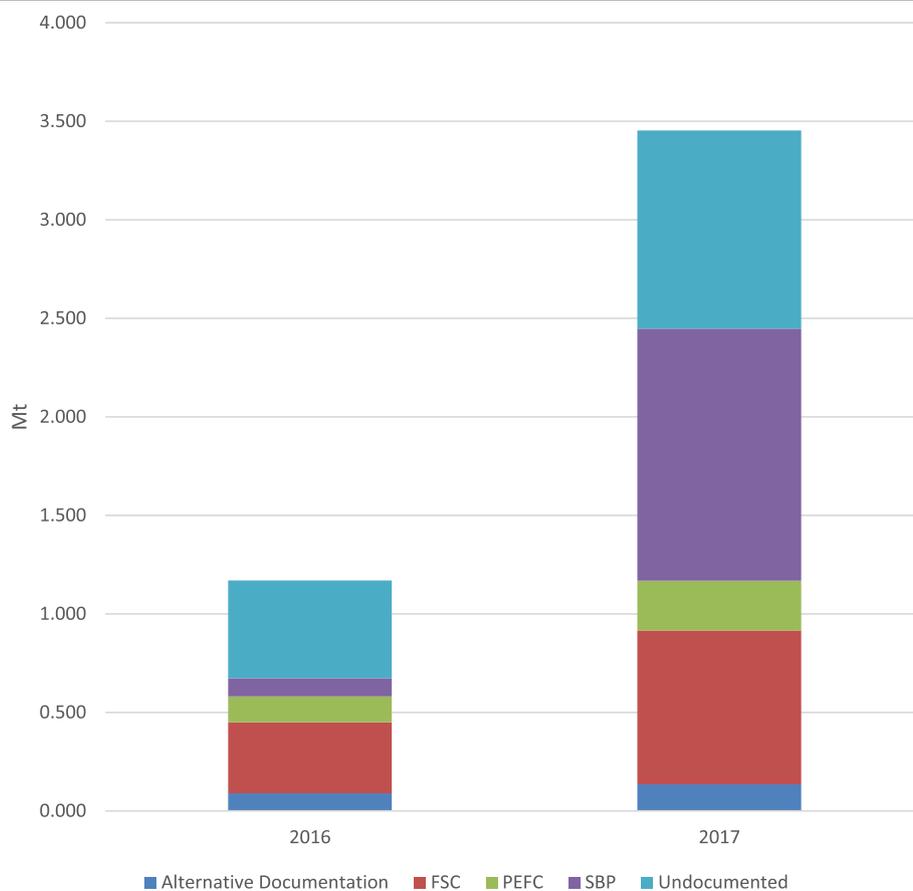


Fig. 3 Forest biomass sustainability documentation systems used by Danish energy companies in 2016 and 2017. Data from "Additional file 1"

biomass and no publicly available details on feedstock types, supply chain levels, etc.

Discussion

Coverage of the IA and its limitations

This study aimed at evaluating the extent of which the current sustainability documentation for forest solid biomass consumed by the Danish CHP and heating sector is in compliance with the requirements of the IA. We found that there is generally a high degree of compliance. However, in order to achieve a thorough assessment of the effect of the IA in Denmark, it is important to consider all solid biomass consumption, also beyond what is liable to the IA. Barriers to getting a more complete picture include the following:

- There is a gradual implementation of the IA (Table 3), and it is not yet (2017) fully phased in.
- The information available from the third-party audited reports submitted under the IA is still incomplete. Three companies did not report to the IA in either 2016 or 2017, and six companies did not report to the IA for any of those 2 years.
- There is no or only little information about the non-compliant wood in the reports, which will perhaps persist for the 10% that can be used with no documentation, also after the IA is fully implemented.
- Solid biomass consumption by energy companies < 20 MWth is not subject to documentation requirements. In 2016, there were 183 such energy companies using wood pellets and/or wood chips in Denmark [37].
- Household consumption is not subject to documentation requirements. Some information on the used amounts is available from two recent Danish surveys, but no information exists on sustainability characteristics of this wood. Also, the surveys focus on fire wood and wood pellets, with no detailed information on the use of wood chips or wood waste by households [26, 27]. In 2017, 57% of the total Danish consumption of wood for energy was covered by the IA, while almost 1.2 Mt wood chips and wood pellets (Table 1) was used outside the energy sector to heat private homes, in industries etc.
- The IA exclusively regulates solid biomass from forest areas as defined by FAO [18]. There is no sustainability requirement in place for wood from outside forests such as hedgerows, landscaping trees, horticultural wood waste or short rotation coppice crops from agriculture. Probably, this source of biomass presently accounts for a small fraction of the total sourcing, but only very little data is available to

evaluate if this is true. A recent national analysis of solid biomass resources shows that a large additional amount of domestic wood from outside forests can potentially be available for the energy sector [69].

- Tertiary biomass, i.e., post-consumer wood, is not subject to the requirements of the IA.

We suggest that a study to assess the total amount of solid biomass used for energy in Denmark, as well as the associated sustainability risk, would be useful as an element in the further clarification of the adequacy of the IA for Denmark.

Two biomass markets

Although wood consumption outside the medium to large-scale energy sector is not liable to the IA documentation requirements, this does not necessarily mean that the used wood does not meet the sustainability criteria of the IA or is covered by some other type of sustainability governance scheme. The small-scale energy sector (< 20 MWth) is liable to the IA, but not the documentation requirements (Table 3). All solid biomass placed on the market in EU Member States is covered by the EUTR [95], which aims at documenting low risk of illegality. Also, some solid biomass might come from forests certified under FSC or PEFC, as is the case with all fire wood and other wood fuels from Danish state forests [76]. The two most recent Danish surveys of household wood pellet and fire wood consumption show, however, that there are no detailed statistics or information on the origins or sustainability properties for the large fraction of solid biomass for energy used outside the medium to large-scale energy sector [26, 27].

There is a risk that this situation will result in two types of markets for solid biomass for bioenergy. The first would be a market with sustainability governance and documentation requirements through the IA, which supplies the medium to large-scale energy companies, mostly with wood pellets and wood chips. This market is ramping from 40% IA coverage in 2016 to 90% in 2019. This market will also be regulated by RED II by 2021 [45]. The second market will be supplying private homes, industry and small-scale energy plants mostly with wood pellets and fire wood. Parts of this market will have sustainability governance possibly with third-party auditing, but it is presently unknown what fraction is covered and by which systems, nor to what extent it will be covered by sustainability governance in the future. A worst-case scenario would be if this market is or develops to be an outlet for “unsustainable” biomass.

Enough information to see biomass sourcing patterns?

The results showed that three or four supply chain levels could be distinguished for solid biomass used in the Danish energy industry. These results are substantiated by a survey conducted by EA Energianalyse [27] that found 94% of the wood pellets consumed in Denmark in 2016 were imported, with most of the wood pellets originating from countries around the Baltic Sea and about 10–15% from global supply chains. Some biomass is not included in the reporting to the IA, but about 63 % of the total amount of the consumed wood pellets in Denmark in were covered 2017 [38], which is probably adequate to show the pattern.

Danish forestry organizations found in 2013 that about 55% of the Danish wood chip production was consumed by small CHPs and heating plants. Large CHPs were responsible for approximately 30%, and approximately 24 % in 2016, of all wood chips consumed in Denmark. The remaining was consumed at small CHPs and heating plants [21, 38]. In accordance to our results, this shows that it is the small energy companies that source most of the local biomass as wood chips. This confirms that local supply chains are the most important for wood chips presently. This might change when a new large CHP in Copenhagen will start operating in 2019 with a total expected consumption of up to 1.2 Mt wood chips per year [62]. The sourcing patterns are thus dynamic, and it is important to follow the development, to see if new concerns arise.

As discussed above, there is only scattered information and statistics available on Danish wood consumption and the energy sector does not provide much more quantitative detail in their IA reports because most energy companies provide little detail about their wood sourcing in relation to country of origin (Additional file 1). Thus, it can be difficult to analyse and evaluate the supply chains of Danish energy companies with only official statistics and IA reports. Sourcing volumes of official statistics cannot be coupled to specific energy companies and IA reports are often not sufficiently detailed.

Adequacy of sustainability frameworks

From 2021 onwards, the RED II will come into effect and overrule subsidies and inclusion of bioenergy in renewable energy targets for biomass not meeting and documenting compliance with the risk-based sustainability criteria of RED II [96].

An important discourse is whether regulatory sustainability criteria such as those in Denmark, the UK, the Netherlands, Belgium and the entire EU from 2021 are sufficiently addressing sustainability concerns, especially in terms of climate change mitigation and carbon stocks. One focal point of these

criteria is ensuring sustainable forest management (Table 2). In recent years, there has been scientific disagreements as well as public debates about whether the use of solid biomass for energy is sustainable and what the climate impact of burning wood for energy is [10, 14, 82]. Even if sustainability criteria are applied for solid biomass used for energy in the EU, there still is an argument from some scientists that it is not sufficient to ensure that there are benefits for climate, while others are concerned with biodiversity preservation. Other researchers come to different conclusions about the climate impacts of solid biomass, e.g. ([6, 83]).

Another issue relates to the complexity of wood markets and wood end-uses as well as their related sustainability governance. It is difficult to make an all-encompassing sustainability scheme that can regulate every use-case and sector, and this might result in wood markets affected differently by sustainability regulation depending on end-use [73].

Adequacy of certification schemes

The biomass certification sector is very dynamic and is likely to see new developments in the near future. Some pellet and energy companies are working to increase transparency of their feedstock sourcing, with online tools to display origin, type and other information, e.g. ENVIVA, [41] and DRAX [25]. Such work is also ongoing in relation to the EUTR [97], as well as work to explore verification of sustainability indicators with spatial data [72]. This might be crucial to verify sustainability for uncertified areas, e.g. as a basis for risk assessments, as required by SBP and RED II. For implementation of RED II criteria, it also seems likely that some adjustments will take place at all regulatory levels, including legislation, in national sustainability systems and within private certification. In sourcing countries with no ratification of the Paris Agreement, new accounting systems might be needed at finer scales to demonstrate that forest carbon stocks are not declining in the long-term in biomass sourcing areas [96].

The FSC, PEFC and SBP systems are accepted by the parties to the IA for showing compliance with the SFM requirements [18]. The FSC and PEFC systems are logical choices as their criteria for SFM represent a relatively long-lasting and high degree of consensus within international and national stakeholder communities. SBP builds on the criteria of these systems, but has made an effort to develop a novel risk-based approach for uncertified forests, where the auditing focuses on criteria assessed with specified risk [91]. Criteria assessed with low risk are typically covered by well-enforced legislation; otherwise, available statistics and data may suggest that risk is low.

Forest biomass has increasingly been used for energy since the 1980s (Fig. 1), and the associated forest practices have not been subject to any major pushbacks from societal actors. Some NGOs in Denmark consider that FSC is the only credible forest certification system [75], but governmental procurement policies have also considered FSC and PEFC as equally credible. Of the Danish forest area, around 20% is certified according to FSC and 40% to PEFC, with the major share being state forest. The risk-based approach by SBP and RED II has not yet been subject to any major criticism in Denmark, even if there has been some pushback in some other EU member states and internationally. Possible reasons can be perceptions of progress compared to existing approaches, and a relatively long tradition for communication between industry, public authorities, government and societal actors, with focus on collaboration, finding solutions and common ground. However, additional studies are possibly needed to confirm this.

Future developments and perspectives

The Danish Council on Climate Change [66] has recently suggested improvements to sustainability assurance frameworks for solid biomass. They suggest that the government establish a task force “for development of accurate and verifiable indicators that can be integrated into the existing sustainability criteria for solid biomass” with a focus on carbon stocks and the carbon cycle as well as LULUCF-regulation and indirect land-use change [66]. This shows that there are calls for strengthened sustainability governance in Denmark—also in addition to what will be required by RED II (Table 2). Some of these topics are already mentioned in the IA under criterion 8 (Table 3), but they are presently only included as encouragement not to use some kinds of solid biomass. Additionally, criterion 8 states: “If standardised methods for documenting retention of forest carbon stock, IWUC- and ILUC effects, are developed, the industry must accept these methods before they can be incorporated into the industry agreement as documentation requirements.” [18]. Thus, a strengthened IA and/or sustainability criteria are already on the agenda in the energy industry as well as at The Danish Council for Climate Change which advises the government. At the time being, there are, however, no specific plans to make changes to the IA, until the implementation of RED II has taken place in 2021. The implementation of RED II into Danish law is not yet subject of any public discussions, and it is presently difficult to predict how it will be performed. It is evident that some of the requirements of RED II are different from the IA (Table 2), but RED II still allows member states to make their own sustainability criteria [96]. It

is still uncertain to which extent it is needed to adapt to RED II and to which extent the current approach will be continued, but it seems likely that actors will want to build on what has been achieved up till now

Conclusion

The Danish voluntary IA has proved effective in governing the medium to large energy company sourcing of solid biomass for energy. In only 2 years, the volume of biomass that is documented to be sustainable according to the IA has gone from zero to approximately 2.5 Mt of biomass out of a total of around 3.4 Mt. This is 71% of the total sourcing of medium to large energy companies participating in the IA and 57% of total Danish solid for energy consumption in 2017. As such, the IA has proved to be successful in including a high fraction of the Danish solid biomass in its sustainability framework from its conclusion in late 2014 to the reported status in 2017.

However, there are also challenges with this type of governance. The IA is phased in gradually from 2016 to 2019, and several energy companies are not complying with the volume requirements or have not published sustainability reports. This leads to uncertainty about the sustainability governance of these non-compliant companies and the fraction not covered by the IA because there is no third-party audited documentation for this fraction of the solid biomass sourcing. Similarly, the small-scale energy companies have no documentation requirements and the entire solid biomass use taking place outside the energy sector is also with unknown sustainability governance. Thus, there is a risk of consuming biomass without sufficient sustainability governance. No documentation exists to evaluate whether or not this is the case.

The supply chain level results show that Danish medium to large energy companies source solid biomass from supply chains at all levels, but most frequently from local or regional supply chains. There is a lack of quantitative information of sourcing regions in the IA reports. Wood pellets constitute 61–65% of the sourcing in 2016 and 2017, respectively, and the large companies source the largest volume of solid biomass. Different certification schemes are used to document compliance with the sustainability criteria. From 2016 to 2017, a shift has taken place from predominantly SFM certification in 2016 to risk-based certification in 2017.

In 2018, the European Union has adopted a new renewable energy directive that introduces sustainability criteria for solid biomass from 2021. The EU criteria are similar to the Danish criteria, but renewable energy subsidies and inclusion in renewable

energy targets are dependent on compliance instead of the voluntary approach presently used. This Danish case study suggests that sustainability criteria for solid biomass for bioenergy are operational for medium to large energy companies and thus demonstrates that risk-based certification is an operational approach for ensuring compliance with sustainability criteria for forest-based solid biomass.

Additional file

Additional file 1: Supplemental information. (XLSX 26 kb)

Abbreviations

CHP: Combined Heat and Power; EU: European Union; EUTR DDS: Due Diligence System according to the EU Timber Regulation; FSC: Forest Stewardship Council; GHG: Greenhouse Gas; IA: Industry agreement to ensure sustainable biomass (wood pellets and wood chips); iLUC: Indirect land-use change; iWUC: Indirect wood-use change; LULUCF: Land use and land-use change and forestry; NGO: Non-governmental organization; PEFC: Programme for the Endorsement of Forest Certification; RED I: The first renewable energy directive from 2009 (Directive 2009/28/EC); RED II: The revised renewable energy directive from 2018 (Directive (EU) 2018/2001); SBP: Sustainable Biomass Program; SFM: Sustainable forest management

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Authors' contributions

SL conceived the idea, performed the data analysis and drafted the first versions of the manuscript. All authors interpreted the data, revised the manuscript and approved the final version.

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Availability of data and materials

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Competing interests

SL is employed by Danish Energy. The other authors declare that they have no competing interests.

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