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INHERENT PROPERTIES OF SCOTS PINE FOREST RESIDUES HARVESTED IN SOUTH NORWAY

Forprosjekt med forslag til videre arbeid



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NIBIO – Norsk Institutt for bioøkonomi and Sintef Energy research

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SUMMARY:

Biomass from forestry sector is able to provide an important contribution to meet the government's targets for increasing bioenergy use. Traditionally it has been stem wood which is used as raw material for energy. For a deeper understanding of trees, knowledge is required not only of the stem wood, but also of the branches and tree tops. Research complex on Norway's industrially important

tree species - Scots pine (*Pinus sylvestris L.*) forest residues (stem wood, stem bark, branches, top of trees) moisture content, basic density and effective heating value were analysed in 2 sampling plots, depending on site index quality in South Norway forest. The vertical dependence of bark proportion was observed. The pattern was similar for both site indexes, lower bark content in the bottom part of stem, slightly increasing approximately to 35 % of the tree height and so increasing towards the tree top. The vertical dependence of bark thickness of Scots pine trees showed an increasing trend towards the top. Bark was significantly thicker near the base than near the top. Bark proportion may be a relevant aspect for the utilization of Scots pine forest residues as potential biomass feedstock. Considerable variations in qualitative properties between stem wood, stem bark and branch wood of Scots pine along the stem were observed. The basic density of stem wood was in range 308.2-418.3 kg/m³, of stem bark 265.1-364.2 kg/m³ and of branch wood 400.5-579.2 kg/m³. The basic density of stem wood was higher in the lower part of stem, vertically decreasing towards to tree top. Contrary, the basic density of stem bark decreased to 40 % height and then slightly increasing again towards the top. The axial dependence of basic density in stem bark was different than the one in stem wood, more regular. Branch density decreased moderately within the axial direction along the crown. Scots pine branch wood examined in this study was denser in the bottom part crown towards less denser branches positioned in the top crown section. More else a clear variation pattern was apparent in basic density variations along the branch. Density declined from the branch base outward first rapidly and then levelled. The highest basic density was found for the branch base. There was not found relationship between basic density of stem wood, stem bark, branch wood and site index quality of stands. The average moisture content of stem wood and stem bark harvested in early spring season increased axially from the base toward tree top, within significantly more pronounced variations on the tree base compare to tree top. Stem bark had relatively higher moisture content compare to stem wood. The moisture content in stem wood was in range 39.9-90.2 %, in stem bark 42.8-94.3 % and in branch wood 43.5-62.8 %. The effective calorific value of stem wood was in range 5.09-5.40 kWh/kg, of stem bark 5.11-5.51 kWh/kg and of branch wood 5.16-5.49 kWh/kg. The vertical dependence trend of effective calorific value for Scots pine stem wood was similar to that for stem bark. Regular decreasing pattern towards the top was observed. We observed significantly higher calorific value at level $p < 0.05^*$ in stem bark than in stem wood. Elevated effective calorific value of stem bark and branch wood make these materials a valuable industrial energy source for bioenergy in Norway.

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PROSJEKTLEDER / PROJECT LEADER

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PREFACE

Biomass from forestry sector is able to provide an important contribution for increasing bioenergy use. The amount of wood of adequate quality for industry is continually decreasing. Therefore, it is necessary to use it more efficiently. The complete tree concept offers a tremendous opportunity for forestry to meet the future industrial demands. Besides stem wood also branch wood with bark, and unmerchantable part of trees, i.e. logging residues, could be used to ensure the forest balance and re-open the possibilities of industrial expansion.

The Norwegian Institute of Bioeconomy Research (NIBIO) was chosen to direct the “Inherent properties of Scots pine forest residues harvested in South Norway” project. A project council subordinated to the Bioenergy Innovation Center (CenBio) was set up to supervise the work. The study is being conducted within the framework program approved by The Research Council of Norway.

The right knowledge about the forest biomass quality can improve the forest-based bioenergy sector and will result in its increased and more efficient use. To analyse Scots pine fuel-wood production there is a need to determine the difference in qualitative properties of raw material. The research results on Scots pine (*Pinus sylvestris L.*), obtained during the early spring period in 2014 are outlined in this report. This study concerns the selected geographical location of Scots pine forest residues properties in South Norway, one of the most valuable tree species from the viewpoint of bioenergy use in Norway. The most important fuel qualitative properties of stemwood, stem bark, branches and tree tops were investigated in order to know the potential of raw material properties available for bioenergy use in Norway.

The material was collected from two forest stands located in South Norway, specifically from Hobøl in 2014 under the direction of Simen Gjølsjø, Eirik Nordhagen and with the practical help of Louis König, Hans Petrat and Thor-Erik Vatne Alstad. Most of the laboratory work and calculations was done by Eva Grodås and Monica Fongen from the Norwegian Institute of Bioeconomy Research. Valuable help and counsel in the course of the research work were received from many other persons.

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Ås, August 2015

Janka Dibdiakova

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1 INTRODUCTION

1.1 Forest biomass for bioenergy use in Norway

Forest land and forest biomass have been given more focus in recent years as a result of the discussions regarding climate change issues and the understanding of forests as an important factor in mitigating climate change. It is a political goal to replace fossil fuels with renewable energy sources, and the current goal is to have a carbon-neutral energy supply in Norway by 2030 (Miljøverndepartementet, 2010; Trømborg, 2011). To achieve this goal, several sources of renewable energy, such as wind, geothermal, wave, hydro, solar and biomass must be utilised. The target for bioenergy is to increase the Norwegian annual consumption of biomass by 14 TWh by 2020 (LMD, 2009).

About 40 % of the Norwegian main land is covered by forest (Granhus et al., 2012). The total forested area in Norway amounts to almost 11 million hectares (ha), of which more than 8 million ha are productive forest (Granhus et al., 2012). Approximately 15 % of the productive forest has been estimated as non-profitable areas due to difficult terrain and remoteness, which means that cost-effective forestry, may only be performed in about 60 % of the forested area (Eid et al., 2002). Trømborg and Leistad (2009) have reported that there is technically potential for the forestry sector to increase bioenergy use in Norway to 39 TWh per year.

Forest contributes to the reduction of CO₂ content in the atmosphere by sequestering CO₂ from the air and binding it as organic carbon through photosynthesis. When biomass from forest is used for bioenergy production, the bound CO₂ is released back into the atmosphere (Timmermann and Dibdiakova, 2013). When bioenergy is used at sustainable rates, the CO₂ binding in the forest will compensate for the CO₂ released during combustion (Zanchi et al., 2010). Establishing new forests can contribute to reducing the CO₂ content in the atmosphere (Parigiani et al., 2011).

Conifers dominate in Norwegian forests. About 45 % of the total standing volume consists of the Norway spruce (*Picea abies* (L.) Karst.) as the dominant tree species in most regions in Norway and 30 % of Scots pine (*Pinus sylvestris* L.) as the second most important tree species. Birches (*Betula spp.*), the most common hardwood species in mountainous areas and in northern Norway, represent 16 % of the standing volume (Granhus et al., 2012).

Biomass from forestry sector is able to provide an important contribution to meet the government's targets for increasing bioenergy use. Traditionally it has been stemwood which is used as raw material for energy. The total amount of stemwood available for bioenergy in Norway is estimated to be 9 TWh per year (NVE, 2010). With the increasing demand for fuel the use of other tree components like branches and tree tops has increased rapidly. The potential amount of energy obtained from logging residues and thinning whole trees is estimated to be approximately 3.5 TWh per year for each source. This can even increase to 1.5 TWh per year if logging residues are utilized at reasonable level (Filbakk, 2012).

For a deeper understanding of trees, knowledge is required not only of the stemwood, but also of the branches and tree tops. The very right knowledge about the forest residues biomass quality can improve the forest-based bioenergy sector and may result in its increased and more efficient use. To analyse Scots pine fuel-wood production there is a need to determine the difference in

qualitative properties of raw material. This study concerns the selected geographical location of Scots pine (*Pinus sylvestris L.*) forest residues in South Norway. The most important fuel qualitative properties of the stemwood stem bark, branches and tree tops were investigated in order to evaluate potential raw materials available for bioenergy use in Norway.

1.2 Qualitative properties of tree biomass

The wood properties of a tree are a combination of its genetic make-up and the environment that it is grown in. There is therefore considerable scope to improve the wood properties of Norway spruce, through both tree breeding and forest management (Hubert and Lee, 2005). Because individual wood properties differ in the extent to which they are under environmental or genetic control, climate, soil, slope, forest density, disease, wildlife and other, the approach taken to improve these individual properties also differs (Repola, 2006). Much of the previous work in this area has focused on the relations between site factors and tree growth (Blyth and Macleod, 1981), while Worrell and Malcolm (1990a, b) found that yield class declined with increasing elevation and was associated with indices of temperature and windiness. Trees growing at higher elevation sites and with increased wind exposure also tend to have poorer form. This is probably due to higher level of leader loss and meristem desiccation in more wind exposed locations (Grace, 1989; Baldwin, 1993). Poor stem form not only reduces the yield of timber material that can be obtained from a stand but is also associated with a higher incidence of compression wood and a higher grain angle (Spicer et al., 2000).

While it is known that the environment is likely to have a considerable effect on the wood density of Scots pine, few studies have actually quantified the inter-site variation in wood density. Bryan and Pearson (1955) found that wood density declined by approximately 10 kg/m³ for every one degree increase in latitude. Based on study by Repola (2006), it was found that latitude alone accounted for approximately 23 % variation in wood density, with a decrease in density of 7 kg/m³ for every one degree increase in latitude. Interestingly, there is a stronger relationship between wood density and longitude ($R^2=0.37$), with sites in the east Scotland having higher density than those in the west. Preliminary results presented by Vihermaa (2010) indicate that average density decreases by approximately 7 kg/m³ for every 100 m increase in elevation.

For the potential industrial utilization of forest biomass are the most important properties basic density, moisture content, and effective heating value.

1.2.1 Study aim

The aim of this study was to clarify the most important wood properties and quality of Scots pine (*Pinus sylvestris L.*) forest residues harvested in South Norway. The wood properties – basic density, moisture content and effective heating value of stem wood, stem bark, and branch wood of Scots pine were examined as well as the differences in quality properties between two different site indexes in selected geographical location. Vertical variations of properties along the stem and along the branch were investigated additionally. This research presents some preliminary results of selected wood properties of Scots pine tree parts, which mostly affect the usability of raw materials for bioenergy use in Norway as well as characteristics and quality of forest-fuel sources.

1.2.2 Biomass components of tree

Knowledge of the distribution of biomass into its main components in an individual tree is the basis for quantitative and qualitative evaluation of forest biomass. The merchantable stem of trees is the main product of forestry. However, for a deeper understanding of the behaviour of forest trees, knowledge is required not only of the stem, but also of the crown and root system. The tree components dealt with are stem, merchantable stem, top, foliage, branches, crown, stump and roots. The components may be broken down further to wood, bark, and foliage fractions (Hakkila, 1989).

Unmerchantable top of stem, henceforth usually simply top, is defined by local logging practice. The bottom diameter of the tree top may vary from 5 to 20 cm.

Branch mass includes all wood and bark of live and dead branches but is free of leaves, shoots, and reproductive organs of a tree. Branch mass is often divided into size classes by diameter, but class division varies from study to study according to conditions.

Foliage includes all leaves and new shoots of branches. Reproductive organs are normally also included in foliage mass.

Crown is defined as all live and dead branches plus all foliage and reproductive organs. However, in many reference studies dead branches are excluded.

Stump is the unutilized above-ground biomass below the bottom of the merchantable stem, and its under-ground projection, excluding the lateral roots.

Roots include all side or lateral roots but exclude the taproot, which is a part of the stump as a natural elongation of the stem. Like branch mass, root mass may also be divided into subclasses by diameter.

Presented study primary focused into qualitative properties of stemwood, stem bark, tops and branches of Norway spruce. Corresponding properties of stumps and roots biomass were beyond the study's aim.

The proportion of the branch mass differs considerably between tree species (Hakkila, 1989, 1991). There are also considerable variations in the branch mass between and within stands of the same species (Hakkila, 1991). Therefore, the profitability of utilising forest residues may vary significantly between stands.

The qualitative properties of whole trees and logging residues are less homogenous than are those of wood. This difference is due to the large differences in the chemical composition of wood, bark and foliage and to the fact that the contents of the different tree parts vary considerable between sites.

1.2.3 Basic density of tree biomass

The density of wood is defined as the dry mass per unit volume, usually in kg/m³. It is a property that is widely studied because is correlated with a number of other physical and mechanical properties.

A number of different definitions of wood density are possible based on the moisture content at which the mass and the volume of the sample are determined. For wood processing industries, the

main interest is usually how much dry material is in a cubic meter of fresh wood. This is given by the basic density. Basic density is calculated on the basis of both the mass and volume of the biomass measured at the same moisture content as received (Hakkila, 1989). The average wood density is affected by a large number of factors such as tree species, geographical location and other environmental factors, site quality, position of the tree in a stand, tree age and size, growth rate and genetic factors (Hakkila, 1966).

1.2.3.1 Variation within a tree

Wood density varies considerably within a tree in both the radial and longitudinal directions.

Radial variation. The radial variation from pith to bark is of great significance in wood utilization. In the juvenile core, wood density decreases from a maximum close to the pith down to a minimum value at between rings 10 and 20, before increasing again towards a quasi-asymptotic value in the mature wood (Mitchell and Denne, 1997; Simpson and Denne, 1997; McLean, 2008). Elliot (1970) attributes the high density observed in the innermost rings to short, small diameter fibres resulting in an increased number of cell walls per unit volume of wood as well as the increased occurrence of compression wood in this region. This radial variation of wood density causes further variation in the axial direction of the stem.

Longitudinal variation. The longitudinal variation in Norway spruce wood density is not as consistent as the radial variation. Some studies have reported a lack of systematic variation in wood density with height up the stem (Jones, 1957; Elliot, 1966), while others have reported a slight decrease (Harvald and Olese, 1987; Mitchell and Denne 1997). Within a growth sheath (layer of wood formed in the same year or years), Simpson and Denne (1997) found that there was a decrease in wood density from the base of the tree up to approximately eight annual growth units from the top, followed by a large increase in density above this height. This decrease is affected by changes in ring width and, above all, the presence of juvenile wood. Some conifers, especially spruces, show only a slight axial variation in wood density. The longitudinal variation in bark density does not necessarily follow the same pattern as the wood density in the same species. For example, data from Tamminen (1962) show for *Picea abies* bark a constant decrease in density from butt to top. The density range is considerable wider in bark than in wood. The densest bark is often found at the tree top and the difference in the basic density between butt and top barks may exceed 100 kg/m³.

Wood density also varies in branches biomass. Since conifer branches contain large proportions of compression wood which occurs on the lower side of the cross-section, wood is significantly denser on the lower portion of the branch. Timell (1986) reviewed several studies of within-branch density variation in conifers, the lower branch portion usually having 10-40 % higher wood density than the upper one. A clear variation pattern is apparent in wood density along the branch. The density declines from the branch base outwards first rapidly, then levels, and may even turn to a slight increase toward the tip.

Wood density indicates the quality of biomass fuel. Heating value is directly proportional to the wood density. The energy content of a unit volume of wood, bark or foliage depends principally on its dry mass and moisture content and, to some extent, on the cell wall composition and content of extraneous components.

1.2.4 Moisture content of tree biomass

In addition to chemical components (cellulose, hemicelluloses, lignin and extractives), wood contains water. This water can exist as absorbed (or free) water in the cell lumens and intercellular spaces, or as adsorbed (or bound) water within the cell walls. The moisture content of wood is calculated as the ratio of the mass of water to the mass of wood that has been oven-dried and is usually expressed as a percentage. Because of this definition, moisture content values exceeding 100 % can and do occur. The moisture content of Norway spruce sapwood is typically in excess of 120 %, while in heartwood it is typically between 40 and 80 %. The average whole-tree moisture content typically ranges from 100 to 160 % (Jeffers and Dowden, 1964).

The moisture content is the main fuel factor affecting combustion efficiency. Moisture content of biomass varies between species, between trees, within a tree, and during the season. In a live tree, the moisture content increases from stem base to stem top and from branch base to branch top, and is generally highest in foliage. Moisture content of conifers is highest during the dormant season and the moisture of hardwoods is at its highest in the spring just before the leaves appear, then drops below the annual average after bursting into leaf, and rises again in the autumn to the higher winter level (Hakkila, 1989).

On the average, approximately one-half of the total mass of a living tree consists of water. However, moisture content varies widely from species to species, from tree to tree within a species, among tree components within a tree, and from week to week or even day to day depending on season, weather conditions, and storage of biomass. Differences in moisture content between species occur partly due to their differences in the basic density. The moisture content decreases with increasing basic density if the amount of water per unit volume of biomass remains constant (Phillips et al., 1976; Hakkila, 1989). The moisture content of Scots pine is significantly higher than that of Norway spruce, partly a result of differences in the basic density of the pine wood. In both species, the moisture content of wood decreases and that of branch bark increases with diameter. Particularly high moisture content in bark is probably because bark is mainly composed of phloem (Hakkila, 1989).

The moisture content of newly-felled trees tends to be too high for efficient combustion and utilization of boiler capacity. Increasing attention is being paid to the moisture content to wood as a cost factor in forest fuels heating plants. In addition to the average moisture content, uniformity of moisture is another crucial quality factor, as irregular variation makes combustion control difficult and results in loss of efficiency (Loo and Koppejan, 2002; Obernberger et al., 2006).

1.2.5 Calorific value of tree biomass

The calorific value (or heating value) of wood is the amount of heat released during the combustion of a specified amount of it and is an important property for assessing the biomass energy resource. For the purpose of the technical specification two different terms apply for the calorific value (CEN/TS 14918, 2005).

The higher calorific value (gross calorific value) explicates the total amount of heat released from the fuel during combustion under a constant volume. When determining the higher heating value, all of the combustion products are returned to the pre-combustion temperature. The higher calorific value is independent of the sample moisture content. This heating value also includes the

heat released from the condensed vapour produced from the bound and free water and hydrogen combustion in the wood. The higher calorific value, usually determined using a bomb calorimeter is expressed as the energy units per dry matter units of substances, e.g., MJ/kg (CEN/TS 14918, 2005).

The lower calorific value (net calorific value/effective calorific value) is calculated by subtracting the heat of vaporisation of all of the water vapour from the higher calorific value (CEN/TS 14918, 2005).

From the practical point of view, in many heating plants, the condensation energy from the water vapour is not utilised; therefore it is often more useful to determine the lower calorific value. The moisture content (MC) (%) and the effective calorific value (W_{ea}) (MJ/kg) of the dry biomass affect the effective heating value of the biomass with given moisture content (W_{em}) (MJ/kg) according to Equation (1) (Hakkila and Parikka, 2001):

$$W_{em} = W_{ea} - 2.45 \times (MC) / (100 - MC) \quad (1)$$

The calorific value not only varies with the moisture content but also with the amounts of different chemical compounds and the element composition of the fuel. In forest fuels, the dry matter consists of 48-52 % carbon, 6-7 % hydrogen, 38-42 % oxygen and 0.5-5 % ash and nitrogen (Hakkila, 1989). Only carbon and hydrogen contribute to the heating value, whereas oxygen, nitrogen and the inorganic ash elements do not. Energy is released according to the following equations (Equation 2 and 3) (Hakkila and Parikka, 2002):



Holocellulose (hemicelluloses, cellulose) and lignin are the main chemical compounds in all tree parts. Compared to other compounds of biomass, cellulose and hemicelluloses are richer in oxygen but poorer in carbon and hydrogen. Consequently, they contain less thermal energy (Hakkila, 1989). The calorific values of cellulose and hemicelluloses are approximately 17-18 MJ/kg and 16-17 MJ/kg, respectively (on a dry mass basis). Lignin has a higher calorific value of 25-26 MJ/kg. In addition, trees also contain extractives, which have calorific values of 33-38 MJ/kg (Kollmann and Cote, 1968). Because the proportions of different chemical compounds vary between trees and parts of the tree, the calorific values also vary. The effective heating values of different parts of the tree are given in Table 1.

Table 1. Effective calorific values (MJ/kg dry weight) at 0 % moisture content of the different parts of tree for some tree species (Nurmi, 1993, 1997).

Tree part	Scots pine	Norway spruce	Downy birch	Silver birch	European aspen
Stem	19.532	19.163	18.571	18.417	18.430
Branches	19.989	19.300	18.644	18.568	18.812
Stumps	22.362	19.175	18.613	18.500	18.319
Roots	19.324	19.334	18.590	18.503	18.298
Foliage	21.004	19.951	19.360	19.761	19.854
Bark	20.302	20.002	21.033	21.422	19.219

Stem wood from conifer trees has higher heating value than does stemwood from broadleaved trees. Stem wood from Scots pine has the highest calorific value (19.5 MJ/kg) of the tree species presented in Table 1. The stem wood from the broadleaved has a calorific value of approximately 18.5 MJ/kg. The higher calorific value found in conifer trees is due to their somewhat higher lignin and extractive contents. Nurmi (1993, 1997) also found that the differences in the calorific values between the different parts of tree were greater than the differences between species. For example, the branches have higher calorific value than does the stem wood in most tree species investigated. The bark generally has an even higher calorific value due to the high concentration of extractives and lignin.

In Table 1, moderate differences in the calorific values between the stem wood from different tree species can be seen. In contrast, there is a large difference in the basic density between the tree species and tree parts, and this difference results in large differences in the heating value per unit volume. Among the common Norwegian species, the Downy birch and oak have high densities, whereas the Norway spruce, European aspen and Goat willow have relatively low densities (Tretetknisk, 2003). The Norway spruce branches have considerably higher densities than the stem wood, whereas the bark in general has a lower density compared to the stem wood of the Norway spruce and the Scots pine (Hakkila, 1989). There are also considerable density variations within individual trees; both between different trees in the same stand and between trees from different sites (Skovsgaard et al., 2011). Because the variations in wood density are considerably larger than the variations in the calorific values, the energy content per volume is predominantly related to the density and not to the calorific value. The energy content per unit dry weight of wood varies considerably less than does the per volume energy content.

2 MATERIAL AND METHODS

2.1 Study sites

Samples of Scots pine (*Pinus sylvestris L.*) trees were selected from one geographical location in South Norway, from east part (Hobøl), Figure 1. The study material was obtained from trees harvested in the early spring season in 2014 (March-April), carried out by the Norwegian Forest and Landscape Institute.

The material consisted of 2 stands of Scots pine tree species in South Norway, Figure 1. The selection of geographical location was based on the specific site altitudes, latitudes and longitudes. Both stands were characterized by representing site indexes. Site indexes represented the low and high forest quality. Selected geographical location is natural growing forest site corresponding to sites typical for Scots pine in Norway (Cajander, 1949).

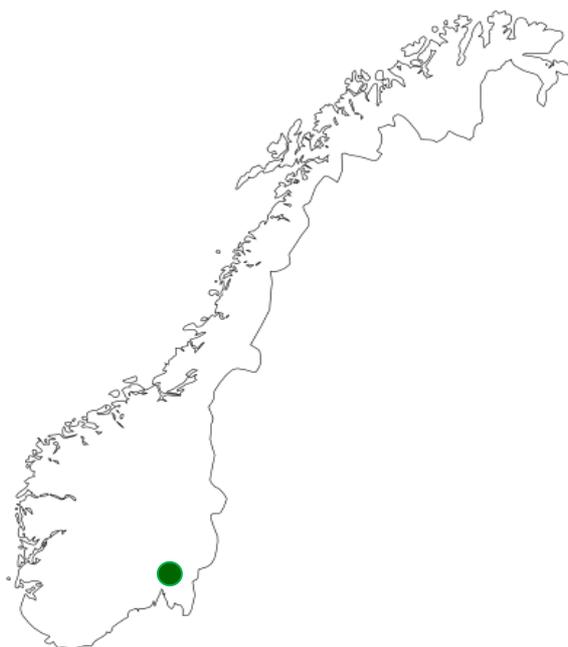


Figure 1. Geographical location of the collected Scots pine trees in South Norway (green dot).

The forest stands of Scots pine located in the eastern part of South Norway illustrates Figure 2 and Figure 3.



Figure 2. Scots pine forest of the site index 17 located in Hobøl (S1).

Figure 3. Scots pine forest of the site index 11 located in Hobøl (S2).



2.2 Sampling procedure

After taking into consideration a number of factors (such a site index quality, simplicity and crown level), in order to minimize the sources of errors, sampling was carried out in the same way in all locations. The representative area of each site (radius 12 m) was labelled, and 30-35 trees were registered with their diameter at breast height (DBH). Trees were grouped into 3 diameter classes, and one tree was selected for each diameter class. After these trees have been felled their height, DBH and crown ratio were measured. The age was recorded.

Each felled tree was divided into three crown levels (bottom, middle, top), based on the corresponding tree height, Figure 4. The crown base was defined to be the lowest living branch towards to tree top. One branch whirl was selected from the bottom crown level, one from the middle and one branch whirl from the top crown level. From each branch whirl three branches including the needles were randomly cut. The number of branch whirls within each crown level was counted. The diameter of branch was measured as an average in the horizontal direction in bottom, middle and top crown level. The cut branches were weighed fresh in the field.

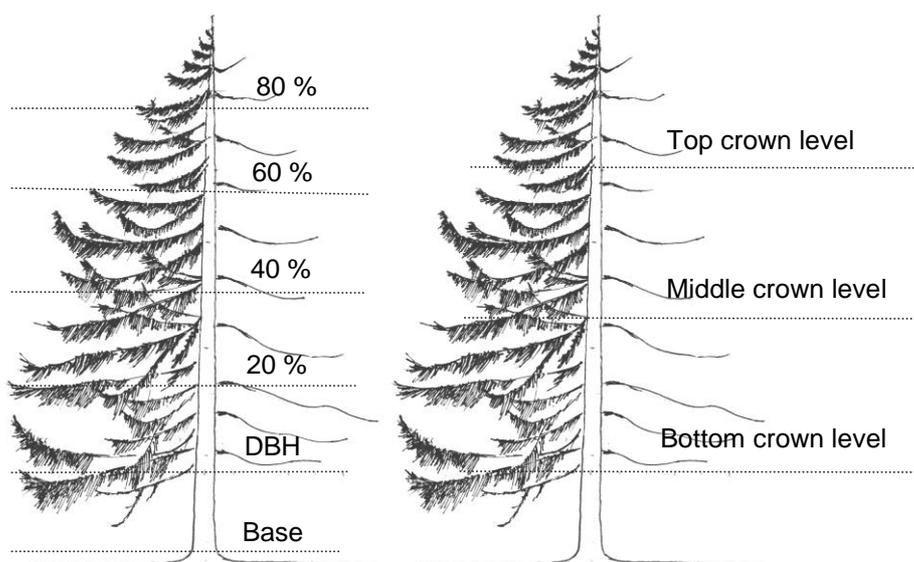


Figure 4. Illustration of the stem level (left) and crown level (right) divisions (Hakkila, 1989).

Cross-sectional discs, 5 cm thick, were cut from each tree in the vertical direction of the stem at given height levels (base, DBH, 20 %, 40 %, 60 %, and 80 %). The stem discs and branches in both Hobøl forest stands were harvested on cool, sunny days in late March, early April 2014. As the samples of stems and branch wood were cut they were placed in sealed plastic bags and kept frozen prior to the measurements in the laboratory.

2.3 Measurements

For the measurements of basic density, moisture content, chemical composition, calorific value and ash content, 5 cm thick wedges were sawn from the sample discs. The wedges were debarked while they were fresh. Branch samples originated from each crown section were cut in 4 segments, one sample being cut at the branch base, in the middle, at the top, and twigs samples including needles,

Figure 5. All four branch segments, which were of approximately the same length of 10 cm, were from the same branch, thus all represented the same age range of tissues and were nearly alike anatomically. The wedges were used to define the basic density and moisture content of the wood and bark separately. Collected branches were not debarked, therefore were investigated with their corresponding bark content.



Figure 5. Branch segment of the collected Scots pine branch samples.

2.3.1 Basic density

The basic density (ρ_k) of all samples expressed as an oven dry mass of sample divided by its green volume was calculated using the Equation 4:

$$\rho_k = m_o / V_{\max} \quad (4)$$

where:

ρ_k is the basic density, (kg/m³)

m_o is the weight of the material at MC = 0 %, (kg)

V_{\max} is the maximum volume of material (MC \geq fibre saturation point), (m³)

The wood volume determination was made with a modified version of the water displacement method (Olesen, 1971). The samples of stem wood, stem bark, and branch wood separately were first soaked in water for a 48-hour period and were performed to ensure that the cell lumens were saturated with water and would not soak up water during the ensuing submersion. After placing 10 L of water in a container, on an electronic balance (1 g) it was tared. Immersion of a sample just under the water surface was done by hand with a needle, assumed to have negligible volume, attached to the sample, Figure 6. Then samples were dried with filter paper. Dry mass was

determined on an electronic balance (1 g) immediately after drying in an oven at 103 ± 2 °C to constant weight, which took 1-2 days. Finally the obtained results were processed with standard statistic methods.

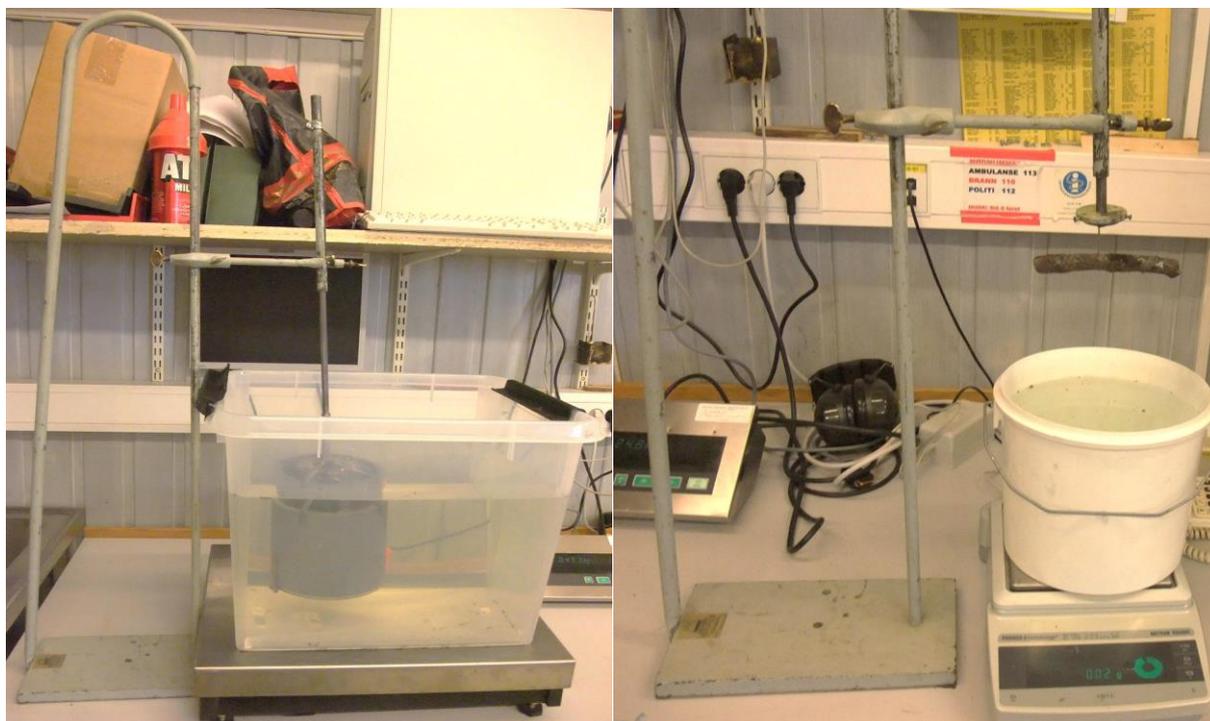


Figure 6. Equipment used for the basic density measurements of the twigs (left) and of the stem wood, stem bark and branch wood (right).

2.3.2 Moisture content

The moisture content M_{ar} of the samples, as received, expressed as a percentage by mass, was calculated according the CEN/TS 14774-1 (2004) using the Equation 5:

$$M_{ar} = (m_2 - m_3) + m_4 / (m_2 - m_1) \times 100 \quad (5)$$

where:

m_1 is the mass of the empty drying container, (g)

m_2 is the mass of the drying container and sample before drying, (g)

m_3 is the mass of the drying container and sample after drying, (g)

m_4 is the mass of the moisture associated with the packing, (g)

The samples of wood, bark and branches separately were dried at a temperature 103 ± 2 °C until constant mass and the percentage moisture was calculated from the loss in mass of the samples, Figure 7.



Figure 7. *Termaks* drying oven used for the moisture content measurements of samples.

2.3.3 Bark proportion and bark thickness

Bark was removed from the fresh wood cross-sectional discs using a peeler knife and weighed separately. The thickness of removed bark was measured with a digital caliper *Mitutoyo* 500-181 in five places and the mean thickness was determined. Both wood and bark samples were oven dried until constant weight and then the dry weight was determined. Bark proportion in each sectional disc was calculated as percentage of the total weight of the cylinder for fresh and dry weight. A non-linear regression model was used to study the relationship between the bark percentage and tree height.

2.3.4 Calorific value

The gross calorific value of a solid biofuels at constant volume and at the reference temperature 25 °C in a bomb calorimeter by combustion of certified benzoic acid was determined according the CEN/TS 14918, 2005.

The samples used for the determination of calorific value were grounded to pass a test sieve with an aperture of 1.0 mm particle size. Due to the low density of solid biofuels they were tested in a pellet form. A pellet of mass 0.7 g was pressed with a suitable force to produce a compact, unbreakable test piece. Produced pellet samples were burned in high-pressure oxygen atmosphere in a bomb calorimeter. The effective heat capacity of the calorimeter was determined in calibration experiments by combustion of certified benzoic acid under similar condition. Water was added to the bomb initially to give a saturated vapour phase prior to the combustion, thereby allowing all the water formed, from the hydrogen and moisture in the sample, to be regarded as liquid water.

The results obtained from the calorimeter, Figure 8, were the gross (higher) calorific value of the analysed samples at constant volume with all the water of the combustion products as liquid water.

In practice, biofuels are burned at constant (atmospheric) pressure and the water is either not condensed (removed as vapour with the flue gases) or condensed. Under both conditions, the operative heat of combustion to be used is the net calorific value of the fuel at constant pressure.

The gross calorific value was calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the fuse and for thermal effects from side reactions such as the formation of nitric acid.

The effective calorific value at constant volume of samples was obtained by calculation from the gross calorific value at constant volume determined on the analysis sample according the equations stated in CEN/TS 14918, 2005. The results were reported as the mean of duplicate determination to the nearest 0.1 %.



Figure 8. Automatic Isoperibol Calorimeter 6300 (left) and its oxygen combustion bomb (right) used for the calorific value measurements.

2.3.5 Statistical analyses

Both ANOVA and non-linear regressions were performed using JMP version 9.0 software. One-way ANOVA was used to test whether or not there were differences in qualitative properties of Scots pine biomass vertically in sectional discs and in branches axially towards top crown. Subsequently, differences of investigated properties within geographical locations of sites in South Norway were compared using the same procedure. The results were carried out using the F-test to verify the significant variation to the level of 95 %. In addition Microsoft excel 2003 was used for statistical measurements.

3 RESULTS AND DISCUSSION

The most important part of this research was to investigate the differences in qualitative properties of Scots pine biomass (stem wood, stem bark, branch wood, twigs and tree tops) originated from one geographical site in South Norway. It was expected that if significant differences in properties could be observed, it should be possible to link these differences to the origin of the geographical location and the corresponding site index quality. The following chapters provide the most important discoveries about the bark proportion and bark thickness, basic density, moisture content and effective heating value of Scots pine forest residues.

3.1 Forest sites characteristics

The total overview about the characteristics of sampled trees is given in Table 2. A striking feature in the material is the high age of the trees in Hobøl sites, more than one hundred years on an average for site S1. This was partly because only trees marked for cutting were taken and due to the over-aged trees in this location.

Table 2. Site characteristics of the collected trees of Scots pine.

Tree part	Site index H40 ^a (m)	Latitude	Longitude	Elevation a.s.l. ^b (m)	No. trees ^c	Height (m)	DBH ^d (cm)	Age	Crown ratio ^e (%)
S1 Hobøl	17	59°43'N	10°52'E	101.9	3	18	23	108	53
S2 Hobøl	11	59°93'N	10°78'E	102.6	3	15	18	76	47

^a Dominant height at the age of 40 years

^b Above sea level

^c Number of felled trees

^d Diameter of tree at breast height (1.3 m)

^e Calculated as the crown length (m) of tree divided by its height (m)

The crown ratio indicates the height of the living crown in per cent of the total tree height. The average crown ratio of sampled trees did vary only slightly, Table 2. For trees sampled from higher site index quality site was measured the highest crown ratio of 53 %, respectively. Contrary, lower site with the poorer site index 11 showed to have slightly lower crown ratio of 47 %. The variation in crown ratio is caused fundamentally by genetic factors and stand density in the different developmental stages of the tree (Hakkila, 1971). It can therefore be explained only fairly inadequately by means of the external tree characteristics. For instance, tree height is not correlated with crown ratio. On the other hand, the height of the lower limit of the living crown from the ground may explain two-thirds of the variation.

3.2 Bark proportion and bark thickness

For many years, bark had been an unwanted by-product of milling operations, since its disposal, typically through burying or combustion often increases the cost of operations (Haygreen and Bowyer, 1996). Bark has been used for centuries, on a small scale, for medicinal purposes, food, baskets, boats, and tannins (Small, 1884). The most basic use of bark is to produce energy and/or heat through combustion. Bark can also be used as a landscape material (Haygreen and Bowyer, 1996).

1.1.1 Bark proportion

Bark proportion has direct impact on the quality of biofuel. Besides the effect of moisture content on the heating value of fuel, high bark content increases the emissions of pollutants during the combustion process. With age, tree size increases and the proportion of bark decrease (Nygård and Elfving, 2000; Guidi et al., 2008). Furthermore, the existences of substantial differences in bark proportion in percentage for diverse DBH stems indicate the possibility to manage Scots pine plantation in order to obtain a better quality of biomass. DBHs lower than 4 cm wide may be considered a threshold under which it is not convenient, from a qualitative point of view, to descend (Guidi et al., 2008). Therefore, large DBH sized stems are preferred in order to match the requirements of high quality of feedstock biomass for energy purposes. Differences in bark proportion and bark thickness of Scots pine stem bark within corresponding site indexes are presented in Table 3.

Table 3. Average values and standard deviation of bark proportion and bark thickness of Scots pine stem bark.

Location	Site index	Bark proportion* (%)						Bark thickness (mm)					
		Tree height (%)						Tree height (%)					
		Base	DBH	20	40	60	80	Base	DBH	20	40	60	80
S1 Hobøl	17	46.0 (4.06)	41.3 (2.70)	18.7 (2.00)	13.1 (4.18)	8.94 (1.16)	7.62 (0.83)	15.2 (4.84)	11.1 (3.09)	5.55 (1.61)	3.55 (2.43)	2.52 (0.74)	2.14 (0.33)
S2 Hobøl	11	45.4 (7.14)	35.4 (3.36)	11.9 (1.67)	7.39 (0.73)	7.04 (0.24)	6.82 (0.53)	15.1 (7.17)	9.88 (2.66)	3.33 (0.81)	2.49 (0.18)	2.39 (0.13)	1.94 (0.35)

*Calculated as percentage of the total weight of the disc cylinder for fresh and dry weight.

The vertical dependence of bark proportion was observed. The pattern was similar for both site indexes, lower bark content in the bottom part of stem, slightly increasing approximately to 35 % of the tree height and so increasing towards the tree top. The bark proportion of trees did not vary significantly when the site index as a variable was added in the model, but did vary vertically at significant level $p < 0.0001^*$. The variations of bark content are the combined effect of the differing rates of axial variation of bark thickness and wood diameter. Guidi et al. (2008) found that as diameter of wood increases total bark amount of stem also increases.

3.2.1 Bark thickness

The vertical dependence of bark thickness of Scots pine trees showed an increasing trend towards the top. Bark was significantly thicker at level $p < 0.005^*$ near the base than near the top. Tree-to-

tree variations of bark thickness in relation to site index showed insignificant difference at level $p > 0.05$. The bark thickness did vary vertically at significant level $p < 0.0005^*$. Figure 9 illustrates the trend in mean values of bark proportion and bark thickness of Scots pine bark residues.

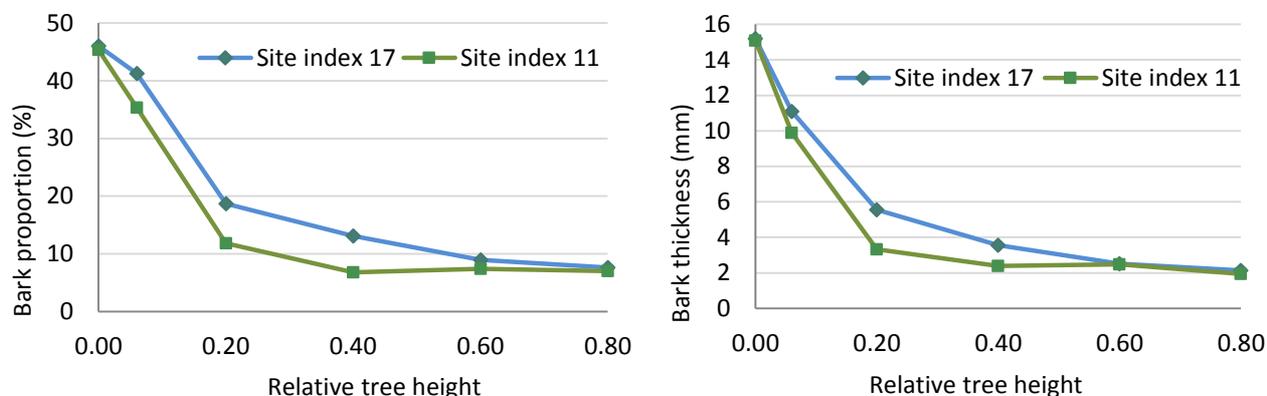


Figure 9. Trend in mean values of bark proportion (left) and bark thickness (right) of Scots pine.

We can conclude that properties such as bark proportion and bark thickness of Scots pine trees harvested in South Norway were highly linear to the tree height. Bark proportion may be a relevant aspect for the utilization of Scots pine forest residues as potential biomass feedstock.

3.3 Basic density

Information on wood basic density variation is a key factor for investigating fuel-wood quality. Next two chapters provide deeper insides about the basic density axial variations in stem wood, stem bark and branch wood of Scots pine.

3.3.1 Basic density of stem wood and stem bark

The basic density vertical variations were found within specific patterns for the stem wood and stem bark. The results obtained for the vertical dependence of Scots pine stem wood and stem bark basic density are presented in Table 4.

Table 4. Average values of basic density (kg/m^3) and standard deviations of Scots pine stem wood and stem bark along the tree trunk towards the top.

Location	Site index	Stem wood						Stem bark					
		Tree height (%)						Tree height (%)					
		Base	DBH	20	40	60	80	Base	DBH	20	40	60	80
S1 Hobøl	17	418.3 (43.5)	408.3 (6.0)	410.6 (36.5)	398.0 (18.2)	369.1 (3.4)	337.2 (19.6)	320.3 (15.2)	313.3 (11.2)	345.3 (5.5)	319.2 (3.6)	321.8 (2.5)	364.2 (2.1)
S2 Hobøl	11	416.6 (44.2)	398.4 (51.7)	378.9 (37.3)	331.4 (17.6)	317.7 (18.8)	308.2 (67.1)	296.9 (15.1)	298.1 (9.9)	288.0 (3.3)	265.1 (2.4)	299.4 (2.5)	330.1 (1.9)

Basic density of the Scots pine stem wood was in range 308.2-418.3 kg/m^3 and of the stem bark 265.1-364.2 kg/m^3 , respectively. The basic density of stem wood was higher in the lower part of stem, vertically decreasing to approximately towards to tree top. Contrary, the basic density of stem bark decreased to 40 % height and then slightly increasing again towards the top, which was

agreement with the earlier findings for Scots pine tree species (Jyske et al., 2008; Peltola et al., 2009). Lower basic density in stem wood on the tree tops can be partly explained by the presence of juvenile wood. Juvenile wood is characterized by wide growth rings and low proportion of latewood what naturally lowers basic density of raw material (Hakkila, 1989).

An axial dependence of basic density for stem bark was different than the one for stem wood, more regular, decreasing towards the top. Our results proofed lower basic density for stem bark than for stem wood, which confirms previous finding (Fearnside, 1997; Peltola et al., 2009). The vertical density gradient of stem bark in the base was roughly 6-12 % steeper to that in tree top.

Wood density depends on the geographical growing position. It has been observed that wood density increases the more southwards the tree grows (Hedenberg, 2003). For more detailed investigation of axial variations of basic density the site index and tree height variables were taken into account. Table 5 presents the p value of arithmetic mean differences of basic density of Scots pine stem wood and stem bark in relation to the site index and tree height.

Table 5. p value of arithmetic means differences of basic density for stem wood and stem bark in relation to the site index and tree height.

Location	Stem wood		Stem bark	
	Site index	Tree height	Site index	Tree height
Hobøl	p=0.4234	p=0.5078	p=0.5574	p=0.1507

Data presented in Table 5 clearly proof that the vertical basic density of stem wood and stem bark did not differ significantly (at level $p > 0.05$) when the tree height was added as a variable in our model. The site index variable did not affected basic density of none of raw materials (stem wood and stem bark). Results presented in Table 4 and Table 5 indicate that the higher site index the basic density of stem wood, as well as of stem bark is higher but not at a significant level.

Average basic density changes, could be explained by the tree age depending on the heartwood part proportion. Results presented in Table 4 show that the trees collected from the forest stand growing on the lower side index with the average age 76 years old proofed to have lower basic density then those collected from higher site index quality stand having an average age 108 years old. In our study the density estimates were based on knot-free stem discs. The wood density in knots and also around them is higher than in knot-free wood. Hakkila (1979) presented a knot correction of +1 % for the dry weight of spruce, pine and birch. This also means that a correction of similar magnitude should be applied to the average wood density in order to obtain realistic values. Wood density depends on the geographical growing position.

3.3.2 Basic density of branch wood

Branches possess a high content of reaction wood which is characterized by thick cell walls and narrow lumina (Hakkila, 1989). Compression wood contains less cellulose and more lignin than doe's normal wood (see chapter 1.2.3). As a consequence of these facts reaction wood is denser than normal wood. This fact should be taken into account in order to understand higher basic density in branch wood compare to stem wood, respectively. The average values of basic density of Scots pine branch wood are listed in Table 6.

Table 6. Average values of basic density (kg/m^3) and standard deviations of Scots pine branch wood along the crown and along the branch.

Location	Site index	Bottom crown				Middle crown				Top crown			
		Branch part				Branch part				Branch part			
		Base	Middle	Top	Twigs	Base	Middle	Top	Twigs	Base	Middle	Top	Twigs
S1 Hobøl	17	579.2 (73.1)	474.1 (45.6)	480.5 (57.5)	443.9 (77.1)	529.2 (32.0)	466.1 (34.3)	474.1 (35.2)	513.2 (76.1)	502.0 (20.3)	473.4 (37.5)	524.9 (23.6)	500.0 (61.2)
S2 Hobøl	11	497.9 (16.1)	453.6 (26.4)	472.3 (28.4)	477.3 (81.2)	463.9 (45.7)	417.7 (29.9)	413.0 (23.8)	403.5 (24.5)	400.5 (69.1)	401.1 (31.3)	402.1 (37.0)	400.3 (59.3)

Basic density of branch wood was in range $400.5\text{-}579.2 \text{ kg/m}^3$, respectively. In average, presented data show a vertically decreasing trend of basic density in branch wood along the crown. Scots pine branch wood examined in this study was denser in the bottom part crown towards less denser branches positioned in the top crown section. More else a clear variation pattern was apparent in basic density variations along the branch. Density declined from the branch base outward first rapidly and then leveled. The highest basic density was found for the branch base, in the part that is embedded in the stem by the natural growth of the tree, i.e., in knots (Hakkila, 1989; Peltola et al., 2009). The differences in branch wood density are result not only of the presence of compression wood but to a great extent also of a corresponding branch part diameter.

For more precise description of basic density in branch wood within the site index, crown level and branch part were taken into account. Table 7 shows the p value of arithmetic means differences of basic density for Scots pine branch wood in relation to the site index, crown level and branch part.

Table 7. p value of arithmetic means differences of basic density for Scots pine branch wood in relation to the site index, crown level and branch part.

Location	Site index	Crown level	Branch part
Hobøl	$p=0.0869$	$p<0.0001^*$	$p<0.0001^*$

Branch wood basic density dependence of site index did not differ significantly (at level $p>0.05$). On the other hand we found that the basic density varied significantly at level $p<0.0001^*$ vertically along the crown and at level $p<0.0001^*$ along the branch. These variations were strongly pronounced within the selected geographical locations in South Norway.

Basic density results obtained for the axial dependence, especially in the upper part of the stem, may be due to how far up the stem the last samples of wood, bark and branches were taken. In general, there is a variability of basic density among individuals of a given species, among geographical locations, with age and along stems (Wieman, 1989; Fearnside, 1997; Peltola et al., 2009). We found that basic density of Scots pine forest residues did not vary significantly among two different site indexes investigated in this study. On the other hand it varied significantly with position of branch along the crown and along the branch itself.

It can be concluded that in average the highest basic density of Scots pine was measured for branch wood, then for stem wood and the lowest one for stem bark, respectively.

3.4 Moisture content

3.4.1 Moisture content of stem wood and stem bark

At a given stem height the proportion of live tissues and sapwood in a tree biomass increases along tree trunk towards tree top, resulting in an increasing moisture content of wood and bark (Hakkila, 1989). The vertical dependence of moisture content of investigated stem wood and stem bark harvested during the early spring season is given in Table 8.

Table 8. Average values of moisture content (%) and standard deviations of Scots pine stem wood and stem bark collected during the summer season along the tree trunk from the base to the tree top.

Location	Site index	Stem wood						Stem bark					
		Tree height (%)						Tree height (%)					
		Base	BH	20	40	60	80	Base	BH	20	40	60	80
S1 Hobøl	17	42.6 (3.6)	44.6 (2.5)	47.4 (3.3)	59.6 (4.4)	77.0 (2.5)	90.2 (1.7)	45.0 (1.6)	48.3 (4.8)	53.4 (13.9)	65.7 (9.4)	79.2 (4.5)	94.3 (6.0)
S2 Hobøl	11	39.9 (4.9)	41.2 (4.5)	48.8 (4.2)	56.4 (9.2)	75.4 (1.0)	81.8 (0.5)	42.8 (5.7)	44.1 (3.5)	54.8 (1.8)	66.8 (6.0)	77.2 (4.0)	82.7 (2.0)

Moisture content of stem wood was in range 39.9-90.2 % and of stem bark 42.8-94.3 %, respectively. The vertical dependence of moisture content for stem wood was similar to that for stem bark. The moisture content in both tissues increased axially from the base upwards the top. Results obtained for the vertical variation in the lower part of the stem were significantly more pronounced (at level $p < 0.005^*$) to that in the top. We measured the higher moisture content for stem bark than for stem wood, which was confirmation with the earlier studies (Adler et al., 2005; Repola, 2006). Hakkila (1989) reported that particularly higher moisture content in bark is probably because bark is mainly composed of phloem.

Repola (2006) found out that the average moisture content of pine wood mostly depends on heartwood specific weight and age of the tree. Average wood moisture content changes, depending on tree age, could be explained by the heartwood part proportion. With an increase of tree age, average wood moisture content value decreases from 111 % (40 years old trees) to 77 % (145 years old trees). Scots pine heartwood moisture content changes a little during the year: 30-34 % for 71 to 146 years old trees; and 34-41 % for 37-70 years old trees. Sapwood moisture content changes from 113 % (in the summer) to 130 % (in the winter), without any reference to the age of the tree.

In order to investigate more precise knowledge in the vertical variations of moisture content the site index and tree height variables were added in our models. Table 9 shows the p values for the differences of the moisture content for Scots pine stem wood and stem bark in relation to the site index and tree height variables.

Table 9. p value of arithmetic means differences of moisture content for Scots pine stem wood and stem bark collected during the early spring season in relation to the site index and tree height.

Location	Stem wood		Stem bark	
	Site index	Tree height	Site index	Tree height
Hobøl	p=0.7900	p=0.0332*	p=0.4409	p=0.0044*

We found insignificant relationship between the moisture content for the stem wood and stem bark and the site index within South Norway geographical location. In addition, the moisture content of stem wood and stem bark did differ vertically at significant level $p < 0.0001^*$.

To conclude, data presented in previous Table 8 show that the stem wood and stem bark originated from stand with corresponding lower site index (11) did have slightly lower moisture content than the other stand with higher site index (17). Earlier study by Oliveira (2003) confirmed that moisture content in wood and bark tends to vary between sites.

3.4.2 Moisture content in branch wood

Hakkila (1989) reported that the differences in the moisture content of branch wood are partly results of differences in their basic density. The vertical differences of moisture content for branch wood along the crown and along the branch harvested during the early spring period 2014 shows Table 10.

Table 10. Average values of moisture content (%) and standard deviations of Scots pine branch wood along the crown and along the branch harvested during the early spring period.

Location	Site index	Bottom crown				Middle crown				Top crown			
		Branch part				Branch part				Branch part			
		Base	Middle	Top	Twigs	Base	Middle	Top	Twigs	Base	Middle	Top	Twigs
S1 Hobøl	17	43.5 (6.2)	51.9 (4.1)	53.8 (4.1)	54.6 (15.4)	48.4 (2.3)	54.6 (2.2)	55.4 (0.7)	61.5 (8.4)	51.3 (2.2)	53.5 (1.5)	50.7 (5.5)	53.7 (2.7)
S2 Hobøl	11	53.5 (0.5)	57.1 (1.6)	57.2 (2.4)	46.9 (18.2)	57.4 (1.3)	59.1 (1.9)	61.3 (0.9)	57.1 (8.9)	62.6 (6.3)	62.0 (2.2)	62.8 (1.5)	57.8 (16.6)

Moisture content of branch wood was in range 43.5-62.8 %, respectively. The vertical dependence of moisture content of branch wood had increasing pattern towards the crown top and the branch top. Results obtained for the vertical dependence, especially in the base part of the branch, may be due to the higher content of inactive heartwood and extraneous material, which elevate the basic density, to that in branch top. This lowers the moisture content expressed as a percentage of the fresh mass (Hakkila, 1989; Peltola et al., 2009).

Statistical analysis presented in Table 11 proofed that the site index variable did not influence the moisture content in branch wood of Scots pine.

Table 11. p value of arithmetic means differences of moisture content for Scots pine branch wood harvested during the early spring period in relation to the site index, crown level and branch part.

Location	Site index	Crown level	Branch part
Hobøl	p=0.1299	p=0.6655	p=0.0028*

On the other hand we found that the vertical dependence of moisture content for branch was regular, increasing towards the branch top and did vary significantly at level $p < 0.0001^*$, Table 11.

It can be concluded that lower moisture content of raw material is considered to be the primary prerequisite for a combustion fuel. Thus, variation in the relative proportion of bark to wood can be expected to have a large impact on the value of energy conversion for a particular raw material feedstock.

3.5 Effective calorific value

3.5.1 Effective calorific value of stem wood and stem bark

Overview about the results obtained for axial dependence of the effective calorific value of stem wood and stem bark are listed in Table 12.

Table 12. Average values of effective calorific value (kWh/kg) and standard deviations of Scots pine stem wood and stem bark along the tree trunk.

Location	SI*	Stem wood						Stem bark					
		Tree height (%)						Tree height (%)					
		Base	BH	20	40	60	80	Base	BH	20	40	60	80
S1 Hobøl	17	5.40 (0.48)	5.31 (0.22)	5.23 (0.26)	5.27 (0.11)	5.22 (0.11)	5.09 (0.46)	5.51 (0.12)	5.47 (0.29)	5.39 (0.09)	5.26 (0.26)	5.15 (0.36)	5.11 (0.06)
S2 Hobøl	11	5.36 (0.16)	5.32 (0.60)	5.22 (0.19)	5.22 (0.20)	5.25 (0.22)	5.24 (0.39)	5.50 (0.15)	5.44 (0.26)	5.34 (0.16)	5.22 (0.24)	5.18 (0.06)	5.16 (0.38)

*Site index

Effective calorific values did differ in raw material origin. Effective calorific value for stem wood was in range 5.09-5.40 kWh/kg and for stem bark 5.11-5.51 kWh/kg, respectively. The vertical dependence trend of effective calorific value for Scots pine stem wood was similar to that for stem bark. Regular decreasing pattern towards the top was observed. We observed significantly higher calorific value at level $p < 0.05^*$ in stem bark than in stem wood. This elevated energy content of stem bark may be due to its corresponding chemical composition, which consequently affects its calorific value. At the same time is important to know the quantity of these components in order to understand the variations in different tree components. Energy content of biomass feedstock is closely correlated with its content of energy rich components – lignin and extractives (resins, fats, oils, etc.) (Tillman, 1978; Krigstin, 1985).

We did not find significant dependence of the site index for effective calorific values of stem wood and stem bark. Contrary, our model proved a significantly strong vertical dependence of the effective calorific value for stem bark at level $p < 0.0001^*$. These statistical differences present Table 13.

Table 13. p value of arithmetic means differences of effective calorific value of Scots pine stem wood and stem bark in relation to the site index and tree height.

Location	Stem wood		Stem bark	
	Site index	Tree height	Site index	Tree height
Hobøl	$p=0.2301$	$p=0.1115$	$p=0.4199$	$p < 0.0001^*$

3.5.2 Effective calorific value of stem wood and stem bark

For better understanding of effective calorific value behaviour of Scots pine branch forest residues the variables of vertical position within the branch and crown were added in the models.

Differences in these dependencies of effective calorific value of branch wood present Table 14.

Table 14. Average values of effective calorific value (kWh/kg) and standard deviations of Scots pine branch wood along the crown and along the branch.

Location	Site index	Bottom crown				Middle crown				Top crown			
		Branch part				Branch part				Branch part			
		Base	Middle	Top	Twigs	Base	Middle	Top	Twigs	Base	Middle	Top	Twigs
S1 Hobøl	17	5.49 (1.28)	5.34 (0.53)	5.19 (0.52)	5.30 (0.23)	5.23 (0.24)	5.20 (0.16)	5.17 (0.23)	5.20 (0.10)	5.20 (0.61)	5.22 (0.50)	5.23 (0.51)	5.24 (0.57)
S2 Hobøl	11	5.28 (0.24)	5.19 (0.21)	5.20 (0.16)	5.16 (0.06)	5.21 (0.06)	5.19 (0.02)	5.21 (0.01)	5.19 (0.04)	5.21 (0.41)	5.21 (0.40)	5.19 (0.31)	5.22 (0.27)

Effective calorific value of branch wood was in range 5.16-5.49 kWh/kg, respectively. The vertical variations of effective calorific value for branch wood showed a decreasing pattern towards the branch top and upwards the crown top. We found decreasing pattern in effective calorific value of branch wood from the branch base towards its top. It is important to note that the twigs part contained mix of wood, bark and needles which all together may elevate the heating value. This trend can be partly explains by the chemical composition of needles, specifically extremely high content of extractives (41.1 %), (Berg et al., 1980).

Statistical analysis presented in Table 15 proofed that the site index variable did not influence the moisture content in branch wood of Scots pine.

Table 15. p value of arithmetic means differences of moisture content for Scots pine branch wood harvested during the early spring period in relation to the site index, crown level and branch part.

Location	Site index	Crown level	Branch part
Hobøl	$p=0.2405$	$p=0.7087$	$p=0.0032^*$

Our model proved that the effective calorific value of branch wood did vary significantly at level $p < 0.05^*$ along the branch towards the twigs. Contrary, the vertical dependence of branch effective calorific value in crown position did not differ significantly at level $p > 0.05$. We can demonstrate that an axial position within crown did not affect the energy content of the branch wood.

4 CONCLUSIONS

There were considerable variations of qualitative properties between stem wood, stem bark and branch wood of Scots pine forest residues vertically along the stem.

In average, the highest basic density showed to have branch wood, lower stem bark and the lowest one stem wood. The basic density of stem wood was higher in the lower part of stem, vertically decreasing towards to tree top. Contrary, the basic density of stem bark decreased to 40 % height and then slightly increasing again towards the top. Branch wood had a higher basic density than stem wood. The basic density of branch wood decreased in the direction from the branch basis to its top. There was not found relationship between basic density of stem wood, stem bark and branches and the site index quality of selected forest stands.

Bark proportion and bark thickens were highly linear to the tree height. Bark proportion and bark thickness may be relevant aspects for the utilization of biomass feedstock from Scots pine forest raw material.

Average moisture content of stem wood and stem bark harvested during the early spring season increased vertically from the base towards to tree top. The lower the moisture content in the biomass fuel the higher is its heating value. Thus, variation in the relative proportion of bark to wood can be expected to have a large impact on the value of energy conversion for a particular feedstock.

Elevated effective calorific value of Scots pine stem bark and branch wood makes these materials a valuable energy source for bioenergy use in Norway.

5 REFERENCES

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6 SUMMARY

Biomass from forestry sector is able to provide an important contribution to meet the government's targets for increasing bioenergy use. Traditionally it has been stem wood which is used as raw material for energy. For a deeper understanding of trees, knowledge is required not only of the stem wood, but also of the branches and tree tops. Research complex on Norway's industrially important tree species - Scots pine (*Pinus sylvestris* L.) forest residues (stem wood, stem bark, branches, top of trees) moisture content, basic density and effective heating value were analysed in 2 sampling plots, depending on site index quality in South Norway forest.

The vertical dependence of bark proportion was observed. The pattern was similar for both site indexes, lower bark content in the bottom part of stem, slightly increasing approximately to 35 % of the tree height and so increasing towards the tree top. The vertical dependence of bark thickness of Scots pine trees showed an increasing trend towards the top. Bark was significantly thicker near the base than near the top. Bark proportion may be a relevant aspect for the utilization of Scots pine forest residues as potential biomass feedstock.

Considerable variations in qualitative properties between stem wood, stem bark and branch wood of Scots pine along the stem were observed. The basic density of stem wood was in range 308.2-418.3 kg/m³, of stem bark 265.1-364.2 kg/m³ and of branch wood 400.5-579.2 kg/m³. The basic density of stem wood was higher in the lower part of stem, vertically decreasing towards to tree top. Contrary, the basic density of stem bark decreased to 40 % height and then slightly increasing again towards the top. The axial dependence of basic density in stem bark was different than the one in stem wood, more regular. Branch density decreased moderately within the axial direction along the crown. Scots pine branch wood exanimated in this study was denser in the bottom part crown towards less denser branches positioned in the top crown section. More else a clear variation pattern was apparent in basic density variations along the branch. Density declined from the branch base outward first rapidly and then levelled. The highest basic density was found for the branch base. There was not found relationship between basic density of stem wood, stem bark, branch wood and site index quality of stands.

The average moisture content of stem wood and stem bark harvested in early spring season increased axially from the base toward tree top, within significantly more pronounced variations on the tree base compare to tree top. Stem bark had relatively higher moisture content compare to stem wood. The moisture content in stem wood was in range 39.9-90.2 %, in stem bark 42.8-94.3 % and in branch wood 43.5-62.8 %.

The effective calorific value of stem wood was in range 5.09-5.40 kWh/kg, of stem bark 5.11-5.51 kWh/kg and of branch wood 5.16-5.49 kWh/kg. The vertical dependence trend of effective calorific value for Scots pine stemwood was similar to that for stem bark. Regular decreasing pattern towards the top was observed. We observed significantly higher calorific value at level $p < 0.05^*$ in stem bark than in stem wood. Elevated effective calorific value of stem bark and branch wood make these materials a valuable industrial energy source for bioenergy in Norway.

Nøkkelord:	Basisdensitet, GROT, brennverdi, furu, bonitet
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