Skog & Trä

2008:2

The solid biofuel market in Sweden – current status

Gustaf Egnell

Swedish University of Agricultural Sciences
Unit for Field-based Forest Research
Vindeln Experimental Forests

ISSN 1403-6398
ISBN 978-91-977896-2-2

Cover photo Dan Bergström
Illustrations Gun Lövdahl, Listera
Layout Ulla Nylander, SLU

SLU

Skog & Trä

2008:2

The solid biofuel market in Sweden – current status

Gustaf Egnell

Content

The solid biofuel market in Sweden – current status

Preface

This report has been written as a part of a cooperation between the Swedish University of Agricultural Sciences (SUAS) and E.ON Sweden AB that started in 2007. E.ON Sweden AB is financing research at the Forestry Faculty, SUAS, with potential to have a positive impact on the future supply of biomass from the forest. The objective with the report is primarily to explain the difference between the physically available biomass in the forest and the amounts that show up on the biomass market and what might have an impact on that. This English version is a translation of the original report written in Swedish and published in 2008.


Photo: Ivar Palo

The solid biofuel market in Sweden – current status

Summary

The ongoing change of the energy system in Sweden and other EU countries with new set targets to increase the proportion of renewable energy sources and reduce green-house gas (GHG) emissions until 2020 has increased the pressure on biomass for energy purposes. With focus on the in Sweden dominant biomass from our forests this report explains the difference between the physically available biomass in the forest and the amounts that show up on the biomass market and what might have an impact on that in the short- and long-term.

Historically Sweden's forests were harvested to meet a growing export market for timber without any efforts to establish a new forest after harvest. Therefore a forest restoration program started about a century ago with the goal to increase the growing stock. Since 1923 up until today the National Forest Inventory has supplied reliable data about the growing stock. During the period the growing stock has increased from 1760 to more than 3000 million cubic meters primarily through good silviculture practices and an annual harvest level that most years has been lower than the annual growth.

An important message to keep in mind is that it takes a long time to increase the growing stock due to the long rotation period of a forest crop in a mostly boreal country like Sweden. In short-term (10-20 yrs) the biomass contribution from our forests primarily depends on the forests we already have, its growth, harvest levels, and possible import of woody biomass. In median- (20-50 yrs) to long-term (50-100 yrs) the supply could be increased through silvicultural practices aiming for increased forest growth. This may happen if forest owners can be convinced about the profitability in such action.

Current growing stock (stem-wood only) in Sweden, recalculated to total biomass including branches, foliage, stumps and roots, corresponds to over 2 000 million tons of dry biomass. In energy units this corresponds to over 36 000 PJ, whereof roughly half in stem biomass and the rest in branches, foliage, stumps and roots. An estimate of the contribution this resource to the energy market needs an accurate assumption about future harvest level. The biomass flow to the energy industry has so far been dependent on harvest levels set by the demand from the forest industry and a silvicultural norm where harvest levels is lower than the annual growth. It is therefore likely to assume that forest owners in Sweden during the coming decades will act as previously, however, higher or lower harvest levels can never be refuted.

The price on different forest assortments will be critical for the harvest level even though it is not directly ruled by a strictly business thinking. Some forest owners look upon their property as an index-linked heritage for the next family generation. In a *"business as usual"* future scenario where harvest levels are kept on the same level as today the annual cut will be around 80 million cubic meters, leaving a biomass resource of logging residues (branches, foliage, stumps and root) corresponding to roughly 430 PJ in the forest. The energy content in the stem-wood is already today fully utilized and roughly 30 PJ of branches is already on the market while stumps only are harvested on an experimental level. Thus, a rough estimate with this scenario shows that there is an additional 400 PJ out in the forest that is physically available after harvest.

The physically available potential constitutes the absolute amount that is out there and the amount that shows up on the market will be considerably less depending on a number of constrains:

- The technical potential is set by technical restrictions, many times linked to the economic potential. That is to say that current technology and logistics sets a limit for the amount of biomass that is realized on the energy market. The development potential in current technology for logging residue harvest is however large as essentially all technical development in forestry has been focused on stem-wood harvest. Today, when biomass in logging residues and small diameter trees has a commercial value there is a lot of development to be done.

- The ecological potential is connected with forest values that foresters in Sweden are expected to consider, namely, biodiversity, long-term site productivity, impact on forest soils and thereby downstream effects on ground and surface waters. The ecological potential is directly influenced by the Swedish environmental and forestry acts together with criteria and indicators that are agreed upon within the certified forestry. Most forestry in Sweden is certified today with Forest Stewardship Council (FSC) and Program for the Endorsement of Forest Certification (PEFC) as the dominating certifying bodies.

- The level of the social potential is set by the public attitudes on the acceptable exploitation of biomass from our forests. This includes alternate land use such as, hunting, mushroom and berry picking and other out-door activities as well as rein-deer herding and protection of cultural and ancient remains in the forests. Part of this is regulated in the cultural heritage, forestry, and rein-deer herding acts.

- The economic potential is basically ruled by the price for biomass for energy purposes and how this relates to the procurement cost from the forest to the end-user. But, as a lot of the forest biomass flows for energy goes through the forest industry, the economic potential is set by the price for pulp-wood and saw-timber and thereby the profitability in that industry. Other important factors are how private forest owners value their property and what they expect from it in terms of profit or other values.

All these factors need to be considered to forecast future biomass potential from the Swedish forests. As all factors are more or less moving targets this proves difficult, thus, different studies end up with different amounts. One example is an estimate from SUAS 1998, that after considering a number of restrictions ended up with an annual logging residue potential (excluding stumps and roots) of 115 PJ whereas an estimate from the Swedish Forest Industries Federation in 2005 ended up with 54 PJ per year.

In addition to logging residues other biomass sources are available in the forests, namely small diameter trees and a larger part of the stem-wood where the price relation between biomass for energy and pulp-wood may alter the minimum top diameter for pulp-wood so that more of the upper stem-wood goes to the energy industry. With respect to this the energy industry has an advantage as the average transport distance from the forest to the heating plant is shorter than to the pulp- and/or paper plant. How much biomass that will be added from these sources depends on the same factors as other biomass and adds uncertainty to the estimates.

In the long-term (50-100 yrs) the supply of woody biomass can be altered through measures that increase forest production. A rule of thumb here is that small, relatively cheap and non controversial measures over large areas gives more than large, costly and controversial measures on limited areas. The knowledge how to increase production is already at hand, but to include this in estimates of future biomass supply remains a play with figures as long as there is no action among the forest owners.

To assure large deliveries of nutrient rich biomass as logging residues, small diameter trees and stumps the profit for the forest owner has to be high enough to compensate for potential future production losses due to the nutrient loss or the cost for a fertilizer to avoid that. A changed silvicultural practice in the young forest to get more biomass from small diameter trees requires development of the technology to harvest small diameter trees.

Investments in the next forest generation is built upon a conviction that the bioenergy market together with the forest industry market will continue to be strong in a long time perspective (50-100 yrs). As the major part of the income for a forest owner comes from saw timber new silvicultural practices focusing on high biomass production in combination with high quality timber production have the prerequisite to attract forest owners.

The biomass potential from the agricultural sector in Sweden has been has been reported in a governmental report (SOU 2007:36, in Swedish). The report shows that the agricultural sector delivered biomass corresponding to 5 PJ in 2005, corresponding to 1 % of the total amount of biomass supplied. A wider perspective on the agricultural biomass potential in Sweden lies in the energy content in the whole production, i.e. food and residues, that sum up to 290 PJ with 108 PJ in residues. The energy input in that production was primarily fossil fuels corresponding to approximately 20 PJ.

More of the residues from agriculture can of course be used and part of the agricultural production may switch towards energy crops if it becomes economically competitive with other crops. Furthermore, there are potential agricultural land under fallow that may be used in the future.

A number of estimates of the biomass potential from agriculture in Sweden have been conducted throughout the years with large differences between estimates. One explanation for that is that the estimates to a large extent are built upon assumptions about biomass that is not grown yet. Therefore, assumptions about the proportion and location of land and what kind of energy crops that will be used for energy production will have a major impact on the results. On top of that agricultural politics and regulations within the European Union and the large number of farmers do not diminish the uncertainty in these assumptions.

The report also analyzed the biomass potential from agriculture given different management control measures favoring energy crops and the reduction in production cost that will be needed to be competitive on the energy market. The conclusion from that analysis was that the contribution from agriculture will be limited and that the conversion of the energy system towards more renewable energy sources to a large extent has to be solved with other sources.

Sweden has 1.6 % of the global peat resources that could be used in the conversion of the energy system. But, despite the fact that electricity produced with peat in approved combined heat and power plants entitles to electricity certificates, the peat industry in Sweden is under pressure. The reason is that peat together with coal is taxed with a sulphur tax and that peat is treated as a fossil fule with the same emission factor as coal on the carbon trade market.

The emission factor for peat will have a decisive influence on the role peat will have on the energy market. Finland argues that peat should be classified as a "slowly renewable biomass" as peat accumulates on most peat-lands.

In Sweden the focus has switched from large, principally open mires towards peat-lands that could be expected to emit more green-house gases (GHG) than they sequester. In that case it could be an advantage to harvest and use the energy in the peat.

Peat-lands with a negative GHG-balance could be peat-lands drained for forestry or agriculture and already ditched peat mines. An estimate shows that 7.4 milliard cubic meters of peat corresponding to 27 000 PJ is potentially available in Sweden on such land. Part of that may be realized on the market if the classification of peat is changed. Support for this comes from the International Panel of Climate Change (IPCC) that has moved peat from "other fossil fuels" to the new class "peat".

Import of biomass is another possibility to satisfy a growing Swedish market, but it is likely that the market within the European Union will be hot as a consequence of the 2020 commitments of the member states.

Russia and Canada have large forest resources with potential to deliver biomass to the global market. As a result of extensive forest die-back and hard times for the forest industry in Canada the conditions for export of forest biomass for energy purposes is there. The situation in Russia is more uncertain due to weak infrastructure, lack of capital and forestry competence together with a protectionistic view on raw material from the forest recently manifested with custom duties on exported round-wood.

Finally there is a future global market potential if larger land areas will be used for fast growing energy crops in countries with a climate securing high and sustainable biomass production. The highest potential is found in Latin America and Africa.

Introduction

The energy market in Sweden, Europe, and the world is under change driven by political resolutions with the aim for a change towards:

- A larger proportion renewable energy sources
- Climate neutral energy sources
- A higher degree of self-sufficiency
- A more energy efficient society

In Sweden a large proportion of this conversion of the energy system will be based on sustainable, renewable biomass from forestry and agriculture. To make vice decisions as bioenergy supplier knowledge about factors controlling the amount of biomass that will reach the market in the short- and long-term on a local, national, and global scale is crucial. This report is intended for civil servants in the energy sector responsible for the supply of biomass with the Swedish market situation as an example.

The idea is that the report should be used as a tool to increase the competence through which the target group gets a better understanding about important factors controlling how much of potentially available biomass that will be available for the energy industry. Important is to understand the difference between physically available biomass and the market available biomass, what might control that and factors that might change physiologically available biomass in the short- and long term. With Sweden as the example focus will be on forest biomass as it totally dominates the market and will do so also in the future.

The Swedish Energy Agency publishes annual statistics showing energy supply and use in Sweden and the world (Anon. 2007). Figure 1 and 2 shows that the energy supply and use shows a steady increase since 1970 up until today – but during the same period the proportion of fossil fuels have decreased. This was made possible through the introduction of nuclear power during the 1970: s and more recently through the introduction of biomass.

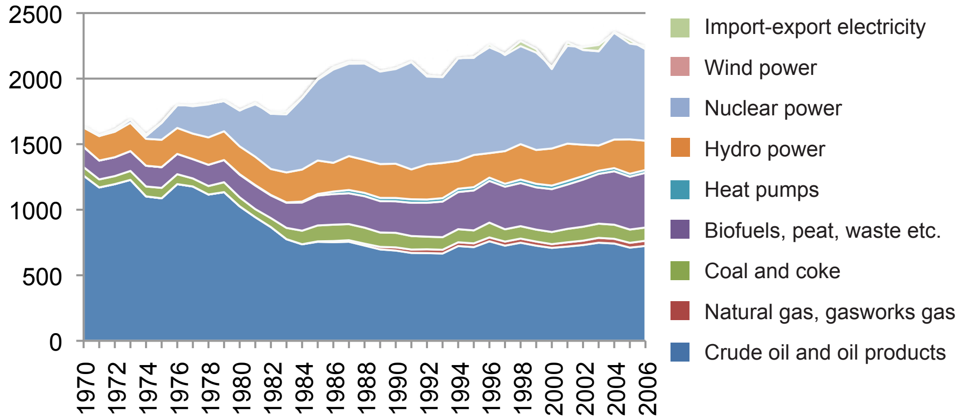


Figure 1. Total energy supply in Sweden 1970-2006 (PJ). Source: SCB, Swedish Energy Agency.

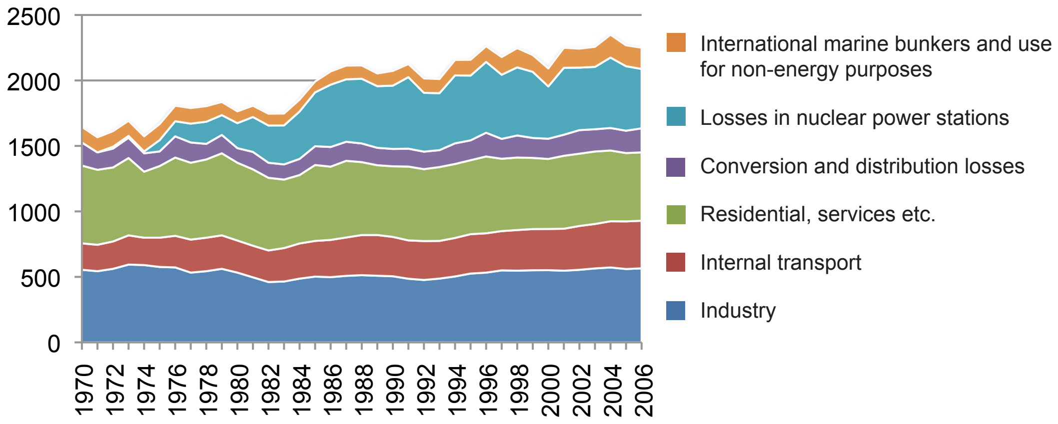


Figure 2. Total energy use in Sweden 1970-2006 (PJ) Source: SCB, Swedish Energy Agency.

When it comes to increasing demand Sweden is not different compared to from the rest of the world, but globally the energy supply is by far dominated by fossil fuels with oil as the number one source (figure 3). The proportion of renewable energy sources today is 13 %, with large variations between regions and countries depending on the conditions in the area.

Based on the energy supply (figure 1) the proportion of renewable energy sources in Sweden reached 29 % in 2006 out of which 19 % were biomass (including peat and refuse). Corresponding figure based on the energy use end up on 40 and 26 % respectively.

The biomass proportion correspond to 418 PJ with 202 PJ used in the industry (predominantly the forest industry) and 151 PJ in district heating (figure 4, 5). The remaining 65 PJ was used in individual houses (fire-wood, pellets and briquettes) and as biofuels (with a large proportion of imported biofuels, i.e ethanol from Brazil).

The figure clearly shows that biomass from forestry by far dominate as a source in Sweden. Only refuse (30 PJ in 2006) and peat (7 PJ in 2006) is visible in the graphs while biomass from agricultural land still represents a small proportion of the supply with approximately 3.5 PJ excluding Salix (0.5 PJ) that is included in wood-fuels.

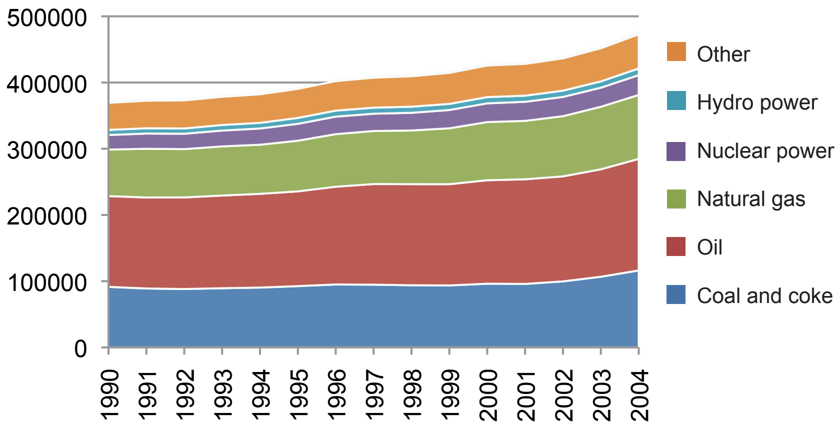


Figure 3. Global supply of primary energy 1990-2004 (PJ). Biomass for energy has a fairly large proportion of ”others”. Source: IEA Energy balance of non OECD countries, 2006. IEA Energy Balance of OECD Countries, 2007. BP Statistical Review of World Energy 2007.

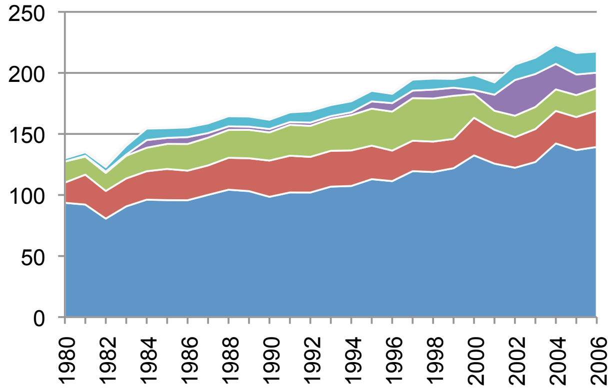


Figure 4. The use of biomass and peat in industry 1980-2006 (PJ) Source: SCB, Swedish Energy Agency.

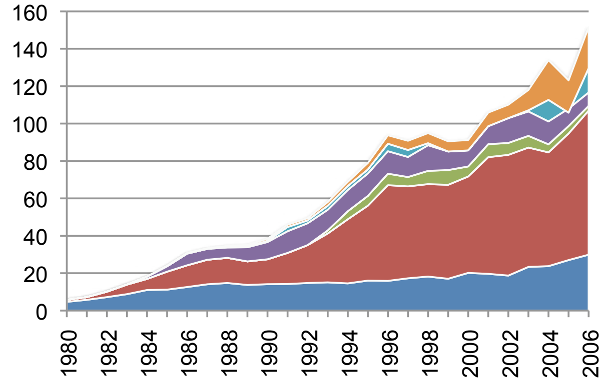


Figure 5. The use of biomass and peat in district heating 1980-2006 (PJ). Source: SCB, Swedish Energy Agency.

The use of wood-fuel in individual houses has been relatively constant for long – particularly on the countryside. Lately the market has grown slightly together with an increased number of stoves and heaters offered for sale. At the same time the use of pellet-burners has increased (figure 6). Out of the total use of pellets in 2006, corresponding to 29 PJ, 3.5 PJ was imported.

The sector where biomass still is small is within the transport sector where fossil fuels still dominate. But also here there has been a relatively large increase during the 20th century, though from a low level (figure 7). Political instruments favoring green cars have a part in this development. It is also possible to distinguish an increase in the use of FAME (Fatty Acid Methyl Ester Fuels) as a result of a decision in August 2006 to permit 5 % FAME admixture in diesel. At the end of the year over 60 5 of the diesel in the country had that admixture.

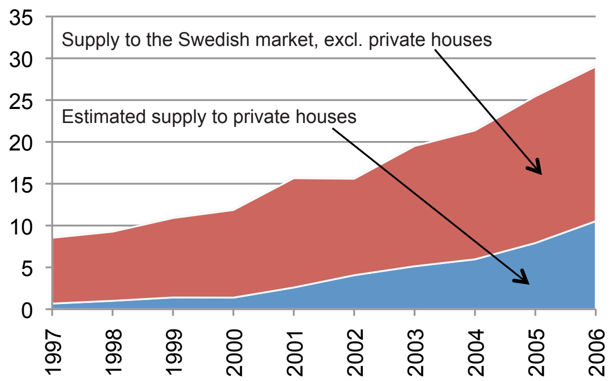


Figure 6. Supply of pellets to the Swedish maket 1997-2006 (PJ). Source: Swedish Association of Pellet Producers (PIR).

The route concerning renewable energy in the transport sector will determine how the market for biomass will develop in the future. If the route is a large proportion of biofuels based on renewable biomass this will have a major impact on the biomass market in the country and in the world even though the energy efficiency in the transport sector will be extensively improved.

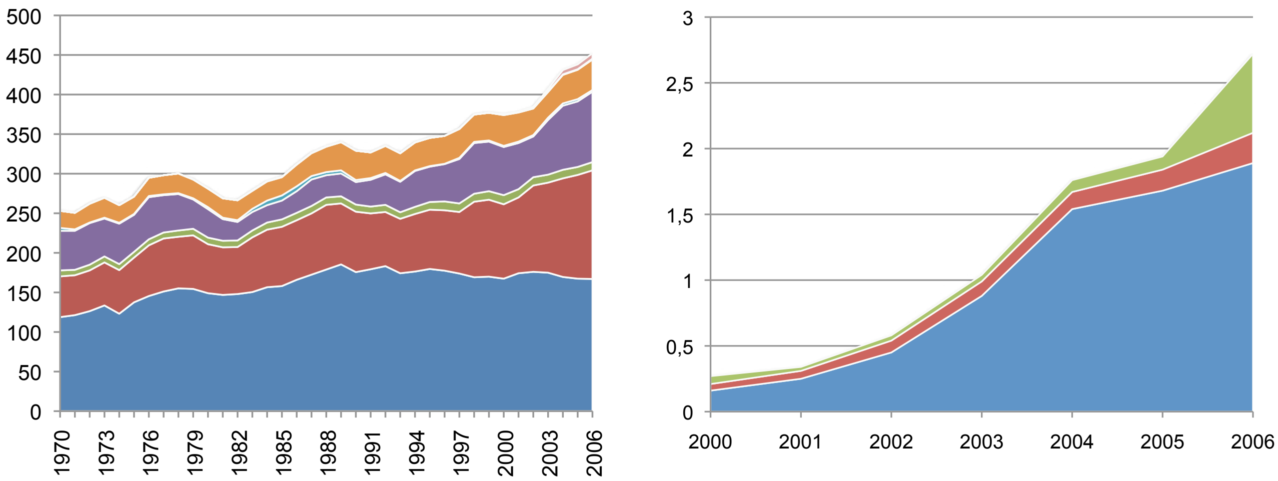


Figure 7. Total energy use in the transport sector 1970-2006 and the amount of renewale biofuels used in Sweden 2000-2006 (PJ). Source: SCB, Swedish Energy Agency, Swedish Gas Association.

Ethanol
Natural gas, including LPG
Aviation fuels etc
Medium / heavy fuel oils
Bunkers oils
Electricity
Diesel / gas oil
Petrol
FAME
Biogas
Ethanol

Over a longer time span the average increase in the use biomass in Sweden has been around 7 PJ (figure 8). This is partly due to an increased production and need for process energy in the forest industry, but since the mid 1980s and onwards district heating in combined heat and power plants is responsible for a lot of the increase (cf. figure 4, 5).

This has made Sweden one of the leading countries when it comes to the use of bioenergy. The preconditions for bioenergy is particularly favorable in Sweden as the country is sparsely populated, with a large forest resource, a well developed forest industry where a lot of the bioenergy is used and a well developed grid for district heating.

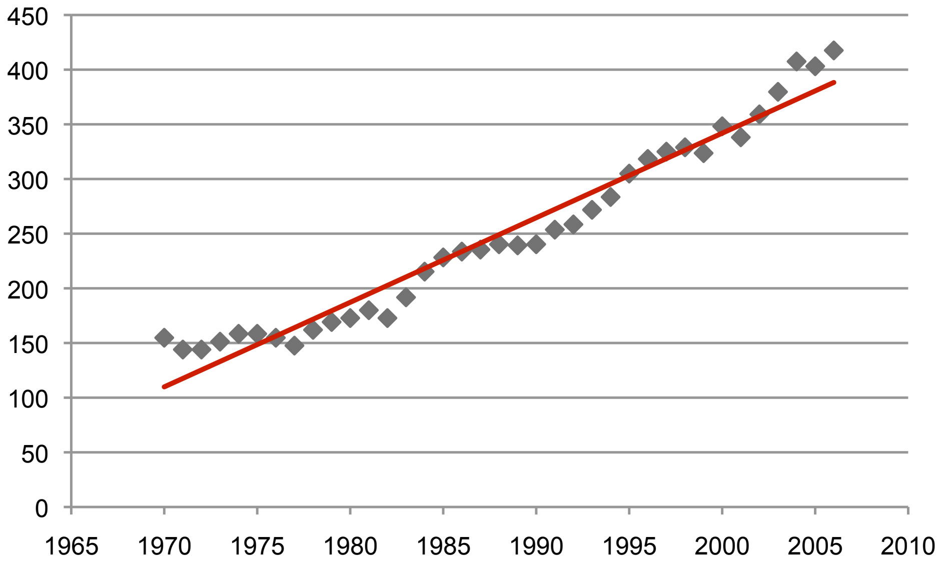


Figure 8. Total supply of biomass, peat and refuse 1970-2006 (PJ). The regresson line indicates an annual growth of 7 PJ. Source: SCB, Swedish Energy Agency.

The harsh climate creates a heat sink that directly can use biomass from our forests where it is simple – namely to give heat in houses. On top of that comes political decisions and instruments to stimulate the use of renewable energy sources like the carbon tax that was introduced in 1991.

The EU Commission has put up targets for the use of renewable energy and decrease in CO_2-emissions within the union that the member states have agreed upon. Common targets for the union until 2020 are to reach:

- 20 % renewable energy sources
- 20 % lover CO_2 emissions compared to 1990
- 10 % of the fuels from renewable sources

The targets are to be reached through a conversion of current energy system and energy efficiency means. The distribution of the burden among the member states, based on the economy and conditions for renewable energy in individual countries, was presented by the Commission on January 23, 2008. Sweden is to increase the proportion of renewable from currently 40 % up to 49 % (based on the energy use) and reduce its CO_2 emissions with 17 % compared with the level 2005 until year 2020. Furthermore, the commission stated that biofuels based on ligno-cellulosic feed stock will be given a favored position compared with biofuels based on agricultural crops.

Percent figures are always difficult to interpret. Looking back makes it easier. The 9 % increase in renewables that Sweden is to reach before 2020 is the same increase as has been achieved during 1983-2006, i.e. during 20 years. Now this is to be accomplished during 13 years at the same time as many of the low hanging fruits already are picked – namely the use of forest industry residues and the broad introduction of district heating. To achieve this a hot market for biomass in Sweden and Europe is to be expected at the same time as all possibilities for solar, wind, wave and hydro power has to be included together with substantial energy efficiency in all sectors.

Heating of houses with biomass from the forest together with demands from the EU Commission to increase the proportion of renewable energy will create a hotter market for biomass in Sweden. Photo: Kristina Ulvcrona

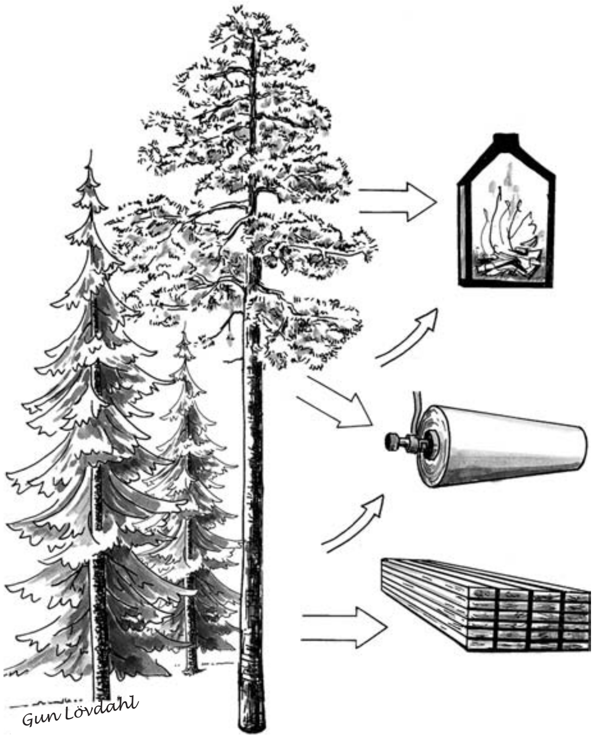
With these partly new circumstances and a forest industry having concerns about both the availability and price of round wood and energy the Swedish bioenergy market is further scrutinized.

Biofuels based on ligno-cellulosic feed stock has been given a favored position in the new EU-directive promoting the use of renewable energy within the union. Photo: Ivar Palo

The biomass potential

From a previous surplus of biomass on the Sweden market there is a potential risk for shortage in the future. Decisions about more investments in combined heat and power plants are already taken and research on the second generation biofuels (biofuels based on lingo-cellulosic feed stock) continues. The new 2020 targets within EU together with a break trough for the second generation biofuels can make a hot market red-hot.

In the short-term this market then has to be saturated by using existing biomass resources as far as possible or through import. In the long-term a higher biomass production is needed. On the other hand new energy technology or changed energy policy can change things fast by reducing the call for more biomass. There is however reason to believe that biomass-based energy technology will get much attention in the foreseeable future.



Forests

Historically the forests in large parts of Sweden were mined for a growing timber export market without any silvicultural measures to establish a new forest. Due to this the growing stock in Sweden went down. More than 100 years ago a forest restoration program, with the goal to increase the growing stock as a wood supply for a growing indigenous forest industry, started. This is also reflected in the first forest act from 1904 with the main objective to secure reforestation and thereby a future availability of raw material in the country.

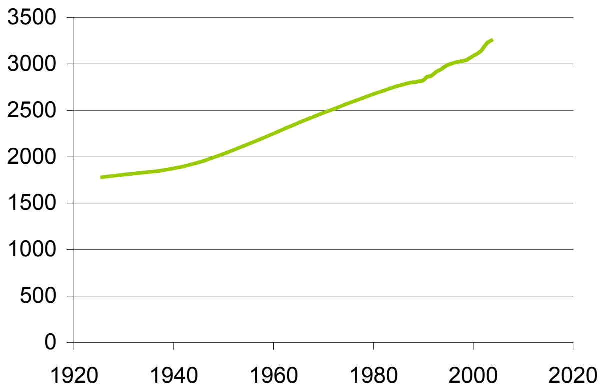


Figure 9. Standing stock (stem-wood only) development in Sweden from the mid 1920s up until today (million m³). Source: National Forest Inventory, Swedish University of Agricultural Sciences.

Available statistics from the National Forest Inventory from 1923 and onwards show that the restoration has been a success (figure 9). In the middle of the 1920s the growing stock was 1 760 million cubic meters, and today it is over 3 000 million. This equals a more than 80 % increase. The rising curve has been achieved through annual harvest levels that have been lower than the annual growth during most of the years.

It is out of this supply – built during a century – we now harvest biomass for the forest and energy industry in the country. There is more out there than current harvest levels. But the production oriented silviculture that built the supply is challenged today by other important forest values that have been neglected during many years. These other values have received much attention during the last decades and influenced the current forestry act that more clearly stress the importance of sustaining these values over time. This will have an impact on the supply of raw material from our forests. Among values that forestry is expected to consider today are:

- Biodiversity
- Social values
  - open-air activities
  - tourism
  - rein-deer herding
- Ancient and cultural remains
- Water quality

One important lesson from this historical description is that it has taken time to build up the growing stock that today allows us to have higher harvest levels. In the short-term (10-20 yrs) the physical harvest potential is set by the growing stock and growth rate of the forest we already have.

The physical potential is then the total biomass found in trees (stem-wood, branches, foliage, roots). All of this biomass is of course not available. The amount that shows up on the market depends on a number of factors. Figure 10 describes this in a principal way where the physical potential is the roof and the amount of biomass realized on the market is essentially lower due to a number of restrictions.

The technical potential is controlled by technical restrictions that often are linked with economical restrictions. This is to say that current technology and logistics in procurement of biomass from the forests sets the limit for profitable biomass. There is however a large improvement potential in current technology as most of the technical development in forestry has been based on a forestry delivering stem-wood to the forest industry. Today when branches, tops, stumps, and small diameter trees has a commercial value there is a lot of improvements to be made.

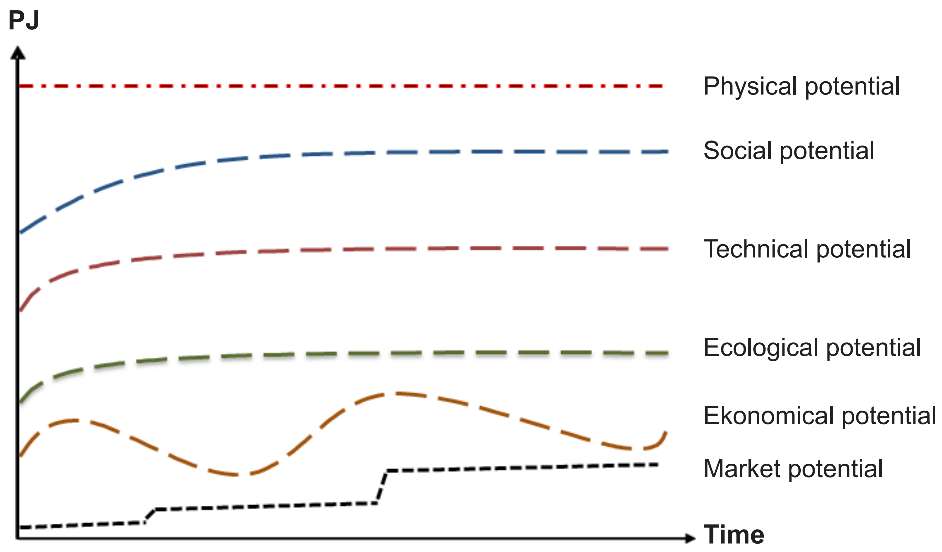


Figure 10. Schematic figure illustrating how the practically realized biomass potential relates to the physical maximum potential over time.

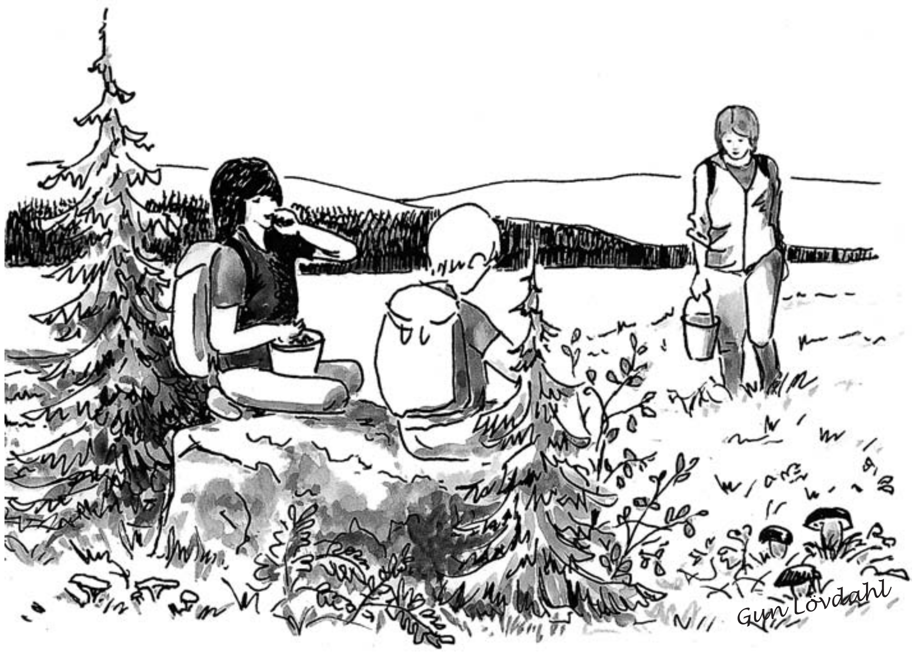
The ecological potential is linked to values that foresters are expected to consider in their daily work, namely biodiversity, long-term site productivity, effects on soil and its indirect effect on ground and surface waters. The ecological potential is also directly affected by the environmental act and the forestry act as well as certifying criteria for the certified part of our forests. This comprise the largest part of our forests certified by either Forest Stewardship Council (FSC) or the Program for the Endorsement of Forest Certification (PEFC).

The level of the socially acceptable potential is among other things set by the public opinion on reasonable exploitation of biomass from the forest. Limits are set by alternative land use like rein-deer herding, hunting, mushroom and berry picking, and other open-air activities in the forest together with protection of ancient remains in the forest. Part of this is regulated in the ancient remain act, forestry act, and rein-deer herding act.

The economical potential is basically ruled by the price for biomass and how this relates to the biomass procurement cost. But the economical potential is also dependent on the profitability and market in the forest industry as a large quantity of the biomass for energy goes through the forest industry where both the amount of logging residues and forest industry residues depends on the market situation in that industry. Other important factors are how private forest owners look upon their forest and what they expect to get from it in terms of money and other values. For instance, some private forest owners see their forest as a value secured property that they wish to leave for their children and they do not intend to harvest much.

This is described in figure 10 where the physical potential stays at a given level relevant for the short-term (10-20 yrs). In longer term there are possibilities to increase the production in our forests – but this will only happen if it is considered a profitable investment for the forest owners.

With this complex picture in mind we will try to look on the conditions for an increased supply of forest biomass on the Swedish bioenergy market.



Potential

The biomass distribution in a tree is to some extent tree size dependent where the proportion stem-wood increases with size. It is also tree species dependent with Norway spruce having more biomass in branches and needles compared with Scots pine. This, together with the fact that Norway spruce usually is found on more fertile sites, giving a larger growing stock, is the reason why spruce dominated stands are more attractive for extracting logging residues (branches and tops) for energy purposes today.

Estimates of biomass in trees are based on allometric functions based on field sampling and measurements of different tree compartments on trees. Photo: Gunnar Karlsson

Based on biomass functions for our two by far most common tree species, Norway spruce and Scots pine, figure 11 shows the relative proportion of biomass in different tree compartments with increasing tree size. The figure shows that branches, top and stump together constitute a relatively large proportion of the total tree biomass. Biomass that traditionally was left in the forest when stem-wood was harvested for the forest industry. Here we have a resource, however, dependent on the round-wood harvest levels.

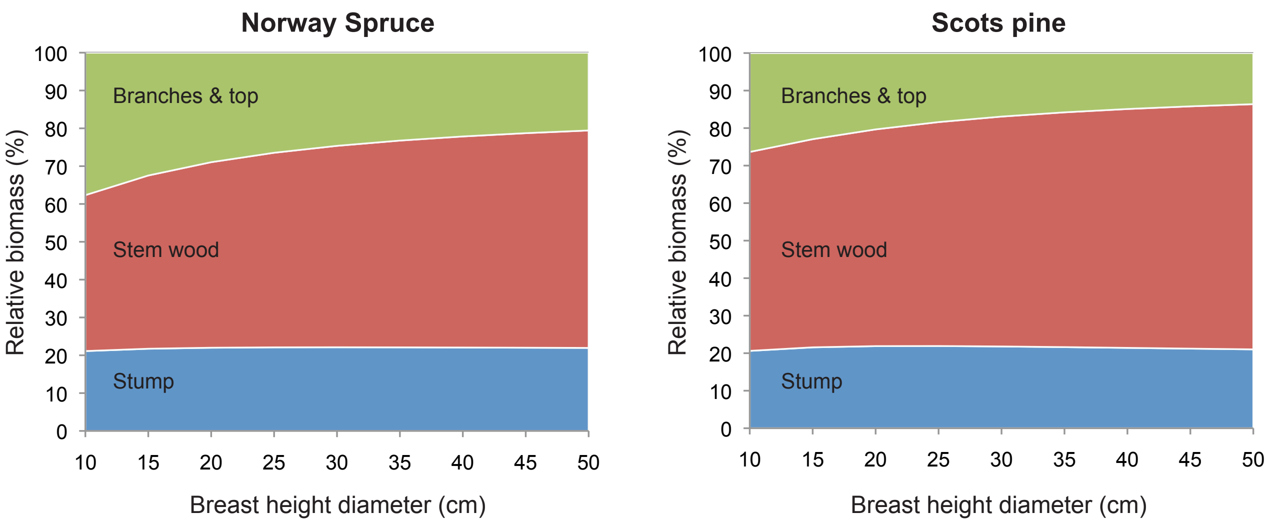


Figure 11. Proportion (%) of biomass in stem-wood, branches & top, and stump including coarse roots with increasing stem diameter in breast height (1.3 m above ground) in Norway spruce and Scots pine, according to biomass functions (Marklund 1988).

With this knowledge we can make simple estimates of the physically available amount of logging residue biomass that is available in the Swedish forest. The growing stock in Sweden is totally dominated by Scots pine (38 %) and Norway spruce (40 %). The average biomass proportion in logging residues for the two tree species is around 22 % for stumps and 21 % for branches and tops (cf. figure 11).

The growing stock built during a century of targeted silviculture (cf. figure 9) is 3233 million cubic meters of stem wood (including the top). With an assumed density of 400 kg per cubic meter this ends up to 1293 million ton of dry biomass that after a reduction for tops left in the forest (5 %) ends up to 1229 ton stem-wood biomass. To that we can add another 917 million tons of logging residues in branches and tops (446) and stumps (471). In total this is 2146 million tons of dry biomass standing there in the forest.

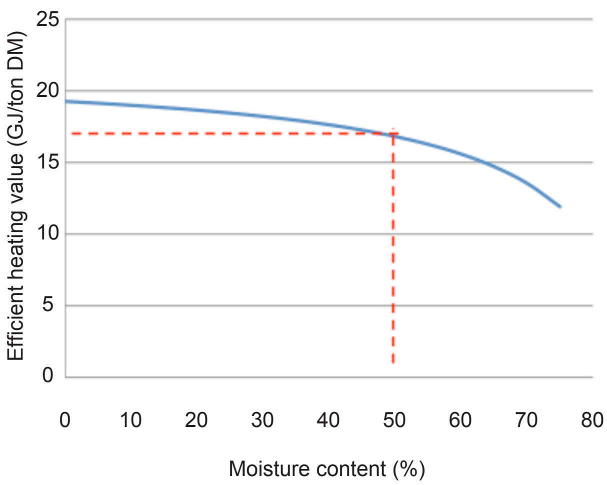


Figure 12. Efficient heating value per ton dry biomass at increasing moisture content based on a gross calorific value of 20.6 MJ per kg biomass. Dashed line shows the energy content at 50 % moisture content.

The energy content in forest biomass depends on the moisture content. Let us assume that the forest biomass has an average moisture content of 50 %. This gives us an efficient heating value around 16.8 GJ per ton dry matter (figure 12), and 36 310 PJ standing in the forests with 20 794 in stem-wood, 7 546 in branches and tops, and 7970 in stumps.

Out of this standing stock a certain quantity is harvested annually with fluctuations depending on price and the overall economy – but also the economy of the forest owner has an impact. Primarily it is the demand from the forest industry that effects harvest levels – but the energy industry has the potential to be an important player to in the future. Looking back annual cut has rarely been higher than the annual growth – thereby the standing stock has increased (cf. figure 9).

What kind of timber and biomass flow should we expect from our forests in the future? Regularly the future Swedish forest resource is analyzed assuming altering management and silvicultural treatments. The base for these analyses is the accurate information about our forests that the national forest inventory gives us. These analyses can be used to estimate the amount of logging residues that will be physically available after future harvest operations. A reasonable assumption in such an estimate is that forestry during the next decades will continue as today – a "business as usual" scenario.

One scenario in the last national assessment (SKA 99) was called "forestry of the 1990s" – that is more or less a "business as usual" scenario. Figure 13 shows how much round wood that would be harvested annually in that scenario. The differences between 10-year periods depend on the structure of the forests we have today and how it will develop according to the models used.

With the same assumption as above the energy potential in logging residues at these harvest levels can be estimated. Figure 14 shows the result of such a calculation with an overall annual potential of more than 430 PJ physically available after logging operations.

A part of this potential in branches and tops is already today available on the Swedish market, whereas the stumps are more or less untouched. Approximately 25-30 PJ is already utilized, thus the increase potential is slightly less than 430 PJ – but still around 400 PJ. And the potential is there even if the annual cut is less than the annual growth – thus, the standing stock will still increase. This shows that there is plenty of room for a further expansion of the bioenergy sector in Sweden. But there are reasons not to build that expansion on the total physically available resource in the forest.

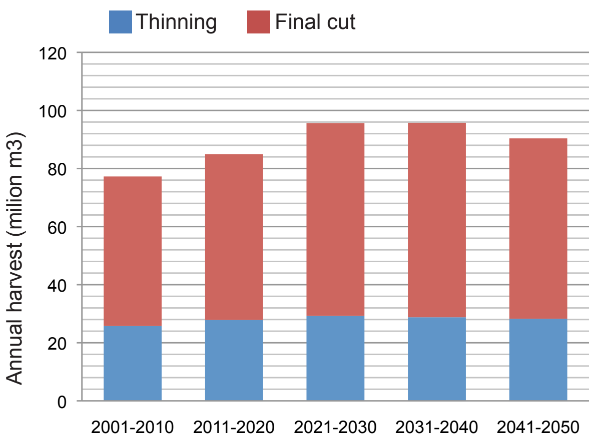


Figure 13. Average annual stem-wood harvest (million cubic meters) in thinning and final cut for10-yr-periods until 2050 with a "Business as usual" scenario" (SKA 99 Swedish University of Agricultural Sciences).

During conventional stem-wood harvest large amounts of energy bound into logging residues are left at site. Today more and more of this resource is utilized. The picture showing a forwarder transporting logging residues. Photo: Ola Lindroos

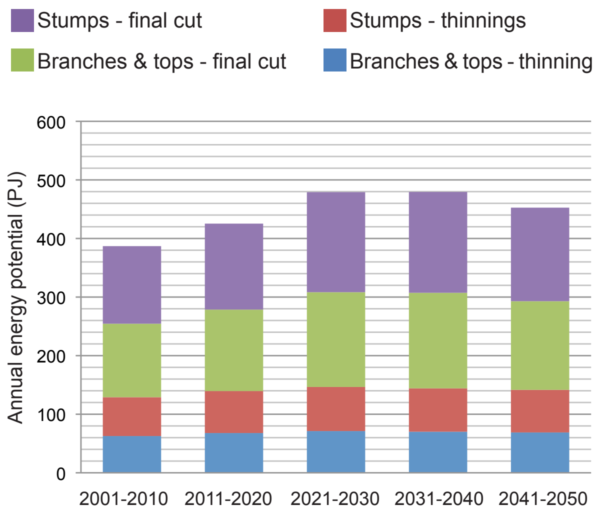


Figure 14. Average annual energy potential for 10-yr-periods until 2050 in logging residues available after logging operations based on a "business as usual" scenario (SKA 99, Swedish University of Agricultural Sciences).

If we look back on figure 10 showing that the market potential is likely to end up far beyond the physical potential. And then on figure 14 and the assortment that hardly exist on the Swedish market yet – namely stumps. Overall average physical stump potential ends up around 227 PJ.

From this 70 PJ that falls out in thinning can be removed. The small stump volumes that falls out in thinning, and the fact that there are remaining trees at the site makes it technically and economically difficult and thereby not profitable. The risk for root and stem damages on the remaining trees also makes it unsuitable from a silvicultural point of view. The only reasonable possibility to get some of the stumps out in thinning is that the harvesting technology develops in a direction that harvest more of the stump biomass together with the stem-wood.

Still there is on average 155 PJ in stump biomass physically available after final cut. There is a recent interest in this potential from forestry in Sweden and the Swedish forest agency has demanded an environmental impact assessment study before stump harvest will be allowed at any scale.

Current knowledge on effects of stump harvest on biodiversity, soil, ground water, surface waters, carbon balance and site productivity has been compiled in a report (Egnell et al. 2007). Apart from environmental consideration social aspects also needs to be considered.

The major limiting factor for stump harvest is difficult to judge with current knowledge – however, biodiversity is a strong candidate. We do know that a large proportion of the threatened forest species in Sweden in some way or the other is dependent on coarse woody debris where stumps following harvest constitute a large proportion today. Many broad leaved species are highlighted as particularly important for biodiversity suggesting that all stumps from broad leaves should be left in the forest. Such a restriction means that another 32 PJ will be left in the forest leaving us with 122 PJ.

Harvested stumps. Photo: Gustaf Egnell

To promote biodiversity it is common practice to leave a number of dead and living trees at harvest. It is unsuitable to harvest stumps close to those trees as it may damage them or jeopardize their stability. Soils with low bearing capacity may be difficult to stump-harvest without causing physical damages to the soil with increased risk for erosion and particle flows out into surface waters. Technical problems will also occur in slopes or at sites with a lot of boulders.

As stump-harvest with current technology leads to a soil disturbance stump-harvest is not suitable close to ancient remains scattered over the forest landscape and particularly not in areas with a high density of these remains. Finally stump-harvest is not suitable in areas important for rein-deer herding. How much all these physical, biological, and social factors will limit the potential is hard to judge today as a lot of experience and knowledge is lacking.

The annual physical potential in branches and tops averages on 216 PJ (cf. figure 14). Also the potential in branches and tops is limited by environmental criteria. However, the thin dead wood in branches and tops available at harvest is not as critical for biodiversity as it, trough weather and wind, is supplied regularly during a forest generation.

Stump-harvest. Photo: Dan Bergström

Technical loss of biomass during harvest operations is likely to be greater when branches and tops are harvested compared with stumps. Even with great effort it is difficult to get more than 80 % of the branch and top biomass. Not the least on soils with poor carrying capacity where some of the logging residues may be needed on the terrain road to avoid soil damages. Thus, compared with the input over a full rotation, the proportion of branch and top biomass that are harvested in thinnings and final cut is far less then for stumps where most of the supply comes at harvest (figure 15). But also when branches and tops are harvested it is recommended to leave some to promote biodiversity – particularly coarse parts and from less common tree species.

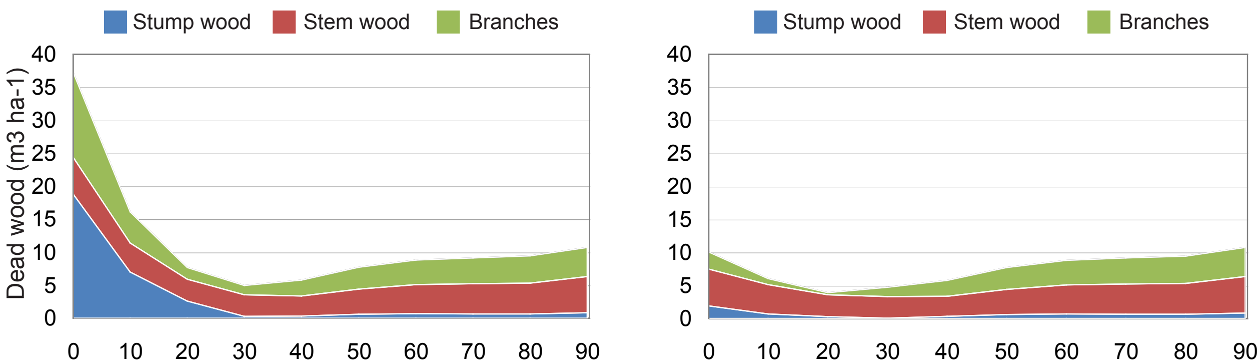


Figure 15. Schematic graph showing amount of dead wood at different forest age in a managed forest of average fertility directly after final cut and the next 90 years. In the left graph only stem-wood is harvested while also 90 % of the stump-wood and 80 % of branches and tops are harvested in the graph to the right (From Egnell et al. 2007).

One issue with branch and top harvest is that this fairly modest increase in biomass harvest increases the amount of nutrients that is harvested substantially (figure 16). This nutrient loss may lead to productivity losses for the forest owner. On Swedish forest soils this is particularly relevant when it comes to nitrogen removal. Productivity loss has also been shown in field experiments. This could make forest owners unwilling to deliver logging residues unless the price is high enough.

This is not a major problem in final cut. Here, any productivity loss in the next tree crop can be counteracted by speeding up the regeneration work. That is possible when logging residues, that otherwise constitute an impediment, are removed. Furthermore, site preparation and planting is simpler when the logging residues are removed. In thinning, however, the production loss is substantial – but it can be compensated for with a fertilizer. To make the forest owner satisfied, the income from the delivered biomass then has to cover for the money spent for fertilization.

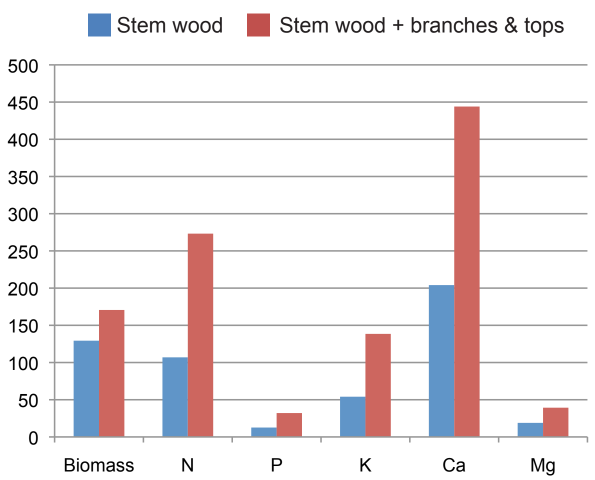


Figure 16. Biomass harvest (tonne/ha) and nutrient harvest (kg/ha) in whole-tree harvest (stem + branches & top) compared with conventional stem-wood harvest in final cut of a spruce dominated stand with a standing stock of 290 cubic meters. The figure shows that the moderate increase in biomass harvest is done at the expense of a substantial increase in nutrient harvest.

Another aspect on the nutrient loss is that the soil gets somewhat more acid. After the acidification debate we have had, mainly due to anthropogenic deposition of sulphur dioxide, some forest owners may hesitate to deliver biomass due to this and the Swedish forest agency recommends wood-ash recycling after harvesting logging residues to counteract the acidifying effect. Apart from adding a cost to the calculation for the spreading of ash, wood-ash can cause a further decrease in production on nitrogen-poor sites – particularly in northern Sweden. Those are all messages that a forest owner has to consider before deciding whether to deliver biomass or not.

Apart from regulations in a number of laws Sweden has expressed a political will to improve the environment by adopting sixteen environmental objectives:

1. Reduced Climate Impact
2. Clean Air
3. Natural Acidification Only
4. A Non-Toxic Environment
5. A Protective Ozone Layer
6. A Safe Radiation Environment
7. Zero Eutrophication
8. Flourishing Lakes and Streams
9. Good-Quality Groundwater
10. A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
11. Thriving Wetlands
12. Sustainable Forests
13. A Varied Agricultural Landscape
14. A Magnificent Mountain Landscape
15. A Good Built Environment
16. A Rich Diversity of Plant and Animal Life

Under these environmental objectives a number of goals have been specified. The objectives together with the goals supplies guidance when for instance authorities like the Swedish forest agency gives suggestions for the future forest policy and for any suggested changes in the Swedish forest act. Many of the environmental objectives are directly or indirectly affected by the ongoing conversion of the Swedish energy system, not the least the increased use of biomass for energy.

In the public debate "Reduced Climate Impact", that directly calls for the use of more renewable energy like biomass against other objectives like "Natural Acidification Only", "Sustainable Forests", or "A Rich Diversity of Plant and Animal Life". When it comes to "Sustainable Forests", the Swedish forest agency claims that more forest land needs to be set aside to reach the goals and this has been suggested to the government. At the same time forest companies refer to "Reduced Climate Impact" and claims that we cannot afford to set aside any more forest land. More information about the Swedish environmental goals can be found at www.miljomal.nu.

Over all these restrictions lies the profitability aspect on logging residue harvest. That is probably the strongest restriction controlling the biomass amounts that reach the market. The price for biomass is naturally crucial – but also the development of efficient technology and logistics to get the biomass from the forest to the end user.

Technical development in traditional forestry delivering stem-wood made these operations vary efficient. Now, when branches, stumps and small diameter trees adds as new assortments this technology does not fit. As biomass is a low priced commodity compared with timber the incentives to invest in technical development is limited. It is, however, likely that new more efficient systems for biomass harvest will be developed in the future. This is likely to increase the proportion of the physically available biomass that eventually reaches the market.

Technical and economical factors that control weather it is profitable or not to harvest stumps, branches or small diameter trees are among others:

- Size of the harvest site. The often smaller harvest sites in southern Sweden is often compensated by a higher standing stock and shorter transport distance.
- Standing volume (biomass) on the site. Generally the standing volume is higher in spruce dominated stands. The value of spruce dominated stands is further strengthen as spruce stumps normally is more easy to harvest and the proportion of branches is higher as compared to pine (cf. figure 11).
- Conditions for the terrain transport. Transport distance, soil bearing capacity, slope, boulders etc.
- Transport distance to the buyer/end consumer. The potential is scattered throughout the country while the market in most cases is found in urban areas. The vehicle is important here as boat transport is cheaper than train that is cheaper than truck.

In the potential estimations above we have had a national perspective. To make vice investment decisions the estimate has to be regionalized. As biomass is sensitive for long transport distances it is important to have good knowledge about current and future forest condition, silvicultural practices/activity, and competitors for the same biomass in the area. The size of the relevant area depends on the transport alternatives available. As soon as train, and even more so boat, is an option the size of the area expands lot at the same time as the number of potential competitors for the same biomass is likely to increase. Biomass on boat is a commodity for the global market.

With data from the National Forest Inventory a rough map showing where the most fertile forest soils, the largest proportion Norway spruce and the largest proportion silviculturally mature forests can be found. The largest biomass potential should be expected where the soils are fertile, spruce dominates, and the proportion of mature forests are high (figure 17). The figure shows that the spruce dominance is more pronounced in southern than in northern Sweden. Furthermore, these forests are located closer to the market.

Another factor that may have an influence on the market potential is the forest ownership where the harvest intensity may vary between categories. In total half of the forest land in Sweden is owned by private forest owners.

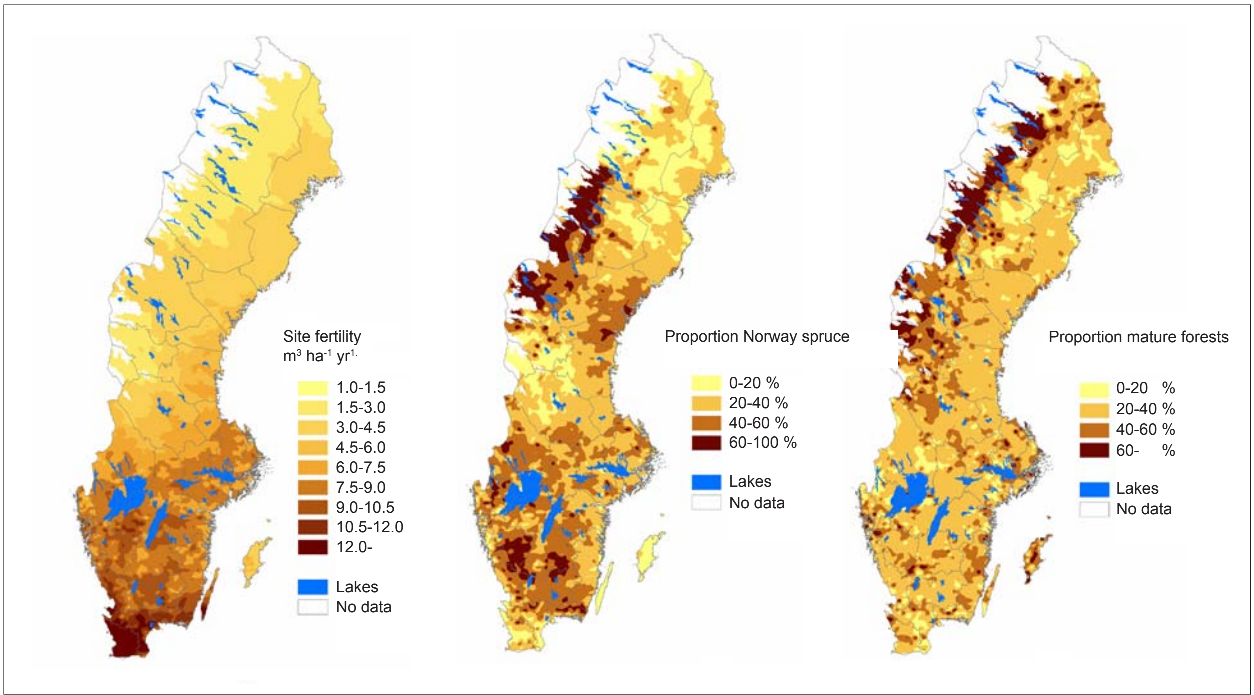


Figure 17. Site productivity (left), spruce proportion by volume (centre), and proportion mature forest stands in Sweden (right). Source: National Forest Inventory, Swedish University of Agricultural Sciences.

Table 1 shows the ownership pattern in the country. The general pattern is that the government and major forest companies dominate in the north whereas individual private forest owners dominate in the south. Within the private forest owners the activity in the forest varies a lot. From research we know that men are more active than women, younger and older forest owners are more active than middle aged, there is more activity among forest owners in southern than in northern Sweden and more activity on larger wood lots than on smaller. Thus, many private forest owners may value other things than the economical value of their property.

From this it becomes clear that it is not a simple task to estimate how much of the physical potential that will show up on the market. A number of estimates have, however, been conducted. The Swedish Forest Industries Federation (SFIF) came up with one in 2005 based on the four timber regions that are used by the national forest inventory (figure 18).

Table 1. Forest land (1 000 hectare) distributed after owner, province or part of the country 2007. Source: The Swedish Forest Agency.

Province or Region	**Govern-ment**	**Govern-mental company**	**Other public owners**	**Private companies**	**Private owners**	**The Swedish church**	**Other private owners**	**Unklnown owner**	**All owners**
Norrbottens	286	1 412	14	358	1 191	1	295	–	3 557
Västerbottens	147	751	29	756	1 275	–	139	–	3 097
Jämtlands	69	56	18	1 310	1 114	8	58	1	2 634
Västernorrlands	3	28	17	841	733	3	32	–	1 657
Gävleborgs	2	82	23	622	630	1	72	–	1 432
Dalarnas	89	203	29	624	783	1	257	–	1 986
Värmlands	4	12	22	463	760	4	40	–	1 305
Örebro	1	170	9	98	232	3	38	11	562
Västmanlands	2	75	11	43	144	1	27	–	303
Uppsala	13	9	6	175	222	–	55	–	480
Stockholms	9	7	16	40	164	1	39	–	276
Södermanlands	6	9	12	45	224	1	37	–	334
Östergötlands	7	46	8	123	367	1	61	–	613
Västra Götalands	14	57	38	48	939	2	71	–	1 169
Jönköpings	2	51	14	23	563	2	32	3	690
Kronobergs	3	60	11	19	466	1	32	–	592
Kalmar	3	76	11	38	565	–	24	1	718
Gotlands	2	–	1	5	106	–	10	–	124
Hallands	6	1	6	19	225	1	10	–	268
Blekinge	1	4	6	9	159	–	4	–	183
Skåne	2	13	8	30	276	1	21	–	351
North N Sweden	433	2 163	43	1 114	2 466	1	434	–	6 654
South N Sweden	74	166	58	2 773	2 477	12	162	1	5 723
Central Sweden	124	485	105	1 488	2 529	11	493	11	5 246
Southern Sweden	40	308	103	314	3 666	8	265	4	4 708
Whole country	671	3 122	309	5 689	11 138	32	1 354	16	22 331

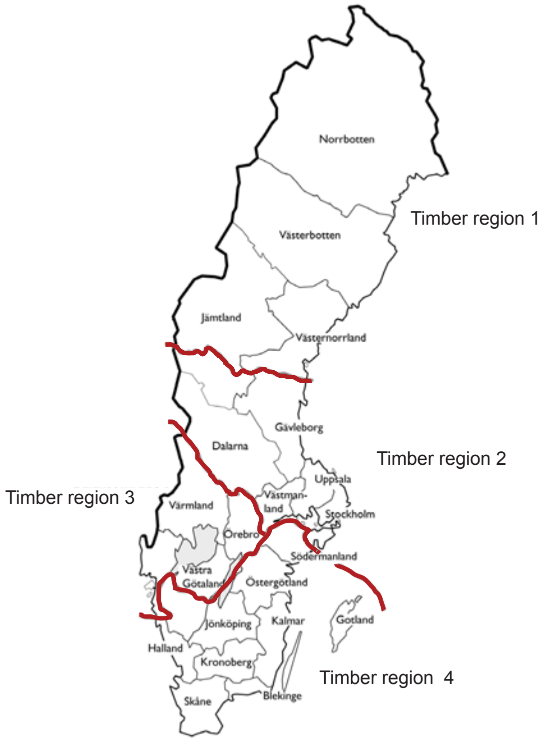


Figure 18. Map showing the four timber regions used by the national forest inventory.

The estimate, based on available data from the national forest inventory and questions to key people in the business, ended up with a market potential of 54 PJ in branches and tops, and 18 PJ in stumps. This should be compared with the estimates above showing a physical potential of 216 and 227 PJ, respectively, and the current harvest level around 30 PJ.

The potential in branches and tops was also presented for the four timber regions (cf. figure 18). This is shown in figure 19 together with the physical potential according to SKA 99 (according to the "forestry of the 1990s" scenario) and current market available biomass (harvest level). The SFIF estimates that 20-30 % of the physically available biomass in branches and tops has the potential to show up on the market with the lowest proportion in northern and the highest in southern Sweden.

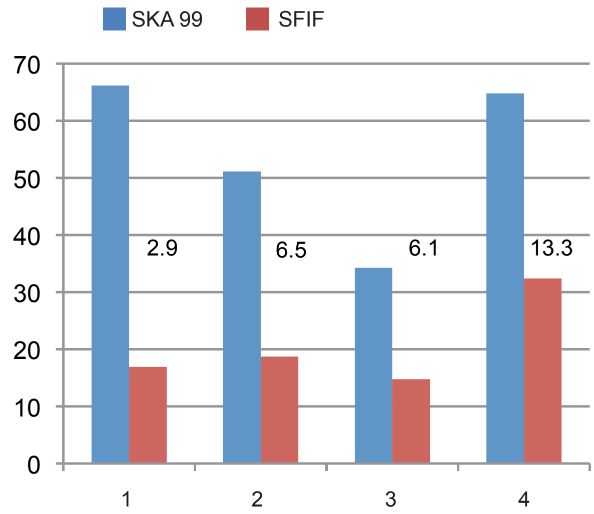


Figure 19. Physical biomass potential in branches and tops (PJ) for the four timber regions in Sweden according to SKA 99 ("forestry of the 1990s") and estimated market potential according to the Swedish Forest Industries Federation. Figurs above the bars indicates current amounts reaching the market.

The SFIF estimate is not the only one in Sweden and the difference between different estimates is often fairly large due to altering conditions and assumptions even though NFI data is used in most cases. The most often cited estimate was conducted by Lönner et al. in 1998. Based on an annual harvest level of 87 million cubic meter stem wood and a number of technical and ecological restrictions they estimated a market potential for branches and tops corresponding to 155 PJ. With additional economical restrictions the market potential was reduced to 115 PJ. That is twice as much as the SFIF estimate (54 PJ).

The "oil commission" led by Sweden's former prime minister Göran Persson estimated a market contribution from chopped fire wood, branches, tops and stumps could reach 72, 144 and 187 PJ by the years 2005, 2020 and 2050, respectively.

Small diameter trees harvested has a biomass potential in early thinnings. Photo: Gustaf Egnell

On top of branches, tops and stumps, there is a potential in small diameter trees that is not included in the estimates above. Traditionally pre-commercial thinning has been practiced in our forests to reduce the number of stems and put more growth on the trees left, thereby reaching commercial dimensions (pulpwood) faster. Today, with an energy market, these small stems cold be harvested as an energy assortment. One problem here is to make this harvest mechanized and thereby profitable.

The estimated annual potential in small diameter trees according to SKA 99 ("forestry of the 1990s") was 11 PJ with current pre-commercial thinning practices. Lönner et al. (1998) ended up on 8 PJ with an extended potential based on a trade-off of small diameter trees in thinning from the forest industry to the energy industry of 28 PJ. There is also an additional potential in technically damaged round wood and in woody biomass from non forest land.

More forest biomass could also show up on the market if a larger proportion of the biomass that traditionally ended up in the pulp and paper industry ended up directly at the energy industry. This is already the case in Sweden today where a proportion of the "pulp wood" goes directly to heat and power plants. The energy industry has an advantage here by being more evenly distributed over the country as compared to the pulp and paper industry, thus the transport distance is in average shorter to the energy industry.

Another trend is that the minimum top diameter on pulp wood increases, thus, more of the stem wood in the upper part of the trees goes with the top to the energy industry. Normally pulp wood goes down to a diameter around 5 cm. By increasing the top diameter you'll get an un-limbed stem that could be delivered directly to the energy industry. This opens for profitable deliveries even from thinning. En estimate in SKA 99 shows that the physical potential in tops would increases from 14 PJ to 60 PJ if the top diameter increases from 5 to 10 cm.

Long-term potential

The discussion above deals with the potential in the biomass we already have in our forests plus additional growth in our forests without any major efforts to change our forest management towards increased production. If society will be determined to increase forest productions and succeeds to convince forest owners that silvicultural practice to achieve that will be profitable the potential for increased growth is fairly high. Current forest policy trends tend to go in that direction at the moment.

It is also obvious that Sweden may end up in shortage of forest biomass to feed it's industries as the energy industry successively increases its demand at the same time as Russia has introduced export tax on round wood with a lower import flow from that area as a result. The latest forest proposition from the government from 2007 says that the increased forest growth is to be promoted within current forest policy and that promotion capacity towards that should be further developed within Swedish Forest Agency.

The knowledge about how to achieve increased growth is already at hand – but in many cases technology and logistics has to be further improved at the same time as long-term impact assessments concerning forest growth and environmental consequences of this increased intensity need to be performed. One important thing to remember is that it takes long time to increase forest growth in temperate and particularly boreal climates and that measures has to be performed on large areas to make a difference in due time. Estimates of the potential in different silvicultural means have been performed. Results from one such estimate is shown in (table 1) with a maximum increase of 42 % and a more probable increase around 20 % compared with today.

It is important to underline that this increase, due to the long rotation periods in forestry in Sweden, not is realized until 50-100 years. The main message in the report was that traditional silvicultural practices such as improved regeneration efforts and the use of improved seedling material has a higher impact on future forest production as they require small decisions and small investments for the forest owner and thereby has the potential to reach large areas. More spectacular measures with a larger growth effect is often more expensive for the forest owner and may require different kinds of environmental assessments before they are approved by authorities. Thereby, they will never reach large areas and have a major impact on the total potential. They may however be important on a local market.

Table 2. Increased growth or harvest potential (%) within 50-100 years through altering silvicultural practices compared with todays levels. Source: Rosvall, 2003.

Means	Total areaa %	Total area milli. hectar	Annual area 1000 hektar	Time to full area (yrs)	Potential increase milli. m^3	Potential max increase milli. m^3	Accuracy	Oncertainty in estimates	Plausible increase milli. m^3
Approved regeneration	20%	4.1	46	90	2.7		Medium	Low	1.5
Intensive regeneration	50%	10.4	115	90		6.2	Medium	High	2
Genetic improvement seed orchard	75%	15.5	173	90	8.3			Low	8
Genetic improvement clonal	75%	15.5	173	90		12.6		High	
Lodge-pole pine 15 000 ha	4%	0.9	15	60	2			Mediium	2
Lodge-pole pine 30 000 ha	9%	1.8	30	60		3.5		High	
Fertilization 60 000 ha	26%	5.4	60	90	1			Medium	1.5
Fertilization 220 000 ha	38%	7.8	220/87	90		3.5		High	
Sum					14	26			15
Clonal forestry	5%	1	23	45	1.3	1.3		High	0.5
Nutrient optimization, spruce	5%	1	18	45	3.7-5.9	4	Low	High	?
Spruce on farmland	3%	0.3	12	25	3.4			High	0.5
Aspen on farmland	3%	0.3	12	25	5.4			High	1
Ditch cleaning	4%	0.9	20/10	90		0.9	Medium	Medium	0.5
Ash recycling	1%	0.3	70	5		1	Medium	Medium	0.5
Sum						12			3
Ditching mist forests	4%	0.9			2	0		Very high	?
Ditching, peatlands	6%	1.3			4.1	0		Very high	?
Total increase milli. m^3						37			18
Total increase %						+ 42%			+ 20%

Farmland

The biomass potential from the agricultural sector in Sweden has been investigated recently and presented in a governmental report (SOU 2007:36) that gives a deeper understanding than what will be included here. Biomass from agriculture delivered biomass corresponding to 5.5 PJ in 2005. That is roughly 1 % of the energy use that year. Energy crops were grown on 3 % of the total arable area (2.7 milli. ha, table 3).

To get some perspective on the potential in agriculture in Sweden the report showed that the all biomass produced in agriculture in 2005, if used as an energy resource, corresponded to less than 290 PJ with 110 in residues (straw, tops). The energy input (mainly fossil fuels) to produce this biomass was 20 PJ.

Table 3. Arable land used for energy crops in Sweden 2006. Source: SOU 2007:36

Crop and use	**Area (ha)**
Grain (wheat) for ethanol	25 000
Grain (oats) for heat	5 000
Straw for heat	Biproduct
Oil plants for RME	25 000
Salix for heat (and power)	14 000
Reed canary grass for heat	600
Pasture for biogas	300
Sum	ca 70 000

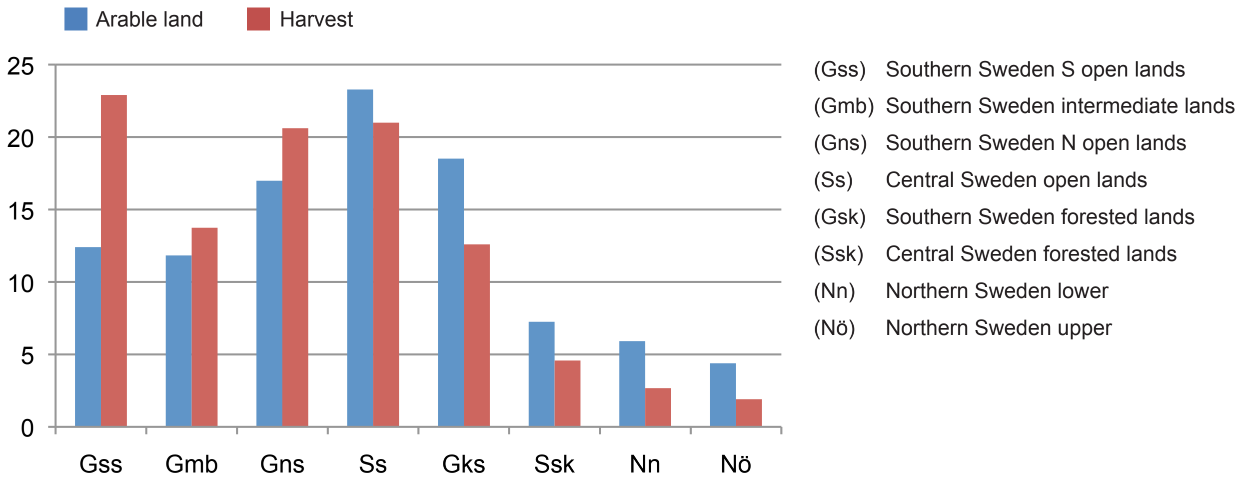


Figure 20. Proportion of arable land and total production in different parts of Sweden 2005 (%). Source: SOU 2007: 36

The report underlines that the biomass potential in agriculture is different in different parts of the country. Partly because arable land is not evenly distributed over the country, but also due to the fact that the fertility varies. Figure 20 illustrates that with both a larger proportion of the area and more fertile soils in southern Sweden. More than 40 % of the area is found in southern Sweden and the production on those 40 % is close to 60 % of the total.

The report refers to other estimates of the biomass potential in agriculture and concludes that it in most cases is difficult to judge if the figures are for the total physical potential or any other potential (cf. figure 10). In many cases it is rough estimates or possible development based on a number of assumptions about future development within the agricultural sector without judging the likelihood for this development. The differences between different estimates are relatively large (table 4). This is due to differences in basic assumptions but also the time frame for the estimate and above all what other restrictions that are included.

Table 4. Other biomass potential estimates from agriculture in Sweden. Source: SOU 2007: 36

	Energy potential (PJ)	**Areal (ha)**	**Year**	**Note**
Solid biofuel commission(1992)	184-212 (40 in straw)	800 000	2002-2007	Practical potential estimated to 36-54 PJ
Sw Environmental Agen.(1997)	100	-	2021	100 PJ was a set target in the study
Climate committe (2000)				
a) with technical, economical, ecological restrictions	4-7	800 000	2010	Agricultural policy critical
b) without restrictions	72-108			
Svebio (2004)	83	500 000–600 000		Based on LRF:s estimates
LRF:s energy scenario (2006)	18 83	500 000–600 000	2010 2020	
Lantmännen (2006)	106-131	Up to 1 milj. ha	2020	
Lars Jonasson (2005)	90	ca 900 000	Long-term	Based on an oil price of $ 100 per barrel
The oil commission (2006)	36	300 000	2020	Unclear basis for area used
,,	115	500 000	2025	

Important factors for the potential according to the report are:

- How large part of arable land that is cultivated
- What kind of crops that is grown
- Where in the country and on what land these crops are grown

How much of this potential that will reach the market depends, according to the report, on the production cost in relation to what the market is willing to pay for the biomass that in turn depends on:

- Market possibilities for refined energy products depending on
  - oil price
  - energytaxes, carbon taxes
  - price on carbon credits and electricity certificates
- Agricultural subsidies
- Competition from imported biomass
- Competition from domestic biomass (forest biomass)
- Competition from food and fodder production
- Human factors such as attitudes towards energy crops v.s. food crops.

The report points out reasons why agriculture so far has been a minor player on the biomass market in Sweden. Primarily it is due to cost of revenue that sets the profitability in biomass production compared to the alternatives. Uncertainties about future energy prices together with future energy and agricultural policy are also important. On top of that there is skepticism against new crops – not the least perennial crops such as *Salix*.

The report also analyzed the potential in biomass from agricultural with different subsidies and taxes favoring renewable energy together with cost reduction in the production to make the biomass competitive on the market. That analysis concluded that the contribution from domestic agricultural biomass will be minor on the Swedish market and that the conversion of the Swedish energy system towards more renewable energy sources has to be solved with other means.

Peat

Peat is not classified as a renewable bioenergy resource and should not be mentioned here as a part of the solid biofuel market. But, as the classification of peat is under continuous discussion at the same time as peat in a mixture with other biomass has a positive effect on the combustion process some room is left for peat here.

Sweden is a country with large peat resources corresponding to 1.6 % of the global resource. Peat is harvested on less than 2 ‰ of the area and more of this resource could be used. In addition to its energy content, peat has some positive features in the combustion process when mixed with i.e. woody biomass. This mixture reduces the risk of fouling and corrosion compared with a pure wood fuel. In April 2004 the EU commission entitled electricity certificates for electricity produced from peat in approved heat and power plants. Despite this the peat business in Sweden is under pressure. Figure 21 shows the use of peat in district heating.

The reason for this falling trend is that peat has become less competitive as a result of a sulfur tax introduced in 1991 for peat and coal and primarily due to uncertainty about future peat prices as peat in the system with trade of carbon credits is treated as a fossil fuel with the same emission factor as coal. Even if the price for carbon credits has not

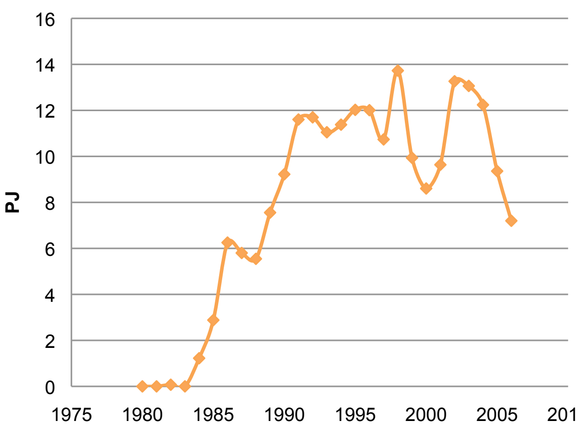


Figure 21. The use of peat in district heating in Sweden 1980-2006 (PJ). Source: SCB, Swedish Energy Agency.

been frightening during the first period there is an uncertainty for the next (2008-2012), when the number of credits will be reduced.

To save the peat industry and peat as a fuel in the Swedish energy system there is a political interest in promoting a new classification of peat within the carbon credit trade system in EU. Finland, another country with large peat resources, is working in the same direction. The finish work has so far resulted in a new classification of peat from the Intergovernmental Panel of Climate Change (IPCC). The classification of peat will determine to what extent peat will contribute on the energy market. Finland argues for peat to be a "slowly renewable biomass" as peat grows, though slowly, on most peat lands.

The Swedish Energy Agency together with the Environmental Agency has on a commission from the government investigated the possibility to adjust the emission factor for peat combustion in installations included in the carbon trade system in Europe. Their conclusion was that acceptance for a changed view on peat cannot be reached until the beginning of the next emission trade period that starts in 2013.

In Sweden focus has gone from harvesting mainly open peat bogs towards peat lands that could be expected to emit more green-house gases (GHG) than they sequester. Thus, from a climate point of view harvest and combustion seems reasonable. This could be previously ditched peat lands where the new humidity conditions have favored decomposition of organic matter. From global warming point of view it is important to know how much of the carbon that is emitted as carbon dioxide (CO_2) and how much that is emitted as methane (CH_4). This is important as methane has a GWP-value (Global Warming Potential) that is 23 times higher than carbon dioxide. A priority when choosing peat land for harvest (mining) is to choose those that emit a lot of GHG.

Potential peatlands are:

- Peatlands ditched to favour forest growth
- Peatlands ditched to gain more agricultural land
- Already exploited peatlands

Hånell (2006) investigated the peat potential in peatlands ditched to increase forest growth in the country based on NFI-data including both soil and forest stand data. The investigation was limited to peat-layers thicker than 1 meter. In total there was 700 000 hectares of peatlands with forest and approximately half of this area was ditched peatlands.

Photo: Ulrika Persson

Table 5. Area of unditched and ditched forested and open peatlands with a peat layer > 1 meter in Sweden (1000 ha). The last column shows the area of available ditched open and forested peatlands larger than 10 ha. Source: Hånell 2006.

	Forested peatlands		Open peatlands		Total	
	unditched	**ditched**	**unditched**	**ditched**	**undit-ched**	**ditched >10 ha**
Norrbottens lappmark	5	6	382	25	31	15
Norrbottens kustland	21	21	334	27	48	35
Västerbottens lappmark	10	10	350	25	35	38
Västerbottens kustland	18	35	150	28	63	49
Norra Norrland	55	72	1216	106	178	137
Jämtland incl Bergs kommun	25	21	250	19	40	28
Svegs kommun	5	0	98	3	3	4
Ångermanland	7	12	79	11	23	18
Medelpad	8	5	37	2	7	0
Hälsingland	16	9	75	11	20	8
Gästrikland	9	4	28	1	5	8
Södra Norrland	70	52	569	47	99	66
Särna-Idre	2	0	37	0	0	2
Kopparberg exkl. Särna-Idre	29	16	195	15	31	17
Värmlands län	19	17	92	6	23	8
Örebro län	11	12	32	2	14	6
Västmanlands län	10	7	13	2	9	7
Uppsala län	10	9	20	1	10	5
Stockholms län	3	6	6	0	6	2
Södermanlands län	5	9	7	1	10	1
Svealand	87	74	402	28	102	48
Östergötlands län	9	11	10	0	11	5
Skaraborgs län	8	15	17	2	17	7
Älvsborgs, Dalsland	1	3	11	0	3	2
Älvsborgs,Västgöta	22	21	26	8	29	13
Jönköpings län	31	26	41	8	34	21
Kronobergs län	33	50	38	9	59	16
Kalmar län	18	15	11	1	16	3
Gotlands län	0	0	0	0	0	0
Göteborgs och Bohus län	3	2	9	0	2	1
Hallands län	15	10	22	3	13	14
Kristianstads län	9	15	12	4	19	1
Malmöhus län	2	1	2	2	3	10
Blekinge län	3	5	2	0	5	1
Götaland	154	172	201	40	212	93
Sweden	365	370	2387	221	591	344

Ditched peatlands with forest was particularly common in the province of Västerbotten (NE Sweden) and in southern Småland (SE Sweden). On top of that there is an additional 2.6 million hectares of open peatlands of which 200 000 ha was ditched. The proportion of ditched open peatlands was particularly large in the provinces of Småland, Hälsingland, Västerbotten and Norrbotten (table 5). Profitable peat business requires a certain area of the peatland. The last column in table 5 shows the area of available ditched open and forested peatlands larger than 10 ha and a peat layer thicker than 1 meter. That restriction leaves us with 180 000 ha ditched forested peatlands and 165 000 ha ditched open peatlands.

With knowledge about the thickness of the peat layer it is possible to estimate the physical peat potential in the country. That kind of estimate is shown in table 6. The estimate shows a considerable peat potential that with harvest levels as in 2005 (3.3 million cubic meters, 50 % energy peat and 50 % gardening peat) would last more than 2000 years.

Table 6. Physical peat potential (milliard m^3) on ditched forested and open peatlands with an area > 10 ha and a peatlayer > 1 m in Sweden. The last column shows the number of years this resource would last with an annual harvest level as in 2005. Source: Hånell 2006.

	Forested peatlands miljarder m^3	**Open peatlands miljarder m^3**	**No of years**
N Norrland	1.5	2	
S Norrland	0.9	0.9	
Svealand	0.9	0.5	
Götaland	2	0.5	
Total	5.3	3.9	2761
After area correction based on NFI data			
N Norrland	1.1	1.8	
S Norrland	0.6	0.8	
Svealand	0.6	0.4	
Götaland	1.6	0.5	
Total	3.9	3.5	2221

According to the Swedish Peat Producers Association the energy content in peat is in average 3 600 MJ per cubic meter of peat. This times the total resource of 7.4 milliard cubic meters (cf. table 6) gives us 26 640 PJ.

Peat under a forest stand will not be available until final cut. Figure 22 shows that the potential even with that restriction is high.

Additional peatland to this is to be found on ditched peatlands converted into agricultural land. In the short-term the contribution from peat will, however, depend on active and non-active concessions and import.

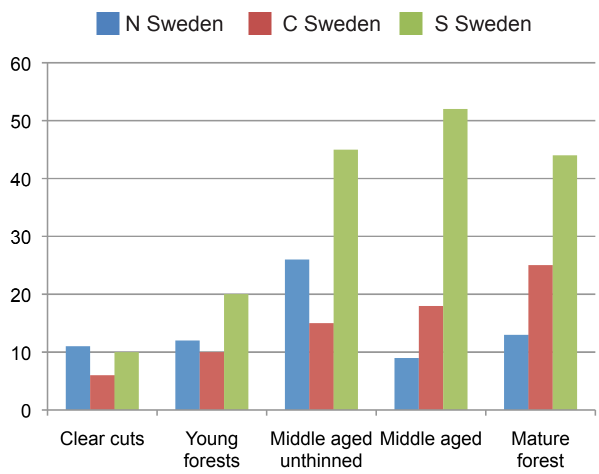


Figure 22. Area of ditched forested peatlands with a peat layer > 1 m splitted into different age-classes by region in Sweden. Source: Hånell 2006

Import

If the domestic market cannot be fed with biomass from Sweden imported biomass may fill that gap. How are the conditions for biomass import? A conclusion to start with is that all EU countries have cogent 2020 targets for renewable and reductions in CO_2 emission (table 7), thus the market for biomass is likely to increase in most of these countries.

These countries forest biomass resources in relation to the population give a rough picture of the forest biomass export potential (figure 23). Finland and Sweden has the biggest forest resource per capita with more than 300 cubic meters per person. A plot of the forest resource per capita against the 2020 targets for renewable reveals a relation between forest resources and target levels (figure 24).

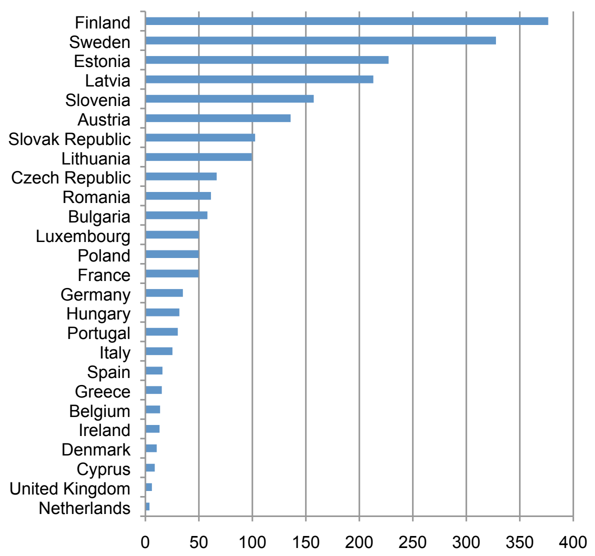


Figure 23. Growing stock per capita for countries within EU year 2000 (m^3/capita). Source: The Global Forest Resources Assessment 2000, Main Report, FAO ISBN 92-1-116735. ISSN 1020-2269.

Table 7. Cogent targets for EU countries decided by the commission Januari 23 2008.

	Reduction in CO_2-emissions in 2020 compared with emissions in 2005	Target for share of energy from renewable sources in gross final consumption of energy, 2020
Austria	-16.0%	34%
Belgium	-15.0%	13%
Bulgaria	20.0%	16%
Cyprus	-5.0%	13%
Czech Repub.	9.0%	13%
Denmark	-20.0%	30%
Estonia	11.0%	25%
Finland	-16.0%	38%
France	-14.0%	23%
Germany	-14.0%	18%
Greece	-4.0%	18%
Hungary	10.0%	13%
Ireland	-20.0%	16%
Italy	-13.0%	17%
Latvia	17.0%	42%
Lithuania	15.0%	23%
Luxembourg	-20.0%	11%
Malta	5.0%	10%
Netherlands	-16.0%	14%
Poland	14.0%	15%
Portugal	1.0%	31%
Romania	19.0%	24%
Slovak Repub.	13.0%	14%
Slovenia	4.0%	25%
Spain	-10.0%	20%
Sweden	-17.0%	49%
Un. Kingdom	-16.0%	15%

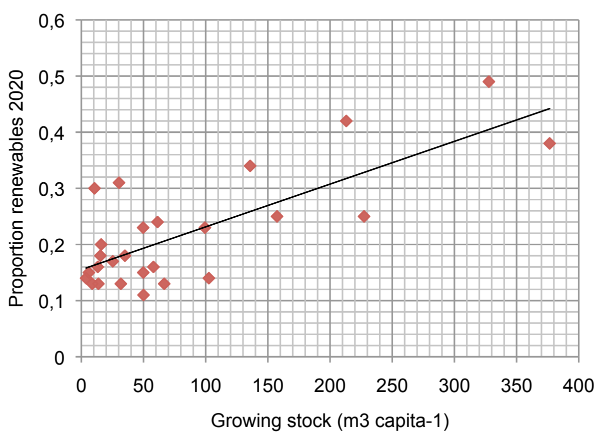


Figure 24. Growing stock per capita in EU-countries plotted against targets for share of energy from renewable sources in gross final consumption of energy, 2020. Source: The Global Forest Resources Assessment 2000, Main Report, FAO ISBN 92-1-116735. ISSN 1020-2269.

This means that the forest biomass markets will be hot in countries with large forest resources while countries like the Netherlands has to use more biomass from agriculture or imported biomass. Countries within the union with an export potential could be countries with a large forest resource and moderate target levels. Here we find the Baltic countries, Slovenia and Slovakia.

With the set 2020 targets the biomass market is likely to become hot for the countries within EU, with the import potential from outside the Union. In the northern hemisphere two countries sticks out with a large biomass resource in forests – namely Canada and Russia. They have estimated standing stocks of 30 and 90 milliard cubic meters, respectively, to be compared with 3 in Sweden. If the wood supply would be split up each Canadian and Russian has 950 and 600 cubic meter of wood, respectively. At the same time these countries have alternative energy resources even though most of them are fossil.

The forest industry in Canada is currently under pressure. Part of the industry in British Columbia and Alberta has been under pressure since a large proportion of the pine forest in the provinces have been attacked and killed by the mountain pine beetle. In 2005 850 million cubic meter of dead pine wood was estimated in the forest. This figure can be closer to one milliard today. Coinciding with this lies competition from tree plantations in tropical regions and the recession in the economy – not the least the for Canada important market in the United States. The situation for the forest industry in the country is extremely bad and measures are needed to avoid a total collapse.

One path that has been discussed ever since the beetle attack is to focus more on the growing global energy market. Wood pellets on a boat are a global commodity that could reach markets throughout the world. One problem is that most of the beetle killed wood is found in western Canada making the transport distance to Europe long and other markets like the US market more competitive.

The wood pellet production in Canada was in 2006 around 1 200 000 ton produced at 23 plants. At the same time another two plants were under construction and another six were in the planning process. Figure 25 shows the production development in Canada from 2001 to 2006. The expectations from the Wood Pellet Association of Canada is that the development will continue steep upwards with a production capacity around 5.5 – 6 million tons in 2010.

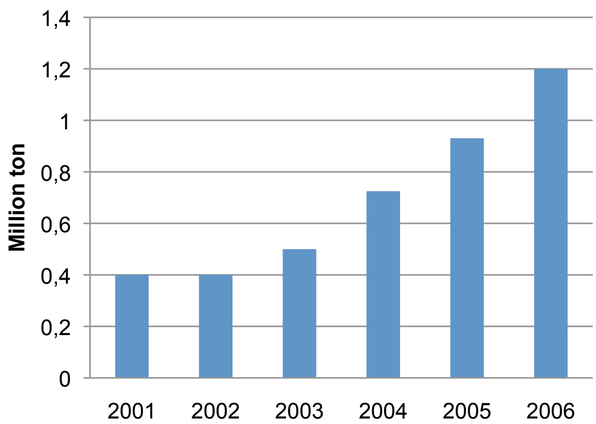


Figure 25. Wood pellet production in Canada 2001-2006 (million tonnes). Source: Wood Pellet Association of Canada.

It is, however, not reasonable to build up a production capacity in line with the huge amount of dead wood that is out there due to the beetle as this resource will reach an end in the coming years. Fresh wood from new pine generations will most likely not go exclusively to the energy industry. More likely it will pass through the pulp and paper industry first. The forest industry in Canada has gone through the same development as in Europe with more and more of the process energy used coming directly from the processed biomass rather than from other sources. Thereby less of the forest industry residues is available on the market.

Unlike the US, Canada has also ratified the Koyoto protocol and has thereby commitments to relate to. Very little have, however, so far been done to reduce GHG emissions in Canada. One reason for this is that the government has changed since the signing of the protocol – but equally important is that the energy policy is set at the province level. As late as in February 2008 British Columbia introduced a carbon dioxide tax on the end consumer. This may well be a first step towards more renewables in the country. If that is the direction a lot of biomass will be consumed within the country. Particularly if there is a breakthrough for the second generation biofuels. But more likely is that Canada will export a lot of forest biomass for energy purposes during the coming years to keep the forest industry and connected forestry, harvest capacity and competence alive.

Russia, with its 800 million hectares of forest land, is the country in the world with the largest forest area. With 20 % of the forest land in the world Russia, in theory, has a large potential to contribute with biomass to the global market. But forestry and forest industry is poorly developed in the country. Annual cut is modest with 120 million cubic meters. That could be compared with Sweden with an annual harvest of 80-90 million cubic meters, harvested on an area corresponding to 3 % of the Russian. Therefore the forest in Russia from a forestry point of view is over mature. The condition of Russian forestry and forest industry depends among other things on poor infrastructure together with lack of competence and capital. Despite the low annual cut some of the round-wood goes directly to industry in Finland and Sweden.

To stimulate the development of domestic refinement of the forest resource Russia has since 2007 introduced custom duties on exported round wood. The plan is to successively increase the duty to reach levels that is most likely to end the export of round wood. If this succeeds and leads to a development of forest industry in Russia there might be a possibility for a flow of forest industry residues and logging residues to the energy market. That is if this is not consumed by the domestic market. The wood pellet industry focusing on the export market has grown a lot during the last years, however from a low level (figure 26). In conclusion, Russia's future contribution to the global bioenergy market is uncertain despite its large forest resource.

Finally, there is a future global bioenergy potential if large areas with fast growing crops are planted in countries with a climate giving large and sustainable production with the largest potentials found in South America and Africa.

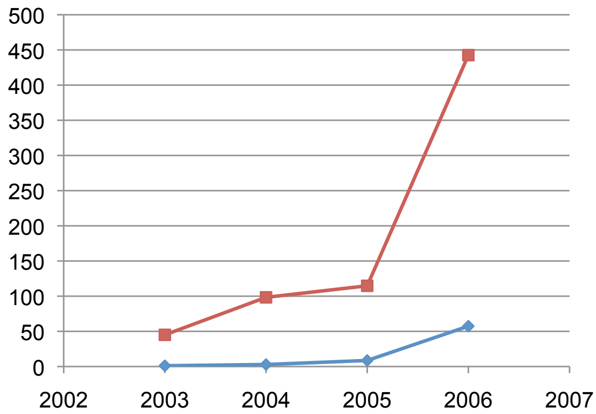


Figure 26. Number of pellet plants (blue) and annual production (1000 tonnes, red) in Russia 2003-2006. Source: Hillring et al 2007.

Ongoing R & D

Current Swedish forest energy research and development focus on ways to increase harvest levels i.e. to find profitable and sustainable ways to harvest more of the biomass that is already in the forest (logging residues, small diameter trees, stumps). Agricultural energy reserach put much efforts on developing *Salix* production.

It is hard to identify R & D efforts that will have the largest impact on amount of biomass that reach the market. A prerequisite is also that research results are communicated with them who have the power to make a difference i.e. foresters and farmers. Generally small measures, that require small investments, small decisions, and thereby has the potential to reach large areas fast have a high potential. Therefore conventional forest fertilization or genetic upgrading of seedlings planted have a larger impact potential than more intense production systems and new fast growing tree species. Introduction of more intense production systems or new fast growing tree species may also require environmental impact assessments before they are approved by public authorities. This slows down the introduction and thereby the impact.

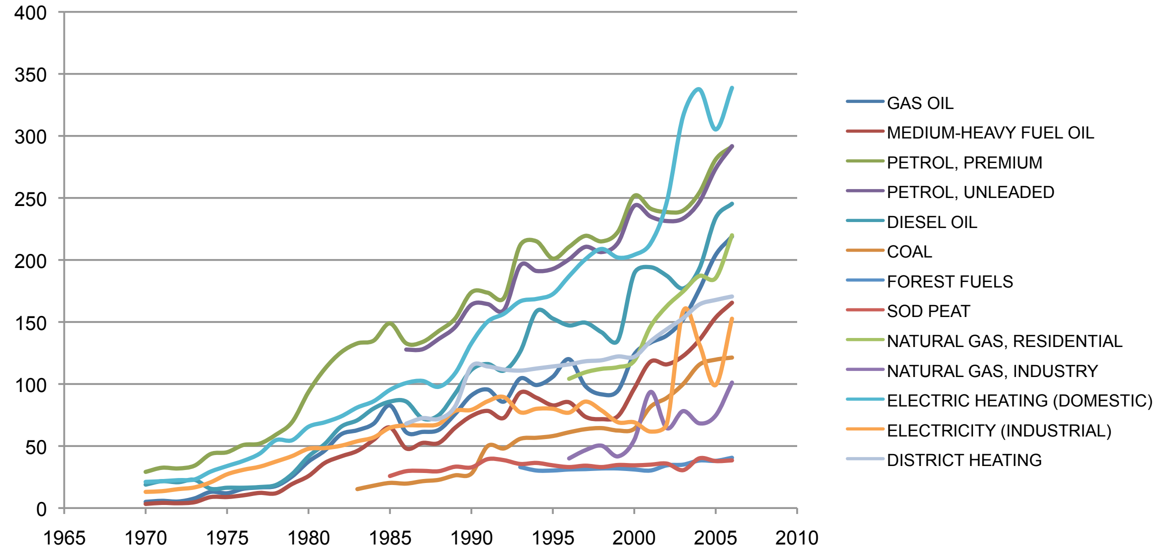
Price development on the solid biofuels market

Statistics shows that price on forest biomass for energy purposes has been fairly stable on the Swedish market at the same time as the price for other energy sources has increased markedly (figure 27). This is partly due to taxes put on fossil energy sources. But the price for forest biomass has also historically been low as long as there was a surplus of residues in the forest industry.

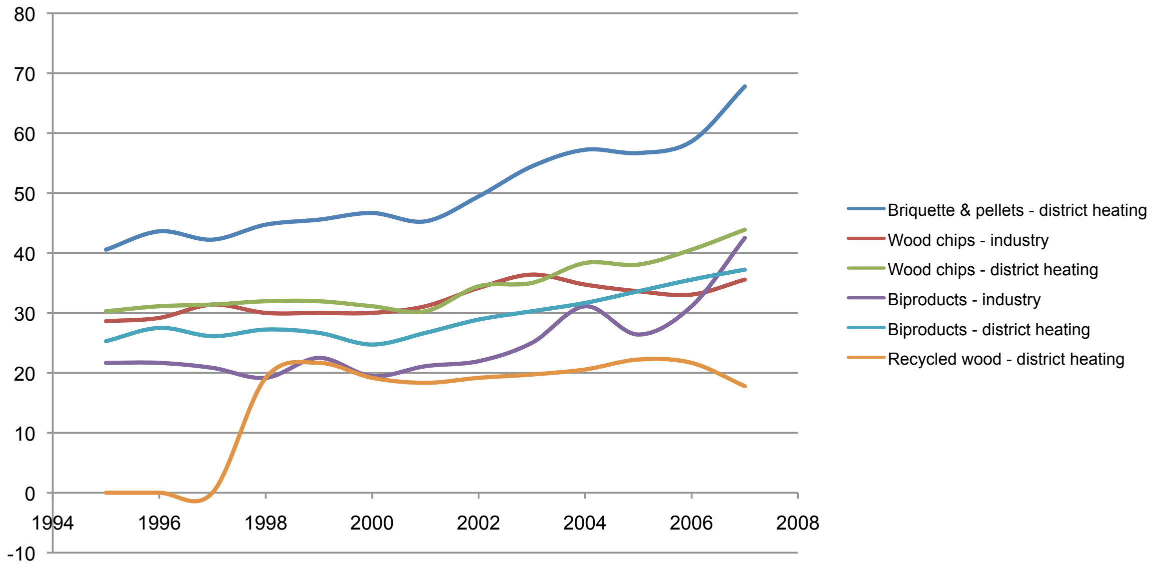
When this resource was fully used by the market new biomass resources were required. The first solution was to use branches and tops that used to be left in the forest at harvest. To adjust a harvest technology designed for round wood harvest and then collect the logging residues cost money that has to be reflected in the market price. Another alternative is import of cheap biomass where the transport cost will add to the price. The biomass potential in countries with a large forest industry but poor biomass market may be significant. We have already mentioned Canada with the potential to have an impact on the biomass price in Europe through a large export.

Even if the price increase for biomass has been moderate compared to other energy sources there is an obvious upward trend during this decade (figure 28). This has happened at the same time as more and more logging residues has been delivered to the market moving from southern up towards northern Sweden as the biomass market has grown. As the recent market growth has been driven by investments in district heating the hottest markets are found around major cities. The new 2020 targets have not yet been reflected on the Swedish market – but this is something that could be expected in the near future. A breakthrough for the second generation biofuels based on lingo cellulosic feed stock is also likely to have a large impact on the demand.

The carbon credit trade has the potential to have an impact on the price for biomass as it favors investments in renewable energy sources. Here biomass compete with hydro, wind, wave and solar. A prerequisite for this is that the price for carbon credits is high enough to stimulate investments. During the first trading period 2005-2007 a system has been tried within the European Union. The generosity has been too high during this first period with too many credits on the market. This has kept the price on a low level – particularly during the end of the period.



Figur 27. Energy price in Sweden (incl. tax) 1970-2006, SEK/GJ. Source: Swedish Energy Agency.



Figur 28. Price for delivered wood fuel (excl. tax) 1995-2007 SEK/GJ. Source: Swedish Energy Agency.

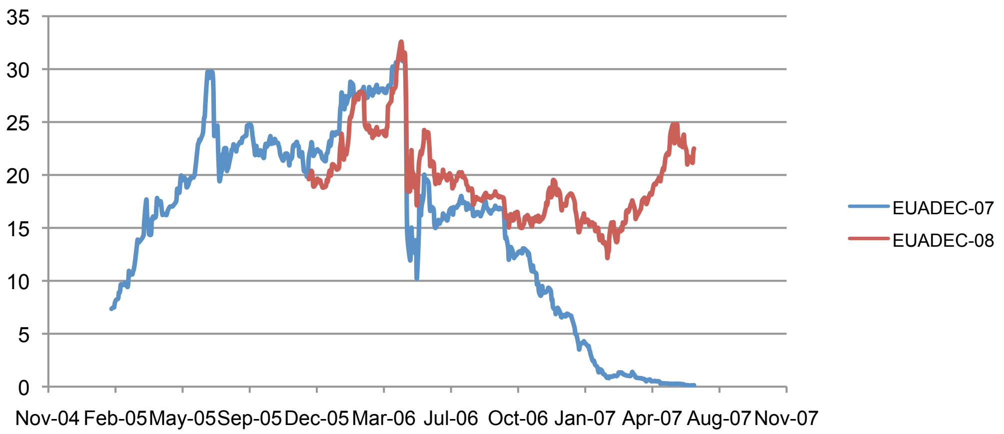


Figure 29. Price development of carbon credits Feb 2005 - juni 2007 (€ per ton CO_2). EUADEC-07 has been traded within Europe during the first period, 2005-2007, while EUADEC-08 is traded for the next period, 2008-2012. Source: Swedish Energy Agency.

References

Anon 2007a. Energiläget 2007. Swedish Energy Egency (In Swedish).

Anon 2007b. Bioenergi från jordbruket- en växande resurs. SOU 2007:36 (In Swedish).

Anon 2006. På väg mot ett oljefritt Sverige. Kommissionen mot oljeberoende juni 2006 (In Swedish).

Hillring, B., Olsson, O., Gaston, C., Mabee, W., Skog, K., and Stern, T. 2007. Energy policies reshaping forest sector: Wood energy development in the UNECE region, 2006-2007. In: UNECE/FAO Forest Products Annual Market Review 2006-2007. Geneva Timber and Forest Study Paper 22. United Nations, New York and Geneva.

Anon. 2000. The Global Forest Resources Assessment 2000, Main Report, FAO. ISBN 92-1-116735. ISSN 1020-2269.

Egnell G., Hyvönen R., Högbom L., Johansson T., Lundmark T., Olsson B., Ring E. and von Sydow F., 2007. Miljökonsekvenser av stubbskörd - en sammanställning av kunskap och kunskapsbehov. Swedish Energy Agency Rapport 40 (In Swedish).

Hånell, B. 2006. Dikad skogsmark och myr med djup torv som resurser för uthålligt torvbruk i Sverige. Projektrapport nr 5. Torvforsk (In Swedish).

Lönner G., Danielsson B.O., Vikinge B., Parikka M., Hektor B. and Nilsson P.O. (1998) Kostnader och tillgänglighet för trädbränslen på medellång sikt. Rapport 51. Institutionen för skogindustrimarknad studier, Sveriges lantbruksuniversitet (In Swedish).

Rosvall, O., 2007. Produktionspotentialen är betydligt högre än dagens tillväxt. Ur: Skogsskötsel för en framtid. Kungliga Skogs- & Lantbruksakademiens Tidskrift nr 4: 13-30 (In Swedish).