Theoretical versus market available supply of biomass for energy from long-rotation forestry and agriculture – Swedish experiences

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KEY MESSAGES

Theoretical biomass potentials are based on estimates of evidently existing biomass (harvest residues) following forestry and agriculture or estimates based on assumptions on available land and annual yields of dedicated energy crops grown on that land in the future.

The major message in this report, based on Swedish experiences, is to have realistic expectations on future market potential of biomass for energy from forestry and agriculture. There are a number of limitations that will make the amount of market available biomass considerably less than theoretically available biomass, and the type of limitations will vary depending on the category of biomass resource and circumstances in the area of production.

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Cover Picture: Courtesy of Pär Aronsson (bales) and Gustaf Egnell (stumps)

1. INTRODUCTION

Bioenergy from forestry and agriculture have the potential to contribute to future energy need and thereby secure the energy supply in countries highly dependent on imported energy sources and to mitigate climate change primarily by substituting fossil energy alternatives. The extent of the contribution is difficult to forecast as it depends on a large number of factors. Estimates of future biomass potentials therefore tend to give different predictions. Berndes et al. (2003) reviewed 17 different studies on the possible contribution of biomass in the future (2050) global energy supply, where the studies ranged from annual deliveries from below 100 to above 400 EJ. Identified crucial parameters for the differences were assumptions about land availability and yield levels, but also differences in expectations about future availability of wood and residues from agriculture and forestry had an effect on the potentials.

Secure feedstock supply is an important issue for investors within the bioenergy business. In most cases it is not the global feedstock supply, but rather the national, regional or local feedstock supply that are of interest to secure an investment, even though import sometimes is a feasible option. In this report we use experiences from Sweden – a country with a comparatively strong market for biomass for energy - to show the difference between theoretically available biomass and market available biomass for energy and examples of limitations that make the difference. This is exemplified with (i) biomass from forestry, i.e. stump biomass following harvest in long-rotation forestry and (ii) biomass from agriculture, i.e. straw from cereal and oilseed cultivation and *Salix*, long suggested as a short-rotation energy crop with high potential in Sweden. Stumps and straw represent biomass that exists, following harvest of a main crop that is fairly easy to estimate. There are, however, a number of reasons why the market potential is far below the theoretical potential based on the physically available biomass. *Salix*, on the other hand, represents a currently almost non-existing biomass where the theoretical potential is based on assumptions of available suitable land, how much of this land will be utilized, soil fertility, and annual yields. In addition there are other uncertainties which will influence the actual yields such as farmer attitudes and practices to produce new, dedicated energy crops, alternative land use, and agricultural policies.

2.1 Biomass supply from long-rotation forestry

Forests cover a large share of Sweden's land area and the forest industry is important for the economy. However, the forest history shows that the forest resource was heavily exploited during the 18th and 19th centuries. At the turn of the 19th century the awareness of the importance of a secure feedstock supply to a growing forest industry resulted in a new forest policy that over time resulted in an increased growing stock (Figure 1). This was a result of primarily two things, namely, harvest levels that rarely exceeded annual growth and an obligation by law to secure afforestation after final cut. In addition, reforestation was established on former forested areas that due to land use had degenerated to *Calluna* heathlands, particularly in southern Sweden.

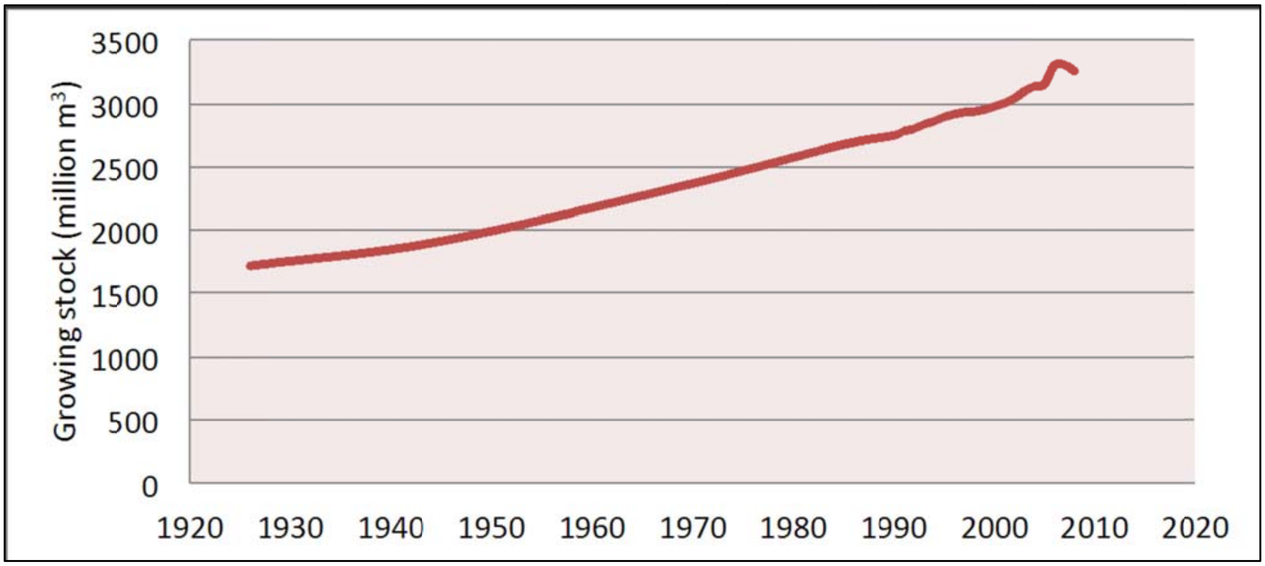


Figure 1. Growing stock in Swedish forests from the 1920's to present. Note: Figures are 5-year averages. Source: The Swedish National Forest Inventory, Swedish University of Agricultural Sciences, Umeå.

This increase in growing stock has successively increased annual growth and thereby the potential annual harvest from Swedish forests supporting a growing forest industry in Sweden over time (Figure 2).

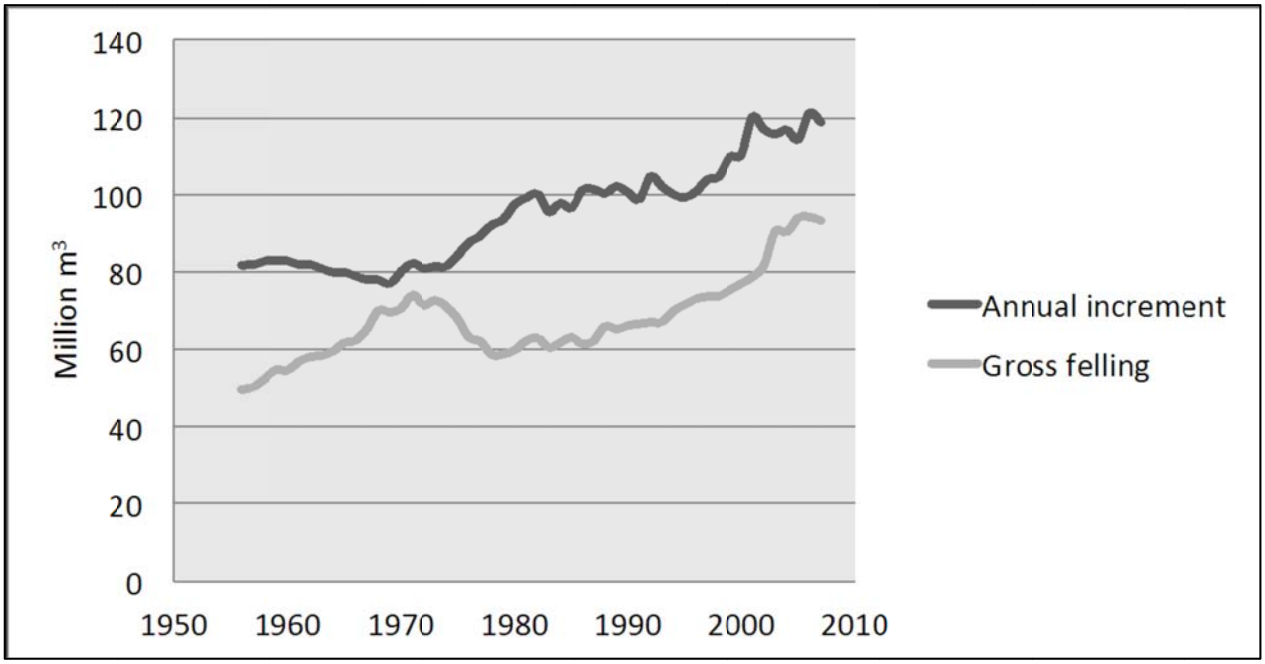


Figure 2. Annual increment and gross felling in Swedish forests 1956-2007. Note: Figures are 5-year averages. Source: The Swedish National Forest Inventory, Swedish University of Agricultural Sciences, Umeå.

An important message from figure one and two is that it takes time to increase forest growth and potential harvest levels in a northern temperate to boreal climate with long-rotation forestry. This means that the forest industry together with an emerging bioenergy industry, in the short-term (0-30 years), to a large extent have to rely on current growing stock. Over exploitation of this resource with annual harvest levels above annual growth is a non-sustainable short-term solution that will drain the forest resource over time (Egnell & Björheden, 2012).

A more sustainable short-term option is to supply the energy industry with forest biomass that is not traditionally used by the forest industry or with low-priced forest biomass that the energy industry can compete with on the market. This has been the experience of Sweden where the first large-scale biomass on the market was residues from the wood-processing industry, i.e. bark, saw dust, shavings, etc. – a resource that is fully utilized today. As the biomass market for energy in Sweden is still growing at a rate of around 14 PJ per year (Figure 3), roughly corresponding to 2 million cubic meters of solid wood (cf. Figure 2), there remains a requirement for more forest biomass to satisfy market demand.

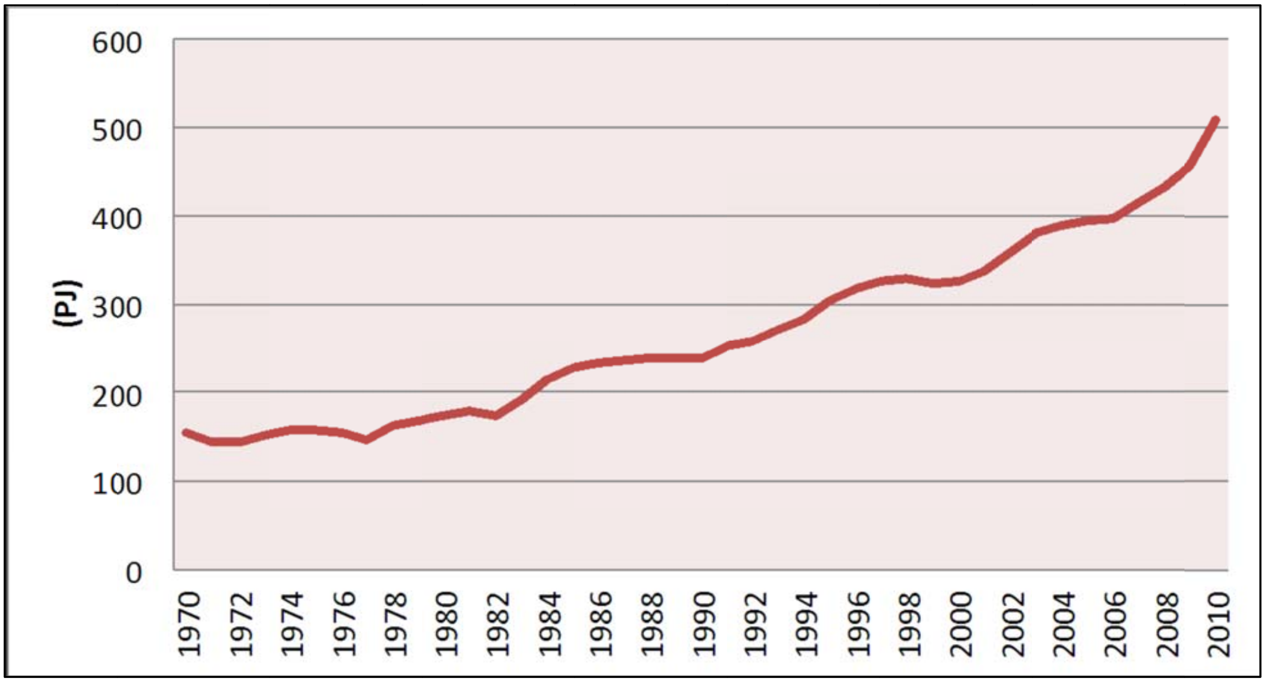


Figure 3. Total supply of biomass for energy in Sweden 1970-2010. Source: Statistics Sweden and the Swedish Energy Agency.

To fill that biomass supply gap, focus today is on forest biomass that traditionally remained in the forest when only stem-wood is delivered to the forest industry. That is e.g. logging residues and stumps following harvest, and small diameter trees. A rather large share of logging residues is already on the market. Therefore the interest in stumps has increased lately in Sweden. This has resulted in a demand for an environmental impact assessment study (EIAS) on stump harvest, by the Swedish Forest Agency, before any large-scale operations could be accepted. One component of that work, dealing with limitations that will restrict the amount of stumps harvested, is presented here as an example of differences between theoretically available biomass and actual market realized amounts.

Thanks to the National Forest Inventory (NFI) in Sweden, accurate data for the growing stock and site characteristics at national and regional level are available. The NFI-data are regularly used to analyze current and expected future timber balances. The latest (SKA-VB 08) was finalized in 2008. In the reference scenario ("business as usual"), average annual harvest levels 2010-2020 were predicted to be 90.5 million cubic meters. Allometric functions for single trees by Marklund (1988) show that the harvestable stump holds a rather stable biomass share over different tree diameters in Norway Spruce and Scots pine (Figure 4).

With an assumption of a wood density of 0.4 kg dm^{-3}, a stump biomass corresponding to 37 % of the biomass in harvested stemwood (cf. Figure 4), and an average heating value of 18 MJ kg^{-1} dry stump biomass, the theoretic energy potential in stump biomass following these predicted harvest level, can be estimated to 240 PJ per year (Figure 5).

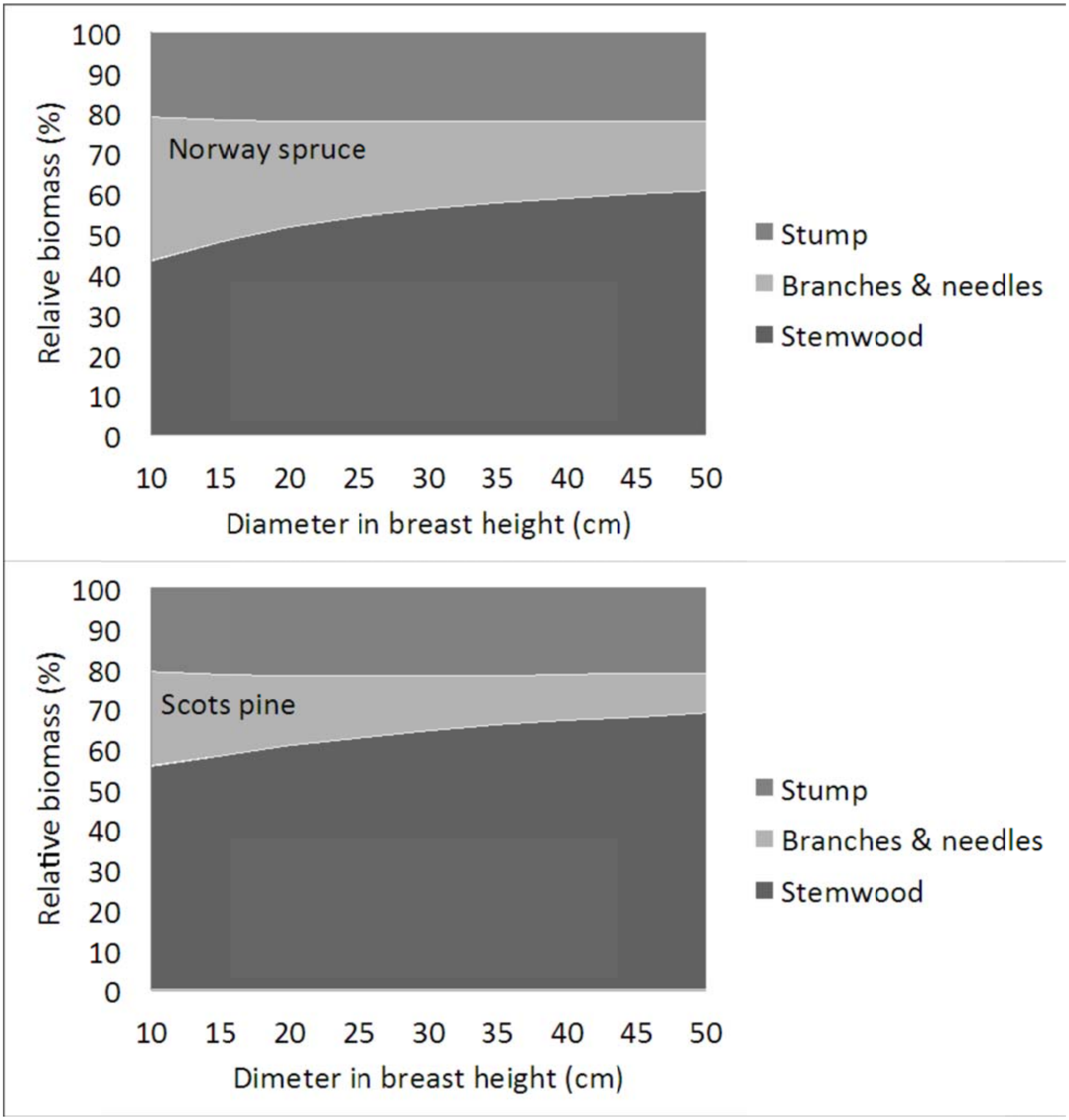


Figure 4. Relative biomass distribution (%) in stump, branches and needles, and stem-wood including bark, with increasing diameter at breast height in Norway spruce and Scots pine according to Marklund (1988).

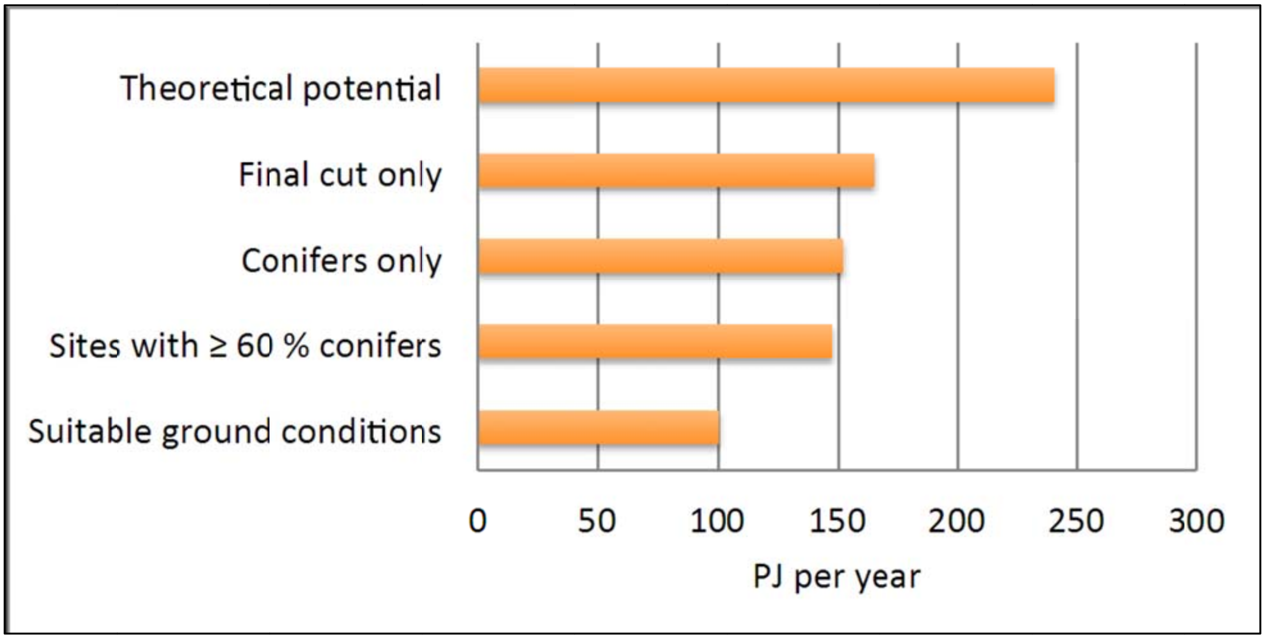


Figure 5. Annual energy potential (PJ) in stump biomass in Sweden, following harvest in a "business as usual" scenario (90.5 million m^3 of stemwood per year). The potential is shown for (i) All tree species and harvest operations; (ii) for final cut only (excluding thinnings); (iii) for Norway spruce and Scots pine only; (iv) as in iii, but only in forests dominated by spruce and pine (≥ 60 % of the volume); (v) as in iv, but with only suitable ground conditions (soil moisture, surface structure, and slope conditions better than class 3, cf. Table 1).

There are a number of reasons why stump harvest is not feasible in thinnings. The stump removal technology is still in development and is currently accomplished with a special harvest device attached to an excavator (Figure 6). This makes it expensive to harvest stumps in a thinned stand with relatively few and small diameter stumps available. There is also an increased risk for root and stem damages on remaining trees in the stand. As 30 % of the harvested volume in Sweden comes from thinnings the potential is reduced to approximately 165 PJ (Figure 5).

Figure 6. An excavator equipped with a special device for stump harvest. Photo: Gustaf Egnell.

A large proportion of the red listed forest species in Swedish forests are dependent on dead wood. For biodiversity reasons only stumps from the two dominating coniferous tree species in Sweden, Scots pine and Norway spruce, are considered suitable for stump harvest in the EIAS (cf. Lindhe & Lindelöw, 2004; Hjälten, et al., 2010). This reduces the stump biomass potential to 152 PJ (Figure 5). For economical reasons suitable stands for stump harvest have to be dominated by pine and spruce. A restriction to stands with spruce and pine holding ≥ 60 % of the standing volume reduced the potential further to about 150 PJ, (Figure 5).

The ground condition on sites that are suitable in terms of tree species composition is also important as it impacts the operation efficiency and may contribute to negative effects on the environment. The economy in stump harvest with current technology does not allow steep slopes or uneven ground surfaces that will slow down the operation. Stump harvest also increase the risk for rutting and soil compaction as logging residues, that can be used to stabilize strip roads, is normally harvested along with part of the root system, that reinforces the soil. In addition, the added harvested volumes necessitate additional terrain traffic. Examples of potential environmental effects resulting from the increased traffic include reduced site productivity, increased soil erosion, and increased emissions of greenhouse gases from the soil. For these reasons moist and wet sites are unsuitable for stump harvest. In the EIAS, it was therefore decided that stump harvest should be restricted to sites with suitable soil moisture, slope, and surface structure (SSS). These variables are also classified in the NFI and stands suitable for stump harvest were those with SSS ≤ 3 (cf. Table 1). This reduced the potential to roughly 100 PJ, or 42 % of the theoretical potential (Figure 5).

Table 1. Soil moisture, slope, and surface structure classification in the Swedish National Forest Inventory.

Class	Soil moisture	Slope	Surface structure
1	Dry	Level	Smooth
2	Mesic	Gentle	Fairly smooth
3	Mesic-moist	Moderate	Somewhat uneven
4	Moist	Steep	Uneven
5	Wet	Very steep	Very uneven

The reductions, down to 42 % of the theoretical stump-potential, are primarily reductions due to unsuitable sites. Further limitations that may reduce the number of suitable sites and thereby the market potential further due to economic, social, and environmental reasons includes:

- Economic
    - Small sites
    - Sites with a low standing stock
    - Sites distant from the market
    - Sites with long terrain transport distances
- Social
    - Sites within the reindeer herding area
    - Sites owned by forest owners that are reluctant to harvest stumps (50 % of the forest land in Sweden is privately owned)
- Environmental
    - Sites with, or close to areas with, high nature protection values
    - Sites with a high density of ancient remnants
    - Sites close to urban areas

There are also within site limitations that will reduce the potential on stump-harvested sites. That includes stumps from tree species that should be left for biodiversity reasons, already accounted for in the estimate above. But there are additional reasons why not all stumps will be harvested within a stump-harvested site. Due to current stump harvest technology, it is not economically feasible to remove small stumps with diameters less than 15-20 cm. The distribution of stumps in different diameter classes is also available in the NFI data and shows that the average clear-cut holds a fairly high number of stumps below 20 cm in diameter (Figure 7).

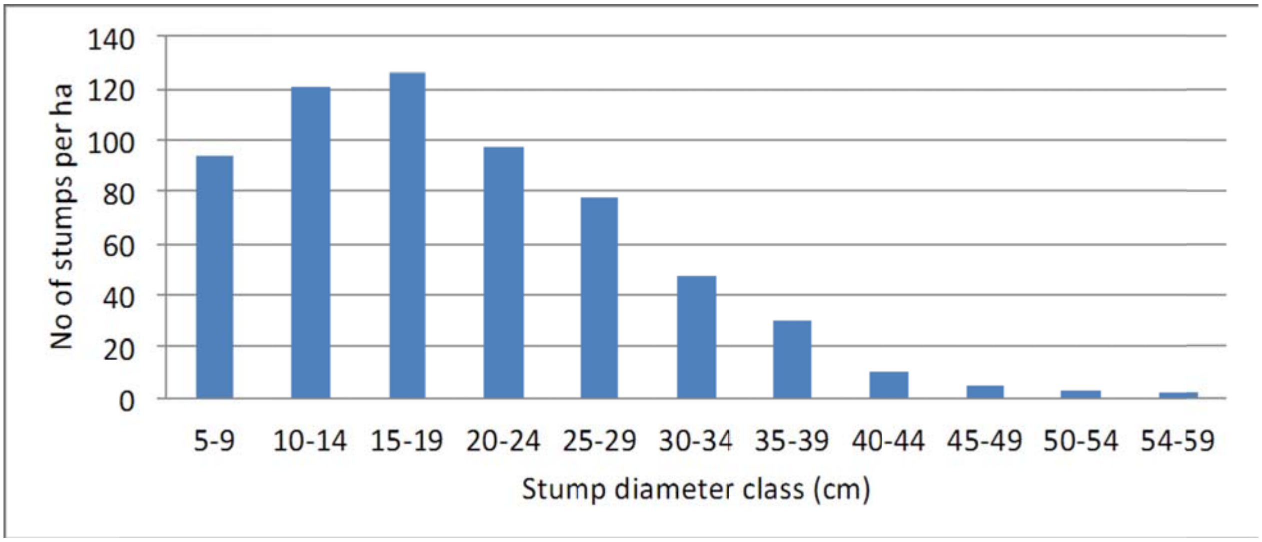


Figure 7. Average number of spruce and pine stumps (st ha^{-1}) in different stump diameter classes on Swedish clear-cuts. Source: The Swedish National Forest Inventory, Swedish University of Agricultural Sciences, Umeå.

A rough conversion of these stump numbers to biomass shows that 7 % of the biomass is found in stumps < 15 cm and 20 % in stumps < 20 cm in diameter. Thus, an additional 10 % reduction of the potential is reasonable, leaving us with about 90 PJ. Other reasons why spruce and pine stumps will be left on stump harvested sites include:

- Some stumps are needed to stabilize the soil along strip roads
- Some stumps are left close to living and dead trees (retention trees left to promote biodiversity) to avoid damage by machinery or wind.
- Stumps are left close to buffer zones along surface waters to counteract potential wind damage

In this analysis, data is lacking for the between and within site limitations not taken into account by the bulleted lists above. A rough estimate indicates that an additional 20 % of the stump potential will be left in the forest , resulting in an annual market available stump potential of approximately 70 PJ which is 30 % of the theoretically available stump potential of 240 PJ.

2.2 Biomass supply from agriculture

The biomass supply from Swedish agriculture is today small compared with the biomass supply from the forest sector, equivalent to some 2-3% (Swedish Energy

Agency, 2011). The supply consists of traditional annual crops, such as grain and oil seed for biofuel production (ethanol and biodiesel), straw for heat production, mainly in farm-scale facilities, and *Salix* for combined heat and power (CHP) production in district heating systems (DHS).

2.2.1 Annual crops

In contrast to biomass from long-rotation forestry, biomass supply from traditional annual food crops could respond and increase rapidly to price signals driven by the energy sector and expectations of improved profitability for the farmers. This is due to the short rotations of annual crops, the existing investments in infrastructure, farm machinery and administrative systems and tools, and the existing knowledge among the farmers regarding the cultivation of traditional food crops. Increased price levels for grain and oilseed can be driven by, for example, political incentives within biofuel policies promoting the first generation (1G) biofuels. Examples of such political incentives are found in the Renewable Energy Directive (RED) in the European Union (EC, 2009). However, there exist various limitations in the scale and pace of growth of the 1G biofuels, which has been identified and debated in a vast amount of publications during the recent years (see e.g. IEA Bioenergy, 2011, for a comprehensive review). Aspects that have to be considered are increased competition of arable land for food and feed production, greenhouse gas (GHG) mitigation efficiency, land use changes etc.

2.2.2 Crop residues

Crop residues in agriculture, such as straw, are a biomass resource which can be increasingly utilized for energy purposes without causing a direct competition of arable land for food and feed production. On the contrary, an increased production of food and feed in the form of grain and oilseed, generates more straw, which could potentially be available for energy purposes. Like biomass from annual crops, the supply of crop residues could respond rapidly to changed prices in the energy sector due to their short rotation.

Energy carriers from crop residues, such as straw, normally show a better environmental performance from a life cycle perspective than energy carriers from annual crops (see e.g. Cherubini and Ulgiati, 2010; Uihlein and Schebek, 2009). There are, however, also limits for the amounts of straw that can be harvested since straw is a soil conditioner which maintain the organic matter content and thereby the long-term productivity of the soil. Furthermore, straw is to some extent used in animal husbandry. The potential of straw for energy purposes thus differs between regions due to technical, ecological and socio-economic factors.

Previous estimations of the theoretical potential of straw in Swedish grain and oilseed cultivation amount to some 100 PJ per year (SOU, 2007). Of this amount, about 70 PJ (60-80%) is estimated to be technically available to harvest when various types of losses on the field are included. The actual harvested potential is further limited by climate conditions, such as rain during harvest seasons, and these limitations increase in northern Sweden due to shorter harvest periods. In addition to this, ecological limitations restrict the straw harvest. The amount of straw that should remain on the field to maintain the organic matter content in the soil varies locally depending on geographical factors, weather conditions and agricultural practices (Bernesson and Nilsson, 2005). Limitations due to climate and ecological factors may vary locally and be equivalent to 20% up to 85%, and a rough estimation is that the net available straw potential in Sweden is then reduced to about 45 PJ (SOU, 2007). A large amount of straw is today used for feed and bedding in animal husbandry. Available straw resources for energy purposes will therefore be smaller in areas with intensive animal production. The use of straw in animal husbandry also differs depending on animal breed and animal production technology utilised. Current Swedish animal husbandry is estimated to utilise some 20 PJ straw per year in total, leading to a market available amount of straw for energy purposes of about 25 PJ per year (SOU, 2007).

This previous estimation of the straw potential for energy purposes in Sweden was based on an assumed straw to grain ratio of 1.1 for wheat, reflecting the situation in the late 1990s (SOU, 2007). Corresponding ratio for barley, oat and rye was estimated to 0.8, 1.3 and 1.5 respectively. The straw to grain ratio has been continuously reduced over time due to plant breeding and the corresponding ratio for wheat was about 1.5 in the late 1980s (Börjesson, 1994). A new study show a further significant reduction of the straw to grain ratio of modern grains equivalent to, on average, 0.6, varying from 0.4 to 1 (Nilsson and Bernesson, 2009). Thus, this reduction of the straw to grain ratio will have a significant impact on the previous estimated straw potential, indicating that this potential should be reduced from 25 to about 15 PJ per year, i.e. 15% of the theoretical potential (Figure 8).

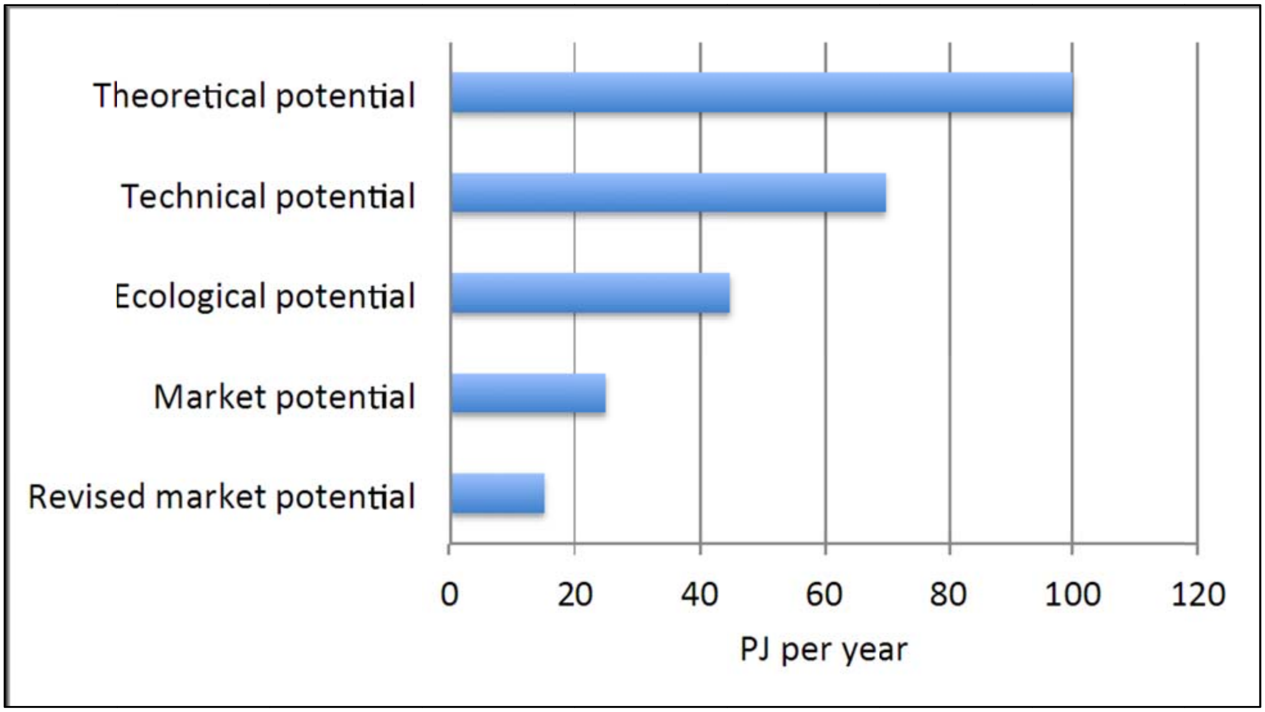


Figure 8. Estimated straw potential in Sweden (adapted data from SOU, 2007; Nilsson and Bernesson, 2009).

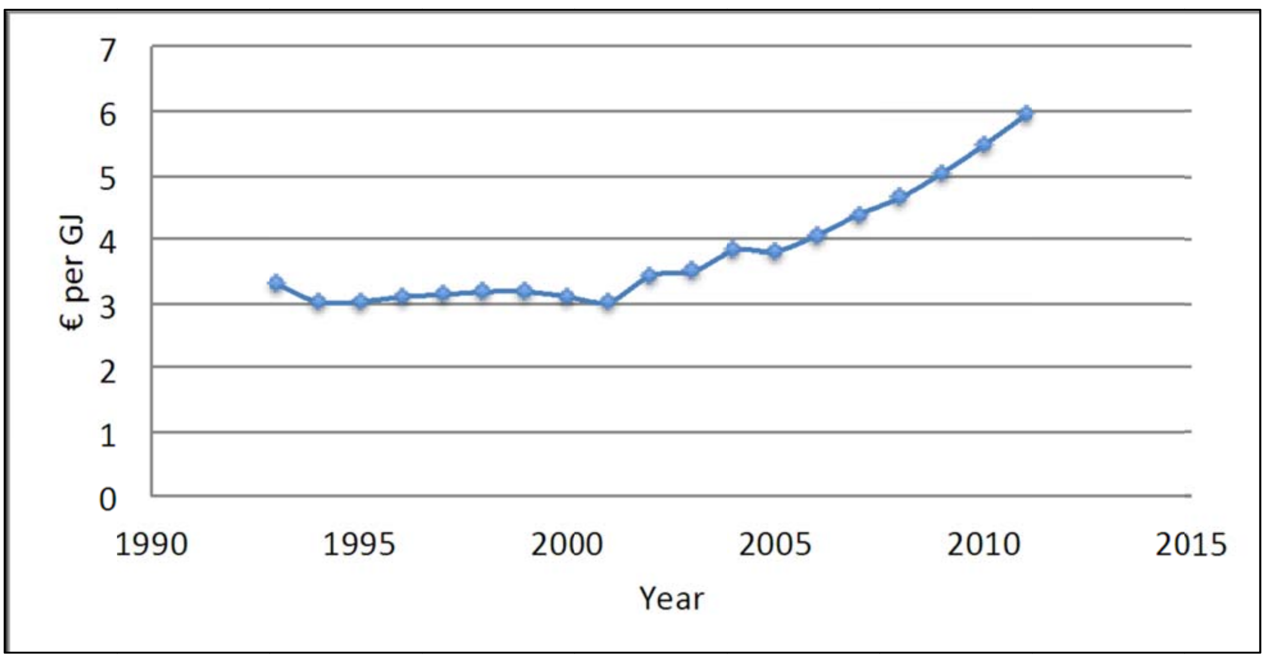
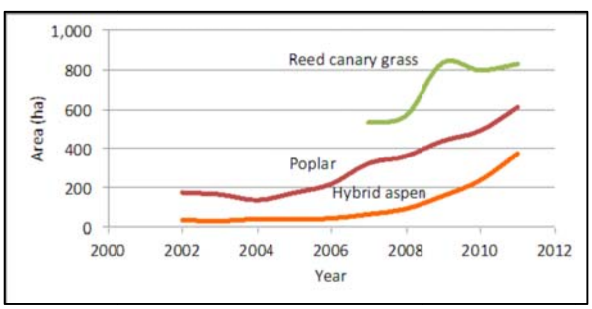


Figure 9. Average annual price of forest fuels (wood chips) delivered to large-scale district heating plants in Sweden during 1993 to 2011 (1€=10 SEK) (data from Swedish Energy Agency, 2011).

An overall conclusion is that estimations of the market available potential of straw for energy purposes in Sweden is 5-7 times lower than the theoretical biological potential (see Figure 8) and could vary significantly depending on the limitations considered, but also depending on the applied time perspective. Furthermore, economical limitations may affect the practical available potential of straw as, for example, straw is distributed over large areas, which sometimes could lead to high handling and distribution costs. The profitability for farmers to harvest straw for energy purposes depends on a several factors both within and outside the agricultural sector. Today, only a minor part of the available straw for energy purposes is harvested and mainly used in farm-scale heating systems. The interest from large-scale district heating plants to use straw as a fuel has so far been limited since the availability of forest fuels at reasonable prices has been sizeable. However, this might change in the near future if biomass prices continues to increase at an equivalent rate as during the past ten years (Figure 9). The revised energy potential from straw of approximately 15 PJ per year is equivalent to about 3% of current biomass supply in Sweden (see Figure 3).

2.2.3 Salix

Salix has been grown commercially in Sweden since the beginning of the 1990s, and *Salix* plantations now amount to some 11,000 hectares, equivalent to 0.4% of the Swedish arable land (see Figure 10). Despite this experience of about 20 years of cultivation, *Salix* production is still an emerging agricultural activity in Sweden with a small land claim, which has been reduced rather than expanded during the last five years. The current amount of biomass from *Salix* plantations, equivalent to some 1.5 PJ per year, is far below the expectations during the 1990s where the cultivation of *Salix* was expected to grow continuously leading to a significant expansion in the near future (Figure 11). Other cellulose-based energy crops currently grown in Sweden are reed canary grass, poplar and hybrid aspen and the plantation area of these are currently expanding, but from relatively low starting level (see Figure 10).



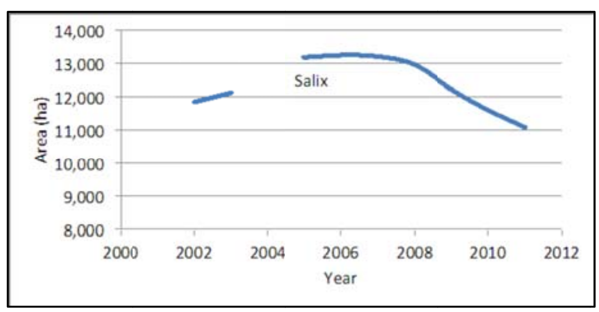


Figure 10. The amount of Swedish farmland utilized for the production of perennial energy crops between 2002 and 2011. Source: Swedish Board of Agriculture, official statistics on crops from the database "Blockdatabasen".

Starting in 1984, *Salix* was seen as the most promising energy crop in Sweden and R&D efforts were quite extensive and well-funded. *Salix* also became an attractive alternative for conventional agricultural crops, which were less stimulated in the

Swedish national agriculture policy from 1991 onwards (Helby et al., 2004). A set-aside subsidy of 900 €/ha was introduced which would be granted for a conversion from cereal production to other crops, such as *Salix*. On top of this, a *Salix* plantation would receive 1000 €/ha to cover the establishment costs (Helby et al, 2004). As a result of these subsidies, the annual growth rate of *Salix* plantations was, on average, 2000 ha during the period between 1990 and 1996 resulting in a total area of some 15,000 ha in 1996 (Figure 11). During this period, the national Swedish deregulation of agriculture, which abandoned price regulations for food crops, was an important advantage for the competitiveness of *Salix*. This rapid growth in establishment of *Salix* plantations was furthermore stimulated by positive prognoses regarding *Salix* as energy crops in the 1990s (see Figure 11).

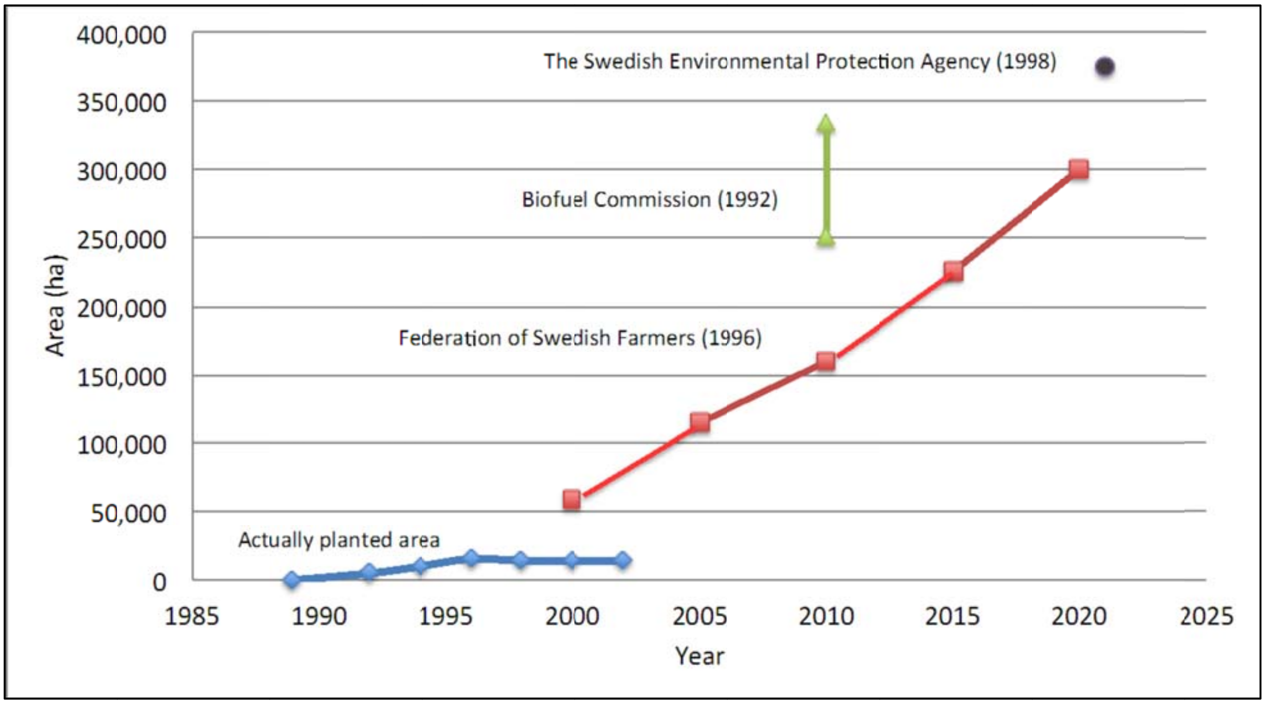


Figure 11. Estimated *Salix* potentials in Sweden by various studies during the 1990s, expressed as hectares of planted area, compared with the actually planted area until 2002 (Helby et al., 2004).

In 1995, Swedish EU membership meant a re-regulation of Swedish agriculture, increasing again quite strongly the incentives to grow food crops, except on set-aside land. In 1997, the subsidies for *Salix* plantations decreased to 300 €/ha after which they increased again in 1999 to 500 €/ha (Helby et al, 2004). As a consequence of this, the competitiveness of *Salix* was reduced and the expansion of *Salix* plantations ended. On set-aside land, however, *Salix* gained an advantage as it could be grown with subsidies that were not available for food crops on this land. Seen from a farmers viewpoint, there was still no stable policy as the amount of set-aside land required by EU regulations varied significantly from year to year.

Because of the *Salix* breeding program, new clones with better characteristics and higher yields became available and dominated the market from the beginning of the 1990s (Helby et al., 2006). These clones showed average annual growth rates of 10-20, and even up to 30 dry tonne/ha-yr in experimental field trials. However, the average annual yield in large-scale plantations was expected to be approximately 10-12 dry tonne/ha-yr when managed well, with proper clone selection and establishment on sites of moderate soil quality (Helby et al., 2006). Good management includes fertilization and weed control. However, as a consequence of the agricultural policy from 1995 and onwards (described above), *Salix* plantations were mainly established on set-aside land having poor soil quality. A result of this was that the practical average *Salix* yields become significantly lower, typically about 5-7 dry tonne/ha and year, than the expected yields based on field trials (SOU, 2007).

The small amount of farmland planted with *Salix*, compared with the expectations during the 1990s, shown in Figure 11, is explained by Helby et al. (2006) by a combination of various factors. First, the wood chip prices stayed low during the period between 1990 and 2005 (see Figure 9) because of abundance of domestic forest residues and declining harvest costs. Secondly, cheap import of wood chips appeared to be possible. Thirdly, the usage of old clones resulted in low yields. Because plantations are replanted after approximately 20 years, many farmers continued to have the low yielding clones while much better clones were available in the market. Fourth, *Salix* was mainly planted on sites with low soil quality due to the subsidy systems in the agricultural policy and due to the low wood fuel prices, which gave low yields and reduced the attractiveness. Fifth, the agricultural policy changed after entering the EU membership resulting in advantages for agricultural crops, which stimulated a shift from *Salix* to these annual conventional crops.

Growing perennial energy crops, such as *Salix*, is from a farmers perspective, a long term investment and is therefore often perceived to involve a higher risk than growing traditional annual food crops. This risk can be divided between a cultivation risk (due to a limited knowledge about potential problems with pests, weeds, etc.), and a price risk (due to uncertainties in future energy prices and prices of traditional food crops etc.) (Helby et al., 2004). Thus, there is a need for a risk premium to the farmer as economic compensation for the increased risk associated with a conversion from traditional food crop cultivation to *Salix* cultivation (Rosenqvist et al., 2012). The size of the risk premium at the farm level depends on the farmer's level of risk aversion and also on the level of expected risk in the investment. In a questionnaire survey of almost one thousand Swedish farmers, using the Choice Experiment method, the farmers willingness to grow different energy crops was investigated (Paulrud and Laitila, 2007). The survey results showed that farmers value energy crops with a short rotation period (preferably annual crops) higher than energy crops with a longer rotation period, such as *Salix*. On average, the farmers required 140 € more per hectare and year in compensation for growing *Salix* instead of growing an annual crop. This is equivalent to approximately 1.2 € per GJ, or about 20 % of the current price of forest fuels (see Figure 9). However, there is a significant variation among different farmers regarding the size of the required risk compensation. The survey included a wide range of farms, including farms judged as "typical *Salix* candidates" but also farms having an operation that makes it unlikely that they would shift to *Salix* production, such as farms cultivating feed crops for their own animal production.

This example of *Salix* production in Sweden clearly illustrates the difficulties in predicting future potentials of biomass from currently non-existing short rotation energy crops. The market potential is significantly affected of both the economic conditions in agriculture (which, in turn, is influenced by the agricultural policy) and future energy prices (and the competitiveness in relation to other biomass-based fuels and fossil fuels). So far, the market potential of *Salix* has been 15 to 30 times lower than the estimated potentials during the 1990s. This gap may, however, decrease in the future if the various barriers hampering the expansion are gradually reduced.

2.3 Conclusions

The major message in this report is to have realistic expectations on future market potential of biomass for energy from forestry and agriculture. There are a number of limitations that will make the amount of market available biomass considerably less than theoretically available biomass, and the type of limitations will vary depending on the category of biomass resource. The theoretical potentials are based on estimates of evidently existing biomass (harvest residues) following forestry and agriculture or estimates based on assumptions on available land and annual yields of dedicated energy crops grown on that land in the future (Figure 12).

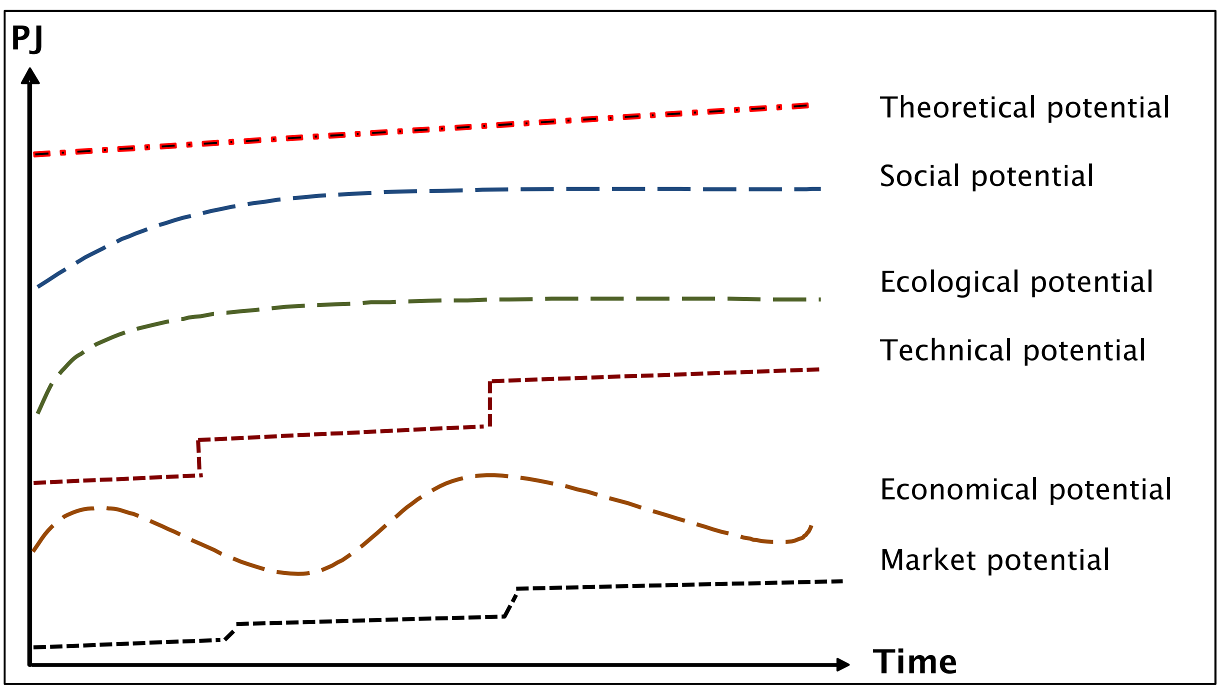


Figure 12. Schematic figure illustrating that the potential market available biomass for energy due to social, ecological, technical, and economical limitations, is far below the theoretical potential.

The *theoretical potential* is typically based on two principally different biomass estimates. The first one is estimates of existing biomass like residues following harvest or residues that appears during refinement of the main crop in ongoing forestry and agriculture and their refinement industries. The second one is estimates of currently non-existing biomass, primarily from dedicated energy crops in agriculture or short-rotation forestry, that is assumed to be grown in the future based on assumptions on available land, soil fertility, and annual yields. Both of these resources have their limitations that have to be considered in realistic estimations of the market biomass potential.

Examples of *social limitations* that will reduce the theoretical biomass potential of existing biomass is stump biomass following harvest within the reindeer herding areas (Kivinen et al., 2010) or close to urban areas. Forest owners could also be reluctant to deliver biomass for energy because it is a low priced commodity and they may be of the opinion that the biomass and its nutrients are needed in the forest to sustain long-term timber production (Thiffault, et al., 2011). Social limitations for currently non-existing biomass like *Salix* includes attitudes from the public, often linked to changes in the visible features of the landscape, and the landowners that often are more familiar with other crops or satisfied with current extensive use of their potentially available arable land.

There are a large number of *environmental limitations* with the potential to reduce the theoretical biomass potential (cf. Lattimore, et al., 2009; Walmsley & Godbold, 2010). These include effects of increased biomass production and harvest on the physical, chemical, and biological status of the soil and thereby on future site productivity. There are also potential negative effects on surrounding water ecosystems and ground water, and on the biological diversity, that will put limits on production and harvest intensity. As one important selling point for bioenergy is that it is close to climate neutral some biomass will be classified as inappropriate due to poor greenhouse gas performance. Concerns about the environment may also limit the possibilities to optimize biomass production by means of genetically improved plants including GMO, exotic tree or plant species, and intensive fertilization regimes.

Technical and economical limitations are tightly linked together. The economy of the operation, with or without subsidies or environmental taxes on alternative non-renewable, energy sources, sets the final limit for market available biomass. Typically a lot of existing biomass potentially available for energy purposes in forestry and agriculture is left in the field because it is not economically feasible to procure. This is because the biomass is a low priced, bulky commodity, distributed over large areas, often far away from the end-user. Furthermore, the harvest technology in forestry and agriculture is developed for the main crop i.e. stem-wood or grain. Technical development of harvest technologies including biomass for energy (branches, stumps, straw, *Salix* etc.) has the potential to increase market available biomass for energy. But again, biomass for energy is a low priced commodity, meaning that economic incentives for more pioneering technical development are low. Therefore it is reasonable to expect a moderate technical development in the near future. Harvest efficiency with current technology still has the potential to improve over time simply by making small improvement along the procurement chains. This includes logistics, small technical improvements, and improved skill of all the operators involved (Junginger et al., 2005). Global market growth for biomass will also have a positive effect on the incentives for technical development. If, for example, *Salix* production starts to expand in Sweden and elsewhere, scale effects from an increased cultivation area will reduce production costs. Another reason is the prospects for learning where future developments in plant breeding, cultivation practice and machinery for *Salix* can be expected to lead to reduced production costs. Both the expanded cultivation and learning can also be expected to lead to reduced risk premium requirements of farmers, as experience and increased knowledge about *Salix* cultivation leads to reduced uncertainties in relation to aspects such as plant diseases, end use markets, and cultivation technology.

The economy in biomass operations also depends on the price for the energy alternatives and the prevailing energy policies including subsidies and environmental taxes on the alternatives. This also includes policies and subsidies for alternative land use or alternative crops – particularly in agriculture (Ericsson, et al., 2004).

This knowledge about the various limitations in biomass potentials and evaluation of realistic market biomass potentials is crucial for investors within the bioenergy sector. This knowledge is also important for policy makers in the development of efficient policy tools and incentives to promote environmental, social and economically sustainable biomass supply systems.

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