The contribution of Danish forestry to increase wood production and offset climate change 2010-2100

Perspectives for the contribution of forests and forestry towards a 'green' bio based economy in Denmark

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Summary: the potential contribution of the forests to produce wood and store carbon

The consumption of wood in Denmark is around 18 million m3 per year of which 8.5 million m3 for energy, 4-5 million m3 for merchantable wood, and the rest for paper. Approximately 3.5 million m3 origins from the Danish Forests, about 3 million m3 are from other domestic sources and as much as 11-12 million m3 are imported. The degree of self-sufficiency is thus below one third with about 20 % of the total consumption originating from the Danish Forests.

At the same time forests store carbon. The above ground woody biomass contains currently 40 million tonnes of carbon, which is growing slightly each year because the annual increment of the forests is larger than the annual harvest of wood. These figures of growth, storage and harvest can be improved significantly.

The harvest of wood towards 2050 could increase by 30 % while, at the same time, storage of carbon in the forests could increase by a similar magnitude. The share of wood for energy could grow from current level of about 2 % of the Danish energy consumption to constitute almost 5 % already in 2020, more than 7 % in 2015 and close to 13 % in 2100.

A parallel growth in the carbon store of the forests, implies that the annual displacement of fossil carbon and build-up of carbon in the forests and forest products may grow from a level below 5 million tonnes of CO2 per year to 6 million tonnes in 2020, 7-9 million tonnes in 2015, and 10-13 million tonnes in 2100, corresponding to an increase from less than 10 % to more than 20 % of the current annual Danish emission of CO2 (level 2011).

For this potential contribution of Danish forests and forestry to be realised will require a continued expansion of the forest area to reach 25 % of the land area by 2100, and forestry would focus more on increasing productivity than at present. If the current Danish targets of reduction of CO2 with 80-95 % are achieved by 2050, the accumulation and displacement by the Danish forests and forestry will correspond to more than half of the annual Danish emissions and in 2100 be at the same level as total Danish emissions.

FOTO: THOMAS NORD-LARSEN

Forests accumulate carbon in the trees and the soil. Old forests typically contain more carbon than young forests, whereas young forests often absorb carbon faster from the atmosphere than old forests.

Introduction

Denmark is faced with challenges of transforming energy supply and counteract climate change. The current Danish plans are that Denmark by 2050 should rely on renewable energy only and that emissions of CO2 should be reduced by 80 %. The goals of this transformation are illustrated in the two diagrams shown in Figure 1.

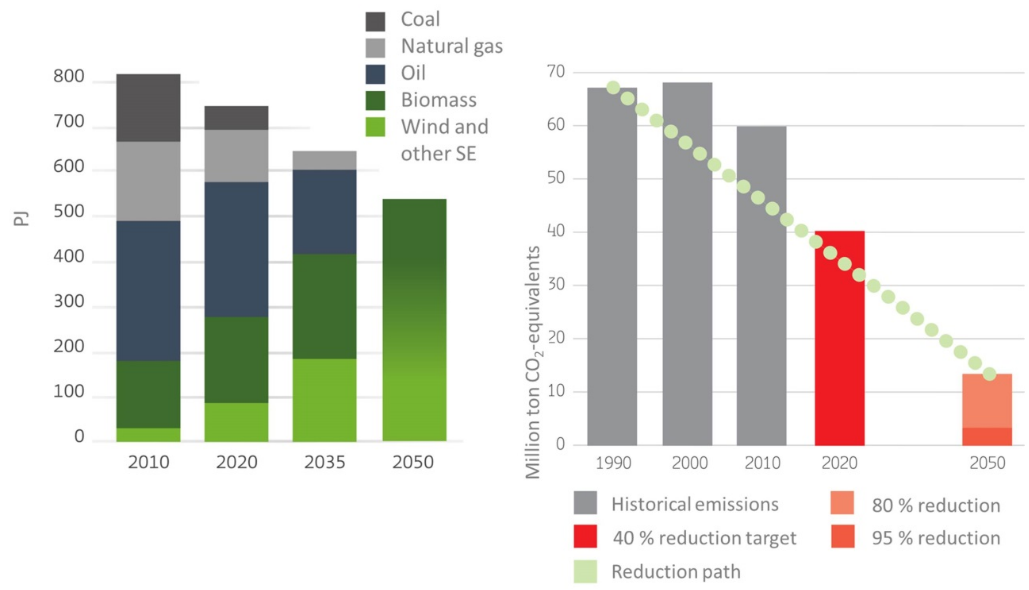

Figure 1:Danish plans for transformation to renewable energy and reduction of CO2 to the atmosphere (Sources: The Danish Government 2011 and 2013, Figure 3.8 (Use of fossil fuels and renewable energy (petajoules, PJ) and Figure 2 (Historical Danish CO2 emissions

In 2013, the Danish Ministry of Environment (now part of the Ministry of Food and Environment), requested the University of Copenhagen to assess how measures in the Danish forests could contribute to this transformation. The assessment is limited to the productive functions of the Danish forests.

Results were published in Danish in 2013 and 2014 in a larger Report, a smaller Booklet (Graudal et al.2013a and 2013b, both available on the homepage of the University of Copenhagen), and an extended abstract in English (Graudal et al.2014)http://www.slu.se/Global/externwebben/s-fak/skogens-produkter/Dokument/SSFE/Roos_A_et.al_20140227.pdf. The present publication is a slightly modified translation of the Booklet (Graudal et al. 2013b) incorporating the extended abstract in English (Graudal et al. 2014).

The purpose of the study

The purpose of the study was to evaluate the opportunities to increase production and optimise use of the wood resources in the Danish forests in a 'climate friendly' way with due consideration to the other functions of the forests in multipurpose forestry as practised in Denmark, including recreation, environmental protection in a more broad sense, and as habitat for biological diversity. The intention was furthermore to contribute to evaluate in which areas there would be a need to develop new and better guidelines for forestry practice.

The main emphasis of the study is to evaluate the options for forestry to mitigate climate change, understood as the effect of different silvicultural strategies on the carbon balance. The overall purpose is to demonstrate how to expand the forest resource and the use of wood to at the same time achieve increased carbon accumulation (storage) and decreased use of fossil energy sources.

Targets for use of wood in the energy supply

The Danish Government goals of 2011 for a 'green' transformation of the society have the implication that Denmark in 2050 should depend on renewable energy sources only. According to the Government strategy, 'Our energy' from November 2011, biomass is expected to play a key role in this transformation. Currently, wood constitutes about half of the biomass used for energy or about 10 % of the total Danish energy consumption. Only a limited share originates, however, from the Danish forests (2-3 % of the energy consumption) and a large share is imported.

Use of wood and forestry to mitigate climate change

In a climate context, the use of biomass for energy is relevant if it is produced in a sustainable manner (often labelled 'CO2 neutral') because it can displace fossil fuel.

Wood used for other purposes, e.g. furniture and buildings or paper is also 'climate friendly' because such products serve to store carbon for a period of time. They may thus not only be CO2 neutral but 'CO2 positive' in the sense that they can contribute to reduce the atmospheric content of CO2 during a period of time.

The question of whether use of wood biomass for energy actually is CO2 neutral or 'friendly' has been debated a lot in recent years. It is important to note that the CO2 neutrality only is valid when certain sustainability conditions are fulfilled. A somewhat simplified way of looking at this sustainability is to say that the wood biomass should originate from forests where the standing volume of wood and soil carbon either remain at the same level or are increased. If the standing volume is increasing, there will be a continuous build-up of carbon which reduces the amount of CO2 in the atmosphere.

The positive 'climate friendly' effects can thus be achieved in two different ways. The first by increasing the carbon store in the forest where a direct reduction of CO2 in the atmosphere takes place, and the second by substituting or displacing the use of fossil based energy. The latter substitution effect is positive with respect to the carbon balance because it prevents release from the permanent fossil stores of carbon. When carbon is released from this fossil store, the 'free' amount of carbon which has to be accumulated by the four 'free' carbon pools (the atmosphere, the oceans, the plants and the soil) will increase.

It is important to distinguish between the five mentioned carbon pools. Release of carbon from the fossil pool delivers an irreversible contribution of more carbon to the four other pools. Between the four other pools exists a complex balance which determine the amount of carbon in the atmosphere. The fossil amounts of carbon are huge and the oceans, the plants and the soil can absorb some of the fossil carbon that is released, but their capacity is limited and furthermore dependent on the composition of the atmosphere and its effect on the climate. The long term consequences of releasing large amounts of fossil carbon are therefore severe changes in climate.

Although the substitution effect mentioned is positive it is not in itself sufficient to achieve a positive effect on the climate. It is important that the balance between the four free carbon pools remains relatively stable to avoid forcing the atmosphere to accumulate an increasing amount of carbon. Harvest of wood for energy should therefore take place from a forest, a plant system, where an amount corresponding to the harvest is build up and stored at the same time. For annual crops or crops in short rotation grown continuously on agricultural land with stable or increasing yields without any significant more permanent carbon pool on the land, CO2 neutrality is usually taken for granted.

For perennial crops – trees – the situation is not quite as simple. For one thing the harvest often constitutes many years of accumulated carbon in the wood, for another, quite large amounts of carbon can be released from the soil if an area is de-vegetated, and furthermore, the increment and accumulation of wood in a forest vary with age and composition. The forest is at the same time store, production machinery and product. When assessing the sustainability of forestry it is therefore necessary to look at larger forestry units as a whole.

A basic principle in modern forestry is to ascertain sustained yield. The ideal is a so-called 'normal' forest where the annual harvest does not exceed the annual increment. In this way the standing volume of wood – and thereby the amount of carbon stored – remains constant or increasing, even if the whole harvest is used for fuel. For the forest as a whole CO2 neutrality will be valid in the short as well as the long term. The relation is illustrated in Figure 2.

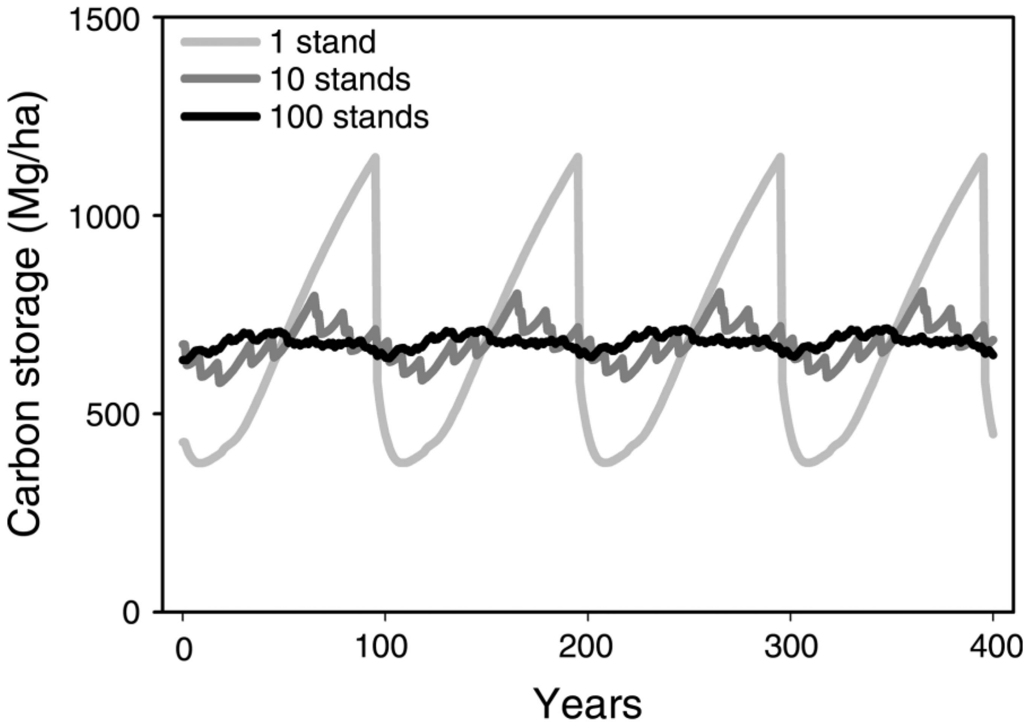

Figure 2:The effect of forest management on the carbon balance needs to be assessed for larger operational units over longer periods. The figure here shows a model for how the amount of carbon per unit area fluctuates depending on the number of stands analysed in a traditional forest management regime with successive generations of planting-growth-harvest. The average carbon store depends among other things on the generation turn-over (Source: reproduced from Mckinley et al. 2011, fig. 3).

In this study we treat the whole Danish forest area as our observation unit. It is crucial not to reduce the carbon store, not to deteriorate the productive capacity and to optimise the harvest products and their use.

Biomass can substitute fossil energy. Effect on the carbon balance depends on from where the biomass origins, how it is converted to energy and which types of fossil fuel are substituted.

The stability of the forests and their carbon 'pulse' depend on how they are renewed. Holistic sustainable forest management is decisive for the outcome.

Wood buildings store carbon and displace fossil based building materials. The effect can be huge, as the production of other building materials like cement and steel requires a lot of energy.

Wood consumption in Denmark

The consumption of wood in Denmark is large. According to FAO, it was in 2011 about 15.5 million m3 of which 5.5 million m3 was used for energy purposes. To this should possibly be added around 3 million m3 used for energy, which are not captured by wood supply statistics (production and trade surveys by Statistics Denmark), but accounted for by wood consumption statistics by the Danish Energy Agency.

The total consumption of wood, illustrated in Figure 3, was thus in 2011 in the order of 18 million m3 distributed with 8.5 million m3 to energy, 4-5 million m3 to timber and the rest for paper. Approximately 3.5 million m3 origins from the Danish Forests, about 3 million m3 are from other domestic sources and as much as 11-12 million m3 are imported. The degree of self-sufficiency is thus below one third with about 20 % of the total consumption originating from the Danish Forests. The numbers are associated with some uncertainty, among other things because different categories of product are registered in different units and some in monetary value rather than quantity.

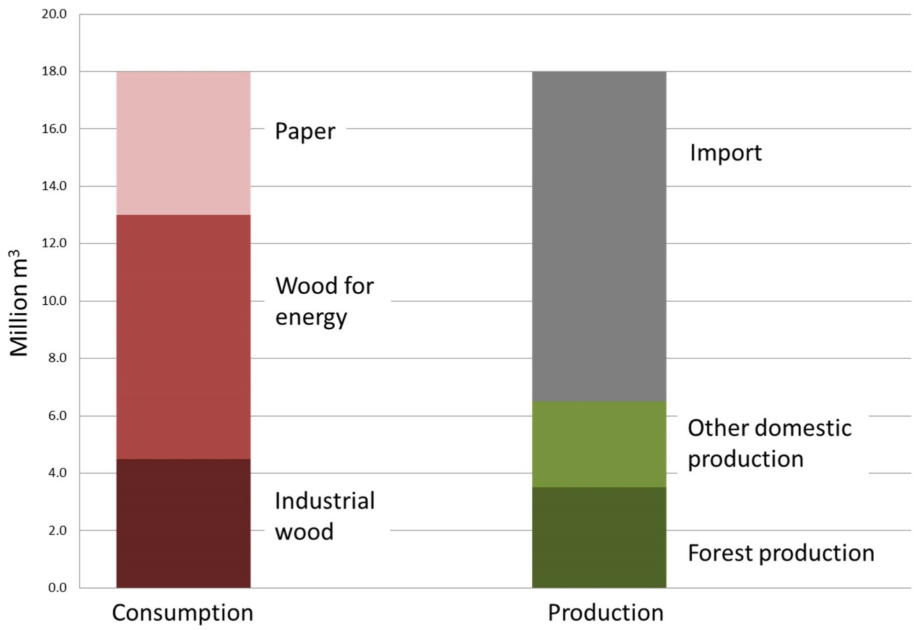

Figure 3: Consumption of wood in Denmark 2011 distributed to main categories of product (paper, energy, and merchantable wood) and origin (import, forest in Denmark, and other domestic sources).

Assessed in a climate and energy context, it is the carbon and energy content which is of interest. 18 million m3 of wood corresponds to approximately 9 million tonnes of dry matter, 4.5 million tonnes of carbon or 16.5 million tonnes of CO2. For comparison, the total Danish emission of CO2 in 2011 was 55.8 million tonnes. The energy content of 18 million m3 of wood is about 162 PJ corresponding to ca. 20 % of the current Danish annual energy consumption.

How can the production of wood and the carbon store of the forests be increased?

To assess how much the growth of the forests can be increased, point of departure has been taken in the current species and age class composition of the forests. How large areas, which species, their age and size, how much and how fast they grow, what and how much currently harvested, how old the trees are when this happens, what the harvested wood is used for, how the harvested trees are replaced by new seedlings, and the kind of reproductive material used in this replacement. All these parameters are known in varying degree of detail from the National Forest Inventory (NFI, Johannsen et al.2013). Each year, as part of NFI, data is collected that provides information on the parameters mentioned. It is therefore possible to prepare models for the wood production of the forests as a function of all these parameters or silvicultural measures, as we also call them because it is possible apply these measures in various degrees and different combinations in the management of the forests.

The effect on growth of nine silvicultural measures (parameters) and four different combinations (scenarios) of these parameters have been modelled. The nine parameters and the four scenarios are shown in Table 1. Other scenarios could be analysed as well, using other combinations of the silvicultural measures.

Table 1: The nine silvicultural measures (parameters) and the four different combinations of these parameters (scenarios) assessed by modelling in the study. BAU is current practice (Business as usual), BIO focuses on biomass production, ENV focus on environmental values and Combi combines production and environmental concerns.

Silvicultural measures/Parameters	**Scenarios**			
	BAU	**BIO**	**ENV**	**Combi**
Establishment of new forest: How much forest is planted on former agricultural land (ha/year)	1900	1900	4560	4560
Which tree species are used for these new forests?	As now	Conifers	Broadleave s	As now
What is the expected rotation age of the new forests?	As now	- 10 years	+ 20 yr (broadleave s) + 5 yr (conifers)	As now
Which species are used for regeneration of existing forests?	As now	Conifers to conifers; 50 % of broadleav es to conifers	Broadleave s to broadleave s; 50 % of conifers to broadleave s	As now
How is the forest regenerated? More intensive regeneration: Higher planting density, use of fast growing cover crops, providing early and higher biomass production	As now	Intensive	As now	Intensive
How large areas are kept out of forest production management to serve e.g. biodiversity (in % of current forest area)	As now	As now	approx. 10 %	approx. 10 %
How many and how much of the individual tree is removed from the forest?	As now	+ 20 % rel. to BAU	- 20 % rel. to BAU	As now
What is the wood used for? E.g. firewood or timber. More or less energy wood.	As now	More energy wood	Less energy wood	More energy wood
How good is the planting material in planted forest in terms of breeding intensity	As now	More breeding	More breeding	Intensive breeding

Graudal et al. (2013a) describe and analyse the individual measures and their effect on production of wood and the carbon store in the forests. Here we limit ourselves to look at four selected scenarios, which all are considered realistic options in future Danish forestry.

Un-touched forest is important for conservation of biological diversity and will typically contain more carbon than managed forest but with age accumulate less and less carbon.

How large is the effect on the production and the volume of wood that is built up in the forests?

Table 2 show total harvest under the four scenarios (see also Figure 5) and how large a share of the domestic consumption this may cover. BAU remains at a self-sufficiency of around 25 %, whereas this may increase to about 30 % under other scenarios in 2050 and continue to increase up to 40-50 % towards 2100 primarily through a combination of increased forest area (Combi and ENV), more intensive silviculture and breeding (BIO and Combi), higher degree of utilization (BIO), but also combined with concern for biodiversity and environment (ENV and Combi).

Table 2: Development in the annual harvest of wood (million tonnes dry matter) from 2012 to 2100 in total and by wood for industry and energy, and self-sufficiency with wood products (% of total consumption) under the four scenarios.

Harvest (million tonnes dry matter)		2012	2020	2050	2100
Total consumption		9	10	10.5	10.5
BAU	Industrial	1.4	1.3	1.3	1.6
	Energy	1.0	0.9	1.0	1.2
	Total	**2.4**	**2.3**	**2.3**	**2.8**
% of consumption		**26.5**	**22.6**	**22.3**	**26.8**
BIO	Industrial	1.0	1.0	1.0	1.5
	Energy	2.3	2.0	2.4	3.6
	Total	**3.3**	**3.0**	**3.3**	**5.1**
% of consumption		**37.1**	**29.8**	**31.7**	**48.6**
ENV	Industrial	0.6	0.6	0.8	1.4
	Energy	1.4	1.2	1.6	2.0
	Total	**2.0**	**1.9**	**2.4**	**3.4**
% of consumption		**22.0**	**18.8**	**22.5**	**32.4**
Combi	Industrial	0.6	0.6	0.8	1.5
	Energy	1.6	1.5	2.6	4.1
	Total	**2.2**	**2.2**	**3.4**	**5.6**
% of consumption		**24.8**	**21.5**	**32.4**	**53.0**

Table 3 focuses on the supply of wood for energy under the 2050 goal of achieving 100 % sustainable energy supply. The table shows domestic production in forest, i.e. excluding production outside forest and import. Imports, primarily in the form of wood pellets currently constitute about half of the Danish energy supply of wood. The potential degree of self-sufficiency with domestic produced wood from the Danish forests is also illustrated in *Figure 4* below.

Table 3: Development from 2012 to 2100 in annual harvest of wood for energy in Denmark (million tonnes dry matter and PJ), share of total energy consumption under the 2050 goal and share of the estimated need for wood energy under this goal (cf. "Vores Energy").

Harvest (energy wood)		2012	2020	2050	2100
Wood energy target (PJ)		81	90	100	100
Total energy consumption (PJ)		814	750	650	550
BAU	(million tonnes dry matter)	1.0	0.9	1.0	1.2
	(PJ)	18.3	17.0	18.0	21.2
% of energy		**2.3**	**2.3**	**2.8**	**3.9**
% of wood energy target		**22.6**	**18.9**	**18.0**	**21.2**
BIO	(million tonnes dry matter)	2.3	2.0	2.4	3.6
	(PJ)	41.5	35.8	42.7	65.3
% of energy		**5,1**	**4.8**	**6.6**	**11.9**
% of wood energy target		**51.2**	**39.7**	**42.7**	**65.3**
ENV	(million tonnes dry matter)	1.4	1.2	1.6	2.0
	(PJ)	25.0	22.4	28.2	36.4
% of energy		**3.1**	**3.0**	**4.3**	**6.6**
% of wood energy target		**30.9**	**24.9**	**28.2**	**36.4**
COMBI	(million tonnes dry matter)	1.6	1.5	2.6	4.1
	(PJ)	29.3	27.1	46.3	73.9
% of energy		**3.6**	**3.6**	**7.1**	**13.4**
% of wood energy target		**36.2**	**30.2**	**46.3**	**73.9**

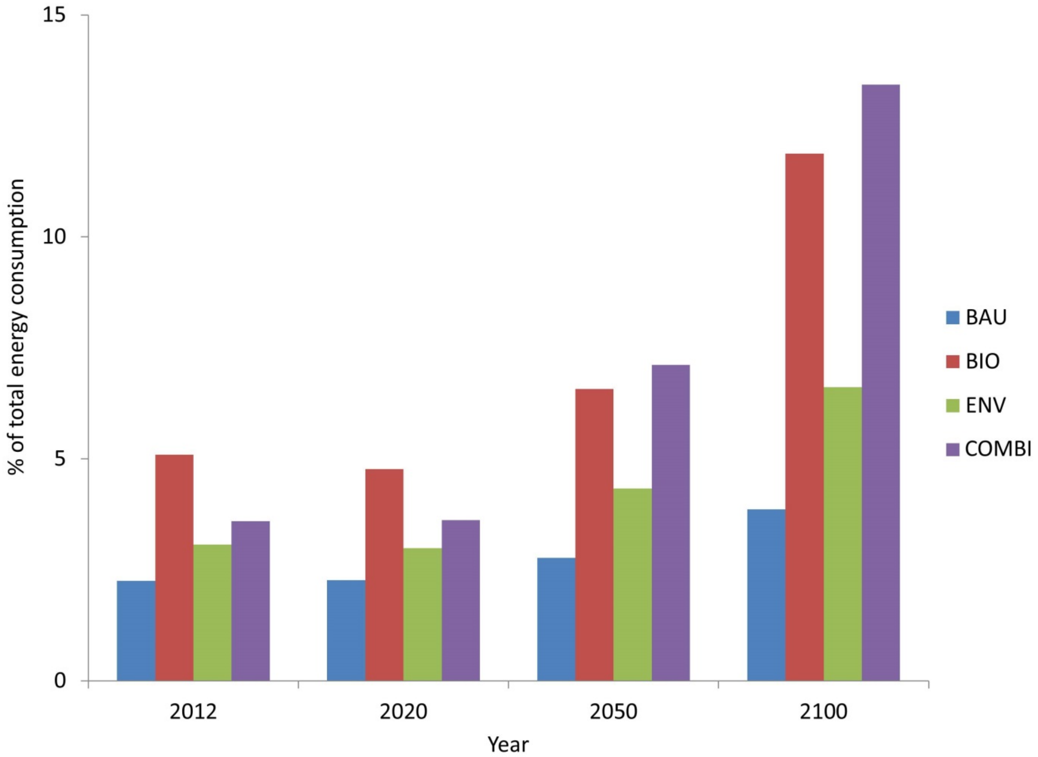

Figure 4: Total modelled harvest of energy wood in the Danish forests in percentage of total energy consumption in the four different scenarios. The development illustrated is a factor of increased forest production as well as reduced energy consumption over time.

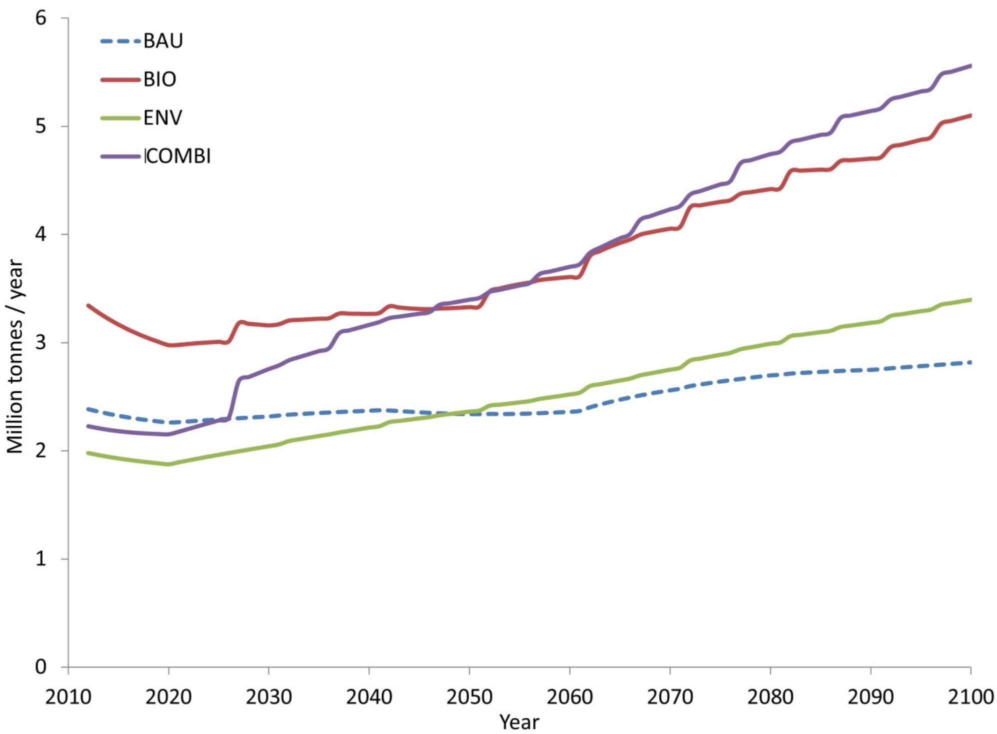

Figure 5:Development of total production for the four scenarios until 2100. Production measured as annual harvest in million tonnes dry matter of industrial wood and wood for energy

Already BAU shows an increasing coverage due to the expectation of increasing energy efficiency (lower energy consumption), but also the increasing forest area. The other scenarios show that with the right combination of parameters it should be possible to live up to the 2050 goal and reach this with decreasing dependency on imports. There is room for either increasing the share of wood for energy supply or use a larger share of wood for other purposes (cf. Table 2), depending on the development of other sources of sustainable energy and to which degree the different silvicultural measures can be implemented in practice. It will of course also depend on what the market demands and at which prices.

What is the combined effect on the CO2 accounts?

Where Figure 4 and 5, and Table 2 and 3 focus on the harvest of products, which have a carbon storage effect in the form of products (part of the industrial wood) and a carbon substitution effect on fossil fuels (the energy wood), Figure 6 shows how much carbon is being built up in the forest itself under the four scenarios, i.e. a carbon storage effect in the form of a living storage of which it is possible to calculate the annual growth after harvest.

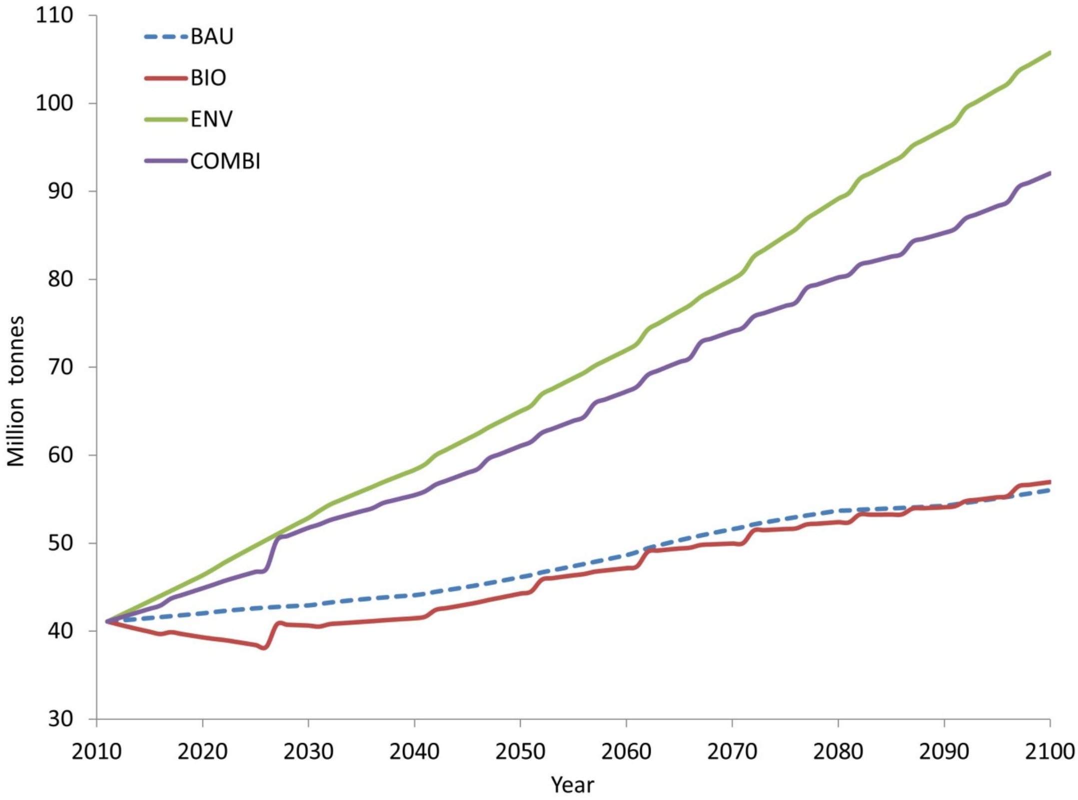

Figure 6:Accumulated amount of carbon in standing volume above ground (million tonnes).

Table 4 shows these three effects converted to annual production and growth respectively measured in CO_2 equivalents.

Table 4: Annual harvest of industrial and energy wood, respectively annual volume increment above and below ground (roots) measured in CO_2 (million tonnes). Total annual substitution and storage in % of emission of CO_2 in Denmark in 2011 (55.8 million tonnes)

	Mio tonnes	**2012**	**2020**	**2050**	**2100**
BAU	Industrial	2.5	2.4	2.5	3.0
	Energy	1.9	1.7	1.8	2.2
	Increment above ground	0.3	0.4	0.9	0.7
	Roots	0.1	0.1	0.2	0.1
	Sum	**4.8**	**4.6**	**5.3**	**6.0**
	% of emission 2011	**8.6**	**8.3**	**9.6**	**10.8**
BIO	Industrial	1.9	1.8	1.8	2.7
	Energy	4.2	3.6	4.4	6.7
	Increment above ground	-1.2	-0.7	0.9	0.6
	Roots	-0.2	-0.1	0.2	0.1
	Sum	**4.7**	**4.6**	**7.2**	**10.1**
	% of emission 2011	**8.5**	**8.3**	**12.9**	**18.0**
ENV	Industrial	1.1	1.2	1.5	2.5
	Energy	2.6	2.3	2.9	3.7
	Increment above ground	2.1	2.2	2.2	2.6
	Roots	0.4	0.4	0.4	0.5
	Sum	**6.2**	**6.0**	**7.0**	**9.3**
	% of emission 2011	**11.1**	**10.8**	**12.6**	**16.7**
Combi	Industrial	1.1	1.2	1.5	2.7
	Energy	3.0	2.8	4.7	7.5
	Increment above ground	1.3	1.4	1.8	1.9
	Roots	0.3	0.3	0.4	0.4
	Sum	**5.7**	**5.7**	**8.4**	**12.5**
	% of emission 2011	**10.2**	**10.2**	**15.0**	**22.5**

The combined effect is also shown in Figure 7.

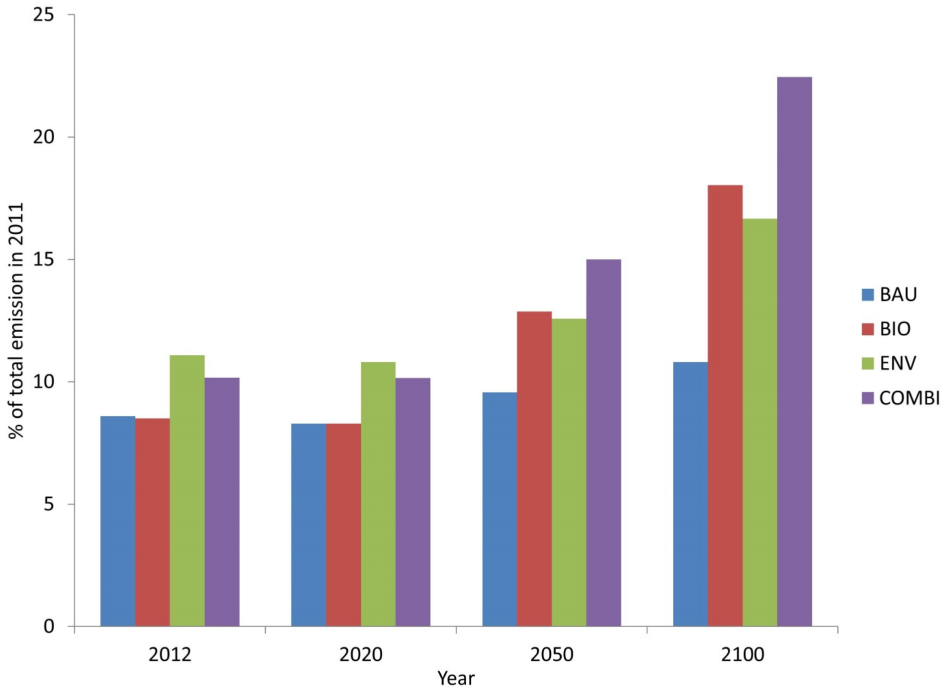

Figure 7: Estimates of the total effect of the Danish forests under the four scenarios, expressed in percentage of the Danish CO2 emission in 2011.

It is seen that the combined annual substitution and build-up of carbon is very significant. Through the scenarios with large forest establishment the effect can be brought up to cover in 2050 around 15 % and in 2100 more than 20 % of the current annual CO2 emissions. As the annual emissions are projected to fall very significantly throughout the period, the relative contribution of the forests to reduce emissions will be even bigger.

Mixed forest cultivation with fast growing 'nurse' trees can increase the early harvest yields of wood for energy and materials very significantly.

Discussion and conclusions

The limitations of the study and welfare economic questions

The complete study presents some results of a series of simulated scenarios that combine different forest management measures which impact the possible production of wood in the Danish forests over the current century.

Focus is exclusively on the effect of the different forest management measures on the amount of wood produced and sold as industrial wood and wood for energy, and on the amount of wood and biomass accumulated in the Danish forests. The welfare economic effects which the measures may have on e.g. recreation, groundwater protection, biodiversity, and landscape values are only marginally dealt with. A qualitative assessment of these effects is discussed in the full study (Graudal et al. 2013a), but not included in this account. Conclusions given here are therefore limited to the issues of wood production and supply.

The supply of wood and the carbon balance

The study shows that it is possible to increase the productivity of the Danish forests considerably and provide a significant contribution to Danish energy targets of achieving a 100 % supply of energy from sustainable sources in 2050 as well as to the reduction of Danish CO2 emissions. The potential for provision of these services from Danish forests is probably bigger than generally acknowledged given the fact that Denmark is a low forest cover country.

An overriding question is of course whether Denmark should prioritise domestic production of wood or continue to rely primarily on imports. The ambition of achieving self-sufficiency in energy supply and the goal of climate friendly production would be in favour of increasing the domestic production. Such a target also constitutes an important driver of development of Danish agriculture, forestry and industry.

Forests more rich in wood volume and of higher productivity will furthermore contribute to mitigation of climate change. In the Danish part of the hemisphere, predicted climate change may contribute to increased forest productivity. A caveat is however that the new forests are able to adapt, which will require investments in research, development and monitoring.

In other parts of the world climate change is likely to result in declining productivity. This underlines the need to look at the supply of wood and the carbon balance in an international perspective. Denmark will by necessity continue to cover a significant share its wood consumption from imports. If this is to be as climate friendly as the domestic production, imports should also be sustainably produced. This would be an argument for using the considerable Danish expertise with Danish as well as international forestry more actively in international co-operation, for instance in the Danish support to implement REDD+ (Reducing emissions from deforestation and forest degradation in developing countries including measures of conservation, sustainable management and enhancement of forest carbon stocks), approved at the climate COP 15 in Copenhagen in 2009 and confirmed at several occasions since then, notably with the declaration on forests at the Climate Summit in New York in 2014.

An expected increase in global demand of wood by a factor 3-4 before 2050, poses a number of challenges for the World's forests. Competition for productive land among different types of land use will demand considerable innovation, technological and political, to assure the supply of wood and agricultural products, in general. Globalisation implies that for example national strategies for conservation of forests or other types of nature may have un-intentional effects of land use change across borders to other countries. It is thus necessary, to integrate plans for expansion of domestic production with the sustainability of alternative imports and the consequences for the nature and the environment at the national as well as the international level.

The most effective measure to increase forest production in Denmark is most importantly an expansion of the forest area. This is in line with current policy from 1989 of doubling the Danish forest area within one forest rotation length of time. This target may be considered an arbitrary choice unless it is specified in terms of the goods and services (productive and environmental) it is going to provide. There is a need to qualify and quantify these goods and services to assure a balanced decision making basis for the extent and the design of the new forests.

A more surprising result of the study is probably that a combination of silvicultural interventions other than establishment of new forests e.g. more intensive plantings using fast growing species combined with breeding, may contribute to provide a potential increase of productivity of a similar magnitude as the expansion of the forest area. Of particular interest is that such high productivity systems can be established without the use of energy demanding fertilizers and pesticides.

The analyses of the study are made at an overall level covering the whole forest area and potential forest area development in Denmark. It is unlikely that such a programme can be implemented at full scale. Implementation will depend e.g. on the size of the estates, their development objectives and access to the relevant silvicultural competence. It is also clear that the potential gains only can be achieved through new investments in research and development of silviculture and tree improvement with focus on adaptation and production.

In the assessment of the forests as a supplier of wood, due consideration needs to be given to the other functions of the forests, e.g. for recreation, groundwater protection, biodiversity, and landscape values.

The right choice of species and tree improvement can contribute significantly to the productivity, health and stability of the forests.

Areas with need for guidance to forestry practice

Where the analyses clearly show the possibilities of improving production, they are more abstract with respect to the ambition of providing guidance for forestry practise.

For the purpose of practical implementation, the study supports a number of recommendations already given by the most recent Danish Forest Policy Commission (Skovpolitisk Udvalg 2011) and the general plan for '+10 million tonnes of biomass' (Gylling et al. 2012). Close interaction between research, development and implementation, together with public and private actors is crucial for these recommendations to become reality.

The study points at areas closely linked to the recommendations referred to and at forest management measures where there is a need to develop better decision making basis and tools for practise. These areas include models for forest establishment which promote productivity, stability and diversity; choice of future species to apply in forestry; cultivation models considering resilient (adaptable) growing systems; use of optimal planting material (with respect to purpose of production and site conditions); and coherence between more product oriented and optimising operation on the one hand and adequate environmental consideration on the other.

A particular challenge is to ascertain the stability and diversity of the forest trees as the underpinning element of the forest structure and the frame of other elements of biodiversity in a future with a different climate, risk of new pests and diseases, or shifts in patterns of interaction between already existing pests, the trees and other organisms.

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