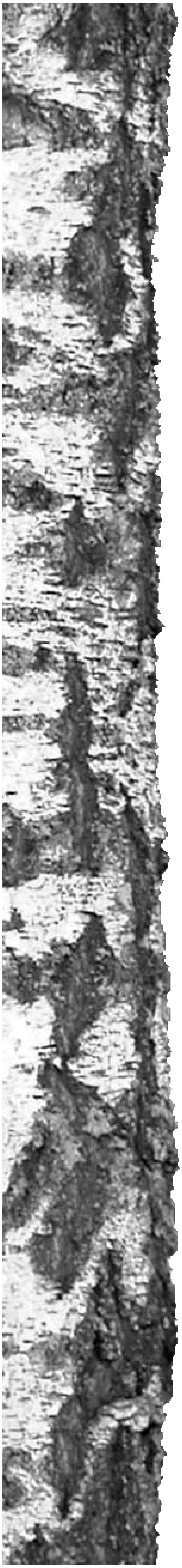

ISSN 1891-2281

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INA fagrapport 17

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2011

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Preface

This report provides an overview over the data used in the two Norwegian forest sector models NorFor and NTMIII. Both models include harvest of timber, processing in industry, demand of final products and trade and transport between regions and to/from Norway.

The development of NTM III is funded by the Research Council of Norway through the research projects “Second generation biofuel – technology development and impacts on biomass markets” (185371/S30) with co-funding from Agder Energi as. Development of NorFOR is funded by the University of Life Sciences –department of ecology and natural resource management.

We thank Per Kristian Rørstad for useful review of the manuscript.

Ås, 15. Juni 2011

Erik Trømborg

Hanne K. Sjølie

Summary

Trømborg, E. & Sjølie, H.K. Data applied in the forest sector models NorFor and NTMIII [Data anvendt i skogsektormodellene NorFor og NTMIII]. INA fagrapport 17, 58 pp.

This report provides an overview of the data used in the two Norwegian forest sector models NorFor and NTMIII. Both models are spatial partial equilibrium models describing the Norwegian forest and bioenergy sectors, including harvest of timber, processing in industry, demand of final products and trade and transport between regions and to/from Norway. Both models have endogenous prices of timber and wood products, but differ in the timber supply side, in the time horizon and the foresight information of agents. NTM has econometrically specified timber supply curves and no option of changing forest management and investment from the predetermined path. In NorFor, simulated growth and yields of all National Forest Inventory plots are included for several future management options. NTM is mostly applied for projections 10 – 20 years into future, while NorFor can currently be applied up to 100 years in future. NTM is a myopic model employing a recursive optimization, assuming that agents do not possess any information about the future beyond the current period. NorFor optimizes for all periods at once, and assumes that agents have perfect foresight.

2008 is base year for both models. Different methods and source are applied to establish the data sets documented in this report. Public statistics from Statistics Norway are used for prices, international trade, harvest and energy consumption. Data from the National Forest Inventory sample plots are used to estimate county-specific timber supply in NorFor. Elasticities of timber supply (only NTM) and demand for final products (both models) are based on econometric studies. Supply curves for harvest residues are based on available biomass and hauling costs. Plant level data in the pulp, paper and board industry are collected through interviews in the forest industries and annual reports. Input-output coefficients in bioenergy production are based on other studies and own analyses of data from Statistics Norway and Enova. Costs for expanding district heating systems are based on the heating market model X-Varme runs. Other parameters are forest management costs (only NorFor), transport costs and GDP growth as a basis for demand growth.

Data quality is an important factor in the quality of the results. Several aspects are related to data quality, as representativeness and data uncertainty. Data representativeness indicates how well the analyzed chain or products are represented, as the data often are taken from other geographical areas or adjacent products. Data limitations always exist, and models are simplified representations of the systems. However, consequences of data deficiency vary with the analyses. In general, data regarding production, prices and trade of wood, energy and forest industrial products based on figures from Statistics Norway are of high quality, whereas data of inputs and costs in the industry have weaker empirical basis and thus higher uncertainty.

Sammendrag

Trømborg, E. & Sjølie, H.K. Data applied in the forest sector models NorFor and NTMIII [Data anvendt i skogsektormodellene NorFor og NTMIII]. INA fagrapport 17, 58 pp.

Denne rapporten beskriver data anvendt i skogsektormodellene NorFor og NTMIII. Begge modellene er romlige, partielle likevektsmodeller, som beskriver de norske skog- og bioenergisektorene, inkludert avvirkningen av tømmer, prosessindustri, etterspørsel av sluttprodukter og handel og transport mellom regioner i Norge og til/fra utlandet. Begge modellene har endogene priser for tømmer og skogprodukter, men er forskjellige når det gjelder modellering av tømmertilbudet, tidshorisonten som analyseres og forutsetninger om aktørenes informasjon om fremtiden. I NTM modelleres tømmertilbudet basert på parametre fra økonometriske studier og det er ingen mulighet til å forandre skogbehandlingen fra den forutbestemte banen. I NorFor simuleres tilveksten på alle Landskogtakseringens prøveflater, og modellen inkluderer flere valg for fremtidig skogbehandling. NTM anvendes for analyser med 10-20 års horisont, mens NorFor kan i dag brukes for analyser med tidshorisont opp til 100 år. NTM er basert på rekursiv programmering hvor investeringen er basert på lønnsomheten i inneværende tidsperiode, dvs. aktørene forutsettes å ikke ha noe informasjon om fremtiden. NorFor optimerer for alle perioder samlet, og forutsetter på den måten at agentene har perfekt informasjon om fremtidige forhold.

2008 er basisåret i begge modellene. Ulike metoder og kilder er tatt i bruk for å etablere datasettene som er dokumentert i denne rapporten. Offentlig statistikk fra Statistisk sentralbyrå er brukt for priser, handel, avvirkning og energiforbruk. Data fra Landskogtakseringens prøveflater er brukt for å estimere tømmertilbudet på fylkesnivå i NorFor. Elastisiteter for tømmertilbud (bare NTM) og etterspørsel etter sluttprodukter (begge modellene) er basert på økonometriske studier. Tilbudskurver for hogstavfall er basert på tilgjengelig biomasse og transportkostnader. Data på fabrikknivå for papir-, masse- og plateindustri er samlet inn gjennom intervjuer og årsrapporter. Input-output koeffisienter for bioenergi er basert på andre studier og egne analyser basert på data fra Statistisk sentralbyrå og Enova. Kostnader for å utvide fjernvarmesystemer er basert på kjøringer med varmemarkedsmodellen X-Varme. Andre parametre er kostnader for skogbehandling (NorFor), transportkostnader og BNP-vekst som grunnlag for etterspørselsvekst.

Datakvaliteten påvirker kvaliteten på resultatene i analysene. Det er flere aspekter ved datakvalitet, slik som representativitet og datausikkerhet. Representativiteten indikerer hvor godt verdikjedene eller produktene er representert. Dataene er ofte hentet fra andre geografiske regioner eller lignende produkter. Begrensinger i dataene vil alltid eksistere og modeller er forenklete beskrivelser av de faktiske systemene som analyseres. Konsekvensene av mangler i dataene er avhengig av analysene som skal utføres. I hovedsak er data for produksjon, priser og handel med trevirke, energi og skogindustriprodukter basert på tall fra Statistisk sentralbyrå av god kvalitet, mens data for innsatsfaktorer og kostnader i industrien har et svakere emirisk grunnlag og derfor høyere usikkerhet.

Contents

1 INTRODUCTION

1.1 Overview

This report provides an overview over the data used in the two Norwegian forest sector models NorFor and NTMIII. Both models are partial equilibrium models describing the Norwegian forest sector, including harvest of timber, processing in industry, demand of final products and trade and transport between regions and to/from Norway. Both models have endogenous prices of timber and wood products, appearing from the optimal solution shadow prices. They differ in the timber supply side, in the time horizon and the foresight information of agents. NTM has econometric specified timber supply curve and no option of changing forest management and investment from the predetermined path. In NorFor, simulated growth and yields of all National Forest Inventory plots are included for several future management options. NTM is mostly applied for projections 10 – 20 years into future, but NorFor can currently be applied up to 100 years in future. A period is equivalent to one year in the NTM and five years in NorFor. NTM is a myopic model employing a recursive optimization, assuming that agents do not possess any information about the future beyond the current period. NorFor optimizes for all periods at once, and assumes that agents have perfect foresight. Structure of the models is described in other reports (NTM: Trømborg and Solberg, 1995; Bolkesjø, 2004. NorFor: Sjølie et al., 2011a; 2011b). The overall components and material flows in the models are shown in Figure 1.

2008 is base year for both models. Base year data for harvest and timber price is used in NTM together with the direct price elasticity to define the timber supply function for each roundwood product and region. Import/export data, industrial production, product prices and price elasticitys are applied to define demand functions as well as to calibrate the material balances in the model. The same base year data are used for NorFor, except that timber supply is modeled differently based

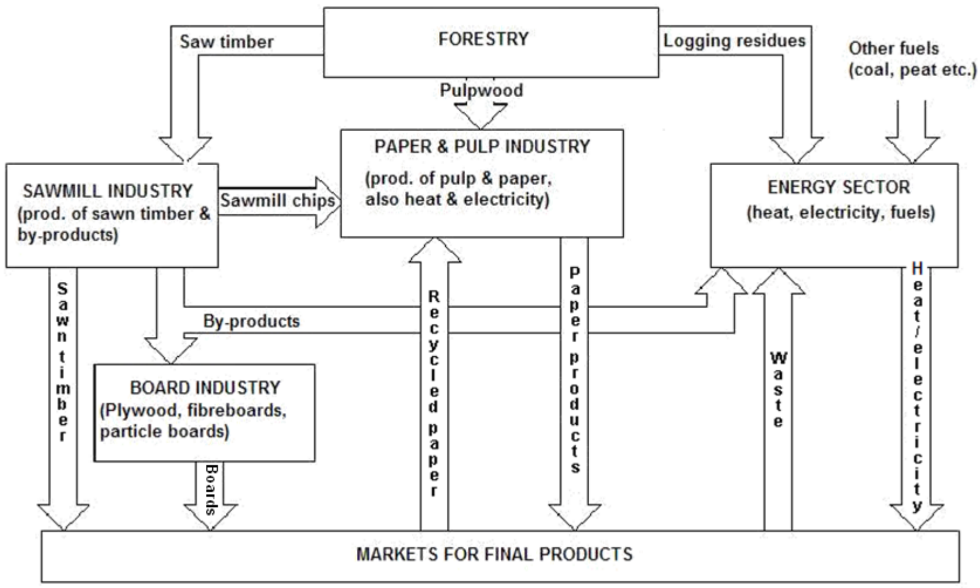

Figure 1. Supply flows in the forest industry complex (From Hällgren 2004)

on forest inventory data in NorFor (The main differences in the timber supply between the models will be described later).

Input-output variables for industrial production and cost of energy and labor for industrial production are used in the industrial sub-models to define the supply functions which might be constrained by specific capacities for a given period. Investments cost are used to define costs for new capacities.

Other parameters are forest management costs (only NorFor), transport costs and GDP growth as a basis for demand growth.

1.2 Products and regions in the models

A large variety of products are manufactured in the forest sector. Modelling of the total product spectre demands detailed cost data associated with each product as well as the linkages between the products. A simplification of the industrial production is applied in the models as the outputs are aggregated into larger categories of products shown in Table 1.

In both models, domestic regions equal counties. In addition, two foreign trade regions are included to balance the markets. Due to extensive border trade with Sweden, Sweden was included as one

Table 1. Products covered by the models. Units in parenthesis.

Roundwood	By-products	Biofuels	Sawnwood	Board	Pulp and paper (all tonnes)	Bioenergy services (all MWh delivered)
Spruce pulpwood (m^3) (SPWD) Spruce sawlogs (m^3) (SLOG) Pine pulpwood (m^3) (PPWD)[1] Pine sawlogs (m^3) (PLOG) Non-coniferous sawlogs (m^3) (NCLOG) Non-coniferous pulpwood (m^3) (NCPWD)	Harvest residues (MWh) Sawdust (tonnes) (DUST) Shavings (tonnes) (SHAV) Bark (m^3) (BARK)	Firewood (MWh) (FIREW) Energy chips (MWh) (CHIPS) Pellets (MWh) (PELL)	Spruce sawnwood (m^3) (SSAW) Pine sawnwood (m^3) (PSAW) Non-coniferous sawnwood (m^3) (NCSAW)	Fiber-board (tonnes) (FIBR) Particle board (m^3) (PART)	Newsprint (NEWS) Coated printing paper (COAT) Liner/Case materials (LINR) Mechanical pulp (MECH) Sulphate pulp (CHEM) Uncoated printing paper(UNCO) Other paper and board (OPBO) Sulphite and dissolving pulp (BORR) Recycled paper (RCYC) CTMP (CTMP)	Space heating-households (BioSpace) Hydronic heating (BioWater) Hydronic heating - industry (BioIndu) Bio-power Biofuel

1) For all species, pulpwood covers both roundwood of pulpwood quality and chips as a byproduct from sawmilling.

region and "ROW" (Rest of the World) as the other, which represents all other foreign trade within the forest sector. The main trading partners are situated in Europe. The numbering of the domestic regions follow the county numbers (Table 2). In the counties Oslo and Finnmark, there no industrial production, and in Finnmark forest inventories are not assessed and no harvest included. However, demand are included for both these counties. No harvest or production are included for the foreign regions, only the trade with Norway.

Table 2: Region numbers and names

Region number in models	Name
1	Østfold
2	Akershus
3	Oslo
4	Hedmark
5	Oppland
6	Buskerud
7	Vestfold
8	Telemark
9	Aust-Agder
10	Vest-Agder
11	Rogaland
12	Hordaland
14	Sogn og Fjordane
15	Møre og Romsdal
16	Sør-Trøndelag
17	Nord-Trøndelag
18	Nordland
19	Troms
20	Finnmark
21	Sweden
22	ROW

2 BIOMASS SUPPLY

2.1 Overview

Timber supply is modeled differently in the NTMIII and in NorFor, and this section is therefore divided in three parts. Timber supply in the NTMIII is first presented, and thereafter timber supply in NorFor. Finally, supply of harvest residues, which is modeled identically in the two models, is described.

2.2 NTMIII

Harvest

Table 3 shows the harvest in 2008 of the main assortments. The data are used to to estimate the roundwood supply functions in NTMIII, and to also to calibrate the biomass- balances in both models (input-output).

Table 3. Harvest of roundwood in Norway in 2008 in 1000 m3 under bark. Source: Statistics Norway 2011a.

Region	Spruce sawlogs	Spruce pulpwood	Pine sawlogs	Pine pulpwood	Non-coniferous pulpwood	Others[1]	Total
01 Østfold	211	178	56	57	4	0.4	**506**
02 Akershus	243	207	65	41	3	0.6	**560**
03 Oslo	16	7	0	1	0	0.0	**24**
04 Hedmark	746	735	398	294	35	32.2	**2239**
05 Oppland	486	464	66	56	1	0.2	**1072**
06 Buskerud	306	339	164	133	2	0.6	**945**
07 Vestfold	168	165	9	5	10	0.7	**358**
08 Telemark	182	207	134	95	9	0.6	**627**
09 Aust-Agder	67	83	102	61	12	1.5	**327**
10 Vest-Agder	51	67	30	15	2	0.9	**165**
11 Rogaland	30	60	5	6	0	0.1	**101**
12 Hordaland	37	50	6	2	0	0.0	**95**
14 Sogn og Fjordane	21	18	4	1	0	0.0	**45**
15 Møre og Romsdal	32	25	21	6	1	0.0	**85**
16 Sør-Trøndelag	132	115	19	12	1	0.3	**280**
17 Nord-Trøndelag	237	254	8	5	2	0.1	**506**
18 Nordland	59	67	4	4	1	0.2	**135**
19 Troms	0	0	0	0	0	0.1	**1**
SUM	**3022**	**3042**	**1090**	**794**	**84**	**38.5**	**8071**

1) Includes non-coniferous sawlogs, logs for poles and other assortments not included in the other roundwood products.

Standing volumes and increment

In NTMIII, where the supply function is econometrically estimated as a function of timber price and growing stock, the supply functions for roundwood shift from period to period according to net growth. That means that if annual harvest for example spruce in a given period and region is less than the annual growth, the supply curve for spruce will shift outwards with the net increase and given volume elasticity. We have assumed that only productive forest land less than 1 km from road is included in the growth functions (80 % of the total volume for spruce, 78 % for pine and 74 % for non-coniferous) and that 85 % of the standing volume under bark can be utilized for harvest. The harvest, standing volumes, growth rates and utilization in 2008 of standing volume is shown in Table 4.

Table 4. Harvest, standing volume, growth and utilization of growth. Based on data from Statistics Norway (2011a) and Skog og Landskap (2010)

Region	Harvest 2008 incl firewood[1]			Standing volume[2]			Growth[2]			Utilization of growth		
	S[3]	P[3]	NC[3]	S	P	NC	S	P	NC	S	P	NC
01 Østfold	396	138	34	12.1	8.5	0.9	3.7 %	3.3 %	4.9 %	88 %	49 %	83 %
02 Akersh./Oslo	485	127	76	16.6	6.3	2.4	4.3 %	3.5 %	4.2 %	68 %	58 %	76 %
04 Hedmark	1513	819	239	44.1	39.0	6.4	4.3 %	3.6 %	4.4 %	79 %	59 %	85 %
05 Oppland	974	142	159	37.8	9.2	5.4	3.7 %	2.4 %	4.0 %	70 %	64 %	73 %
06 Buskerud	660	344	166	20.4	16.9	4.6	4.3 %	3.1 %	4.9 %	76 %	66 %	74 %
07 Vestfold	339	18	132	5.9	1.2	3.2	6.7 %	3.1 %	5.2 %	87 %	46 %	79 %
08 Telemark	400	265	225	14.8	16.7	5.8	4.7 %	2.4 %	5.1 %	57 %	67 %	76 %
09 Aust-Agder	153	193	76	5.7	10.9	2.6	3.9 %	3.0 %	3.3 %	70 %	60 %	86 %
10 Vest-Agder	122	64	91	3.9	7.7	3.8	6.3 %	2.9 %	3.2 %	50 %	29 %	75 %
11 Rogaland	91	18	56	0.9	2.4	1.9	8.7 %	3.4 %	4.1 %	111 %	22 %	73 %
12 Hordaland	92	19	80	3.6	4.6	3.0	7.3 %	2.8 %	3.6 %	35 %	15 %	73 %
14 Sogn og Fjord.	42	16	91	3.1	4.5	4.0	5.8 %	2.6 %	3.1 %	24 %	14 %	73 %
15 Møre og Rom.	63	39	152	5.7	5.3	5.3	6.4 %	2.5 %	3.9 %	18 %	29 %	73 %
16 Sør-Trønd.	253	45	79	10.7	6.9	2.9	3.5 %	2.3 %	3.7 %	68 %	29 %	74 %
17 Nord-Trønd.	503	20	68	19.8	3.3	1.7	3.7 %	2.2 %	5.2 %	69 %	27 %	75 %
18 Nordland	131	12	130	6.9	1.8	5.7	4.2 %	2.5 %	3.1 %	44 %	26 %	74 %
19 Troms	1	5	154	0.4	1.4	6.9	7.1 %	3.6 %	3.1 %	2 %	10 %	73 %
Total	**6.2**	**2.3**	**2.0**	**212.3**	**146.6**	**66.5**	**4.3 %**	**3.0 %**	**4.0 %**	**68 %**	**52 %**	**76 %**

1) The estimated harvest of firewood is based on firewood consumption from Statistics Norway, import of firewood and an allocation on firewood with 6 % spruce, 16 % pine and 78 % non-coniferous. The harvest of firewood is allocated on region according to growth of the given specie.

2) Standing volume and growth are for productive forest land located less than 1 km from road. The volumes reduced by 15 % from standing volume under bark to cater for non-utilized wood, environmental considerations etc.

3) S = spruce, P = pine and NC = non-coniferous

Elasticities of timber supply

The price elasticities for timber supply are used in NTMIII to estimate the regional timber supply functions together with base year harvest and price.

Rørstad and Solberg (1991), Løyland et al. (1995), Bolkesjø and Baardsen (2002), Bolkesjø and Solberg (2003), Størdal et al. (2006) and Bolkesjø et al. (2007, 2010) report short-term price elasticities varying from 0.53 to 1.54 and volume elasticities (increment/sustainable yield) from 0.10 to 0.78 depending on sample and property sizes.

0.4 is used as the price elasticity for sawlogs in eastern and southern Norway (region 1-10), 0.3 at the west coast and northern Norway (region 11-15 and 18-19) and 0.4 is used for Trøndelag (region 16 and 17). 0.6, 0.4 and 0.5 is used for pulpwood in the same regions. Volume elasticity is set to 0.65 for all regions, based on the observed utilisation shown in Table 4.

Prices

Table 5 shows roundwood prices delivered roadside in Norway 2008. The estimated transport costs from the landing site at the forest road to mill gate within the region are estimated based on transport costs for sawlogs and pulpwood adjusted for the trade balances. The base year timber prices are inputs to the NTM to estimate the base year timber supply curves.

2.3 NorFor

Where NTM has econometrically estimated timber supply curves with prices and growing stock as factors, the timber supply curves in NorFor are formed by using biological data, costs, non-timber benefits and the market's willingness to pay. The biological data impacting timber supply are current and future growth of existing and future stands, while the costs include logging and silviculture costs. Amenity values of old-growth forest (and depending on the scenario, carbon values) can also be seen as a cost added to harvest. Due to the intertemporal optimization, future prices are decision factors affecting forest owners' supply in NorFor. The market's willingness to pay for timber to region centre coupled with the above-mentioned supply factors determine the regional timber prices. In the following, these factors are described more in detail.

Forest data

The forest data in NorFor are constituted by the National Forest Inventory (NFI) plots of Norway. The NFI consists of 12 700 permanent sample plots, which together cover all forest in Norway outside the Finnmark county. 20 % of the plots are measured every year, thus all plots are measured during a five-year period. The sample plots are permanent, and are laid out in a 3 x 3 km grid, where each plot

Table 5. Roundwood prices delivered roadside 2008, NOK/m3 under bark. Source: Statistics Norway 2010a.

Region	Spruce sawlogs	Spruce pulpwood	Pine sawlogs	Pine pulpwood	Non-coniferous pulpwood	Transport cost in the region
01 Østfold	439	255	431	221	207	54
02 Akershus	454	255	454	226	213	51
03 Oslo	423	263	374	229	227	-
04 Hedmark	465	252	473	231	229	48
05 Oppland	461	252	447	230	223	52
06 Buskerud	437	259	461	232	217	55
07 Vestfold	443	253	454	227	193	42
08 Telemark	425	256	425	228	195	55
09 Aust-Agder	438	253	425	231	202	53
10 Vest-Agder	399	256	420	226	211	55
11 Rogaland	388	239	370	230	229	49
12 Hordaland	393	219	371	218	220	50
14 Sogn og Fjordane	369	216	388	199	196	54
15 Møre og Romsdal	415	261	478	234	213	60
16 Sør-Trøndelag	443	252	458	230	220	60
17 Nord-Trøndelag	441	257	408	232	240	56
18 Nordland	416	259	394	242	231	60
19 Troms	392	241	419	228	210	60

covers 250 m^2 (NFLI 2007; s.a.). 8991 NFI plots are included in NorFor, which together represent close to all the productive Norwegian forest area. Those data were collected during the five years 2003-2007.

Applying the stand simulator Gaya (Hoen 1990; Hoen and Eid 1990), the yield and growth for existing and harvested stands are simulated for several different management regimes. Yields are simulated for the three tree species Norway Spruce *(Picea Abies)*, Scots Pine *(Pinus Sylvestris)* and Birch *(Betula Pendula* and *Betula Pubescens)*.

Forest management options

As described in Sjølie et al. (2011b), modeling of forest growth and management are carried out in two steps in NorFor. First, growth for existing and regenerated stands is simulated in Gaya for various management regimes. Thereafter, these yield tables are imported to NorFor, where the management regime for existing and for regenerated stands together with timing of final harvest for each hectare of forest are endogenously determined as a part of the optimization procedure. After final harvest, a regeneration scheme and a new management regime is selected for each hectare.

Thus, two sets of yield tables are simulated. For existing stands, growth is simulated for possible management activities[1]. Stand simulations are also carried out for different regeneration schemes and management activities for harvested stands. Management activities and criteria for when the activities can take place are exogenously set. The possible combinations of management activities, management regimes, are displayed in Table 6. Simulated management activities are identical in regenerated and existing stands. Included regeneration schemes are displayed in Table 7. Regeneration variables are method (planting, natural), species composition, density and waiting time.

Even if the total number of management regimes is seven, most stands will have much fewer simulated management regimes due to the stand criteria. However, all stands have the management regime “no management”. No regeneration after final harvest is not an option. The conditions of the regenerated stand are in most cases independent of the conditions of the old stand, and the regeneration schemes varies only with site index. However, in the cases of shelter wood and seed tree cut, where regeneration takes place under the old stand, there is a dependency. The negative waiting time seen in Table 7 for these cases indicate the age of the new stand when the old trees are clear-cut.

Mortality rates are an important aspect of the forest dynamics. In the simulations for NorFor, the default mortality rates of Gaya were applied: 0.72 %, 0.54 % and 1.12 % annually of the number of trees (Braastad, 1982), with relative diameter being 0.7.

[1] "Management activity" means here one certain action occurring at a point of time in the management of forest between regeneration and final harvest (e.g. precommercial thinning). "Management regime" refers to a set of subsequent management activities which can take place between regeneration and final harvest (e.g. planting and precommercial thinning)

Table 6. Included management activities and criteria

Management activity		Criterias for management				
Type of management	**Description**	**Species**	**No. of trees (N/ha)**	**Site index**[2]	**Age (years)**	**Others**
No management	No management	None				
Precommercial thinning favoring coniferous	1700 trees/ha after operation; of which 10 % is broadleaves	Spruce or pine	≥ 2300	≥ 15.5	9-14	No former precommercial thinning carried out
	1400 trees/ha after operation; of which 10 % is broadleaves	Spruce or pine	≥ 2300	< 15.5	9-14	
	1700 trees/ha after operation; of which 70 % is broadleaves	Spruce, pine or birch	≥ 2300	≥ 15.5	9-14	
	1400 trees/ha after operation; of which 70 % is broadleaves	Spruce, pine or birch	≥ 2300	< 15.5	9-14	
Thinning	Take out 25 % of the basal area, rel.diameter =0.9	Spruce or pine	None	≥ 21.5	46-51	No former thinning carried out
				15.5 - 21.5	50-55	
				12.5 -15.5	55-60	
				9.5 - 12.5	65-70	
				< 9.5	70-75	
		Birch	None	≥ 24.5	46-51	
				18.5 - 24.5	50-55	
				12.5 -18.5	55-60	
				< 12.5	60-65	
Shelter wood cut	Take out 50 % of the basal area, rel.diameter =0.9	Spruce	None	≥ 21.5	66-71	One thinning carried out; no precommercial thinning carried out; vegetation types: Small-fern woodland or low-herb woodland[3]
				15.5 - 21.5	70-75	
				12.5 - 15.5	85-90	
				9.5 - 12.5	95-100	
				< 9.5	105-110	
Seed tree cut	Leave 50 trees/ha; rel.diameter =0.9	Pine	None	≥ 21.5	65-70	One thinning carried out; no precommercial thinnings carried out
				15.5 - 21.5	70-75	
				12.5 - 15.5	75-80	
				9.5 - 12.5	85-90	
				< 9.5	100-105	

[2] The Norwegian site index system H40 refers to the average height of the 100 largest trees per hectare at breast height age 40 years (NLH, 1987).

[3] English names of vegetation types as of Fremstad (1997). Corresponding Norwegian names: Småbregneskog (Small-fern woodland),lågurtskog (low-herb woodland)

Table 7. Management regimes

Management activities components
No management
Precommercial thinning favoring coniferous
Precommercial thinning favoring broadleaves
Thinning
Thinning + Shelter wood/seed tree cut
Precommercial thinning favoring coniferous + Thinning
Precommercial thinning favoring broadleaves + Thinning

Costs

Logging costs varying with county and harvesting system are included (Table 9). These costs are average costs based on parameters as tree size, density, harvest volume, distance to roads, terrain slope, etc.

Planting costs are assumed to be 4.75 NOK/plant, independently of the planting density. This is close to numbers from Statistics Norway (2009a), 4.47 NOK/plant. Ground preparation is assumed to cost 1000 NOK/ha, based on Statistics Norway (2009b) where the average cost is 2100 NOK/ha, and ground preparation is assumed carried out on about half of the area. Costs for precommercial thinning are based on the functions applied in Gaya (Hoen and Gobakken 2004), but increased by 150 % in accordance with current market prices (pers. comm., Jensen 2008), and vary from 1643 to 3342 NOK/ha depending on the number of stems taken out and the height. For fertilization, a flat rate, 1462 NOK/ha, is applied. Full regeneration costs are displayed in Table 8, but for all silviculture, only a third of the costs are counted for, due to tax deduction rules (Norwegian Agricultural Authority, s.a.)

Table 8: Criteria and description for regeneration of new stands after final harvest

-------------Criteria-------------		------------------------------------ Description ------------------------------------								
Site index	Other criteria	Dominating species new stand	Method	Spruce (#/ha)	Waiting time Spruce (years)	Pine (#/ha)	Waiting time Pine (years)	Birch (#/ha)	Waiting time Birch (years)	Regeneration costs (NOK/ha)
≥ 15.5	None	Spruce	Planting	3000	0	0		200	0	14250
≥ 15.5	None	Spruce	Planting	2500	0	0		500	0	11875
≥ 15.5	None	Spruce	Planting	1800	0	0		800	0	8550
≥ 15.5	None	Spruce	Natural regeneration	1200	5	100	800	1500	0	1000
≥ 15.5	None	Pine	Natural regeneration	500	8	1500	8	500	0	1000
≥ 15.5	None	Birch	Natural regeneration	200	10	200	10	2000	5	0
≥ 15.5	Old stand Spruce	Spruce	Natural regeneration under shelter wood	2000	-10	100	-5	700	-10	0
≥ 15.5	Old stand Pine	Pine	Natural regeneration under seed trees	500	-10	1500	-10	500	-10	1000
< 15.5	None	Spruce	Planting	2000	0	0		200	0	9500
< 15.5	None	Spruce	Planting	1500	0	0		500	0	7125
< 15.5	None	Spruce	Planting	900	0	200	10	800	5	4275
< 15.5	Old stand Spruce	Spruce	Natural regeneration under shelter wood	1500	-15	50	-10	400	-15	0
9.5 - 15.5	None	Spruce	Natural regeneration	900	10	200	10	1000	5	1000
9.5 - 15.5	None	Pine	Natural regeneration	400	15	1200	15	400	5	1000
9.5 - 15.5	None	Birch	Natural regeneration	200	15	200	15	1600	10	0
9.5 - 15.5	Old stand Pine	Pine	Natural regeneration under seed trees	400	-10	1200	-10	400	-10	1000
< 9.5	None	Spruce	Natural regeneration	600	15	100	15	800	10	1000
< 9.5	None	Pine	Natural regeneration	300	20	900	20	300	10	1000
< 9.5	None	Birch	Natural regeneration	100	20	100	20	1200	15	0
< 9.5	Old stand Pine	Pine	Natural regeneration under seed trees	300	-5	900	-5	300	-5	1000

Table 9: Logging costs in counties and for different harvesting systems. NOK/m^3

County	Thinning	Shelter/seed tree cut	Final harvest
01 Østfold	131	119	104
02 Akershus	130	114	107
03 Oslo	193	148	134
04 Hedmark	130	117	109
05 Oppland	150	136	118
06 Buskerud	148	125	124
07 Vestfold	138	122	106
08 Telemark	144	127	143
09 Aust-Agder	152	136	140
10 Vest-Agder	164	146	137
11 Rogaland	172	148	137
12 Hordaland	198	167	146
14 Sogn og Fjordane	208	171	153
15 Møre og Romsdal	197	150	133
16 Sør-Trøndelag	158	142	142
17 Nord-Trøndelag	146	138	134
18 Nordland	125	109	141
19 Troms	138	113	144

Amenity values of old-growth forests of old forest are included. As shown by Gan et al. (2001), a high discount rate plus amenity values have the same impacts on the optimal forest stock and harvest level as a low discount rate,such that the optimal forest stock and harvest level are the same for a discount rate of *r* and an amenity value of *a* (expressed as non-timber benefits divided by timber harvest benefits) as for a discount rate of magnitude *r-a*. In NorFor, the magnitude of the amenity value was found by iterating the discount rate and the amenity value, using a perfectly elastic demand function for logs, until a combination which came close to historical data was found. One such combination is 4 % p.a. (real discount rate) an and amenity value of 5 NOK/(m^3 yr) for forest older than 90 years, which is used.

2.3 Harvest residues

The methodology in this study is in line with the method described in Rørstad et al. (2010). This study uses biomass functions from Lehtonen et al. (2004) when estimating the quantity of stand level harvest residues. Functions are estimated for Scotch pine, Norway spruce and broadleaved and for different parts of the trees (tree compartments), e.g. branches, stem, bark and foliage. It is assumed that the total usable amount of forest residues equals 10 % of the stem biomass and bark – in order to account for tops and other stem parts not usable as sawn or pulp wood – plus biomass in living and dead branches. Foliage is not included since it is assumed that these will drop off during forwarding and storing/drying at landing. However, foliage biomass is included when estimating forwarding costs, as it is assumed that the residues are forwarded immediately after roundwood harvest.

The functions represent the upper bound for the quantity of logging residues, as it is neither physical possible nor profitable to harvest all the residues. Lack of data concerning recovery makes it hard to include these factors in the analysis and it is assumed a fixed recovery rate of 60 %. Due to lack of empirical data on operation costs, these studies use an engineering approach when estimating the harvest costs for the forest residues, based on productivity data in the literature. The costs are estimated in monetary units per tonne dry matter logging residues.

The transportation of the logging residues from the stand to the landing is split into four operations: loading of the residues on to the forwarder, terrain transport to the road landing, unloading and driving empty back to the stand. It is assumed a constant operating cost of NOK 800/E0-h.

In order to estimate the supply of harvest residues for bioenergy the hauling costs and harvested residues for each harvested stand is estimated. Next, the forest harvesting area is sorted according to the quantity of forest residues they provide in ascending order of hauling costs, thus obtaining the accumulated quantities of forest residues harvested as a function of harvest costs. Finally, accumulated harvested biomass of forest residues on harvest costs are regressed to obtain the basic supply functions. These functions can be viewed as industry marginal cost curves. Assuming profit maximizing forest owners, these functions give the amount of forest residues (in tonne d.m.) that is profitable to harvest given the road side price of forest residues (in NOK/tonne d.m.). The functions are converted to energy terms – by assuming a constant energy density of the dry matter – and be modified to include other costs components in the supply chain such as chipping and road transport to end users.

Data from the national forestry inventory was applied to allocate the average harvest from 1996 to 2008 on species, soil productivity and forwarding distance. It is assumed that the same distribution regarding site indexes (soil productivity) and forwarding distances in year 2020 as in the current younger stands (relative age class I and II) and that the harvest per hectare for a given site index is the same as in the existing older stands (relative age class IV and V). Figure 2 shows the regional supply of harvesting residuals. It is assumed that 60 % of the available harvesting residues on forest land above site index 8 (annual production 3.5 m^3/ha/yr and above) are available for supply.

The supply functions for harvesting residues in Figure 2 are linearized in the models and given a maximum level. The supply curves are given on county-level, and are independent of harvest level. This is not considered a problem if the harvest level do not change significantly and since the harvest residues supply curves are fairly conservative, partly due to environmental constraints and partly due to the currently low volumes.

The supply function is given as:

*Costs = intercept + slope*quantity*

where costs are given in NOK cents/MWh and quantity in MWh/year.

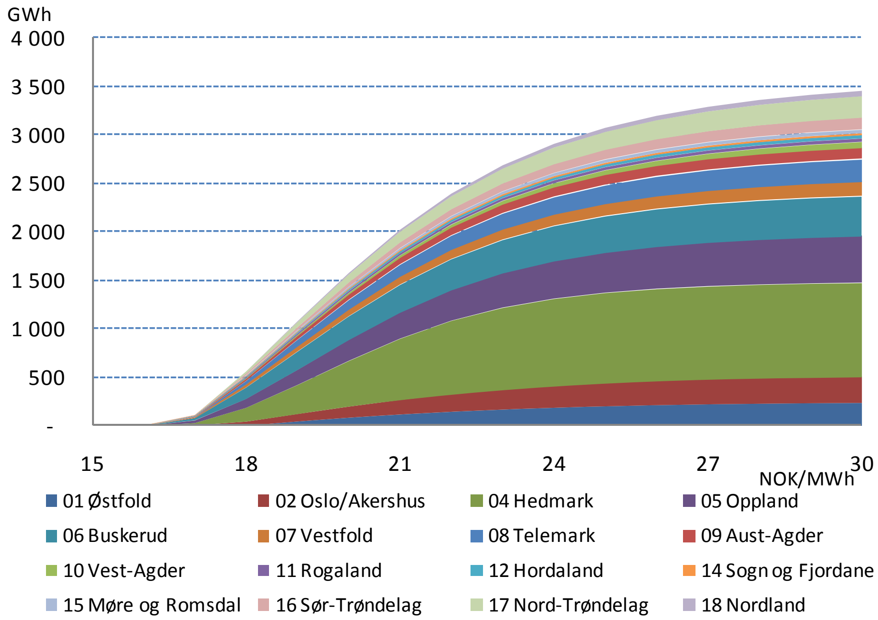

Figure 2. Supply of harvesting residues, based on average harvest 1996-2008 and utilization of 60 % of the available residues on forest land above site index 8.

3 Forest industrial production

3.1 Sawnwood

Production

Statistics Norway reports production in larger enterprises, but it is not possible to extract the production of sawnwood from the figures. The Norwegian Sawmills Association (Treindustrien) collects production figures for their members. These production figures represent all the medium and large scale sawmills and about 90 % of the production. The sawnwood production is however not allocated on spruce and pine in the data. The sawnwood production per country allocated on spruce and pine and on mill category is estimated in the following way:

- The total sawnwood production is estimated based total wood consumption and a sawnwood output of 51.7 % which is the average for the members in Treindustrien. Import statistics for coniferous sawlogs are not specified on spruce and pine. The import of 57 000 m^3 in 2008 is assumed to be spruce.
- The estimated production of 219 000 m^3 not covered by the members of Treindustrien is allocated between counties using the same allocation of small scale producers as in 2003 given by Bolkesjø (2004).
- The allocation the production on spruce and pine is based on the harvest in each country and sat to the harvest in counties with net export of sawlogs and adjusted with export figures for adjacent counties for counties with net import.

The production is allocated on three categories of mills: *Sawmills*, that is members of the sawmill associations and *Misc* that covers the remaining producers and represents small sawmills and other consumers of sawlogs. All mills are assumed to produce on the capacity limit in 2008. Revenues and costs related to plainings are not included.

The production of sawnwood allocated on producer category and county is shown in Table 10.

Input-output

The input-output relations for sawnwood production as based on data from the Norwegian Sawmill Association (Nøkkeltallsanalysen fra Treindustrien 2008) and showed in Table 11. One technology is defined for each product.

Particle boards

The input-output relations for particle boards are based on interviews with and websites for the individual plants and shown in Table 12.

Table 10. Sawnwood production in 2008 by county, mill category and share of pine. Based on data from Statistics Norway (2010a), Treindustrien (2010) and Bolkesjø (2004).

County	Category[1]	Total production	Share of pine
01 Østfold	Misc	5 200	21 %
02 Akershus	Sawmill	216 078	22 %
02 Akershus	Misc	11 143	22 %
04 Hedmark	Sawmill	560 952	32 %
04 Hedmark	Misc	20 409	32 %
05 Oppland	Sawmill	265 354	14 %
05 Oppland	Misc	58 962	14 %
06 Buskerud	Sawmill	148 703	35 %
06 Buskerud	Misc	19 119	35 %
07 Vestfold	Sawmill	139 017	35 %
08 Telemark	Sawmill	34 074	41 %
08 Telemark	Misc	10 400	41 %
09 Aust-Agder	Sawmill	106 135	63 %
10 Vest-Agder	Misc	2 972	36 %
11 Rogaland	Misc	1 486	13 %
12 Hordaland	Sawmill	51 691	18 %
14 Sogn og Fjordane	Sawmill	9 400	16 %
15 Møre og Romsdal	Misc	6 915	38 %
15 Møre og Romsdal	Sawmill	10 913	38 %
16 Sør-Trøndelag	Sawmill	86 119	16 %
16 Sør-Trøndelag	Misc	43 832	16 %
17 Nord-Trøndelag	Sawmill	205 377	5 %
17 Nord-Trøndelag	Misc	12 629	5 %
18 Nordland	Misc	3 715	6 %
19 Troms	Misc	1 485	82 %
SUM		**2 032 080**	

Table 11. Input-output for sawnwood production.

Product	Sawlogs	Pulpwood	Labour	Electricity	Sawdust	Bark	SHAV[1]	Other costs
Spruce sawnwood	**1.91**	**-0.67**	**0.69**	**0.12**	**-0.22**	**-0.22**	**-0.035**	**292**
Pine sawnwood	**1.91**	**-0.67**	**0.69**	**0.12**	**-0.22**	**-0.22**	**-0.035**	**241**
Non-coniferous sawnwood	**1.91**	**-0.67**	**0.69**	**0.12**	**-0.22**	**-0.22**	**-0.035**	**241**

1) SHAV is shavings used as input in pellets production

Table 12. Input-output for particle board production

Plant	Region	Capacity	Prod. 2008, 1000 m^3	Number of employees	Biomass input	External energy use MWh/m^3
Arbor Hattfjelldal	Nordland	55	40	55	0.46 SPWD, 0.02 NCPWD, 0.16 Dust	1.38
Forestia Kvam	Hordaland	41	39	45	0.06 SPWD, 0.32 PPWD, 0.32 Dust, 0.74 Shavings	0.74
Forestia Braskeridfoss	Hedmark	300	261	167	0.19 SPWD, 0.96 Dust, 0.45 Shavings	0.15

3.2 Pulp, paper and fiberboard

Products and production

The production and market structure for pulp and paper are shown in Table 13.

Table 13. Production and market structure for pulp and paper. Source: NPPA 2010.

Product category	Abbr.	Number of mills	Production 2008 in 1000 tonnes[1]
Mechanical pulp and CTMP	MECP	3	112
Chemo-thermo mechanical pulp	CTMP	1	96
Sulphate pulp	CHEM	1	387
Sulphite and dissolving pulp	BORR	1	154
Newsprint	NEWS	2	525
Uncoated printing paper	UNCO	2	590
Wood containing coated printing paper	COAT	1	118
Liner/Case materials	LINR	2	303
Other paper and board	OPBO	5	204

1) Source: NPPA 2011. http://www.norskindustri.no/nokkeltall/

Input-output

The production, capacities and input-output relations for the pulp and paper sector is based on interviews and websites for individual mills and shown in Table 14.

Recycled paper

Recycled paper is used as input in paper and paper board production. The amount of waste paper has increased by about 50 % since 1995 in Norway and was about 1.2 mill tonne in 2009 (Miljøstatus 2011). About 50 % of the waste paper is recycled. Table 15 shows the collection and use of waste paper for paper and board production in Norway.

Table 14. Production, capacities and input-output relations for pulp and paper mills in Norway 2008.

Mill	Product	Region	Capacity 1000 tonnes	Production 1000 tonnes	Employees	Biomass input/ton	ENERGY input MWh/ton
Glomma Papp	OPBO	OSTF	40	37	30	1.08 REC	2.16
Borregaard	BORR	OSTF	160	154	800	6.25 SPWD	
Hellefoss	UNPR	BUSK	50	50	125	2.60 SPWD, 0.1 MECH	1.60
Huthamaki	OPBO	BUSK		8	100	0.1 CHEM, 0.95 RECP	
Hunsfos	OPBO	VAGD	58		125		3.44
Hunton	FIBO	OPPL	145	145	74	0.52 SPWD	0.52
Huntonit	FIBO	VAGD	*55*	51	220	0.16 SPWD, 1.78 PPWD, 0.16 NCPWD	2.69
Nordic Paper Greåker	OPBO	OSTF	30	30	80	1.02 CHEM	4.67
Follum	NEWS	BUSK	140	179		2.40 SPWD	2.02
Follum	WCCO	BUSK	140	118	380	1.75 SPWD, 0.05 CHEM	2.02
Saugbrugs	UNPR	OSTF	550	540	570	1.30 SPWD, 0.1 CHEM	2.59
Skogn	NEWS	NTRO	590	530	500	1.89 SPWD	2.37
Peterson-Moss	LINR	OSTF	280	265	259	1.20 SPWD, 2.8 PPWD, 0.04 CHEM	1.75
Peterson-Ranhem	LINR	STROE	110	113	120		1.66
Rygene	MECH	AAGD	60	32	19	2.08 SPWD, 0.52 PPWD	1.56
SCA Hygiene Drammen	OPBO	BUSK	22	19	99		3.82
Sødra Cell Tofte	CHEM	BUSK	400	209	340	3.03 SPWD, 1.51 PPWD	
Sødra-kortfiber	CHEM	BUSK		187		2.45 NVPWD (euc)	-0.07
Sødra Cell Folla	CTMP	NTROE	100	96	62	2.68 SPWD	1.64
Vafoss	MECH	TELM	70		45	2.40 SPWD	1.14

Table 15. Collection and recycling of waste paper in Norway, Source NPPA 2011.

	2005	2006	2007	2008	2009
Total collection	621	670	683	676	659
Export	232	261	293	287	285
Domestic procurement	389	409	390	389	374
Import	52.5	60.0	74	80	103
Total supply	441	469	464	469	477
Stock change	+0.1	-5.3	+2.4	+6.5	-14.4
Domestic consumption	441	474	465	475	463

3.3 Energy and labor costs in forest industries

Energy costs

The energy costs for electricity and for petroleum products for stationary consumption per unit are shown in Table 16. We have applied the average costs per unit for 2007-2009 in the models.

Table 16. Energy costs in NOK/MWh in the forest industries. Source: Statistics Norway 2010b

	2007		2008		2009		Average 2007-2009	
	Electric.	Petrol. products	Electric.	Petrol. products	Electric.	Petrol. products	Electric.	Petrol. products
Wood and wood products	429	409	517	468	500	473	482	450
Pulp, paper and paper products	233	245	245	330	267	269	248	281

Labour costs

Table 17 shows average labour costs per man-year for manufacturing in Norway for the years 2004 and 2008, as well as for solid wood and the pulp- and paper industries. As seen by the table, the labour costs per man-year in the solid wood sector is significantly lower than the industrial average (75 % for 2008), whereas the pulp and paper industries have labour costs about the average (98 %). The figures for 2008 is divided by 1720 hours per man-years when the per hour costs are specified per product output in the models.

Table 17. Labour costs in NOK per man-year. Source: Statistics Norway (2010c).

Sector	2004	2008
Manufacturing	464 600	587 000
Production of wood and wood products	363 155	444 700
Production of pulp, paper and paper products	450 566	577 100

3.4 Investment costs

There are three types of capacity costs in the models: Capital rent, maintaining capacity and new (expanding) capacity. For each unit of installed capacity , a cost equaling 5 % of new capacity costs have to be paid yearly as a capital rent. In NorFor, capacity is automatically depreciated with 68 % over 5 years, but depreciation can be avoided if the industry maintains the capacity. Maintaining capacity costs is given as 10 % of new capacity costs. In the NTM, the costs for new capacity are amortized (using 10 % interest rate and 15 years), but not in NorFor, where all investment costs are paid in the investment year. Table 18 shows the investment cost per unit new capacity applied in the models.

Table 18. Investment costs for the products included in the models. NOK per unit

Product	New investment costs
Spruce sawn-wood	3 000
Pine sawn-wood	3 000
Non-coniferous sawn-wood	3 000
Fiber-boards	10 000
Particle-boards	10 000
Mech. pulp	3 150
Chem. pulp	5 070
CTMP	7 200
Newsprint	8 700
Uncoated paper	7 500
Coated paper	9 600
Liner-board	3 750
Other papers and boards	14 000
BORR	8 400

4 TRANSPORT AND TRADE

4.1 Transport costs

Transport costs in the NTM are given in two steps. First, transport costs within each county (Table 5) are added to the timber price (i.e. prices are given as CIF). For transport between regions, costs are found by the use of functions given in Table 19, as well as costs for transport by ship, as of Trømborg and Solberg (1996) and Bolkesjø (2004). The lowest costs between each pair of regions are included in the model. Cost functions by train and truck consist of a constant cost and a distance-dependent cost. Region centers are used for calculating the distance. For timber traded between two regions, total transport costs equal costs within the region and costs between the regions.

Timber prices in both models are CIF delivered to the region centre. In NTM, the intra-regional transport cost is added to the base year timber price inputs, while this cost appear implicit in the price as the willingness to pay for the timber delivered to the region centre in NorFor. However, transport costs for interregional trade is modeled identically in the two models and the functions for estimation of transport costs are shown in Table 19.

Table 19: Functions for transport cost between regions for different product groups and transport method.

Product group / Mean of transport	Truck	Train
Roundwood and chips (NOK/m^3)	18.50 + 0.55*km	50.00 + 0.25*km
Sawnwood and particleboards (NOK/m^3)	10.00 + 0.60*km	50.00 + 0.25*km
Pulp, paper and fiberboards (NOK/tonne)	10.00 + 0.60*km	50.00 + 0.30*km

4.2 Trade

Trade figures are used to map trade flows, domestic consumption and export prices in the models. Foreign trade data are reported by Statistics Norway (2011) a group according to product categories shown in Table 20.

Supply and demand of timber and wood products from/to the foreign regions are in both models specified as constant elasticity curves. Because of more trade barriers (partly due to hygienic measures) and higher transport costs for timber, timber supply/demand is less elastic than

Table 20. Import, export and export prices 2008 (in 000 and NOK /tonne-m3). Based on data from Statistics Norway (2010d)

	Import	Export	Export price
Pine pulpwood	1369	611	369
Spruce pulpwood	867	65	275
Non-coniferous pulpwood	345	51	200
Sawlogs	199	256	527
Pine sawnwood	16	123	1361
Spruce sawnwood	427	65	1402
Particle board	121	167	2041
Firewood	138	2	369
Newsprint	118	563	4295
Coated printing paper	129	112	4736
Fiberboard	138	34	7595
Liner/Case materials	46	297	3505
Mechanical pulp	2	216	2951
Sulphate pulp	34	0	2366
Uncoated printing paper	3	1	9781
Other paper and board	41	152	9319
Sulphite and dissolving pulp	23	160	6928

manufactured product supply/demand with regard to price. The elasticities are identical for Sweden and ROW. Supply elasticity for timber is 0.8 and demand elasticity -0.8, the corresponding elasticities for manufactured wood products are 2 and -2, respectively. The demand curves in foreign regions shift with GDP growth as in domestic regions, with GDP growth and related elasticity magnitudes being identical across regions, as described in Chapter 5.1

5 CONSUMPTION AND DEMAND FOR FOREST PRODUCTS

5.1 Consumption of final products

Consumption data consist of GDP growth, elasticity of demand with regard to GDP and price, respectively, base year consumption and prices.

Base year consumption

National consumption of products is calculated as production-exports+imports. The national consumption was divided into county-specific consumption by the use of population sizes in counties. Export prices (at border) were used for domestic prices. Domestic consumption and prices are displayed in Table 21.

Table 21: Domestic consumption and prices of final products.

Product	Consumption	Price (NOK/unit)
PSAW	738 011	1 402
SSAW	1 780 892	1 361
NSAW	5 757	1 361
PART	339 955	2 041
FIBR	304 482	7 595
NEWS	285 321	4 295
UNCO	601 174	9 781
COAT	156 466	4 736
LINR	138 591	3 505
OPBO	420 479	9 319

Elasiticities of demand

GDP growth is determined by GDP growth per capita and population growth. Due to lack of data of county-specific GDP growth, national GDP growth and county-specific population growth are used as proxies. Projected GDP growth is for the years until 2030 given from IPCC B2 scenario (medium economic growth), and equals 1.3 %/year for the period 2011-2020, and 0.8 %/year for the period beyond 2020. It is assumed the same for the Abroad regions (All Western European countries have the same GDP growth in the IPCC scenario). For the years beyond 2030, the growth is assumed the same as in 2030 (0.8 %). Statistics Norway's prognoses of population growth in different counties (the middle alternative - M) are used (StatBank Norway, s.a.).

Elasticity of demand with regard to GDP and price is constant across regions, but vary between products, as shown in Table 22.

Table 22: Elasticity of demand with regard to GDP and price for final products.

Final product	GDP elasticity	Price elasticity
Spruce sawn-wood	0.7	-0.5
Pine sawnwood	0.7	-0.5
Birch sawn-wood	0.7	-0.5
Fiber-boards	1	-0.3
Particle-boards	0.5	-0.5
News-print	0.5	-0.48
Uncoated printing paper	0.5	-0.89
Coated paper	0.5	-0.89
Linerboard	0.8	-0.3
Other papers and boards	0.8	-0.3
Bioenergy services	0.5	-0.7

6 BIOENERGY PRODUCTION AND ENERGY PRICES

6.1 Bioenergy production and consumption

Energy balance for bioenergy

The production of bioenergy has increased from 10 TWh in 1990 to 15 TWh in 2009 and represents about 7 % of the net domestic energy consumption in Norway (Statistics Norway, 2010b). The overall figures for the bioenergy consumption in Norway is shown in Table 23.

Bioenergy consumption in households

The bioenergy consumption in households is mainly firewood in private households. The figures from Statistics Norway are based on household surveys and there is uncertainties in the absolute figures due to stock changes and market characteristics. The wood consumption is relatively stable or declining (Table 23), but is partly compensated by higher energy efficiency in the wood stoves which was calculated to 54 % in 2008 (Statistics Norway 2010e).

The utilized energy from wood stoves by county is shown in Table 24.

Pellets

The domestic consumption of wood pellets in Norway was 40 000 tonne in 2008 and 43 000 tonne in 2009 (Nobio 2010). The share of pellets sold in small and large bags was 41 % in 2008 which gives an energy input of 72 GWh. The energy from pellets is assumed to be consumed in the household market in our analyses and allocated between counties proportional to the fire wood consumption in Table 24 below.

Table 23. Bioenergy production and consumption in Norway 2007-2009 in GWh. Based on data from Statistics Norway (2010b)

	2007	2008	2009[1]
Production of primary energy carrier	14 361	14 928	14 791
Imports	388	369	267
Exports		6	19
Net domestic supply	14 749	15 290	14 969
Energy converted[2]	2 833	3 152	3 280
Net domestic consumption	11 917	12 138	11 689
Consumption by sector			
Manufacture of paper and paper products	3 472	3 616	2 700
Other manufacturing (incl sawmills)	1 500	1 345	1 454
Households	6 916	7 040	7 337
Other sectors		**137**	**198**

1) Data for 2009 are preliminary figures.

2) Energy converted includes biomass in district heating, dual purpose and thermal power plants

Table 24. Energy consumptions in households. Source: Statistics Norway 2010e

	2005	2006	2007	2008*
Electricity	34 006	33 646	34 948	34 512
WOOD (TEPS)[1]	7 874	7 376	6 763	6 875
Other energy resources (TPES)	2 994	3 158	2 753	2 513
Utilized energy from wood	3 714	3 809	3 629	3 679
Utilized energy from other energy resources	2 341	2 474	2 191	2 059

1)TPES = total primary energy supply

Central and district heating

The energy delivered to consumers in Norway has increased steadily from 1.5 TWh in 1999 to 3.3 TWh in 2009. 68 % of the energy from district heating was delivered to the service sector and 21 % to households in 2009 (Statistics Norway 2011). In 2009, 48 % of the fuel in district heating came from waste, 18 % from wood chips and bark and 17 % from electricity, 4 % from waste heat and 13 % from oil and gas.

We have used plant level data collected by Statistics Norway to analyse input-output in existing district heating plants. Table 26 shows the use of wood chips and bark and delivered energy on county level in 2008.

Accurate figures for energy production in central heating systems (including local heating centrals that distribute heat to a few buildings), are not available. We have used data from Statistics Norway for consumption of wood in service and agricultural sectors as the base year consumption in local heating centrals (used as a term for central heating and local heating centrals). The consumption figures for pellets in bulk are used to allocate production between wood chips and pellets in local heating centrals. The split between wood chips and pellets assumed to be constant in all counties as data for pellets consumption on county level is not available.

Table 25. Utilized energy from wood stoves by county. Source: Statistics Norway 2010e. TWh

	2005	2006	2007	2008	2009
Østfold	0.21	0.18	0.19	0.21	0.20
Akershus	0.22	0.25	0.22	0.21	0.26
Oslo	0.08	0.06	0.08	0.08	0.08
Hedmark	0.21	0.24	0.23	0.19	0.23
Oppland	0.27	0.21	0.19	0.21	0.25
Buskerud	0.17	0.18	0.19	0.19	0.24
Vestfold	0.15	0.16	0.16	0.19	0.16
Telemark	0.16	0.19	0.17	0.21	0.19
Aust-Agder	0.10	0.09	0.08	0.11	0.12
Vest-Agder	0.14	0.14	0.14	0.14	0.14
Rogaland	0.23	0.22	0.22	0.23	0.24
Hordaland	0.25	0.29	0.23	0.23	0.28
Sogn og Fjordane	0.12	0.13	0.12	0.1	0.12
Møre og Romsdal	0.19	0.18	0.22	0.19	0.2
Sør-Trøndelag	0.23	0.24	0.2	0.24	0.25
Nord-Trøndelag	0.20	0.19	0.2	0.19	0.18
Nordland	0.20	0.21	0.17	0.17	0.18
Troms	0.10	0.14	0.12	0.09	0.10
Finnmark	0.07	0.08	0.08	0.06	0.05
Total	**3.30**	**3.39**	**3.21**	**3.24**	**3.45**

Table 27 shows the estimated production in local heating centrals by county and fuel type.

Bioenergy in forest industries

The use of biomass for heating in the manufacturing sector decreased from 5 TWh in 2008 to 3.5 TWh in 2009 mainly due to lower production in the pulp and paper industries (Table 27).

Table 26. Use of wood chips and bark and delivered energy in district heating plants 2008. GWh. Based on data from Statistics Norway (2011).

County	Use of wood chips, GWh	Delivered energy, GWh
01 Østfold	0.0	0.0
02 Akershus	5.0	4.6
03 Oslo	201.5	175.2
04 Hedmark	130.7	116.3
05 Oppland	3.4	3.0
06 Buskerud	37.2	33.9
07 Vestfold	0.0	0.0
08 Telemark	5.1	4.3
09 Aust-Agder	0.0	5.4
10 Vest-Agder	6.0	0.0
11 Rogaland	0.0	0.0
12 Hordaland	0.0	0.0
14 Sogn og Fjordane	0.0	0.0
15 Møre og Romsdal	0.0	0.0
16 Sør-Trøndelag	27.6	23.8
17 Nord-Trøndelag	0.0	0.0
18 Nordland	8.9	5.4
19 Troms	27.0	26.2
20 Finnmark	0.0	0.0
Sum	**452**	**398**

Table 27. Production (biomass consumption) in local heating centrals 2008.

County	Gross production	Estimated delivered energy based on wood chips	Estimated delivered energy based on pellets
01 Østfold	2.2	0.1	1.8
02 Akershus	40.9	3.2	33.2
03 Oslo	8.4	0.5	7.0
04 Hedmark	29	1.6	24.3
05 Oppland	42.4	4.1	33.6
06 Buskerud	2.9	0.3	2.3
07 Vestfold	2.2	0.1	1.8
08 Telemark	1.5	0.1	1.3
09 Aust-Agder	2.1	0.5	1.3
10 Vest-Agder	2.3	0.1	1.9
11 Rogaland	15.8	7.7	5.6
12 Hordaland	5.7	0.4	4.7
14 Sogn og Fjordane	0.8	0.0	0.7
15 Møre og Romsdal	2.2	0.1	1.8
16 Sør-Trøndelag	3	0.2	2.5
17 Nord-Trøndelag	3.7	0.2	3.1
18 Nordland	1.4	0.1	1.2
19 Troms	1.7	0.1	1.4
20 Finnmark	0.6	0.0	0.5
Sum	**168.8**	**19.4**	**130.1**

Table 28. Energy use in the manufacturing sector. Source: Statistics Norway 2010f. GWh

	Total energy use including transport	Purchased electricity	Purchased fossil fuels for stationary use	Self produced energy from waste of wood, black liquor and hazardous waste	Self produced electricity
Wood and wood products	1 807	741	166	627	0
Pulp, paper and paper products	10 636	5 133	1 056	3 653	313
Other manufacturing sectors	67 707	44 292	10 292	802	53
Total 2008	**80 150**	**50 166**	**11 514**	**5 082**	**366**
2009					
Wood and wood products	1 672	633	127	692	0
Pulp, paper and paper products	8 792	4 520	1 058	2 573	190
Other manufacturing sectors	59 134	36 527	8 385	271	122
Total 2009	**69 598**	**41 680**	**9 570**	**3 536**	**312**

6.2 Bioenergy technologies

Forest biomass resources for energy production are mainly used for heat production in Norway. The chemical pulp mill Sødra Cell Tofte is producing some electricity (54 MW installed capacity). Statistics Norway reports an electricity production in pulp mills of 313 GWh in 2008 and 190 GWh in 2009 (Table 28).

The bioenergy technologies in NorFor and NTMIII are shown in Table 29.

The cost structure and energy efficiency for the bioenergy technologies are shown in Table 30. The data are partly based on data from Statistics Norway (plant level data for district heating), analyses of applicants to ENOVA and studies by Xrgia (2007). The lack of empirical data gives uncertainty about the assumed costs and energy efficiency. Especially the investment cost will vary from plant to plant and the assumed input-output relation should be seen as average estimates for the give technologies.

The distribution costs for new district heating is estimated as a function of the utilised technical capacity per region. The aggregated figures are shown in Figure 3.

Table 29. Bioenergy technologies in NorFor and NTMIII.

Technology	Description	Energy type	Sector
Woodstove	Wood stoves and fireplaces heating	Space heating	Private households
Pellet stove	Pellet stoves for wood pellets	Space heating	Private households
Local heating centrals-chips	Central heating and smaller heating centrals based on wood chips, for larger buildings including apartment houses. Conversion of existing oil burners	Hydronic heating	Households, agriculture and service sectors
LHC-pellets	Central heating and smaller heating centrals based on pellets, for larger buildings including apartment houses. Conversion of existing oil burners.	Hydronic heating	Households, agriculture and service sectors
LHC-industry (chips)	Central heating and smaller heating centrals based on wood chips, for industry. Conversion of existing oil burners	Hydronic heating and steam production	Industrial sector
Expansion of existing district hearting	Expansion (and densification) of existing district heating	Hydronic heating	Apartments and service sectors
New district heating	Replacement of existing oil burners with district heating and installation of water born heating in new buildings	Hydronic heating	Apartments and service sectors
Bioheat-forest industry	Combustion of bark, sawdust and black liquir etc for drying and heating in forest industries	Heating and drying	Forest industries
Bio-electricity	Electric production based on biomass	Electricity	Electricity market

Table 30. Energy efficiency and cost structure of bioenergy technologies in NorFor and NTMIII ex VAT.

Technology	Energy efficiency	CAPEX energy prod.[2]	CAPEX energy distrib.	Depr. Time (year)	Capital costs with 10 % interest rate	Estimated fuel cost (deliv.)	Other prod. cost	Estimated total production costs new capacity in base year
Woodstove	54 %[1]	-	0	0	0	741	0	741
Pellet stove	90 %	2 000	0	15	239	4573	111	807
LHC-chips	80 %	2 080	0	20	222	250	90	562
LHC-pellets	85 %	2 000	0	20	214	372	60	645
LHC-industry (chips)	80 %	2 080	0	20	222	250	90	562
DH-existing	80 %	684	680	20	146	250	140	536
New DH	80 %	1 600	1 500	20	331	250	140	721
Bioheat-forest industry	70 %	-	0	0	0	143	80	223
Bio-el	45 %	4 000	0	20	427	444	80	952

1) The energy efficiency is assumed to increase up to 65 % by 1 % per year up due to replacement of old wood stoves with new wood stoves.

2) CAPEX is the capital costs for energy production in the heating facility. CAPEX in energy distribution is the capital cost for distribution of the heat to the customers in the heating grid.

3) The pellet price for pellet stoves is the price for small bags NOK 411/MWh on 2008, the pellets prices for LHC is for bulk – NOK 316/MWh (Nobio 2010).

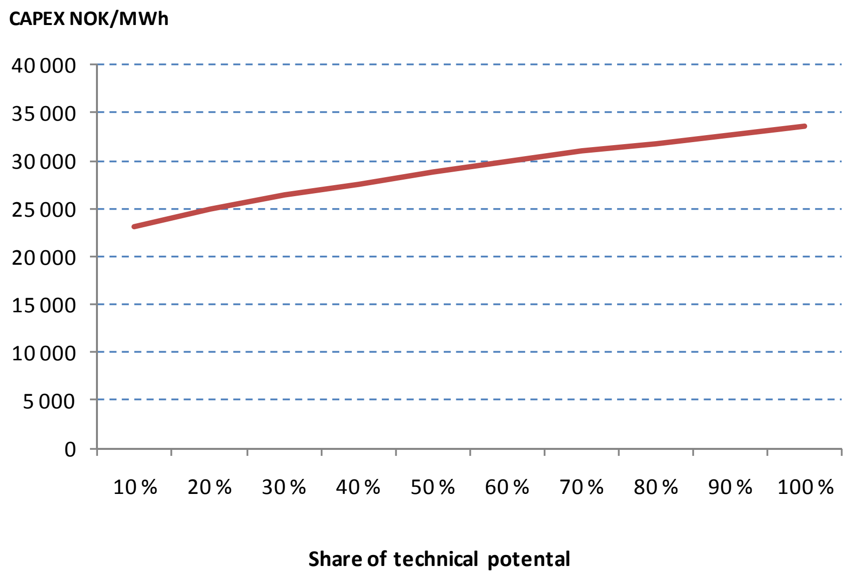

Figure 3. Estimated CAPEX for heat distribution in new district heating es a function of the estimated technical potential.

6.3 Energy prices

Electricity prices

The Norwegian electricity market is divided into 6 market or price areas. Electricity prices vary between regions and by time. Electricity is traded on the Nordpool and current and historical data are available on the website http://www.nasdaqomxcommodities.com/.

Customers have to pay taxes and grid rent in addition to the electricity price. The electricity tax was NOK 105/MWh in 2008, but is not paid by the power intensive industry or in Finnmark and northern municipalities in Troms. Figure 4 shows how the electricity prices and grid rent varies between consumer group.

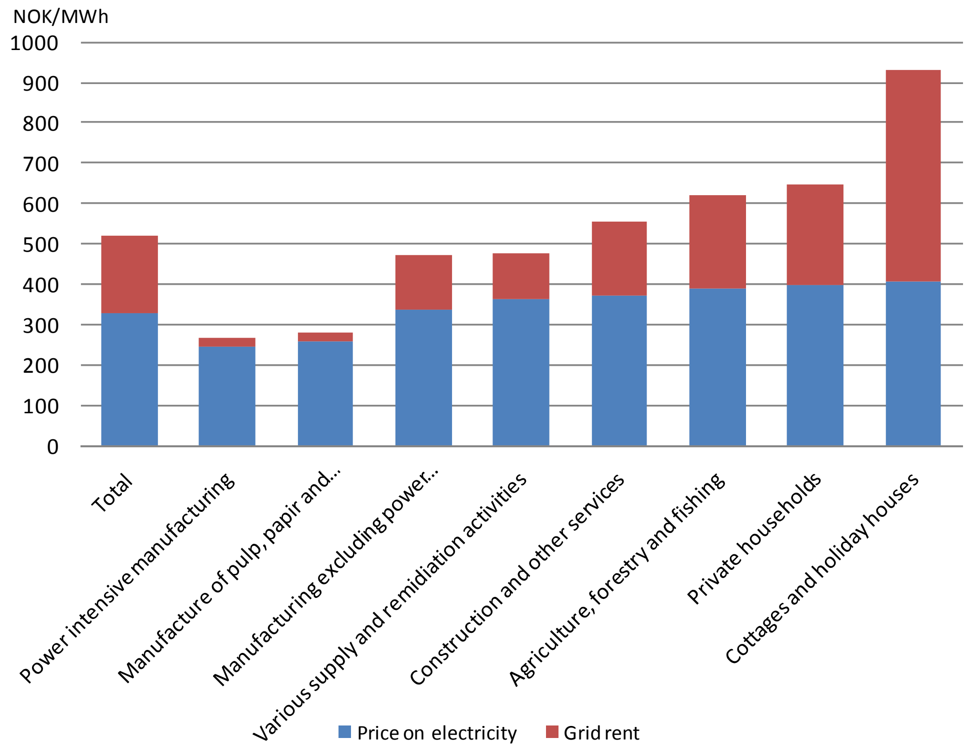

Figure 4. Prices of electricity and grid rent by consumer group 2008. Source: Statistics Norway 2010g

Heat prices

Electricity is the main source for heating in Norway which imply that the electricity prices set the heat price for bioenergy producers and represent the value of space heating in households. The heat prices will hence vary by region and consumer group. Heating by bioenergy is also mainly done in the colder periods, meaning that the annual variation must be considered. Finally is also the heat prices as obtained by the bioenergy prices lower than the electricity prices, partly to give margin for costs covered by the consumers, such as investments in conversion from oil or efforts for storage of wood, emptying of oil etc. The heat price obtained by the district heating producers was NOK 593/MWh ex VAT in 2008 (Statistics Norway 2011), whereas the service sector paid NOK 684/MWh ex VAT the same year. The difference of about 13 % is not adjusted for seasonal variation.

We have estimated the heat price for different sectors based on differences in electricity prices, grid rents and also analysed how the electricity consumption and el-spot price varies over the year based on electricity data from 2002 to 2010. We have assumed a heat price is 90 % of the electricity price for district heating and 85 % of the electricity price for space heating. The analyses showed that the electricity price in the heating season from October to April was 6.8 % higher than the annual average. Table 31 shows the assumed heat price compared to the annual average spot price for electricity for different regions and sectors as applied in the models. The spot price of NOK 328.8/MWh (average Elspot price for Oslo in 2008) is used as the base line defining the heat prices per county and sector in the base scenario in the models.

Table 31. Estimated heat prices compared to average spot price for electricity in 2008. Based on data from Nordpool and Statistics Norway.

	Households (space heating)	Service sector/DH/LHC	Industry
01 Østfold	158 %	145 %	97 %
02 Akershus	142 %	131 %	87 %
03 Oslo	146 %	134 %	89 %
04 Hedmark	163 %	150 %	100 %
05 Oppland	160 %	148 %	98 %
06 Buskerud	147 %	136 %	90 %
07 Vestfold	151 %	139 %	92 %
08 Telemark	150 %	139 %	92 %
09 Aust-Agder	157 %	145 %	96 %
10 Vest-Agder	156 %	144 %	95 %
11 Rogaland	147 %	136 %	90 %
12 Hordaland	148 %	137 %	91 %
14 Sogn og Fjordane	161 %	149 %	99 %
15 Møre og Romsdal	171 %	158 %	105 %
16 Sør-Trøndelag	167 %	154 %	102 %
17 Nord-Trøndelag	190 %	175 %	116 %
18 Nordland	173 %	160 %	106 %
19 Troms	164 %	152 %	101 %

6.4 Production and prices of biofuels

Firewood

Firewood prices are not available in public statistics. Norsk Ved (association for firewood producers) collects market information for firewood on an annual basis. The prices vary according to species, region and way of packing.

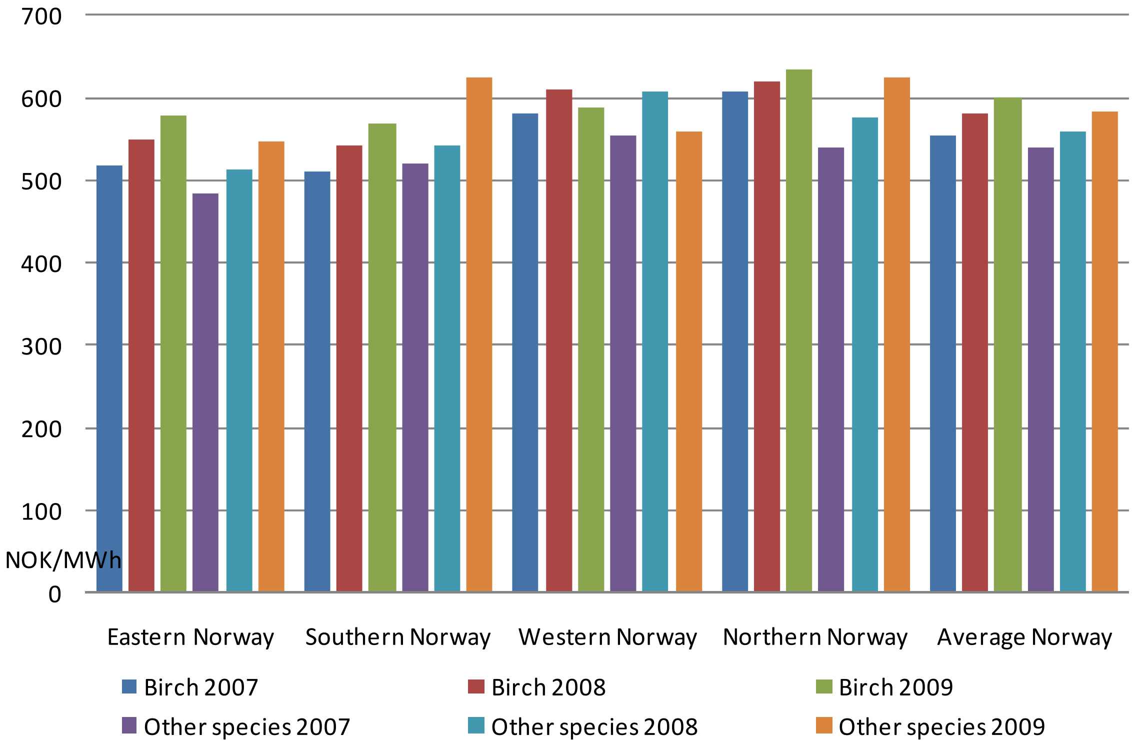

Figure 5. Firewood prices NOK/MWh for firewood packed in large bag (Euro size). Heating value per solid m3 is assumed to be 2.55 MWh for birch and 2.10 MWh for other species. Source: Norsk Ved 2008-2010.

The roundwood costs for firewood producers varied in 2008 and 2009 from NOK 120 to 190 per MWh. We have used the prices of pulpwood including transport costs and the firewood prices to estimate the production costs including profit for firewood production in the models.

Wood chips for energy production

Wood chips for energy production are made from roundwood (pulpwood) and harvest residues in model. No chipping costs are included.

Wood pellets

The price of wood pellets varies according to way of packing. The Norwegian Bioenergy Association collets market data from the pellets producers on an annual basis. Prices, production and international sales 2003-2009 are shown in Figure 6.

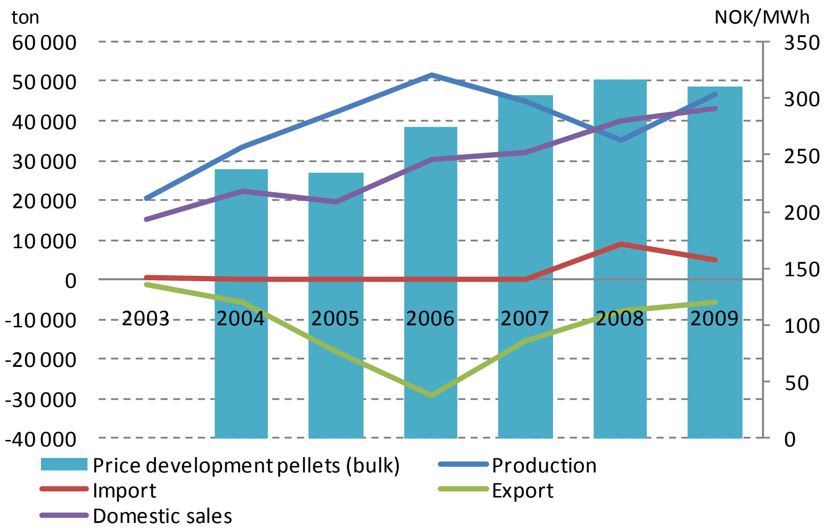

Figure 6. Price development, production and trade of wood pellets in Norway 2003-2009. Source: Norwegian Bioenergy Association 2010.

Statistics Norway started to collect data in wood pellets in 2009 and reports export price of NOK 1715/tonne, which corresponds to a price of NOK 357/MWh. The bulk price for consumers was around NOK 445/MWh + VAT. Public statistics for consumer prices for wood pellet is not available. Current market price (2011) for wood pellets delivered in Oslo (52 bags of 16 kg) is NOK 776/MWh incl VAT. Bulk prices are about 20 % lower.

The most important pellets producers in Norway are shown in Table 32. The production data are based on a survey. In addition to the pellets production specified in the table, about 50 000 tonnes of briquettes was produced in 2008. The production of briquettes is exogenously treated as pellets in the models.

Table 32. Pellets producers in Norway

Plant	County	Capacity	Prod 2008	Biomass input	Comment
FORFOREDLING BA	17 Nord-Trøndelag	3 500	3500	Pulpwood	
Møre Biovarme	15 Møre og Romsdal	n.a	3000	Dry residues	
Norsk Pellets Vestmarka (Arbaflame/Pemco)	04 Hedmark	n.a	n.a	n.a	
Pemco Trepellets AS	04 Hedmark	11 000	9500	Dry residues	
Vi-Tre AS	04 Hedmark	5 000	4500	Dry residues	
Rendalen biobrensel	04 Hedmark	2 000	n.a	Pulpwood	
Geilo Biobrensel	06 Buskerud	16 000	5000	Pulpwood	
Agder	09 Aust-Agder	500	500	Pulpwood	
GRAN TRE ANS	05 Oppland	500	500	Dry matter	
Biowood Norway	15 Møre og Romsdal	450 000		Pulpwood	Start up in 2011

The biomass input for plants using dry matter is mainly dry shavings from plaining of sawnwood and is assumed to be 1:1 (one tonne biomass give one tonne wood pellets). For plants using wet material, the biomass is pulpwood with an input of 2.5 m3 per tonne pellets. The power input is around 0.15

MWh/tonne, whereas the heat input is around 0.9 MWh per tonne pellets for wet production lines. In the models, other production costs are estimated as the difference between the pellets price and the input of biomass and energy.

6.5 Potentials for biomass heating

Space heating

The potential for heating with wood stoves are limited by several factors. First of all is a chimney required. Secondly will the construction of the house limit how much energy is possible to supply from one point. Finally will the need to feed the stove give some practical limitation on how much wood it is possible to use as modern wood stoves often have limited filling capacity.

Pellet stoves have limitation due the need for chimney and heat supply from a fixed source, but more capacity to burn all day round and possibilities for automatic filling makes it possible produce more heat on an annual basis for pellets stoves compared to wood stoves.

We have used data heating systems in dwellings from the population and building census in 2001 (Statistics Norway 2002) and assumed that the maximum heat production in single houses and apartments with chimneys are 7 and 4 MWh respectively and that 90 % of the use of kerosene/light heating oil can be converted to pellet in pellet stoves.

Local heating centrals and district heating

In principle can most of the current deliveries of transport fuel, heat and power be substituted by bioenergy. The costs of substitution vary however significantly. Replacement of oil burners by burners for wood chips or wood pellets have relatively low costs compared to replacement of electric space heaters where the system for hydronic heating distribution has to be installed. In practice and to the costs specified for local heating centrals or district heating in existing buildings in Table 30, the technical potential depends on the availability of existing hydronic heating systems. The economic potential depends on as the profitability of competing technologies of which use of electricity in heat pumps are the most prevalent at the moment, in addition to heat prices, costs of biofuels, investments and other operation costs. We have used results from the energy model X-varme (Havskjold et al. 2003) to estimate the technical potential scenarios by year 2020 for local heating centrals, expansion existing district heating and new district heating, as well as the economical potentials under different energy prices. Information from Statistics Norway about energy consumption in the period of 1991-2007, population forecasts for year 2020, employment and income data form the base for the forecast. Ex post, we apply information from Matrikkelen, the Norwegian Property Register, which enable us to classify the energy demand after building sizes. The final output from this model is projected heat demand in 2020 for each municipality in Norway classified by zone, sector and type of consumption. The forecast is performed for all 430 communities, and for the three sectors (1) Households, (2) Service sector and (3) Industry. Energy consumption in industry is assumed to be constant at the present level.

The model uses temperature statistics from The Norwegian Meteorological Institute, price statistics from Statistics Norway and complementary electricity consumption statistics from the Norwegian Water Resources and Energy Directorate. To be able to extrapolate the potential heat demand, the short term substitutable demand is identified for the existing building stock. To be of interest for renewable heat supply, the infrastructure for heating has to be hydronic. For all sectors the demand for heating is classified according to the existing fuel as reported by Statistics Norway (2010b). The only relevant products for substitution by wood chips in existing buildings are heating oil, electricity (electric boilers) and natural gas.

We assume that hydronic infrastructure will be installed in all new and rehabilitated buildings. The background for this assumption is the new building regulations, and that we are projecting the situation in 2020. This is of course a simplification, but we lack adequate information to perform a more detailed projection. Table 33 shows current delivered bioenergy production (2008) and estimated potential for delivered bioenergy by 2020.

Table 33. Current and technical 2020 additional potential for bioenergy production (delivered GWh)

		Additional potential					
	Current production (delivered)	**LHC house-holds/ service**	**Expansion of existing DH**	**New district heating**	**LHC industry**	**Wood stoves**	**Pellet stoves**
01 Østfold	1 157	86	225	42	76	205	62
02 Akershus	332	257	343	90	36	393	47
03 Oslo	478	604	768	199	65	26	58
04 Hedmark	673	61	92	29	45	223	32
05 Oppland	341	70	101	27	17	303	25
06 Buskerud	1 792	138	131	56	26	238	55
07 Vestfold	236	99	84	45	50	178	37
08 Telemark	269	51	77	24	15	125	34
09 Aust-Agder	148	31	40	12	18	113	22
10 Vest-Agder	159	80	68	36	24	134	15
11 Rogaland	255	165	126	78	69	387	19
12 Hordaland	250	255	354	95	68	328	38
14 Sogn og Fj.	104	51	22	25	51	115	7
15 Møre og R.	231	102	68	42	74	263	17
16 Sør-Trønd.	314	167	214	49	36	189	24
17 Nord-Trønd.	489	45	57	13	18	239	7
18 Nordland	222	125	88	55	123	291	18
19 Nordland	158	87	104	41	25	180	13
20 Finnmark	62	65	12	44	11	72	9
Total	**7 670**	**2 542**	**2 974**	**1 003**	**847**	**4 003**	**540**

1) The potential for new district heating is a part of the potential for LHC.

2) The potential for wood stoves can also be utilised by pellet stoves.

Figure 7 shows the current production and the total delivered additional potential in the heat market. The high level of bioenergy production in Østfold, Buskerud and Nord-Trøndelag is caused by the large pulp and paper plants in these counties. The estimated total additional potential is 11 TWh delivered energy, which will require around 15 TWh of additional biomass.

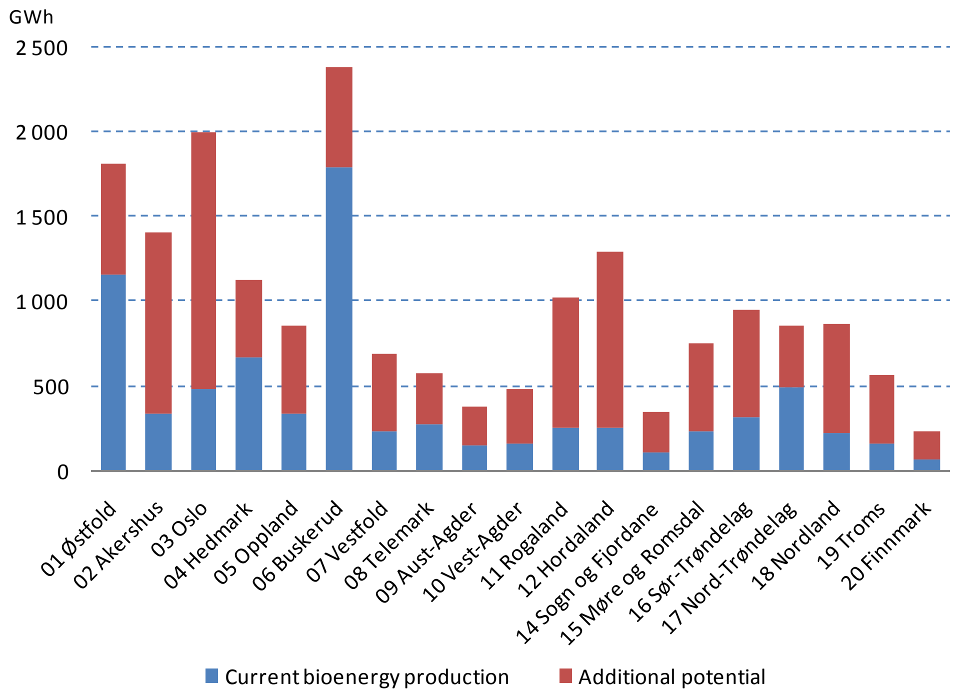

Figure 7. Current (2008) and estimated potential additional bioenergy production by county in the heat market. Delivered GWh. Existing production by Statistics Norway (2010b)

7 CARBON FLOWS IN NORFOR

7.1 Overview of carbon flows

In NorFor, carbon flows in the major pools throughout the sector are estimated. The following fluxes are included:

- Carbon sequestration during forest growth, and decay of old forest and of harvest residues left in forest
- Harvest residues taken out of the forest for energy
- GHG (greenhouse gas) emissions from the use of machinery in forest operations, transport of timber and products and processing in industry
- Carbon pools in wood products; substitution effects of the use of these products and emissions and substitution effects after the products go out of use

Based on stand parameters, biomass in tree parts were calculated and included in NorFor. The parameters from the soil model YASSO (Raymer et al., 2009) were included to calculate the CO_2

release from dead wood and soil. The functions for yield, biomass and decay are displayed in the following.

7.2 Biomass functions

For calculations of carbon dynamics in forests, biomass was estimated for bark, needles, living branches, dead branches, tip, stump, large and small roots. For each species, the functions and references are given in the following.

D: Breast-height diameter in cm.
H: Dominant height of stand in meters (average height of the 100 trees/ha with the largest diameter)
N: number of trees

Spruce

Bark volume Spruce: 12 % of stem volume with bark (Forestry planning handbook - average)
Needles Spruce: kg = exp(-1.8551+ 9.7809*(D/(D+12))-0.4873*LOG(H))*N (Marklund, 1988. Function G16)
Living branches Spruce: kg = exp(-1.2063+10.9708*(D/(D+13))-0.0124*H-0.4923*LOG(H))*N (Marklund, 1988. Function G12)
Dead branches Spruce: kg = exp(-4.6351+ 3.6518*(D/(D+18))+0.0493*H+1.0129*LOG(H))*N (Marklund, 1988. Function G20)
Tip spruce without Bark m^3= 8.04 - 0.39*D + 0.0048*D*D + 0.11*H (Vestjordet, 1968)
Tip spruce with Bark m^3= 9.50 - 0.41*D + 0.0049*D*D + 0.11*H (Vestjordet, 1968)
Stump Spruce: kg = exp(-3.3645+10.6686*(D/(D+17)))*N (Marklund, 1988. Function G26)
Large Roots spruce: kg = exp(-6.3851+13.3703*(D/(D+ 8)))*N (Marklund, 1988. Function G28)
Small Roots spruce: kg = exp(-2.5706+ 7.6283*(D/(D+12)))*N (Marklund, 1988. Function G31)

Pine

Bark volume Pine: 18 % of stem volume with bark (Forestry planning handbook - average)
Needles Pine: kg = exp(-3.4781+12.1095*(D/(D+ 7))+0.0413*H-1.5650*LOG(H))*N (Marklund, 1988. Function T-18)
Living branches Pine: kg = exp(-2.5413+13.3955*(D/(D+10))-1.1955*LOG(H))*N (Marklund, 1988. Function T14)
Dead branches Pine: kg = exp(-5.8926+ 7.1270*(D/(D+10))-0.0465*H+1.1060*LOG(H)) (Marklund, 1988. Function T22)
Tip pines without Bark m^3= 9.60 - 0.55*D + 0.0075*D*D + 0.13*H (Vestjordet, 1968)
Tip pine with Bark m^3= 11.55 - 0.64*D + 0.0088*D*D + 0.14*H (Vestjordet, 1968)
Stump Pine: kg = exp(-3.9657+11.0481*(D/(D+15)))*N (Marklund, 1988. Function T28)
Large Roots Pine: kg = exp(-6.3413+13.2902*(D/(D+ 9)))*N (Marklund, 1988. Function T31)
Small Roots Pine: kg = exp(-3.8375+ 8.8795*(D/(D+10))*N (Marklund, 1988. Function T31)

Birch

Bark volume Birch: 3 % of stem volume with bark (estimated)
Living branches Birch: kg = exp(-3.3633+10.2806*(D/(D+10)))*N (Marklund, 1988. Function B11)

Dead Branches Birch: kg = exp(-6.6237+11.2872*(D/(D+30))-0.3081*H+2.6821*LOG(H)) (Marklund, 1988. Function B16)
Tip birch without Bark m^3= 9.60 - 0.55*D + 0.0075*D*D + 0.13*H (Vestjordet, 1968)
Tip birch with Bark m^3 = 11.15 - 0.64*D + 0.0088*D*D + 0.14*H (Vestjordet, 1968)
Stump Birch = (Stem volume + bark +living branches+ dead branches)*0.0665 (estimated)
Large Roots Birch = (Stem volume + bark +living branches+ dead branches)*0.1 (estimated)
Small Roots Birch = (Stem volume + bark +living branches+ dead branches)*0.0978 (estimated)

Biomass in old trees is assumed decaying the same period as it is dying. For harvest residues left in forest, the decay functions based on Yasso (Liski et al., 2005; Raymer et al., 2009) are used (Table 35).

The conversion factors to tonnes CO_2 in biomass and in the products are displayed in Table 34. For biomass parts, the formula

tonnes CO_2/m^3 = tonnes dry matter/m^3 * carbon content of dry matter * mass CO_2/C

has been applied. 50 % of the dry matter is carbon, and the CO_2 - C ration is 44/12. A corresponding formula where tonnes replaces m^3 in the abovementioned formula was used for biomass parts in tonnes.

For solid wood products, the carbon content was assumed the same as for biomass parts. The carbon content in paper is based on the wood input. The energy content in the energy carriers was assumed to be 2 MWh/m^3.

Table 34: Carbon content in biomass parts and manufactured products. All biomass parts measured in tonnes are in tonnes dry matter.

Product group	Biomass/product (unit)	CO_2 content tonnes/unit
Biomass parts	Tip (m^3)	0.7
	Bark of tip (m^3)	0.77
	Needles (tonnes)	1.84
	Living branches (tonnes)	1.84
	Dead branches (tonnes)	1.84
	Stump (tonnes)	1.84
	Large roots (tonnes)	1.84
	Small roots (tonnes)	1.84
	Spruce stem (m^3)	0.7
	Pine stem (m^3)	0.77
	Birch stem (m^3)	0.92
Solid wood	SSAW (m^3)	0.7
	PSAW (m^3)	0.77
	NSAW (m^3)	0.92
	PART (m^3)	0.7
	FIBR (tonnes)	1.84
Paper	NEWS (tonnes)	1.26
	COAT (tonnes)	1.15
	UNCO (tonnes)	1.44
	LINR (tonnes)	1.39
	OPBO (tonnes)	1.39
Energy carriers	FIREW (MWh)	0.35
	PELL (MWh)	0.35
	CHIPS (MWh)	0.35

Table 35: Share of the carbon stored in various harvest residues parts in each period of storage in harvest period.

5-year period	Tip	Tip bark	Needle	Branches
1	0.8	0.62	0.51	0.62
2	0.64	0.28	0.2	0.28
3	0.51	0.15	0.11	0.15
4	0.4	0.11	0.08	0.11
5	0.31	0.09	0.07	0.09
6	0.25	0.08	0.06	0.08
7	0.2	0.07	0.06	0.07
8	0.16	0.07	0.06	0.07
9	0.13	0.07	0.06	0.07
10	0.11	0.06	0.05	0.06
11	0.1	0.06	0.05	0.06
12	0.09	0.06	0.05	0.06
13	0.08	0.06	0.05	0.06
14	0.07	0.06	0.05	0.06
15	0.06	0.05	0.04	0.05
16	0.06	0.05	0.04	0.05
17	0.06	0.05	0.04	0.05
18	0.05	0.05	0.04	0.05
19	0.05	0.05	0.04	0.05
20	0.05	0.04	0.04	0.04

Greenhouse (GHG) emissions from forestry operations are included as displayed in Table 36.

Table 36. GHG emissions from forestry operations included in NorFor.

Acticity	Emissions	Unit	Reference	Remarks
Planting	1.8 kg	kg CO_2eq/m^3 log	Michelsen et al. (2008)	Estimate from Western Norway. Includes seedling production and planning.
Scarification of ground (ground preparation)	85 kg	kg CO_2/ha	Berg & Karjalainen (2003)	Estimates from Sweden
Silviculture	0.2 kg	kg CO_2eq/m^3 log	Michelsen et al. (2008)	Estimate from Western Norway.
Partial and final harvest	11.4 kg	kg CO_2eq/m^3 log	Michelsen et al. (2008)	Estimate from Western Norway.

GHG emissions from transport of wood and wood products were calculated using the unit emission factor 0.22 kg Co_2eq/tonne km, which is based on Trømborg et al. (2009) added 50 % for partly empty backhaul. GHG emissions from processing are included (Table 37).

Table 37: GHG emissions from processing

Product	kg CO_2eq/unit	Reference	Remarks
SSAW	3.83	Wærp et al. (2008)	
PSAW	3.83	Wærp et al. (2008)	
NSAW	3.83	Wærp et al. (2008)	
PART	58.2	Rivela et al. (2006)	Estimate from Spain
FIBR	215.7	Rivela et al. (2007)	Estimate of MDF from Spain and Chile
NEWS	826	Keiti (2008)	Korean estimate
COAT	145	Keiti (2008)	Korean estimate
UNCO	145	Keiti (2008)	Korean estimate
LINR	329	Keiti (2008)	Korean estimate
OPBO	826	Keiti (2008)	Korean estimate, assumed as newsprint
BORR	197	Keiti (2008)	Korean estimate, as pulp
FIREW	5.4	Raymer (2006)	
PELL	0.3	Raymer (2006)	Efficiency in combustion accounted for
CHIPS	1.9	Raymer (2006)	

Use of wood products is assumed to decrease the consumption of competitions products. The substitution is assumed to be one-to-one, i.e. that one unit of wood product replaces one unit of a competing product. Sawn wood is assumed replacing half concrete and half steel, and boards is assumed to replace only steel. Waterborne bioenergy is supposed to replace domestic heating oil, and bio space heating assumed to replace electricity, of which half is based on coal power and half on hydropower (Table 38).

Table 38: Substitution effects of use of wood products

Product	Tonnes CO_2eq/unit	Reference
SSAW	0.796	Petersen and Solberg (2002)
PSAW	0.796	Petersen and Solberg (2002)
NSAW	0.796	Petersen and Solberg (2002)
PART	0.53	Petersen and Solberg (2002)
FIBR	0.53	Petersen and Solberg (2002)
Paper	0	
Biowater	0.301	Sjølie et al. (2010)
BioSpace	0.379	Sjølie et al. (2010)
BioIndu	0.301	Sjølie et al. (2010)

Over time, products go out of use. Based on Lunnan et al. (1991) and Raymer (2005), the share of the products manufactured in a certain period still assumed to be in use after some time, is given in Table 39.

Table 39: Share of products still in use in each 5-year period after production.

5-year period	Sawn wood	Board	Paper	Bioenergy carriers
1	0.9128	1.0000	0.0030	0.0030
2	0.8841	1.0000	0.0010	0.0010
3	0.8668	0.7050	0.0010	0.0010
4	0.8315	0.4980	0.0010	0.0010
5	0.8056	0.3510	0.0010	0.0010
6	0.7862	0.2480	0.0010	0.0010
7	0.7714	0.1750	0.0010	0.0010
8	0.7601	0.1230	0.0010	0.0010
9	0.7515	0.0870	0.0010	0.0010
10	0.7449	0.0610	0.0010	0.0010
11	0.7395	0.0430	0.0010	0.0010
12	0.7354	0.0310	0.0010	0.0010
13	0.7322	0.0220	0.0010	0.0010
14	0.7296	0.0150	0.0010	0.0010
15	0.7277	0.0110	0.0010	0.0010
16	0.6297	0.0080	0.0010	0.0010
17	0.5450	0.0050	0.0010	0.0010
18	0.4713	0.0040	0.0010	0.0010
19	0.4078	0.0030	0.0010	0.0010
20	0.3532	0.0020	0.0010	0.0010

Due to a general land filling ban in Norway, end products are assumed to be combusted in large heating facilities when going out of use. Electricity being half based on coal, half based on hydropower, is supposed being replaced by the combustion of wood products. Substitution effects amount to 0.379 tonnes CO_2eq/MWh (Sjølie et al., 2010). Assumed energy content in the wood products is given in Table 40.

Table 40: Assumed energy content in forest industry end products.

Product	MWh/unit	References
SSAW	2.12	Demirbas (1997)
PSAW	2.34	Demirbas (1997)
NSAW	2.61	Demirbas (1997)
PART	2.12	Assumed as SSAW
FIBR	2.12	Assumed as SSAW
NEWS	4.88	Ucundu and Vesilind (s.a.)
COAT	4.88	Ucundu and Vesilind (s.a.)
UNCO	4.88	Ucundu and Vesilind (s.a.)
LINR	4.5	Ucundu and Vesilind (s.a.)
OPBO	4.5	Ucundu and Vesilind (s.a.)

8 DISCUSSION

8.1 General consideration of data quality

Data quality is an important factor in the reliance of the results. Several aspects are related to data quality, as representativeness and data uncertainty. Data representativeness indicates how well the analyzed chain or products are represented, as the data often are taken from other geographical areas or adjacent products. Data limitations always exist, and models are simplified representations of the systems. However, consequences of data deficiency vary with the analyses. In general are data regarding production, prices and trade of wood, energy and forest products based on figures from Statistics Norway of high quality, whereas data of inputs and costs in production will have higher unvertainty. In the following, we will discuss what we believe are the major data limitations, possible impacts and future improvements.

8.2 Specific comments

Biomass supply

While the forest growth in NorFor is assumed being rather well represented in the data, the limited number of possible management activities may impact on the results, with suboptimal management as possible consequence. However, as the main management activities undertaken in Norwegian forestry are incorporated, the range of activities is rather well represented. Fertilization, carried out on very limited areas today, is not included, but should be included on a later stage, as it may become profitable with inclusion of CO_2 price. Logging costs vary by region and type of harvest, but are fixed. Actual harvest costs are likely to increase with harvest level, and including such upward sloping costs could make timber supply less elastic. The magnitude of the amenity value was found iterating the amenity value and discount rate until the harvest level came close the actual harvests. However, the size of the amenity value is uncertain, and even if the overall harvest level is close to historical data, this may not be true on a disaggregated level, which may cause biases in supply areas. Since the harvest species composition is fixed to the stand species composition, biases in supply and prices may occur compared to historical data. Including a single-tree simulator would improve the flexibility in timber supply.

NTM has a more simplistic representation of roundwood supply based on base year harvest, prices and price elasticities. As described in Chapter 2.2, the estimated prices elasticities vary from study to study. It is also plausible to expect that the price elasticities vary from region to region (county to county) due to differences in forest conditions and ownership characteristics. The observed prices and harvest are however ensure however a realistic representation for timber supply in the short and medium term. The uncertainty will increase when model estimates are further away from observed prices and quantities. The volume elasticity in the base scenario is set to 0.65 based on the observed utilization of the increment in productive forest less than 1 km from forest roads. Both price and volume elasticities are subject to changes over time as both forest owners and forest resources change and should be treated as scenario parameters.

The engineering approach for modeling of the supply wood chips from harvest residues (same module in both models) is based on Norwegian forest conditions and prices, but time estimates from Swedish and Finnish studies. Utilization of harvest residues is in the beginning in Norway the production is likely to develop over time. The supply function applied in the models represent at future state, less wood chips will be available at the given prices in the short run. There are also uncertainties regarding how forest owners will respond to the opportunity to utilize harvest residues. The estimated supply is based on average roundwood harvest in the period 1996-2008. Significant increase or decrease in the roundwood harvest will give a similar change in the supply of wood chips based on harvest residues.

Forest industrial production

Due to limitations in available data, only one technology is defined for each species in sawn wood production. With more available data in the future, it would be of interest to disaggregate production, for instance by saw mill size or type of sawn wood purchaser. With data included as of today, the models are not well suited to analyze competition within the sawmill industry. However, for studies of other parts of the forest industry, this data limitation should not be a large drawback, as the overall sawnwood production data are assessed to be rather reliable.

Data for pulp and paper are collected on plant level and especially wood and energy inputs give a realistic representation of the actual situation. Other production costs are schematically estimated based on product prices and the costs of biomass, energy and labor in other to avoid bias caused by product aggregation in the model. The data are not suited to evaluate short run profitability of individual plants, but should give a realistic picture of likely impacts of changes in markets and policies over time.

Bioenergy production

Studies of costs of bioenergy production are limited and the data applied in the model are based on limited availability of data. There will be examples of costs that differ from the average numbers applied per technology in the model. The main uncertainty is however how potential producers and consumers of bioenergy will respond to changes in energy prices as bioenergy represent only one of many possible energy technologies. The potentials applied in the models are hence uncertain. The production of heat in wood stoves can serve as an example; Higher energy prices makes increased use of firewood profitable, but the increased production imply more work for the consumer (carrying of wood, emptying of ash), will also make heat pumps more profitable and the consumer can also replace the old wood stove with a wood stove with higher energy efficiency that demands less firewood for the same output of heat.

Carbon flows in NorFor

Carbon flows in forest biomass are based on much applied biomass functions which are considered reliable. Only the net growth is known from the data, and not the gross growth and the continuous decaying of biomass parts. Therefore, dead biomass parts are assumed decayed instantly. This simplification may result in an underestimation of the biomass carbon stock, as gradual decay result in greater carbon stocks. Based on emission rates from the YASSO model (Raymer, 2005), gradual decay of harvest residues are included. Due to lack of data, emissions from soil due to harvest operations and scarification of ground are not included.

The mortality functions are central to the future biomass carbon flows. The applied mortality functions are based on stands which to a large extent are managed and thinned, are may therefore underestimate the mortality in high-density stands and old stands.

GHG emission rates for harvest, transport and processing based on Norwegian data were used where possible. Due to data limitations, emission data based on production chains which do not correspond completely were used for some forest industry products. Using emission rates for paper production from other countries are not necessarily a limitation, as the production technologies may be rather similar through countries.

The assumed substitution rates are more uncertain. Substitution of other products with wood products is assumed one-to-one, i.e. that one unit of wood product replaces one unit of other products, but this rate is also uncertain. In addition, which products that are actually replaced with wood products is uncertain, as which type of energy carrier various types of bioenergy substitutes, and which materials solid wood replaces. Actual replacements depend probably on technological aspects, market situation and policy measures, and may vary over time.

To conclude, mortality rates in dense, old stands and substitution effects are considered as the most important uncertainties in the GHG emission accounting. Consequently, more studies of these aspects would be of great interest.

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