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WORKING PAPER

Estimates of carbon sequestration coefficients for forestry grown on Norwegian agricultural land

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by

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Summary

This working paper documents how carbon sequestration coefficients for forest grown on agricultural land in Norwegian counties were derived. We consider both active re-planting and natural afforestation. Estimates range from 0.8 to 30.5 tons CO_2 per hectare per year – depending on, amongst others, the location and which species that is considered (confer Table 24).

Contents

Preface

This working paper documents the derivation of carbon sequestration coefficients for forest grown on Norwegian agricultural land. These figures will serve as input to the established model Jordmod – an economic model of the Norwegian agricultural sector. The purpose is to carry out greenhouse gas policy analysis. Associated with this paper is a GAMS program (The General Algebraic Modeling System), which computes the figures. The structure of this working paper is made to facilitate reading the program (given in Appendix A).

The main issue is the expected woody biomass production on agricultural land. While there is plenty of data and information about wood productivity of *forest* land, agricultural land is not classified in terms of its abilities to produce woodwork. So our main point of departure is to look at forest land statistics, and from that, construct coefficients to be applied on the agricultural land.

Main methods

We shall develop two different methodologies for estimating carbon uptake coefficients: *Natural afforestation* and *active planting*.

Natural afforestation

This method presumes that a given piece of land is returned to state of the representative forest in the area. So we combine statistics on the actual site qualities in the county with actual growth figures to estimate productivities.

Active planting

This method presumes a number of active choices: For instance selection of the most productive species, and appropriate management practices, such as thinning etc, in order to achieve the potential site quality available at hand.

In both methods we assume that forest land suitable for cultivation is more productive than non-cultivable forest land.

Sets

We start by declaring various sets.

Regions

There are various degrees of geographical aggregation of the statistics applied, ranging from nationwide to municipality. The most aggregated level of geographical specification (other than nationwide) divides the country in two:

SET L Part of country /

1 'SørogØstlandet' (South and Eastern Norway)

2 'NordogVestlandet' (North and West Norway)

The first region is mainly inland while the second is coastal. This division is only used when transforming the productivity of spruce into that of pine and birch.

The main geographical entity we work with is county. There are 19 of them, and they are listed in Table 1.

Note that county 03 (Oslo) is included in 02 (Akershus). The relationship between the sets F and L (declared as the **set FL(F,L)**) is that counties 01 to 09 is in part 1 of the country, while the remaining counties are in part 2.

Table 1. Relationship between counties and regions in Jordmod.

SET F Counties		SET R Regions in Jordmod	
01	Østfold	011101	Fredrikstad
02	Oslo/Akershus	021101	Oslo
		021103	Skedsmo
04	Hedmark	041101	Ringsaker
		041203	Elverum
		041205	Trysil
05	Oppland	051103	Gjøvik
		051205	Nordre Land
06	Buskerud	061101	Drammen
		061205	Ål
07	Vestfold	071101	Larvik
08	Telemark	081103	Skien
		081203	Bamble
		081205	Notodden
09	Aust-Agder	092205	Arendal
10	Vest-Agder	102205	Kristiansand
11	Rogaland	112102	Stavanger
		112203	Strand
		112105	Rennesøy
		112205	Karmøy
12	Hordaland	123205	Bergen
14	Sogn og Fjordane	143205	Flora
15	Møre og Romsdal	153205	Ålesund
16	Sør-Trøndelag	164104	Trondheim
		164204	Skaun
		164205	Oppdal
17	Nord Trøndelag	174104	Steinkjer
		174205	Namsos
18	Nordland	185206	Bodø
19	Troms	195206	Tromsø
		195207	Nordreisa
20	Finnmark	205207	Alta

The Jordmod model operates with 32 production regions, listed in Table 1.

The relationship between the Jordmod regions and counties (declared as the **set RF(R,F)**) is that the two first digits in the Jordmod region constitutes the corresponding county number (see Table 1).

Finally, the **set RFL(R,F,L)** combines the sets RF and FL. For instance, its first element is Fredrikstad.Østfold. SørogØstlandet.

Species

Norwegian forest statistics, have categorized various items, such as growth, across spruce, pine and coniferous forest. We assume that the latter can be represented by birch. Further, the species sitka is very productive in terms of producing biomass, so we include it for analysis. Thus, we operate with the following set S of species.

SET S species /
SIT 'Sitka'
SPR 'Spruce'
PIN 'Pine'
BIR 'Birch'/

Not all species can grow in all regions. We assume that pine and birch can do so; that spruce can grow everywhere but in Finnmark, and that sitka can only grow in the coastal counties 10 – 19. These feasibilities of regions and species are declared in the **set FS(F,S)**.

Site quality classification systems

In the Norwegian forest survey, forest area is classified, amongst others, by its capabilities to produce timber. We distinguish between the *actual* productivity and the *potential* productivity. The former is the productivity with the current tree species and forest management. The latter is the productivity that can be achieved if adopting various management practices such as thinning etc.

The classification system applied in the National Forest Inventory, is the “height above breast height (1.3 m) at 40 years of age”, the $H_{1.3}40$ system – H40 for short. The categories in the H40 system incude eight classes: 6, 8, 11, 14, 17, 20, 23, 26.

The H40 index is species specific. If a given piece of land is F17, it means that a typical pine tree (Furu in Norwegian) is 17 meter high at 40 years age, when the age is measured as number of growth rings at breath height (1.3 m). Similar prefixes for spruce (Gran in Norwegian) is G, for birch it is B, and for sitka S. For most of the statistics we make use of, the reference tree is spruce. Hence, unless otherwise stated, a site quality of say 20 means G20.

A simpler classification system for site quality is applied in the Norwegian land survey (Digitalt MarksalgsKart =DMK):

L 'Low'
M 'Medium'
H 'High' /

The data base also operates with the class for unproductive forest. This class corresponds to that which is below the lowest category in the H40 system, thus it does not play a role in our setup. According to Bjørdal and Bjørkelo (2006, p 15), the DMK data base has a category Very High. But in the actual database, this class has been combined with the class ‘High’. Thus, we are left with the three categories listed above.

The relationship between the two site quality systems are given next. It is taken from Bjørdal and Bjørkelo (2006, Table 1). The H40 categories 6 and 8 belongs to the DMK category Low, 11 and 14 to Medium, and 17 and above to High. These relationships are declared in the **set H40SQ(H40,SQ)**.

Data

Area

We start by introducing the various statistics we make use of, and start with land area. The figures are taken from the National Forest Inventory[1]. This database operates with one common category for classes 23 and 26. We split them into two and assume, arbitrary, that two thirds of the area is 23, and the remaining third 26. This applies to both area of actual site quality and potential site quality.

Table 2. Distribution and total of forest area over H40 *actual* site quality.

	H40 site quality								
County	6	8	11	14	17	20	23	26	Total km^2
01 Østfold	7 %	23 %	22 %	17 %	16 %	11 %	3 %	1 %	2 324
02 Oslo/Akershus	3 %	15 %	24 %	27 %	21 %	8 %	2 %	1 %	3 279
04 Hedmark	10 %	26 %	27 %	19 %	13 %	4 %	1 %	0 %	13 740
05 Oppland	11 %	33 %	24 %	17 %	11 %	4 %	0 %	0 %	5 522
06 Buskerud	9 %	26 %	23 %	21 %	14 %	5 %	1 %	1 %	5 730
07 Vestfold	3 %	11 %	16 %	19 %	18 %	19 %	10 %	5 %	1 242
08 Telemark	11 %	28 %	25 %	20 %	9 %	5 %	1 %	1 %	4 341
09 Aust-Agder	10 %	26 %	27 %	25 %	10 %	2 %	1 %	0 %	3 184
10 Vest-Agder	9 %	24 %	30 %	18 %	12 %	5 %	1 %	1 %	2 444
11 Rogaland	6 %	28 %	31 %	16 %	9 %	5 %	4 %	2 %	1 430
12 Hordaland	9 %	29 %	28 %	14 %	8 %	6 %	4 %	2 %	2 792
14 Sogn og Fjordane	8 %	28 %	31 %	16 %	6 %	5 %	3 %	2 %	2 673
15 Møre og Romsdal	8 %	20 %	29 %	21 %	11 %	8 %	2 %	1 %	2 854
16 Sør-Trøndelag	13 %	33 %	26 %	18 %	8 %	2 %	0 %	0 %	4 196
17 Nord-Trøndelag	12 %	28 %	28 %	21 %	8 %	2 %	0 %	0 %	6 232
18 Nordland	20 %	39 %	25 %	13 %	3 %	0 %	0 %	0 %	6 205
19 Troms	28 %	51 %	18 %	3 %	0 %	0 %	0 %	0 %	4 235
20 Finnmark	42 %	55 %	3 %	0 %	0 %	0 %	0 %	0 %	3 193
Total	13 %	30 %	25 %	17 %	10 %	4 %	1 %	1 %	78 645

We note that while Hedmark has by far the most forest, Vestfold has a high share of very productive sites. Counties in the northern part of Norway – which appear towards the bottom of the Table 2 have less high quality area.

The figures in Table 2 represent the *actual* site quality and will be used to compute natural increment coefficients. By contrast, if appropriate management practices are applied, the *potential* site quality could be achieved. The figures are taken from the Norwegian Forest Inventory and are presented in Table 3.

[1] Available here: http://www.skogoglandskap.no/artikler/2007/Landsskogdata_enkel_tabell . There is no entry for the county Finnmark in this database. Figures for that county are therefore taken from Statistics Norway (2012).

Table 3. Distribution and total of forest area over H40 *potential* site quality.

County	H40 site quality								Total km^2
	6	8	11	14	17	20	23	26	
01 Østfold	7 %	22 %	22 %	18 %	15 %	12 %	3 %	2 %	2 324
02 Oslo/Akershus	2 %	15 %	23 %	27 %	20 %	9 %	2 %	1 %	3 279
04 Hedmark	8 %	26 %	27 %	21 %	13 %	4 %	1 %	0 %	13 740
05 Oppland	9 %	31 %	26 %	18 %	11 %	5 %	0 %	0 %	5 522
06 Buskerud	8 %	26 %	23 %	21 %	14 %	5 %	2 %	1 %	5 730
07 Vestfold	3 %	10 %	15 %	18 %	17 %	19 %	13 %	6 %	1 242
08 Telemark	10 %	27 %	25 %	20 %	9 %	5 %	2 %	1 %	4 341
09 Aust-Agder	10 %	25 %	26 %	26 %	10 %	2 %	1 %	0 %	3 184
10 Vest-Agder	7 %	18 %	19 %	21 %	20 %	11 %	3 %	2 %	2 444
11 Rogaland	4 %	9 %	11 %	21 %	4 %	20 %	8 %	4 %	1 430
12 Hordaland	5 %	7 %	7 %	19 %	28 %	20 %	9 %	4 %	2 792
14 Sogn og Fjordane	2 %	7 %	13 %	20 %	26 %	10 %	9 %	4 %	2 673
15 Møre og Romsdal	4 %	5 %	13 %	21 %	18 %	23 %	5 %	3 %	2 854
16 Sør-Trøndelag	10 %	28 %	27 %	21 %	10 %	3 %	0 %	0 %	4 196
17 Nord-Trøndelag	12 %	28 %	27 %	21 %	9 %	2 %	0 %	0 %	6 232
18 Nordland	11 %	23 %	32 %	26 %	8 %	1 %	0 %	0 %	6 205
19 Troms	13 %	25 %	33 %	22 %	7 %	0 %	0 %	0 %	4 235
20 Finnmark	42 %	55 %	3 %	0 %	0 %	0 %	0 %	0 %	3 193
Total	10 %	24 %	23 %	20 %	13 %	6 %	2 %	1 %	78 645

The figures reflect the fact that the *potential* site quality at any given place may be better than the actual site quality. The distribution is similar to actual site quality, yet slightly skewed to the right.

The final land statistics we shall make use of has forest area split into whether it is cultivable or not, and the site quality on the DMK scale. The figures are available on municipality level, and we have aggregated them to county level. They are displayed in 4.

Table 4. Forest area suitable for cultivation.

County	Site quality class			Total km^2
	L	M	H	
01 Østfold	7 %	11 %	82 %	145
02 Oslo/Akershus	2 %	12 %	86 %	319
04 Hedmark	24 %	44 %	33 %	1 841
05 Oppland	32 %	36 %	33 %	717
06 Buskerud	21 %	20 %	60 %	217
07 Vestfold	2 %	4 %	94 %	94
08 Telemark	8 %	27 %	64 %	80
09 Aust-Agder	5 %	31 %	64 %	76
10 Vest-Agder	6 %	14 %	80 %	38
11 Rogaland	1 %	6 %	93 %	35
12 Hordaland	1 %	4 %	95 %	23
14 Sogn og Fjordane	1 %	9 %	91 %	53
15 Møre og Romsdal	2 %	8 %	89 %	254
16 Sør-Trøndelag	24 %	55 %	21 %	414
17 Nord-Trøndelag	10 %	45 %	45 %	816
18 Nordland	9 %	61 %	30 %	390
19 Troms	10 %	68 %	22 %	519
20 Finnmark	62 %	25 %	13 %	65
Total	17 %	40 %	43 %	6 097

The figures should be read as follows: Take for instance Østfold: It has 145 km^2 of forest suitable for cultivation. Of these 145 km^2, 82 percent is on site quality that is High, 11 percent on Medium and 7 percent that is Low.

Growth

We next look at the growth there of the various species: spruce, pine and birch. The figures are taken from the National Forest Inventory[2], and we start with spruce (Table 5). It should be noted that these figures contain all types of spruce (including sitka).

Table 5. Increment in standing volume of spruce by county and site quality (1000 cubic meters per year).

		H40 site quality							
		6	8	11	14	17	20	23-26	Total
01	Østfold	1	17	51	85	119	161	90	524
02	Oslo/Akershus	3	25	100	234	317	154	84	917
04	Hedmark	43	189	430	623	732	312	91	2 420
05	Oppland	42	174	303	452	488	236	61	1 757
06	Buskerud	32	94	168	283	344	167	106	1 193
07	Vestfold	1	8	19	55	77	123	190	472
08	Telemark	26	116	162	204	183	177	116	984
09	Aust-Agder	2	11	51	117	77	31	19	308
10	Vest-Agder	0	3	14	45	105	93	51	311
11	Rogaland	1	3	6	13	42	72	120	258
12	Hordaland	0	5	12	32	71	145	252	518
14	Sogn og Fjordane	0	2	4	19	56	126	174	382
15	Møre og Romsdal	0	1	8	29	97	202	119	456
16	Sør-Trøndelag	12	57	112	177	142	43	3	456
17	Nord-Trøndelag	19	111	212	316	263	48	7	976
18	Nordland	6	50	146	242	104	25	7	581
19	Troms	1	7	21	39	10	0	0	79
20	Finnmark	0	0	0	0	0	0	0	0
		189	874	1 820	2 966	3 228	2 114	1 490	12 680

We next look at pine (Table 6).

[2] Also available here http://www.skogoglandskap.no/artikler/2007/Landsskogdata_enkel_tabell
Once again, the figures for Finnmark are taken from Statistcs Norway (2012). There, however, growth figures are only given as total (not distributed over site qualities). We have assumed that the growth is evenly distributed across the different site quality areas.

Table 6. Increment in standing volume of pine by county and site quality (1000 cubic meters per year).

		H40 site quality							
		6	8	11	14	17	20	23-26	Total
01	Østfold	18	72	77	67	59	13	1	306
02	Oslo/Akershus	8	51	76	71	52	8	1	267
04	Hedmark	45	265	375	385	241	56	8	1 375
05	Oppland	12	100	107	60	26	11	1	317
06	Buskerud	25	99	132	188	121	29	3	597
07	Vestfold	4	12	14	11	8	9	2	58
08	Telemark	35	116	126	125	58	20	9	489
09	Aust-Agder	26	84	102	120	40	6	0	378
10	Vest-Agder	23	71	88	58	22	8	0	270
11	Rogaland	7	27	33	23	20	4	3	117
12	Hordaland	16	71	59	32	10	3	4	194
14	Sogn og Fjordane	11	37	53	39	8	4	1	154
15	Møre og Romsdal	14	35	65	41	15	12	1	182
16	Sør-Trøndelag	26	67	65	40	8	1	0	207
17	Nord-Trøndelag	22	47	19	4	3	0	0	94
18	Nordland	12	25	20	7	0	0	0	64
19	Troms	6	19	17	2	0	0	0	44
20	Finnmark	21	27	1	0	0	0	0	49
		330	1225	1428	1270	691	186	34	5163

Finally we present growth figures for deciduous trees, which we have assumed may be represented by the species birch (Table 7).

Table 7. Increment in standing volume of birch by county and site quality (1000 cubic meters per year).

		H40 site quality							
		6	8	11	14	17	20	23-26	Total
01	Østfold	2	10	20	24	32	29	17	133
02	Oslo/Akershus	1	17	39	49	64	26	6	202
04	Hedmark	22	67	91	108	79	62	27	457
05	Oppland	21	88	67	72	84	49	8	389
06	Buskerud	9	36	45	78	110	51	35	364
07	Vestfold	1	7	21	46	60	72	49	256
08	Telemark	13	58	121	113	107	62	28	503
09	Aust-Agder	6	29	53	63	33	7	6	197
10	Vest-Agder	10	43	84	58	33	9	5	241
11	Rogaland	2	27	50	37	12	4	3	136
12	Hordaland	6	37	79	57	32	16	9	237
14	Sogn og Fjordane	8	47	95	59	23	14	11	257
15	Møre og Romsdal	4	34	97	119	49	30	6	339
16	Sør-Trøndelag	8	34	49	54	39	5	1	191
17	Nord-Trøndelag	8	42	68	83	44	27	2	274
18	Nordland	39	149	123	71	9	2	1	393
19	Troms	45	154	92	8	1	0	0	301
20	Finnmark	41	54	3	0	0	0	0	98
Total		245	936	1199	1100	812	464	212	4969

Computed productivities

The productivities are expressed by growth per unit area per year. We shall discuss two types of productivities: That which actually has occurred and those that are potentially possible. The former are used for natural regrowth coefficients, while that latter are used for active planting.

Actual productivities

Both annual increment and area of the different H40 site quality class for each county are provided from the Norwegian Forest Survey (except Finnmark where a simple classification is available from Statistic Norway). Actual productivities for each H40 class can be calculated by dividing the increment with the area. The results are presented in Table 8.

Table 8. Actual productivities by county and H40 site quality (cubic meters per hectare per year).

		H40 site quality							
		6	8	11	14	17	20	23-26	Total
01	Østfold	1.3	1.9	2.9	4.3	5.9	7.2	9.9	4.1
02	Oslo/Akershus	1.3	1.8	2.6	4.0	6.4	6.7	10.6	4.2
04	Hedmark	0.8	1.4	2.3	4.0	6.0	7.5	8.2	3.1
05	Oppland	0.9	1.5	2.5	4.4	7.1	9.2	15.7	3.3
06	Buskerud	1.2	1.5	2.6	4.4	7.2	8.5	12.7	3.8
07	Vestfold	1.6	1.9	2.7	4.5	6.4	8.7	11.6	6.3
08	Telemark	1.3	1.9	2.9	4.1	7.1	10.4	11.6	3.7
09	Aust-Agder	1.1	1.5	2.3	3.6	4.9	7.1	9.0	2.8
10	Vest-Agder	1.7	2.0	2.4	3.0	4.3	5.7	7.1	3.4
11	Rogaland	1.1	1.5	1.6	2.0	3.0	4.8	9.2	3.6
12	Hordaland	0.9	1.5	1.5	1.8	2.5	2.5	8.8	2.9
14	Sogn og Fjordane	0.8	1.1	1.3	1.7	2.4	4.2	6.9	3.0
15	Møre og Romsdal	0.9	1.1	1.2	1.8	3.2	5.6	7.8	3.4
16	Sør-Trøndelag	0.8	1.1	1.8	3.0	5.0	5.7	7.0	2.2
17	Nord-Trøndelag	0.6	1.1	1.7	3.0	5.8	7.0	4.8	2.2
18	Nordland	0.5	0.8	1.4	2.6	3.5	9.3	12.7	1.7
19	Troms	0.4	0.7	1.0	1.5	1.7	0.1	0.0	1.0
20	Finnmark	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.5
Total		0.9	1.4	2.1	3.3	5.0	6.2	9.2	3.0

A significant share of the forest land has too poor soil quality for cultivation. The limitation factors for agriculture, shallow soil and low water holding capacity, will also limit forest production. Agricultural land is therefore expected to be more productive than the mean for forest. In preparation for that, we compute next the actual productivities according to the DMK classification system for site qualities, by making use of the relationship given in the set H40SQ. The results are given in Table 9. The data in Table 9 are based on aggregation of the same data as table 8, only aggregated before division.

Table 9. Actual productivities by county and DMK site quality (cubic meters per hectare per year).

County	Site quality class			
	L	M	H	Total
01 Østfold	1.7	3.5	7.2	4.1
02 Oslo/Akershus	1.7	3.4	7.1	4.2
04 Hedmark	1.3	3.2	6.6	3.1
05 Oppland	1.3	3.4	8.3	3.3
06 Buskerud	1.5	3.5	8.3	3.8
07 Vestfold	1.9	3.8	9.2	6.3
08 Telemark	1.8	3.5	9.1	3.7
09 Aust-Agder	1.4	3.1	5.7	2.8
10 Vest-Agder	1.9	2.9	6.9	3.4
11 Rogaland	1.4	2.4	10.5	3.6
12 Hordaland	1.3	2.3	9.7	3.4
14 Sogn og Fjordane	1.1	2.2	9.4	3.0
15 Møre og Romsdal	1.1	2.5	8.4	3.4
16 Sør-Trøndelag	1.1	2.7	6.0	2.2
17 Nord-Trøndelag	1.0	2.3	6.2	2.2
18 Nordland	0.8	2.6	6.5	1.7
19 Troms	0.7	2.1	7.4	1.0
20 Finnmark	0.5	0.5		0.5
Total	1.1	3.0	7.7	2.9

Potential productivities

Spruce and Sitka

While the previous section computed productivities based on actual growth figures, this section reports the potential productivity if having active management, such as thinning etc. The potential productivities are given in Table 10 for spruce and sitka.

Table 10. Potential productivities for sitka and spruce (cubic meters per hectare per year).

Species	H40 site quality, Spruce							
	6	8	11	14	17	20	23	26
Sitka	4.23	6.94	12.0	16.0	20.0	24.0	28.0	32.5
Spruce	1.23	2.01	3.48	5.26	7.35	9.72	12.37	15.27

The figures for spruce come from Øyen and Bøhler (2011, p 10, formula 1a) saying that the productivity of spruce is given by 0.05624*(H40)^1.720 cubic meters per hectare per year.

When it comes to sitka, we have done the following. First, as already stated, the H40 index is species specific, with spruce as the reference. So, what does category 14 on spruce correspond to for sitka? Here we have made use of the calculator for conversion of site qualities with change of species available by the Norwegian Forest Research Institute[3]. They report that the site quality for sitka is equal to that of spruce plus 3. For instance, if an area with spruce is H40 category 20, that area will be sitka class 23.

3 http://www.skogoglandskap.no/kalkulator/konvertering_treslag/konvertering_treslag/ny_skift_kalkulator?calculator_mode=True

The next question is then what the productivity of sitka class 23 is. Here we use figures from Øyen (2005, Table 5). He reports that sitka class 23 produces 24 cubic meters per hectare per year. Hence, spruce category 20 gives productivity of sitka equal to 24.

Øyen (2005) provides productivity figures for sitka for site quality categories 14-29, i.e. spruce categories 11-26. So we miss figures for sitka for spruce categories 6 and 8. For spruce, category 11 was 3.48 while category 8 was 2.01, which is 2.01/34.8 = 58 percent of category 11. We assume that the same holds for sitka, so that sitka 8 is 58 percent of sitka 11, i.e. 0.58*12.0 = 6.94. Similarly, sitka class 6 is assumed to be (1.23/2.01)*6.94 = 4.23.

Pine and Birch

We now ask: What is the productivity of planting pine in a place where spruce is say H40 quality 20 producing 9.72 cubic meters per hectare per year?

Øyen and Tveite (1998) give yield conversion functions that map spruce yield into that of birch and pine. They consider West Norway and we assume these conversion functions apply to the North as well (thus part of country L = 2). They also report functions for the South and East (part of country L = 1) which were taken from Braastad (1983, 1985).

Table 11. Yield conversion functions from spruce to birch and pine in various part of the country (cubic meters per hectare per year).

From	To	West and North	South and East
Spruce	Pine	1.90 + 0.290xPG	1.984 + 0.6224xPG
Spruce	Birch	0.87 + 0.209xPG	0.913 + 0.4068xPG

In Table 11, “PG” is the potential yield of spruce per hectare, i.e. the figures in Table 10. The resulting figures are given in Table 12 and Table 13.

Table 12. Potential productivities for pine and birch in region 1 (South and East) (cubic meters per hectare per year).

	H40 site quality, Spruce							
Species	6	8	11	14	17	20	23	26
Pine	2.75	3.235	4.15	5.258	6.559	8.034	9.683	11.488
Birch	1.413	1.731	2.329	3.053	3.903	4.867	5.945	7.125

Table 13. Potential productivities for pine and birch in region 2 (West and North) (cubic meters per decare per year).

	H40 site quality, Spruce							
Species	6	8	11	14	17	20	23	26
Pine	2.257	2.483	2.909	3.425	4.031	4.719	5.487	6.328
Birch	1.137	1.290	1.597	1.969	2.406	2.901	3.455	4.061

For low site qualities, these figures are a bit higher than those in Bjørdal (2007, Table 3), in particular for pine.

As for actual productivities, we also need potential productivities classified over the DMK system. To get that, we start with combining the theoretical productivities, with feasibility of species across regions.

For instance, sitka is not feasible in the county Østfold, so the potential productivity for Østfold and sitka is 0. Moving on to a place where sitka is feasible, consider VestAgder. According to Table 3, 19 percent of the forest area in that county has potential site quality 11, while 21 percent is category 14. According to Table 10, these categories have productivities 12 and 16 respectively of sitka. As they together make up the DMK category Medium, we assume that the aggregated productivity is (19%*12.0 + 21%*16.0)/(19% + 21%) = 14.12 cubic meters per hectare per year. Figures for other DMK site qualities and other counties are given Table 14.

Table 14. Potential productivities of sitka over the DMK site quality system (cubic meters per hectare per year).

	Site quality class		
County	L	M	H
01 Østfold	-	-	-
02 Oslo/Akershus	-	-	-
04 Hedmark	-	-	-
05 Oppland	-	-	-
06 Buskerud	-	-	-
07 Vestfold	-	-	-
08 Telemark	-	-	-
09 Aust-Agder	-	-	-
10 Vest-Agder	6.16	14.12	22.47
11 Rogaland	6.13	14.65	23.48
12 Hordaland	5.84	14.90	23.36
14 Sogn og Fjordane	6.32	14.45	23.49
15 Møre og Romsdal	5.77	14.45	22.83
16 Sør Trøndelag	6.21	13.76	21.18
17 Nord-Trøndelag	6.11	13.76	21.14
18 Nordland	6.05	13.78	20.36
19 Troms	6.00	13.63	20.08
20 Finnmark	-	-	-

We next report figures for Spruce (Table 15).

Table 15. Potential productivities of spruce over the DMK site quality system (cubic meters per hectare per year).

	Site quality class		
County	L	M	H
01 Østfold	1.83	4.28	9.11
02 Oslo/Akershus	1.91	4.45	8.56
04 Hedmark	1.83	4.26	8.30
05 Oppland	1.83	4.21	8.27
06 Buskerud	1.82	4.33	8.56
07 Vestfold	1.85	4.47	10.22
08 Telemark	1.80	4.27	9.07
09 Aust-Agder	1.79	4.38	8.17
10 Vest-Agder	1.79	4.42	8.86
11 Rogaland	1.78	4.66	9.49
12 Hordaland	1.69	4.77	9.42
14 Sogn og Fjordane	1.83	4.57	9.50
15 Møre og Romsdal	1.67	4.57	9.08
16 Sør-Trøndelag	1.80	4.26	8.06
17 Nord-Trøndelag	1.77	4.26	8.04
18 Nordland	1.75	4.27	7.57
19 Troms	1.74	4.20	7.40
20 Finnmark	-	-	-

For pine and Birch, there are also regional differences in theoretical productivities, see Table 12 and Table 13. These are accounted for in the two tables next.

Table 16. Potential productivities of pine over the DMK site quality system (cubic meters per hectare per year).

County	Site quality class		
	L	M	H
01 Østfold	3.12	4.65	7.66
02 Oslo/Akershus	3.17	4.75	7.31
04 Hedmark	3.12	4.63	7.15
05 Oppland	3.12	4.60	7.13
06 Buskerud	3.12	4.68	7.31
07 Vestfold	3.13	4.76	8.34
08 Telemark	3.10	4.68	7.63
09 Aust-Agder	3.10	4.71	7.07
10 Vest-Agder	2.42	3.18	4.47
11 Rogaland	2.42	3.25	4.65
12 Hordaland	2.39	3.28	4.63
14 Sogn og Fjordane	2.43	3.23	4.65
15 Møre og Romsdal	2.39	3.23	4.53
16 Sør-Trøndelag	2.42	3.14	4.24
17 Nord-Trøndelag	2.41	3.14	4.23
18 Nordland	2.41	3.14	4.09
19 Troms	2.41	3.12	4.05
20 Finnmark	2.39	2.91	5.14

Table 17. Potential productivities of birch over the DMK site quality system (cubic meters per hectare per year).

County	Site quality class		
	L	M	H
01 Østfold	1.66	2.65	4.62
02 Oslo/Akershus	1.69	2.72	4.39
04 Hedmark	1.66	2.62	4.28
05 Oppland	1.66	2.62	4.28
06 Buskerud	1.65	2.67	4.40
07 Vestfold	1.67	2.73	5.07
08 Telemark	1.64	2.65	4.60
09 Aust-Agder	1.64	2.69	4.24
10 Vest-Agder	1.24	1.79	2.72
11 Rogaland	1.24	1.84	2.85
12 Hordaland	1.22	1.87	2.84
14 Sogn og Fjordane	1.25	1.83	2.86
15 Møre og Romsdal	1.22	1.83	2.77
16 Sør-Trøndelag	1.25	1.76	2.56
17 Nord-Trøndelag	1.24	1.76	2.55
18 Nordland	1.24	1.76	2.45
19 Troms	1.23	1.75	2.42
20 Finnmark	1.22	1.60	3.21

Expected cultivable productivities

Actual productivities

No data exist about productivity of forest on agricultural land. However, agricultural land is assumed to have higher productivity for forest than existing forest. It can be assumed that land with the highest quality already has been selected for cultivation. In addition, agricultural soil generally has higher nutrient content because of regularly fertilization and liming. On the other hand, the highest site quality classes, H23 and H26, are most frequently on steep terrain unsuitable for agriculture.

As a conservative estimate for forest productivity and cultivated land, the productivity of culivatable forest land can be used. Recall Table 9, it says that for instance in Østfold, the actual productivity on category Low land was 1.7, Medium 3.5 and High 7.2, with a total average 4.1. Recall now Table 4, the distribution of cultivable forest land. It says that 7 percent of the forest land that is cultivable in Østfold, is of DMK quality Low, 11 percent on Medium and 82 percent on quality High. Suppose next, only for illustration, that these figures were 0 percent, 0 percent, and 100 percent respectively. It would mean that all of the forest that is on cultivable land was of quality H. If the question had been what would be sacrificed in terms of lost sequestration when expanding agricultural land, one surely would lose 7.2. We assume that this holds the other way as well: If one returns some agricultural land to forestry, one would gain 7.2 in sequestration. Returning next to the real Østfold, we assume that when some piece of agricultural land is returned to forestry, it will with probability of 7 percent be quality Low, with probability 11 percent become class Medium, and with a probability of 82 percent be quality High.

The expected productivity achieved when returning some cultivable land to forestry is then 7 percent *1.7 + 11 percent *3.5 + 82 percent *7.2 = 6.4. It is substantially higher than the total average of 4.1 (confer Table 8 or Table 9) which applies to all forest, that which is on land that may be cultivated and that which is not. This reflects that agricultural land is more productive for forestry than the average forest land. The figures for all counties are given in Table 18.

Table 18. Actual productivities weighted by cultivable area (cubic meters per hectare per year).

County	Productivity
01 Østfold	6.40
02 Oslo/Akershus	6.53
04 Hedmark	3.69
05 Oppland	4.53
06 Buskerud	7.94
07 Vestfold	6.65
08 Telemark	6.98
09 Aust-Agder	4.60
10 Vest-Agder	6.06
11 Rogaland	9.94
12 Hordaland	9.28
14 Sogn og Fjordane	8.73
15 Møre og Romsdal	7.77
16 Sør-Trøndelag	2.96
17 Nord-Trøndelag	3.91
18 Nordland	3.62
19 Troms	3.10
20 Finnmark	0.46
Total	4.67

Potential productivities

We follow the method for actual productivities and give here potential productivities aggregated by cultivable area shares. In contrast to the previous section where we assumed that the composition of species would follow that which actually is there, we consider here active planting with numbers for each species. The figures are given in Table 19.

Table 19. Potential productivities weighted by cultivable area (cubic meters per hectare per year).

		Species			
County		Sitka	Spruce	Pine	Birch
01	Østfold	-	8.1	7.0	4.2
02	Oslo/Akershus	-	7.9	6.9	4.1
04	Hedmark	-	4.8	5.0	2.9
05	Oppland	-	5.0	5.1	2.9
06	Buskerud	-	8.2	7.1	4.3
07	Vestfold	-	7.4	6.6	3.9
08	Telemark	-	7.2	6.4	3.8
09	Aust-Agder	-	6.7	6.1	3.6
10	Vest-Agder	20.3	7.8	4.2	2.5
11	Rogaland	22.8	9.1	4.6	2.8
12	Hordaland	22.8	9.1	4.5	2.8
14	Sogn og Fjordane	22.6	9.0	4.5	2.8
15	Møre og Romsdal	21.8	8.5	4.4	2.7
16	Sør-Trøndelag	13.5	4.5	3.2	1.8
17	Nord-Trøndelag	16.3	5.7	3.6	2.1
18	Nordland	15.1	5.0	3.4	1.9
19	Troms	14.3	4.7	3.2	1.8
20	Finnmark	-	-	2.6	1.3

From productivities to CO_2 coefficients

In the previous section, we showed productivities according to two different methods: based on *actual* growth, and *potential* growth. The former was based on actual growth figures, and in some sense dealt with an "average" tree type. As the various species have different characteristics such as densities and carbon content that come into effect when computing CO_2 coefficients, we need to characterize the composition of the county-specific representative tree. To get that, we take the total growth figures given in Table 5, Table 6 and Table 7 and divide by the sum. The results are given in Table 20.

Table 20. Composition of actual growth tree.

County	Species		
	Spruce	Pine	Birch
1 Østfold	54 %	32 %	14 %
2 Oslo/Akershus	66 %	19 %	15 %
4 Hedmark	57 %	32 %	11 %
5 Oppland	71 %	13 %	16 %
6 Buskerud	55 %	28 %	17 %
7 Vestfold	60 %	7 %	33 %
8 Telemark	50 %	25 %	25 %
9 Aust-Agder	35 %	43 %	22 %
10 Vest-Agder	38 %	33 %	29 %
11 Rogaland	50 %	23 %	27 %
12 Hordaland	55 %	20 %	25 %
14 Sogn og Fjordane	48 %	19 %	32 %
15 Møre og Romsdal	47 %	19 %	35 %
16 Sør-Trøndelag	53 %	24 %	22 %
17 Nord-Trøndelag	73 %	7 %	20 %
18 Nordland	56 %	6 %	38 %
19 Troms	19 %	10 %	71 %
20 Finnmark	0 %	33 %	67 %

It should be noted that actual growth of sitka is contained in the figures for spruce.

We next present a few parameters we need to go from productivities of various kind, to CO_2 sequestration coefficients.

Table 21. Various parameters.

	Sitka	Spruce	Pine	Birch
Basis density, kg per m^3	335	400	385	475
Carbon content	52,3 %	52,3 %	52,4 %	47,4 %
Biomass share trunk and bark	48 %	48 %	48 %	48 %
CO_2 coefficient	1 336	1 595	1 538	1 717

Basis density is the dry matter content (in kg) per solid cubic meter raw material in non-shrunken condition. Carbon content is the share of carbon in dry trunk. We assume that it applies to the whole tree. The densities and carbon contents for spruce, pine and birch, are taken from Belbo and Gjølsjø (2008, Tables 1 & 2). The density for sitka is taken from Vadla (2007, Table 1) and its carbon share is assumed to be the same as for spruce.

The figures for productivities in the previous sections, accounted for biomass in trunks and bark. There is moreover also sequestration of carbon occurring in the roots, branches and other parts of the tree as well. How the biomass of a tree is distributed on its various parts, is taken from the Ministry of Agriculture and Food (2008-2009, p 117) stating that 43 percent is in the stem, and 5 percent in the bark. We assume that this distribution holds true for all species. Thus, the figures for trunk and bark comprise 48 percent of the total biomass.

The last row in Table is simply the product of the first two, divided by the third, and multiplied by 3.67 (which is the conversion factor from C to CO_2).

We next combine the productivity figures for actual productivity in Table 18 with the actual composition in Table 20 and the coefficients in Table 21. The result, given in Table 22, are our final estimate for sequestration coefficients if adopting natural regrowth.

Table 22. CO_2 sequestration coefficients for natural regrowth (tons CO_2 per hectare per year).

County		Producivity
1	Østfold	10.2
2	Oslo/Akershus	10.5
4	Hedmark	5.9
5	Oppland	7.3
6	Buskerud	12.7
7	Vestfold	10.8
8	Telemark	11.3
9	Aust-Agder	7.4
10	Vest-Agder	9.8
11	Rogaland	16.0
12	Hordaland	15.0
14	Sogn og Fjordane	14.2
15	Møre og Romsdal	12.6
16	Sør-Trøndelag	4.8
17	Nord-Trøndelag	6.3
18	Nordland	5.9
19	Troms	5.2
20	Finnmark	0.8
Total		7.5

If we take Østfold, the figure is computed as follows: The average growth tree in Østfold has 54 percent spruce, 32 percent pine and 14% birch. Thus, the representative CO_2 coefficient from Table is 54%*1595 + 32%*1538 + 14%*1717 = 1594. The actual productivity in Østfold according to Table 18 is 6.40 cubic meteres per hectare per year. Thus the CO_2 sequestration coefficient becomes 6.40 * 1594 = 10201 kg=10.2 tons.

We now turn to the potential productivities. The figures are given in Table 23. The figures in the first four columns are simply the product of those in and Table 18 and table 21. For instance, for spruce in Østfold we had a productivity of 8.1. The CO_2 coefficient for spruce from Table 21 is 1595. So 8.1*1595 = 12921 kg=12.9 tons. The column to the right in Table 23 simply picks the largest value in the previous columns, indicating what species that gives the most sequestration and how much sequestration we get.

Table 23. CO_2 sequestration coefficients for active planting (tons CO_2 per hectare per year).

County		Species				
		Sitka	Spruce	Pine	Birch	Max
1	Østfold		12.9	10.8	7.2	12.9
2	Oslo/Akershus		12.6	10.6	7.0	12.6
4	Hedmark		7.7	7.7	5.0	7.7
5	Oppland		8.0	7.8	5.0	8.0
6	Buskerud		13.1	10.9	7.4	13.1
7	Vestfold		11.8	10.2	6.7	11.8
8	Telemark		11.5	9.8	6.5	11.5
9	Aust-Agder		10.7	9.4	6.2	10.7
10	Vest-Agder	27.1	12.4	6.5	4.3	27.1
11	Rogaland	30.5	14.5	7.1	4.8	30.5
12	Hordaland	30.5	14.5	6.9	4.8	30.5
14	Sogn og Fjordane	30.2	14.4	6.9	4.8	30.2
15	Møre og Romsdal	29.1	13.6	6.8	4.6	29.1
16	Sør-Trøndelag	18.0	7.2	4.9	3.1	18.0
17	Nord-Trøndelag	21.8	9.1	5.5	3.6	21.8
18	Nordland	20.2	8.0	5.2	3.3	20.2
19	Troms	19.1	7.5	4.9	3.1	19.1
20	Finnmark			4.0	2.2	4.0

Finally, we take the results in Table 22 and Table 23 and summarize them in one table (Table 24), on the regional basis used in Jordmod.

Table 24. CO_2 sequestration coefficients in each Jordmod region for natural regrowth and active planting (tons CO_2 per hectare per year).

	Countiy	Region nr	Region name	Natural afforestation	Active planting
1	Østfold	11101	Fredrikstad	10.2	12.9
2	Oslo/Akershus	21101	Oslo	10.5	12.6
		21103	Skedsmo	10.5	12.6
4	Hedmark	41101	Ringsaker	5.9	7.7
		41203	Elverum	5.9	7.7
		41205	Trysil	5.9	7.7
5	Oppland	51103	Gjøvik	7.3	8.0
		51205	Nordre Land	7.3	8.0
6	Buskerud	61101	Drammen	12.7	13.1
		61205	Aal	12.7	13.1
7	Vestfold	71101	Larvik	10.8	11.8
8	Telemark	81103	Skien	11.3	11.5
		81203	Bamble	11.3	11.5
		81205	Notodden	11.3	11.5
9	Aust-Agder	92205	Arendal	7.4	10.7
10	Vest-Agder	102205	Kristiansand	9.8	27.1
11	Rogaland	112102	Stavanger	16.0	30.5
		112203	Strand	16.0	30.5
		112105	Rennesøy	16.0	30.5
		112205	Karmøy	16.0	30.5
12	Hordaland	123205	Bergen	15.0	30.5
14	Sogn og Fjordane	143205	Flora	14.2	30.2
15	Møre og Romsdal	153205	Aelesund	12.6	29.1
16	Sør-Trøndelag	164104	Trondheim	4.8	18.0
		164204	Skaun	4.8	18.0
		164205	Oppdal	4.8	18.0
17	Nord-Trøndelag	174104	Steinkjer	6.3	21.8
		174205	Namsos	6.3	21.8
18	Nordland	185206	Bodø	5.9	20.2
19	Troms	195206	Tromsø	5.2	19.1
		195207	Nordreisa	5.2	19.1
20	Finnmark	205207	Alta	0.8	4.0

Notes

When it comes to planting costs, Klif (2010) applies 2000 plants per hectare, which they report is the average for site index G20-26. The unit cost is 5 kr/plant.

References

Belbo, H. and Gjølsjø, S. (2008). Trevirke – brennverdier og energitetthet. Skogens ressurser, Viten fra Skog og landskap, 01/08 (In Norwegian).

Bjørdal, I. (2007). Markslagsklassifikasjon i økonomisk kartverk. Håndbok frå Skog og landskap 01/2007, Norway.

Bjørdal, I. and Bjørkelo, K. (2006). AR5 KLASSIFIKASJONSSYSTEM – Klassifikasjon av areal ressurser. Håndbok fra Skog og Landskap 01/2006.

Braastad, H. (1975). Yield Tables and Growth Models for Picea abies. Reports from The Norwegian Forest Research Institute 31.9.

Braastad, H. (1983). Produksjonsnivået i glissen og ujamn granskog. Rapport fra Norsk institutt for skogforskning 7/83: 42 s.

Braastad, H. (1983). Forholdet mellom høydebonitet og produksjonsevne for gran, furu og bjørk på samme voksested. Akt. St. Fagtj. Landbr. 1983(3): 50-59.

Braastad, H. (1985). Relationship between site index class and potential yield of Picea abies, Pinus sylvestris, Betula verrucossa and Betula pubescens on the same site. In Broadleaves in Boreal silviculture – an obstacle or an asset? B. Hägglund and G. Peterson (eds), SLU, Department of silviculture, Report 14, pp 175-187.

Holtsmark, B. (2012). Harvesting in boreal forests and the biofuel carbon debt. *Climatic Change* 112, 415-428.

Kjønaas O, Aalde JH, Dalen LS, de Wit HA, Eldhuset T, Øyen BH (2000) Carbon stocks in Norwegian forested systems. *Biotechnol Agron Soc Environ* 4:311–314

Klif (2010). Tiltak og virkemidler for økt opptak av klimagasser fra skogbruk. TA 2596-2010. The Climate and Pollution Agency (in Norwegian).

Ministry of Agriculture and Food (2009). Report No. 39 to the Storting (2008-2009). Climate Challenges – Agriculture part of the Solution.

Øyen, B.-H. (2005). Growth and yield in stands of Sitka spruce (Picea sitchensis (Bong.) Carr.) in Norway. Rapport fra skogforskningen 4/05: 1-46.

Øyen, B.-H. and Tveite, B. (1998). En sammenligning av høydebonitet og produksjonsevne mellom ulike treslag på samme voksested i Vest-Norge. Rapport fra skogforskningen 15/98: 32 s.

Øyen, B.-H. and Bøhler, F. (2011). Conversion functions for estimating site index and yield projections between noble hardwood species and Norway spruce in South Norway. Forskning fra Skog og landskap 2/11.

Skjelvik, J.M. and Vennemo, H. (2011). Samfunnsøkonomiske gevinster av skagreising med sitkagran. Rapport 2011/03, Vista Analyse.

Statistics Norway (2012). National Forest Inventory 2007-2011. Statistics Norway, Oslo, Norway. (available http://statbank.ssb.no//statistikkbanken/default_fr.asp?PLanguage=1)

Storaunet, K.O., Rolstad, J. (2002). Time since death and fall of Norway spruce logs in old-growth and selectively cut boreal forest. *Can J For Res* 32:1801–1812.

Vadla, K. (2007). Siktagran – Utbredelse, Egenskaper og Anvendelse. Skog og Landskap.

Appendix A: The GAMS code

```
* This program computes carbon sequestration coefficients

SETS

ME Method /
NR        'Natural Regrowth'
AP        'Active Planting'
/,

L Landsdel  /
1          'SoerogOestlandet'
2          'NordogVestlandet'
/,

F Counties /
010000     'Oestfold'
020000     'OsloAkershus'
040000     'Oppland'
050000     'Hedmark'
060000     'Vestfold'
070000     'Buskerud'
080000     'Telemark'
090000     'OestAgder'
100000     'VestAgder'
110000     'Rogaland'
120000     'Hordaland'
140000     'SognFjordane'
150000     'MoereRomsdal'
160000     'SoerTroendelag'
170000     'NordTroendelag'
180000     'Nordland'
190000     'Troms'
200000     'Finnmark'
/,

FL(F,L) Fylke Landsdel relationship /
010000.1
020000.1
040000.1
050000.1
060000.1
070000.1
080000.1
090000.1
100000.2
110000.2
120000.2
140000.2
150000.2
160000.2
```

```
170000.2
180000.2
190000.2
200000.2
/,

R Regions in Jordmod /
011101        'Fredrikstad'
021101        'Oslo'
021103        'Skedsmo'
041101        'Ringsaker'
041203        'Elverum'
041205        'Trysil'
051103        'Gjoevik'
051205        'NordreLand'
061101        'Drammen'
061205        'Aal'
071101        'Larvik'
081103        'Skien'
081203        'Bamble'
081205        'Notodden'
092205        'Arendal'
102205        'Kristiansand'
112102        'Stavanger'
112203        'Strand'
112105        'Rennesoey'
112205        'Karmoey'
123205        'Bergen'
143205        'Flora'
153205        'Aelesund'
164104        'Trondheim'
164204        'Skaun'
164205        'Oppdal'
174104        'Steinkjer'
174205        'Namsos'
185206        'Bodoe'
195206        'Tromsoe'
195207        'Nordreisa'
205207        'Alta'
/,


RF(R,F) Region Fylke relationship /
011101.010000
021101.020000
021103.020000
041101.040000
041203.040000
041205.040000
051103.050000
051205.050000
061101.060000
061205.060000
```

```
071101.070000
081103.080000
081203.080000
081205.080000
092205.090000
102205.100000
112102.110000
112105.110000
112203.110000
112205.110000
123205.120000
143205.140000
153205.150000
164104.160000
164204.160000
164205.160000
174104.170000
174205.170000
185206.180000
195206.190000
195207.190000
205207.200000
/,

RFL(R,F,L) Region Fylke Landsdel relationship;

RFL(R,F,L)$(RF(R,F) and FL(F,L)) = yes;

SETS

S Species /
SIT     'Sitka'
SPR     'Spruce'
PIN     'Pine'
BIR     'Birch'
/;

TABLE FS(F,S) Feasibility of species on regions

              SIT         SPR         PIN         BIR
010000                    YES         YES         YES
020000                    YES         YES         YES
040000                    YES         YES         YES
050000                    YES         YES         YES
060000                    YES         YES         YES
070000                    YES         YES         YES
080000                    YES         YES         YES
090000                    YES         YES         YES
100000        YES         YES         YES         YES
110000        YES         YES         YES         YES
120000        YES         YES         YES         YES
140000        YES         YES         YES         YES
150000        YES         YES         YES         YES
```

```
160000        YES        YES        YES        YES
170000        YES        YES        YES        YES
180000        YES        YES        YES        YES
190000        YES        YES        YES        YES
200000                              YES        YES
;

SETS

H40 Site quality categories in the H40 system /
06
08
11
14
17
20
23
26
/,

SQ Site quality categories in DMK system /
L         'Low'
M         'Medium'
H         'High'
/,

H40SQ(H40,SQ) H40 and DMK system relationship /
06.L
08.L
11.M
14.M
17.H
20.H
23.H
26.H
/;

SCALARS
DIH Number of decares per hectare / 10 /,
HSQ Share of 23-26 site quality area that is in category 23 / 0.67 /;

TABLE
PRO_POT_T(H40,SQ,S,L) Theoretical production potential by H40 and species
in cubic meters per decare per year

            SIT.1        SPR.1
06.L        0.423        0.123
08.L        0.694        0.201
11.M        1.200        0.348
14.M        1.600        0.526
17.H        2.000        0.735
20.H        2.400        0.972
23.H        2.800        1.237
```

```
26.H          3.250          1.527
;

PRO_POT_T(H40,SQ,'SIT','2')$H40SQ(H40,SQ) = PRO_POT_T(H40,SQ,'SIT','1');
PRO_POT_T(H40,SQ,'SPR','2')$H40SQ(H40,SQ) = PRO_POT_T(H40,SQ,'SPR','1');
PRO_POT_T(H40,SQ,'PIN','1')$H40SQ(H40,SQ) = 1/DIH*( 1.984 +
0.6224*(PRO_POT_T(H40,SQ,'SPR','1')*DIH) ) ;
PRO_POT_T(H40,SQ,'PIN','2')$H40SQ(H40,SQ) = 1/DIH*( 1.900 +
0.2900*(PRO_POT_T(H40,SQ,'SPR','2')*DIH) ) ;
PRO_POT_T(H40,SQ,'BIR','1')$H40SQ(H40,SQ) = 1/DIH*( 0.913 +
0.4068*(PRO_POT_T(H40,SQ,'SPR','1')*DIH) ) ;
PRO_POT_T(H40,SQ,'BIR','2')$H40SQ(H40,SQ) = 1/DIH*( 0.870 +
0.2090*(PRO_POT_T(H40,SQ,'SPR','2')*DIH) ) ;

ALIAS
(H40,H40a),
(SQ,SQa),
(S,Sa);

SCALARS
BMS Share of Biomass in trunks and bark /0.48/,
C2C Factor when going from C to CO2 /3.66/;

PARAMETERS
DEN(S) Densities of various species in kg dry mass per cubic meter raw
matter /
SIT      335
SPR      400
PIN      385
BIR      475
/,

CAR(S) Carbon content of dry mass as share of total mass /
SIT         0.523
SPR         0.523
PIN         0.524
BIR         0.474
/;


$INCLUDE
M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableARE_ACT_H.txt
$INCLUDE
M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableARE_POT_H.txt
$INCLUDE M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableARE_CUL.txt

$INCLUDE
M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableGRO_ACT_SPR.txt
$INCLUDE
M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableGRO_ACT_PIN.txt
$INCLUDE
M:\Dokumenter\Dokument\SNF\Skognotat\Regning\Data\TableGRO_ACT_BIR.txt
```

```
PARAMETERS
ARE_ACT_D(F,H40,SQ) Area actual site quality from hectare to decare and
splits category 23-26 into two
ARE_POT_D(F,H40,SQ) Area potential site quality from hectare to decare and
splits category 23-26 into two

ARE_ACT(F,H40,SQ) Area actual site quality and adds 1 decare to spots where
the figure is zero to avoid division by zero later
ARE_POT(F,H40,SQ) Area potential site quality and adds 1 decare to spots
where the figure is zero to avoid division by zero later

ARE_POT_DMKW(F,SQ)  Distribution in percent of area potential site quality
DMK system
ARE_CUL_DMKW(F,SQ)  Distribution in percent of area cultivable site quality
DMK system
ARE_POT_W(F,H40,SQ) Distribution in percent of area potential site quality
H40 system

GRO_ACT(F,H40,SQ,S) Actual growth in cubic meters pr year for each species
GRO_ACT_W(F,S) Composition of representative actual growth tree

PRO_ACT(F,H40,SQ) Productivities actual representative tree in cubic meters
pr decare pr year
PRO_POT(F,L,H40,SQ,S) Production potential that is feasible in terms of
species and region

PRO_ACT_DMK(F,SQ) Productivities actual DMK in cubic meters pr decare pr
year
PRO_POT_DMK(F,L,SQ,S) Productivities potential DMK in cubic meters pr
decare pr year

PRO_ACT_CUL(F) Produced actual cultivable weighted
PRO_POT_CUL(F,L,S) Produced potential cultivable weighted

SCS(S) Sequestration coefficients of for each tree from cubic meters of
stem and bark to kg CO2

FE(F,L,ME) Final estimate in kg pr decare pr year
;

ARE_ACT_D(F,H40,SQ)$H40SQ(H40,SQ)  = ARE_ACT_H(F,H40,SQ)*DIH;
ARE_POT_D(F,H40,SQ)$H40SQ(H40,SQ)  = ARE_POT_H(F,H40,SQ)*DIH;
ARE_ACT_D(F,'23',SQ)$H40SQ('23',SQ)  = ARE_ACT_H(F,'23',SQ)*HSQ*DIH;
ARE_POT_D(F,'23',SQ)$H40SQ('23',SQ)  = ARE_POT_H(F,'23',SQ)*HSQ*DIH;
ARE_ACT_D(F,'26',SQ)$H40SQ('26',SQ)  = ARE_ACT_H(F,'23',SQ)*(1-HSQ)*DIH;
ARE_POT_D(F,'26',SQ)$H40SQ('26',SQ)  = ARE_POT_H(F,'23',SQ)*(1-HSQ)*DIH;

ARE_ACT(F,H40,SQ)$H40SQ(H40,SQ)  = max(ARE_ACT_D(F,H40,SQ), 1);
ARE_POT(F,H40,SQ)$H40SQ(H40,SQ)  = max(ARE_POT_D(F,H40,SQ), 1);

ARE_POT_W(F,H40,SQ)  = ARE_POT(F,H40,SQ)/sum( (H40a,SQa),
ARE_POT(F,H40a,SQa) );
ARE_CUL_DMKW(F,SQ)   = ARE_CUL(F,SQ)/sum( SQa, ARE_CUL(F,SQa) );
```

```
GRO_ACT(F,H40,SQ,"SPR") = GRO_ACT_SPR(F,H40,SQ);
GRO_ACT(F,H40,SQ,"PIN") = GRO_ACT_PIN(F,H40,SQ);
GRO_ACT(F,H40,SQ,"BIR") = GRO_ACT_BIR(F,H40,SQ);

GRO_ACT_W(F,S) = sum( (H40,SQ), GRO_ACT(F,H40,SQ,S) )/sum( (H40,SQ,Sa),
GRO_ACT(F,H40,SQ,Sa) )  ;

PRO_ACT(F,H40,SQ)$H40SQ(H40,SQ) = sum( S, GRO_ACT(F,H40,SQ,S)
)/ARE_ACT(F,H40,SQ) ;
PRO_POT(F,L,H40,SQ,S)$FL(F,L) = PRO_POT_T(H40,SQ,S,L)$FS(F,S);

PRO_ACT_DMK(F,SQ)   = sum( (H40,S), GRO_ACT(F,H40,SQ,S) )/sum( (H40),
ARE_ACT(F,H40,SQ) );
PRO_POT_DMK(F,L,SQ,S)$FL(F,L) = sum( H40,
PRO_POT(F,L,H40,SQ,S)*ARE_POT_W(F,H40,SQ) )/sum( H40, ARE_POT_W(F,H40,SQ)
);

PRO_ACT_CUL(F)   = sum( SQ, PRO_ACT_DMK(F,SQ)*ARE_CUL_DMKW(F,SQ) );
PRO_POT_CUL(F,L,S)$FL(F,L) = sum( SQ,
PRO_POT_DMK(F,L,SQ,S)*ARE_CUL_DMKW(F,SQ) );

SCS(S) = DEN(S)*CAR(S)*C2C/BMS ;

FE(F,L,'NR')$FL(F,L) =  sum( S, GRO_ACT_W(F,S)*PRO_ACT_CUL(F)*SCS(S) );
FE(F,L,'AP')$FL(F,L) = smax( S, PRO_POT_CUL(F,L,S)*SCS(S) );
```

Appendix B. Input data files

TABLE

ARE_ACT_H(F,H40,SQ) Forest area by actual site qualities and county in hectares

	06.L	08.L	11.M	14.M	17.H	20.H	23.H	26.H
010000	15461	53295	52503	40570	36700	25577	10044	0
020000	9614	50505	79823	87390	67627	25490	7448	0
040000	79904	246193	183711	126900	81254	29981	4277	0
050000	136370	359726	368902	265724	171812	57391	15022	0
060000	3311	13525	19473	23994	21740	23434	18772	0
070000	54161	148368	131592	122392	79145	27554	9831	0
080000	57994	149821	136098	107079	48186	24385	10573	0
090000	32322	82305	85486	80518	30293	5059	2423	0
100000	20826	58987	73354	44370	28530	13211	5144	0
110000	9141	39883	43868	23270	12514	6627	7722	0
120000	25599	80079	78095	39443	22884	16231	16917	0
140000	22513	75115	83416	41806	16889	13638	13895	0
150000	21571	58056	82176	60583	30506	22970	9544	0
160000	55889	136386	107823	78897	33546	6492	604	0
170000	77793	175328	172624	133457	52328	9465	2163	0
180000	123652	241610	153382	79071	20091	2048	602	0
190000	118517	216149	75095	12200	1533	0	0	0
200000	134106	175615	9579	0	0	0	0	0

TABLE

ARE_POT_H(F,H40,SQ) Forest area by potential site qualities and county in hectares

	06.L	08.L	11.M	14.M	17.H	20.H	23.H	26.H
010000	15461	51946	50812	41308	35782	28079	10907	0
020000	7537	49763	75224	89645	66054	30742	9229	0
040000	71441	234354	192084	132212	82289	36013	4727	0
050000	106416	353250	372410	288932	181527	53433	18980	0
060000	3184	12162	18479	22873	21077	23293	23179	0
070000	47532	147421	134388	122618	80317	28411	13529	0
080000	54844	146671	136503	108249	46701	27985	14532	0
090000	31111	79791	81487	82578	33473	7543	3029	0
100000	17653	43600	45821	51645	48404	26831	11149	0
110000	5261	12356	15156	29746	34471	28561	17473	0
120000	12979	19095	20587	54167	78781	56300	37339	0
140000	5201	17373	33445	53101	68508	54371	35274	0
150000	10131	13380	37523	59500	80461	65344	22721	0
160000	43177	116428	114737	89767	42241	11927	1963	0
170000	77523	175148	170460	133682	54176	11358	3516	0
180000	69582	141875	198204	158413	48557	3223	602	0
190000	56344	106407	137929	94507	27766	541	0	0
200000	134106	175615	9579	0	0	0	0	0

TABLE

ARE_CUL_H(F,SQ) Forest land usable for agricultural production by old site quality in hectares

	L	M	H
010000	9929	16561	118953
020000	6253	38431	274487
040000	435702	804421	600954
050000	226123	255642	235477
060000	44660	42357	130155
070000	1892	4122	87561
080000	6708	21630	51305
090000	4027	23446	48851
100000	2310	5435	30177
110000	167	2222	33002
120000	303	899	21533
140000	501	4538	48101
150000	5427	21299	227327
160000	99342	228861	85861
170000	81490	366374	368574
180000	34791	237798	116937
190000	52736	352884	113786
200000	40063	16163	495

TABLE

GRO_ACT_SPR(F,H40,SQ) Increment in standing volume of spruce by actual site quality and county in cubic meters pr yr

	06.L	08.L	11.M	14.M	17.H	20.H	23.H	26.H
010000	687	17359	50677	85464	119092	160523	90315	0
020000	2817	24932	100020	233876	317213	153712	84165	0
040000	42176	174274	303286	451923	488403	235677	61028	0
050000	43157	188833	429947	623158	731951	312100	91078	0
060000	729	8197	19106	54500	76581	122870	189714	0
070000	31675	93607	167820	283162	344398	166666	105795	0
080000	26483	115681	162346	203722	182524	177033	116103	0
090000	2405	10974	51052	117414	76517	30506	18858	0
100000	380	3223	13512	44910	105115	92603	50767	0
110000	502	3346	6296	13211	42341	72360	119760	0
120000	329	5339	11775	31837	71475	145059	252251	0
140000	40	1990	4042	19095	56062	126373	174406	0
150000	88	562	8265	28498	97487	202250	118658	0
160000	11883	57251	112415	177396	141584	42973	2580	0
170000	18761	110819	212275	315982	262791	48426	7148	0
180000	5956	49746	146348	242314	103985	25204	7092	0
190000	947	7491	21177	39179	10044	0	0	0
200000	0	0	0	0	0	0	0	0

TABLE
GRO_ACT_PIN(F,H40,SQ) Increment in standing volume of pine by actual site quality and county in cubic meters pr yr

	06.L	08.L	11.M	14.M	17.H	20.H	23.H	26.H
010000	17651	71556	76824	66632	59195	13215	811	0
020000	7930	51131	76420	70571	52005	7855	584	0
040000	11948	99849	106961	59837	25757	11196	1073	0
050000	45023	264570	375190	384912	241317	55955	8142	0
060000	3526	12130	13555	10583	7556	8873	1648	0
070000	25170	99170	131881	187679	120798	29428	3245	0
080000	35212	115928	125774	124894	57940	20384	8651	0
090000	26379	84122	101827	119533	39762	6385	0	0
100000	23264	70532	88014	58000	22248	8164	244	0
110000	6397	27257	33116	22698	20120	4109	3379	0
120000	15892	70993	58661	31898	10121	3025	3789	0
140000	11077	37340	52604	39325	8141	4421	1276	0
150000	13849	34804	64563	41400	14609	11721	565	0
160000	25745	67465	64685	40088	7780	1101	321	0
170000	22021	46995	18513	3535	3410	0	0	0
180000	11870	24717	20435	6811	159	254	0	0
190000	5994	19029	17380	1495	0	0	0	0
200000	20580	26950	1470	0	0	0	0	0

TABLE
GRO_ACT_BIR(F,H40,SQ) Increment in standing volume of birch by actual site quality and county in cubic meters pr yr

	06.L	08.L	11.M	14.M	17.H	20.H	23.H	26.H
010000	1827	9844	20197	24049	31954	28518	16799	0
020000	981	16782	39281	48816	64077	26377	5695	0
040000	20518	88484	67087	72449	83608	48945	8032	0
050000	21581	67265	91223	107861	79302	62419	27267	0
060000	1080	6860	20672	46283	59990	72107	48968	0
070000	8559	36407	45210	78188	110366	50508	34971	0
080000	13454	58250	121393	113439	106582	61927	27875	0
090000	6002	29360	53199	63489	32963	6535	5592	0
100000	9699	43108	83848	57804	32980	9065	4530	0
110000	2401	27160	49828	36598	12128	4381	3212	0
120000	6289	37378	78837	57382	31884	15860	8906	0
140000	7538	47310	95430	59253	23009	14089	10860	0
150000	4083	34077	97069	118817	49363	30004	5963	0
160000	7996	34209	49093	53539	39395	5033	1298	0
170000	8089	42220	68443	82879	44019	26566	1923	0
180000	39235	148642	123312	70563	8729	1859	579	0
190000	44965	154482	92231	8429	1330	0	0	0
200000	41159	53899	2940	0	0	0	0	0

This working paper documents the derivation of carbon sequestration coefficients for forest grown on Norwegian agricultural land. These figures will serve as input to the established model Jordmod – an economic model of the Norwegian agricultural sector. The purpose is to carry out greenhouse gas policy analysis. Associated with this paper is a GAMS program (The General Algebraic Modeling System), which computes the figures. The structure of this working paper is made to facilitate reading the program (given in Appendix A).

The main issue is the expected woody biomass production on agricultural land. While there is plenty of data and information about wood productivity of forest land, agricultural land is not classified in terms of its abilities to produce woodwork. So our main point of departure is to look at forest land statistics, and from that, construct coefficients to be applied on the agricultural land.

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