Energy, environment and economy aspects of short rotation forestry in the Baltic sea region
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ENERGY FORESTS WITH WILLOW AS A CARBON SINK

INTRODUCTION

The United Nations Kyoto Convention on Climate Change (Kyoto Protocol ... 1997) accepted in December 1997 the principle of forest sinks as a means to combat the threatening climate change. The increasing emissions to atmosphere of carbon dioxide can be counterbalanced by sequestering the excess carbon from the atmosphere down to the biosphere. The growing forests were understood to be the most realistic sink onto which man can have an immediate and sufficient effect.

The acceptable forest sinks were defined with rather strict characteristics. First of all, the forest sinks must be a result of direct, human induced activity, limited to afforestation and reforestation. The natural forests were ruled out, because they are acting as sinks even without direct human activity. Secondly, only the afforested or reforested age classes since the beginning 1990, of the commitment period, are counted. The end of the commitment period was defined as 2008 to 2012. This is parallel to the calculation of carbon dioxide emission over the same commitment period. And thirdly, the changes in stocks of dry matter or carbon of the afforested or reforested areas must be such that they can be measured in a verifiable manner.

Afforestation and reforestation refer to land use change where the land has been treeless for a long time. For the difference between afforested and reforested sites the Intergovernmental Panel for Climate Change (IPCC ... 1996) defines the time span of 50 years: ”They (plantations) are either on lands that previously have not supported forests for more than 50 years (afforestation), or lands that have supported forests within the last 50 years and where the original crop has been replaced with a different one (reforestation)”.

The time span of 50 years can to some extent be justified with human memory. If the present or the previous generation do not remember the particular site as a forest, then it can be afforested. And if they do remember that there has been forest on that site, then the site is reforested. For the sake of clarity, reforestation must be separated from forest regeneration. This is a normal activity in sustained forestry; regeneration establishes a new tree generation on a harvested forest land. Regeneration does not cause any land use change: the forest stays as a forest. Regeneration has neither any affect on the carbon stock of that particular site, in the long run at least, whereas reforestation builds up a new carbon stock.

Afforestation is typically artificial establishment by planting or seeding of forest on an area of agricultural land. In Finland, other Nordic countries or Baltic countries afforestation may well be an establishment of long rotation forest of silver birch, *Betula pendula* Roth on an agricultural land. For saw log production a long rotation of 60 years is needed. Afforestation can also establish a medium rotation forest of hybrid aspen, *Populus x wettsteinii* Hämet-Ahti. For pulp production a medium rotation of 30 years is sufficient. A more recent approach is to afforest the agricultural field with a short rotation willow, like osier, *Salix viminalis* L. For bioenergy purposes a short rotation of 3-5 to years, or to 10 years can be applied. Afforestation of old agricultural fields in Finland in 1980s and 1990s has varied between 2000 - 18 000 ha per annum (Metsätilastollinen ... 1997). Towards the end of 1990s and beyond 2000 the afforestation rate can be expected to be 5000 ha per annum.

For reforestation the best example from Finland, other Nordic countries or Baltic countries may be the cut-away areas of peatlands which have been utilised by peat industry enterprises for fuel and growing peat. Large scale peat fuel industry was initiated in Finland in 1971. Towards the end of the 1990s the area of active peat fuel production has stabilised to 50 000 ha. As the time span of peat fuel excavation with modern machinery reaches over 20-25 years, the first cut-away areas have already been vacated. In 1998 they amount to 8000 ha and will be vacated at a rate of 2000-3000 per annum in the coming years (Pohjonen 1998). Before the peat harvesting started, the Finnish peat bogs were growing mostly peatland forest, and only partly they were open. The start of peat industry effected a land use change (deforestation) in the area. Reforestation returns these open areas back into forests.

The total area of technically and economically suitable peat production bogs in Finland covers 622 000 ha (Lappalainen and Hänninen 1993), out of which the Finnish peat industries have reserved 123 000 ha. Wettest bottom parts of the of the peat cutaway areas, maybe some 15-20 per cent of the total, will be reserved for regeneration of marshes and small lakes. The potential area for reforestation can therefore counted to be some 100 000 ha, which is of the same order than the vacated agricultural fields for afforestation

Reforestation of cutaway peatlands has been studied in Finland over 40 years (Mikola, P. and Mikola, I. 1958, Kaunisto and Aro 1996). If the peat has been harvested to a remainder thickness of 30 cm of the bottom peat, the recommendable species for long rotation reforestation is silver birch. It benefits if the roots can penetrate through the remaining bottom peat into the bottom mineral soil. If the remainder peat thickness is over 30 cm a more recommendable species is downy birch, *Betula pubescens* Ehrh. Of the short rotation willows the best results has given tea leaved willow, *Salix phylicifolia* L. (Hytönen et al. 1995). Exotic willows to Finland, like *Salix viminalis*, *Salix burjatica* Nasarov *and Salix x dasyclados* Wimmer have suffered badly from the harsh microclimate of the peatland sites, from spring, summer and autumn frosts.

In the calculations of excess carbon movements between the atmosphere and the biosphere it is important to separate the concepts of carbon stocks and carbon flows. The excess carbon flow from the biosphere to the atmosphere is expressed as carbon dioxide emissions. The emissions are caused by man and his activities like burning of fossil fuels or deforestation of the natural forests. The carbon dioxide emissions are known from the national energy statistics. For the deforestation they can be calculated from the world forestry statistics. For instance, in Finland the carbon dioxide emissions in 1996 were 60 million tons (Energiatilastot 1996). In many countries the carbon dioxide emissions are subject to energy or environment taxation. In Finland the CO2 tax in 1998 is 82 Finnish marks per tonne CO2, equivalent to 14.9 USD per tonne CO2.

The flow of excess carbon from the atmosphere to the forest sinks, also called carbon sequestration, is expressed as carbon dioxide removal. The CO2 removal can be thought as a negative CO2 emission, or vice versa. The downwards flow of carbon dioxide from the atmosphere cannot be measured directly. Instead, it is measurable indirectly by determining the changes of carbon stock in the forest sink over a commitment period, which can be one year, 5 years, 10 years, or a period between 1990-2008. The measurement is a modification of a routine forest inventory. First, the forest sink is measured in one year by its cubic meters (m3/ha), or rather by its dry matter biomass (tn/ha). The same is repeated in the second year. Bearing in mind that 50 per cent of dry woody biomass is in elementary carbon, the change in carbon stock (tn C per ha per annum) is calculated. This change has been caused by the removal of carbon dioxide from the atmosphere. The removal is calculated by multiplicating the change in carbon stock by the atomic weights ratio 44/12 and finally expressed in tons of CO2.

Which kind of change in the carbon stock is verifiable, as required by the Kyoto Protocol? An immediate possibility is to measure only the above ground woody biomass, using standard non-destructive forest mensuration methods. It is known, at least academically, that an important part, some additional 25 - 50 per cent or even more, of the forest sink is in the roots of the trees and in the soil humus. However, as the underground forest sink cannot currently be measured in a non-destructive verifiable manner, it was ruled out from the Kyoto Protocol.

The determination the effect of forest sinks in the sense of the Kyoto Protocol requirements can be simplified to the following three steps. First, starting from the beginning of the commitment period, from year 1990, the number of hectares which have been afforested or reforested, are determined year by year. Second, the above ground woody biomass stock over the total afforested and reforested lands is determined either year by year or at least for the beginning year 1990 and for the ending year 2008 (or 2012). Third, the annual changes in carbon stock are calculated and converted into carbon dioxide removals from atmosphere to the forest sinks, again starting from 1990 and ending in 2008 (or 2012).

This paper examines by simulation means the value of short rotation energy forests as carbon sinks. Two special cases are considered: *Salix viminalis* in southern Finland on agricultural land with 7 years rotation and *Salix phylicifolia* in northern Finland on peat cutaway land with 10 years rotation. The commitment period in both cases is 30 years starting from 1998 and ending in 2027. A special attention is given to the time points of 2008 and 2012 mentioned in the Kyoto Protocol.

The rotation of 7 years rotation for *Salix viminalis* is 2-3 years longer than in the standard Swedish energy forest approach. The aim is to raise the woody biomass and carbon stock to somewhat higher level which is beneficial in the forest sink calculations. The growth of the energy forest plantation continues still after the 4th or 5th year, not at highest but moderate level at least, as shown by Hytönen (1995). He let *Salix burjatica* plantation grow until 7 years of coppice age. Similarly, the rotation of 10 years for *Salix phylicifolia* is longer than normally anticipated. This rotation time is based on experience and long-term measurements from Piipsanneva peat cutaway trial area in Finland (Hytönen et al. 1995, Hytönen 1998).

CASE 1: SALIX VIMINALIS AFFORESTATION ON AGRICULTURAL LAND

For the simulation standard plantations of *Salix viminalis*, using Swedish energy forestry approach and technology are established on agricultural soils in Southern Finland. The planting starts in the year 1998 and ends in 2027. The plantation establishment rate is 5000 ha per annum, so in 30 years a total area of 150 000 ha of energy forest carbon sink will be established. After the first growing year the willow stems are cut down to allow for sufficient coppicing. Then the willows are let grow for seven years and cut again. The first harvest therefore takes place at age of 8 years. The consecutive coppice stands are always harvested after 7 years.

The yield target of 60 tn/ha is set for the *Salix viminalis* at harvest. For the first rotation of 8 years this equals to mean annual increment (MAI) of 7.5 tn/ha/a. For the coppice rotation of 7 years the MAI is 8.6 tn/ha/a. The provisional growth and yield tables are presented in Table 1. The carbon stock target at the end of all rotations (time of harvesting) is 30 tn C/ha.

Table 1. Provisional growth and yield table for *Salix viminalis* energy forest growing on an agricultural land in Southern Finland. Standard Swedish energy forest approach. CAI for Current Annual Increment, MAI for Mean Annual Increment. Carbon content of the dry matter is 50 per cent

Growth and yield: 'S. viminalis, First rotation

year	Cumul Y tn/ha	CAI tn/ha/a	MAI tn/ha/a	Carbon tn/ha
1	0	0.0	0.0	0.0
2	5	5.0	2.5	2.5
3	14	9.0	4.7	7.0
4	26	12.0	6.5	13.0
5	36	10.0	7.2	18.0
6	45	9.0	7.5	22.5
7	53	8.0	7.6	26.5
8	60	7.0	7.5	30.0

Growth and yield: S. viminalis, Coppice rotation

year	Cumul Y tn/ha	CAI tn/ha/a	MAI tn/ha/a	Carbon tn/ha
1	5	5.0	5.0	2.5
2	14	9.0	7.0	7.0
3	26	12.0	8.7	13.0
4	36	10.0	9.0	18.0
5	45	9.0	9.0	22.5
6	53	8.0	8.8	26.5
7	60	7.0	8.6	30.0

Each year the planting of 5000 ha makes an age class or block, which starts to grow according to the growth and yield table. The first age block (1998) is harvested in autumn 2005, the coppice continues the growth according to the coppice growth and yield table and it is again harvested in autumn 2012, 2019 and 2026. Each year the carbon stock is summed over the already established and grown age blocks. The carbon sequestration starts in 1999, after the first year cut back of the first-year shoots. The later harvestings are seen in the carbon accumulation as slight bends. After the 30-year commitment period the total amount of carbon sequestered over 150 000 ha is 2.4 mill. tons (Figure 1).

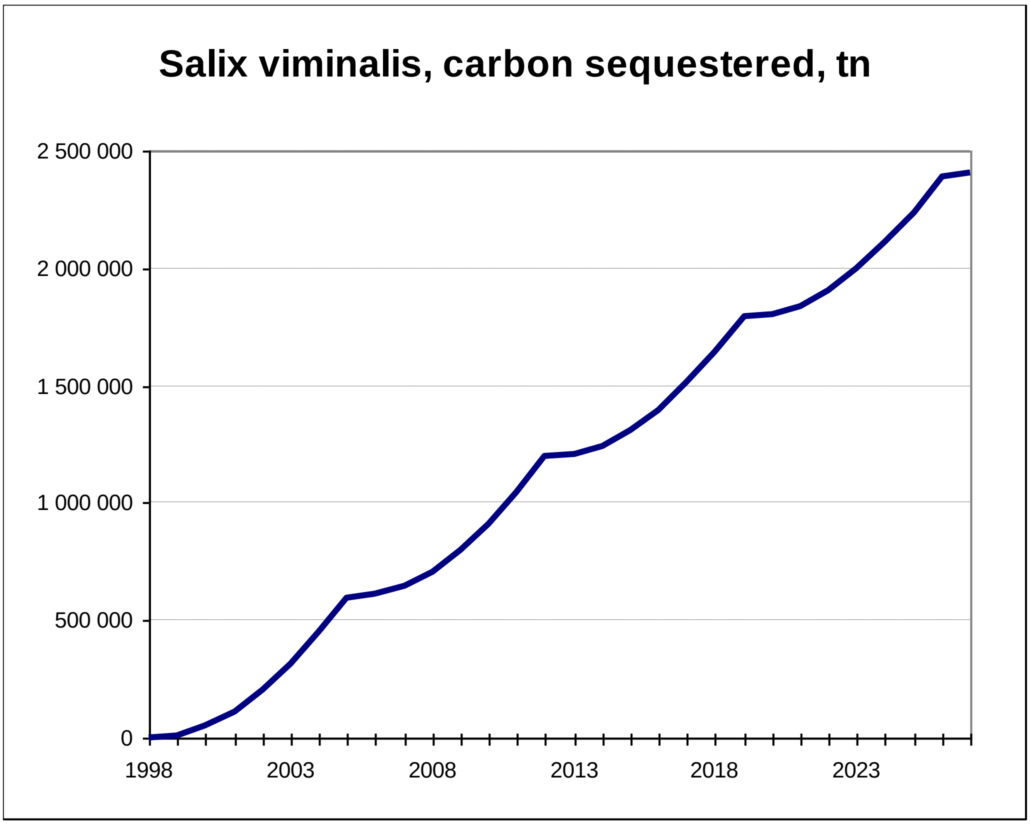

Figure 1. Carbon sequestration in the *Salix viminalis* energy forest area of 150 000 ha, between 1998 and 2027. Each year an age block of 5000 ha has been planted. The age blocks are grown with 1+7 years (first) and 7 years (coppice) rotations.

By the end of 2008 the area afforested has risen to 55 000 ha. The total amount of carbon sequestered is 0.71 mill. tn, which corresponds to CO_2 removal of 2.60 mill. tn. Correspondingly, by the end of 2012 the area afforested has risen to 75 000 ha. The total amount of carbon sequestered is 1.20 mill. tn, which corresponds to CO_2 removal of 4.38 mill. tn.

The mean carbon, tonnes C per ha, is a concept analogical to mean volume, m3/ha, in conventional forest management. The mean carbon is calculated by dividing the sequestered carbon in the forest by the area that has already been planted. Building a carbon sink with a forest is essentially an aim at raising the mean carbon of the forest as quickly and as high as possible and keeping it there. In the energy forest of *Salix viminalis* the mean carbon raises within 7 years to 15 tn C/ha and is kept in the long run at level of 15-16 tn C/ha (Figure 2). By the end of 2008 the mean carbon is at 13 tn C/ha and by the end of 2012 at 16 tn C/ha.

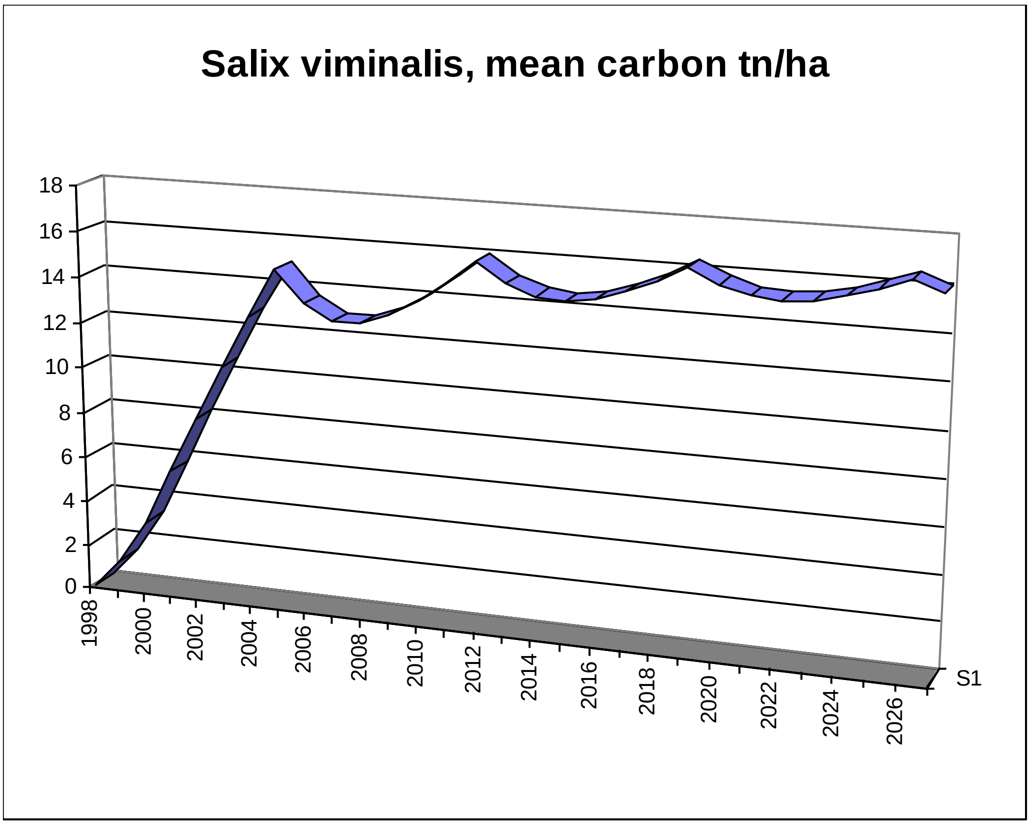

Figure 2. Mean carbon tn C/ha in the *Salix viminalis* energy forest area of 150000 ha, between 1998 and 2027.

The total amount of carbon, 2.40 mill tn, sequestered over 150 000 ha and over 30 years, is equivalent of 8.81 mill. tons of carbon dioxide removal. Applying the carbon dioxide tax of 82 FIM (14.9 USD) per tonne CO2 this accrues a total saving of 722 mill. FIM (131 million USD) in the carbon dioxide taxes during the commitment period 1998-2027. By the end of 2008 the saving is 213 mill FIM and by the end of 2012 it is 359 million FIM. Calculated over the whole energy forest area of 150 000 ha this makes a sink value of *Salix viminalis* energy forest at 4816 FIM (876 USD) per ha Correspondingly, at the time points of 2008 and 2012 the sink value is 3881 FIM/ha and 4791 FIM/ha. The development of the sink value (in USD/ha) of the *Salix viminalis* energy forest as a function of time is shown in Figure 3.

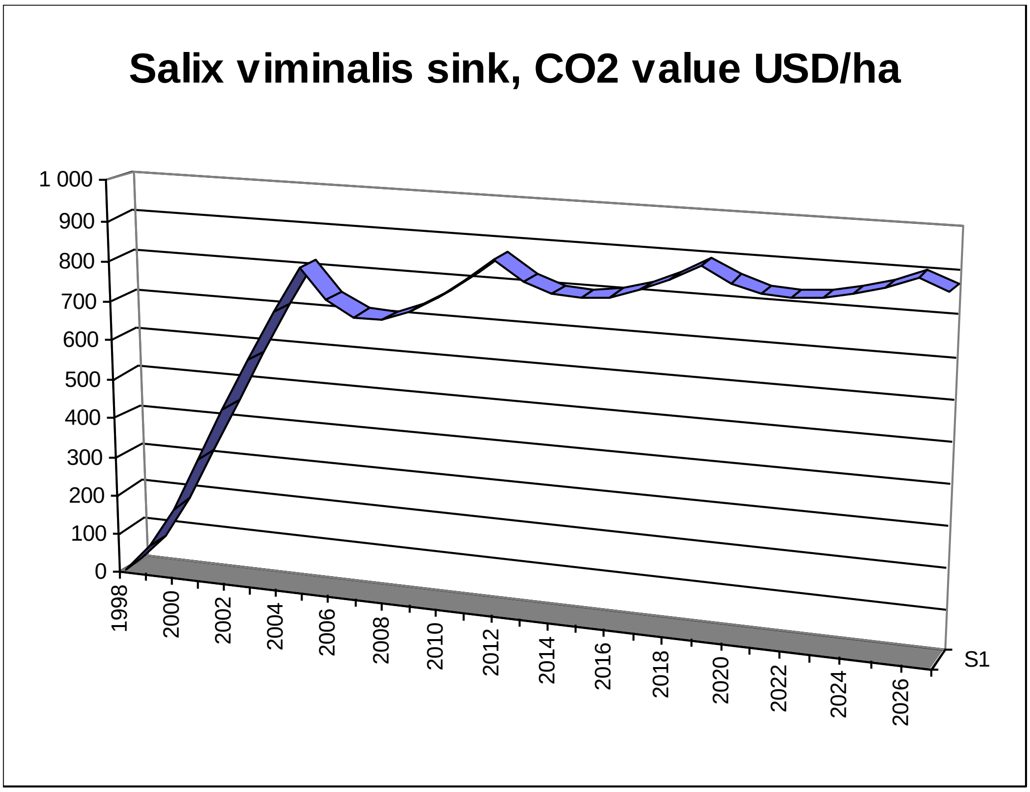

Figure 3. Development of the per hectare sink value in the *Salix viminalis* energy forest area of 150 000 ha, between 1998 and 2027. Carbon dioxide fee of 82 FIM (USD 14.9) per ton CO2. Sink value has been calculated based on CO2 removal from the atmosphere. (file 195valu1.xls)

The sink value can be thought to be an additional value of the energy forest, besides its main function: to produce the biomass which can be used to substitute the fossil fuels. In practical terms the per hectare sink value can be thought as a partial payment for the afforestation cost. The sink value is of course strongly dependant on the national level of the carbon dioxide tax.

CASE 2: SALIX PHYLICIFOLIA ON CUTAWAY PEATLAND

Rather substantial research work into growing energy forests on cutaway peatlands has been carried out in Finland between 1979 and 1995, as has been summarised by Hytönen (1996). Common to the experiments has been the early reliance on the exotic willows *Salix burjatica* and *Salix x dasyclados* Wimmer. The results with the exotics have been poor. The more recent interest has been shifting to the possibilities of the frost hardy indigenous willows, for which there is a range of 21 species for selection (Pohjonen 1991).

Little is known on the growth of indigenous willows of Finland on cutaway peatlands. Some early results were given by Lumme and Törmälä (1988), but without biomass growth data. The only trial of 1980s with large enough plots for woody biomass measurement was established in Piipsanneva peat cutaway area in Haapavesi, 100 km south of the city of Oulu in 1984. The trial has been measured twice, at the age of 6 years (Hytönen et al. 1995) and at the age of 11 years (Hytönen

1998). Of the tested species *Salix phylicifolia* produced best. At the age of 6 years it had a biomass stock of 38 tn/ha. Between the 6-11 years the growth was even higher. The woody biomass stock was raised to 96 tn/ha (Table 2). It equals to mean annual increment of 8.7 tn/ha/a.

Table 2. Woody biomass of various deciduous trees in Piipsanneva peat cutaway trial area at the ages of 6 and 11 years. The original planting density for willows 40 000 cuttings per ha, for the others 20 000 seedlings per ha. The trial was established in 1984 (Hytönen et al. 1995, Hytönen 1998).

dry tn/ha at age of	6 a	11 a
Betula pendula	21	81
Betula pubescens	25	72
Alnus incana	24	52
Salix phylicifolia	38	96
Salix triandra	31	62
Salix x dasyclados	16	

It is notable that the production of the exotic willow *Salix x dasyclados* was poor (16 tn/ha) over the first six years. Besides, it died away between 6 and 11 years. The other indigenous, fully winter hardy species, *Salix triandra* L. performed moderately. It is natural and more suitable on mineral soils, whereas *Salix phylicifolia* typically grows on peatlands and other moist soils in Central and Northern Finland. The rather high production of longer rotation birches and grey alder, *Alnus incana* (L.) Moench can partly be explained at exceptionally high planting density, 20 000 seedlings per ha.

For the simulation and based on the experience from Piipsanneva peat cutaway area standard plantations of *Salix phylicifolia,* again using Swedish energy forestry approach and technology are established on peat cutaway soils. The climatic conditions refer to Northern and Middle Finland where the peat soils dominate, and the peat industries are situated. The planting starts in the year 1998 and ends in 2027. The plantation establishment rate is 2000 ha per annum, so in 30 years a total area of 60 000 ha of energy forest carbon sink will be established. After the first growing year the willow stems are cut down to allow for coppicing. Then the willows are let grow for 10 years and cut again. The first harvest is therefore taken place at age of 11 years. The consecutive coppice stands are always harvested after 10 years.

The yield target of 70 tn/ha is set for the *Salix phylicifolia* at harvest. For the first rotation of 11 years this equals to mean annual increment of 6.4 tn/ha/a. For the coppice rotation of 10 years the

MAI is 7.0 tn/ha/a. The provisional growth and yield tables are presented in Table 3. The carbon stock target at the end of all rotations (time of harvesting) is 35 tn C/ha.

Table 3. Provisional growth and yield tables for *Salix phylicifolia* energy forest growing on an peat cutaway land in Northern and Middle Finland. Standard Swedish energy forest approach. CAI for Current Annual Increment, MAI for Mean Annual Increment. Carbon content of the dry matter is 50 per cent.

Growth and yield: 'S. phylicifolia, First rotation

year	Cumul Y tn/ha	CAI tn/ha/a	MAI tn/ha/a	Carbon tn/ha
1	0	0.0	0.0	0.0
2	3	3.0	1.5	1.5
3	8	5.0	2.7	4.0
4	15	7.0	3.8	7.5
5	24	9.0	4.8	12.0
6	34	10.0	5.7	17.0
7	44	10.0	6.3	22.0
8	52	8.0	6.5	26.0
9	59	7.0	6.6	29.5
10	65	6.0	6.5	32.5
11	70	5.0	6.4	35.0

Growth and yield: S. phylicifolia, Coppice rotation

year	Cumul Y tn/ha	CAI tn/ha/a	MAI tn/ha/a	Carbon tn/ha
1	4	4.0	4.0	2.0
2	10	6.0	5.0	5.0
3	19	9.0	6.3	9.5
4	30	11.0	7.5	15.0
5	39	9.0	7.8	19.5
6	47	8.0	7.8	23.5
7	54	7.0	7.7	27.0
8	60	6.0	7.5	30.0
9	65	5.0	7.2	32.5
10	70	5.0	7.0	35.0

Each year the planting of 2000 ha makes again an age class or block. It starts to grow according to the *Salix phylicifolia* growth and yield table. The first age block (1998) is harvested in autumn 2008, the coppice continues the growth according to the coppice growth and yield table and it is again harvested in autumn 2018. Each year the carbon stock is summed over the already established and grown age blocks. The carbon sequestration starts in 1999, after the first year cut back of the first-year shoots. The later harvestings are seen in the carbon accumulation as slight bends. After the 30-year commitment period the total amount of carbon sequestered over 60 000 ha is 1.11 mill. tons (Figure 4).

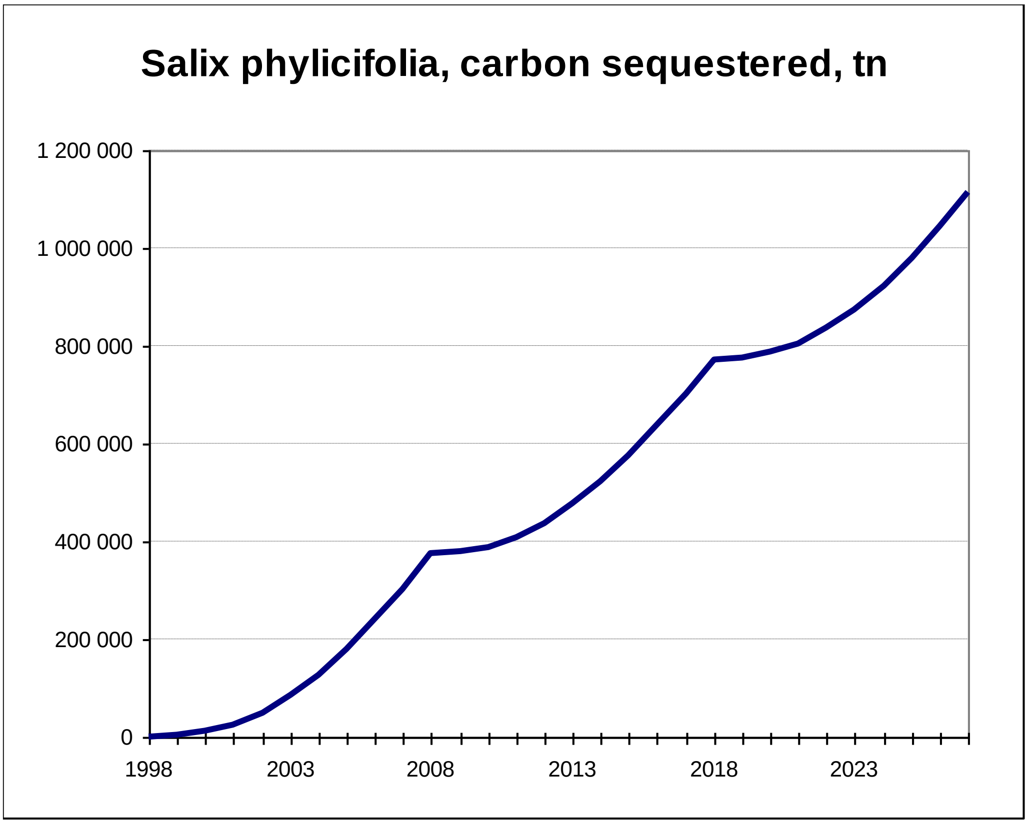

Figure 4. Carbon sequestration in the *Salix phylicifolia* energy forest area of 60 000 ha, between 1998 and 2027. Each year an age block of 2000 ha has been planted. The age blocks are grown with 1+10 years (first) and 10 years (coppice) rotations.

By the end of 2008 the area afforested with *Salix phylicifolia* has risen to 22 000 ha. The total amount of carbon sequestered is 0.37 mill. tn, which corresponds to CO2 removal of 1.37 mill. tn. Correspondingly, by the end of 2012 the area afforested has risen to 30 000 ha. The total amount of carbon sequestered is 0.44 mill. tn, which corresponds to CO2 removal of 1.60 mill. tn.

In the energy forest of *Salix phylicifolia* the mean carbon raises within 10 years to 17 tn C/ha and is kept in the long run at that level (Figure 5). By the end of 2008 the mean carbon is at 17 tn C/ha and by the end of 2012 at 15 tn C/ha. The slight drop is caused by the first harvesting of some age blocks. The mean carbon with longer rotation *Salix phylicifolia* is only slightly higher than with shorter rotation *Salix viminalis* (15-16 tn C/ha).

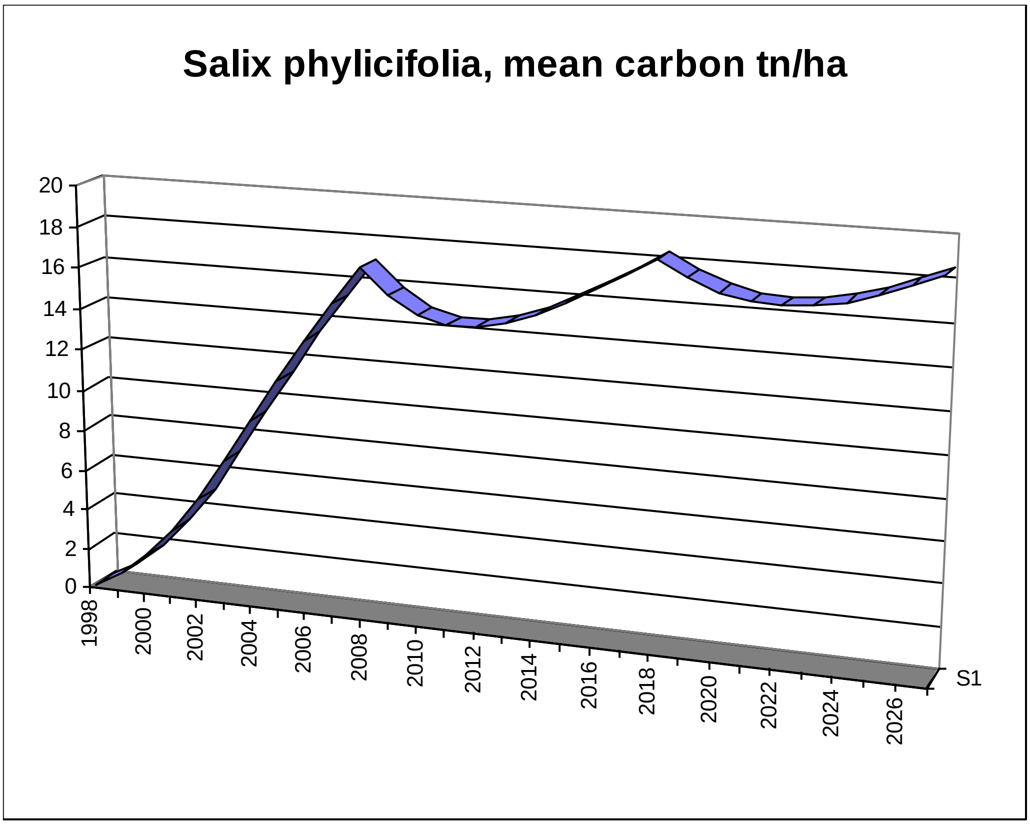

Figure 5. Mean carbon tn C/ha in the *Salix phylicifolia* energy forest area of 60 000 ha, between 1998 and 2027.

The total amount of carbon, 1.11 mill tn, sequestered over 60 000 ha and over 30 years, is equivalent to 4.07 mill. tons of carbon dioxide removal. Applying again the carbon dioxide tax of 82 FIM (14.9 USD) per tonne CO2 this accrues a total saving of 333 mill. FIM (61 million USD) in the carbon dioxide taxes during the commitment period 1998-2027. By the end of 2008 the saving is 112 million FIM and by the end of 2012 it is 131 million FIM. Calculated over the whole energy forest area of 60 000 ha this makes a sink value of *Salix phylicifolia* energy forest at 4455 FIM (1010 USD) per ha Correspondingly, at the time points of 2008 and 2012 the sink value is 5111 FIM/ha and 4380 FIM/ha. The development of the sink value (in USD/ha) of the *Salix phylicifolia* energy forest as a function of time is shown in Figure 6.

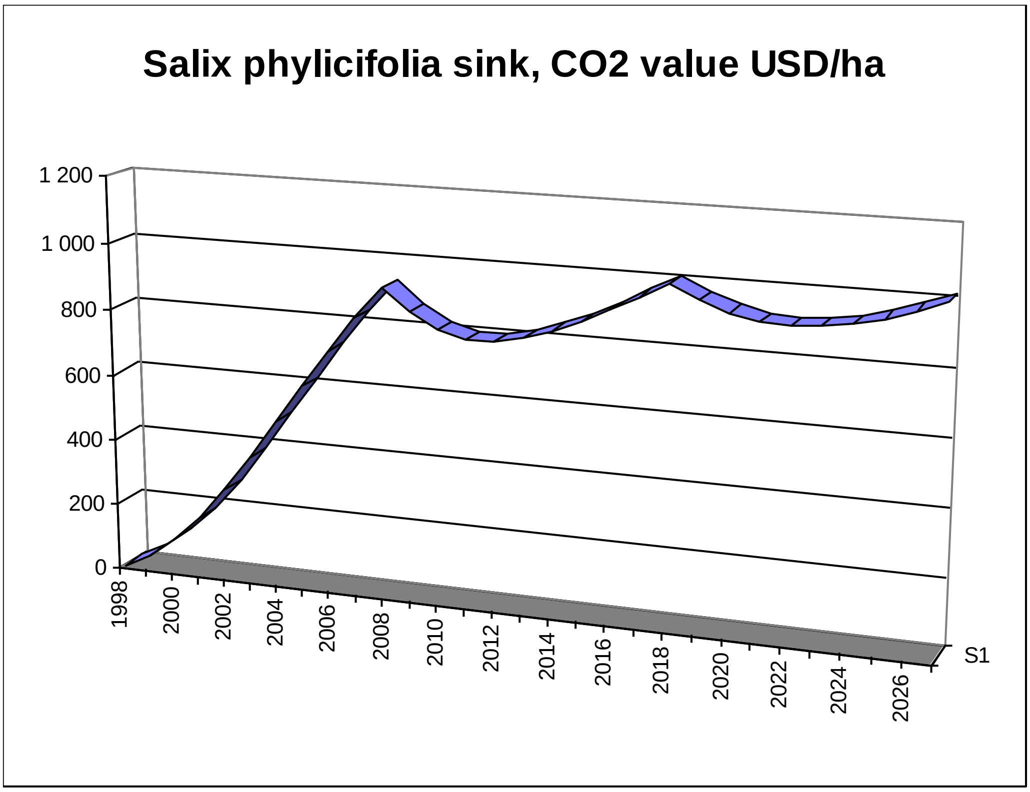

Figure 6. Development of the per hectare sink value in the *Salix phylicifolia* energy forest area of 60 000 ha, between 1998 and 2027. Carbon dioxide fee of 82 FIM (USD 14.9) per ton CO2. Sink value has been calculated based on CO2 removal from the atmosphere.

CONCLUSIONS

The Kyoto protocol and the concept of afforestation and reforestation as a means to establish carbon sinks gives additional value to energy forestry with willows. On rotations from 7-10 years a mean carbon density of 15-20 tons C per hectare can be built. Of all the bioenergy crops on agricultural, or otherwise arable, this give an advantage to the short rotation willow. Reed canary grass (*Phalaris arundinacea*), rape seed (*Brassica* sp.) for biodiesel or *Miscanthus* sp. do not build a carbon sink in the sense the Kyoto protocol defined. The carbon density of the short rotation energy forest will always remain lower than the carbon density in the long rotation forests (typically about 50 - 50 tn C/ha in Finland), but on the other hand the carbon sink is built exceptionally fast with willows.

The carbon sinks between *Salix viminalis* on agricultural lands and *Salix phylicifolia* do not differ much. Rather than selection of species the building of carbon sinks depends on selection of sites. Agricultural lands all over Europe are most obvious land resource for afforestation. Reforestation possibilities are smaller, like the cutaway peatlands in Finland. Also, some other exploited land areas may become available, like old quarries, although their land area might be small.

The Kyoto convention also accepted the principle of joint implementation for establishment of forest sinks in various parts of the world. For the carbon dioxide sinks building the joint implementation opened up a possibility for joint afforestation or reforestation so that the forests are planted in a second or third country later the first country can count for the carbon dioxide sink benefit in her national energy statistics, if the mutual country agreement so defines. The commitment period between 1990 and 2008 (2012) is again valid. As an example, this could mean that Finland or Sweden (or a private enterprise in those countries) participates in an energy forestry project with willows in Estonia, Latvia or Lithuania. Later, in 2008-2012, Finland or Sweden (or the private enterprise in them) can count for the benefit of the carbon sink, if thus agreed in the beginning of the plantation project. The procedures are still subject to after-Kyoto formulation, but the principle was agreed to. The joint implementation could be a flexible channel to speed the development of energy forestry in the Baltic Sea region.

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