Different Aspects of Green Wood Chips Production - Case Study from Slovenia

Krajnc Nike*, Matevž Triplat, Klun Jaka, Robert Robek, Tine Premrl, Tina Čebul, Piškur Mitja
Slovenian Forestry Institute, Department of Forest Technique and Economics
Večna pot 2, 1000 Ljubljana, Slovenia
nike.krajnc@gozdis.si

Abstract:
Use of fossil fuels for producing energy is becoming a luxury, due to its high prices. This is also the main reason that the use of wood is rising rapidly in Slovenia. With the development of wood biomass market and with higher demand for wood chips in Slovenia and in neighbourhood countries, the interest in green wood chips from forest residues has arisen. With cutting to length systems, selective cutting and predominate harvesting technology, the concentration of forest residues is rather small and the detailed economics of these operations has not been analyzed in detail yet. The main aim is to study in detail different aspects of forest residue extraction. Two 0.25 ha plots were selected in similar conditions, with the objective to compare different systems of felling, using the same type of technology. On both plots production of roundwood and green wood chips was planned. On the first plot production of green wood chips was promoted and on the second plot production of roundwood including the one with smaller diameter was promoted. For studies of technologies used for extraction of forest residues, time studies have been set up and carried out. The comparison of productive times has shown time savings (20%) in case of green wood chips production. According to the results in case of spruce forests of similar age, the optimisation of green wood chips can lead to higher productivity of all operations. The assortment structure differs significantly on selected plots, so the same conclusion can be done thru industry perspective because promotion of wood chips increases the relative share of pulpwood for mechanical pulping. In the particular case study the contractor (for production of wood chips) had losses. The main factor was the transport distance which was 150km in one direction.

Keywords: green wood chips, time study, forest residues, costs

1 Introduction

Along with rising prices of fossil fuels, economical crisis and in line with EU and national targets, importance of wood as fuel is rising in Slovenia. The main source of wood for energy production (wood biomass) are forests, followed by wood wastes from wood processing industry, recovered wood and wood coming from non-forest land. Nearly 25% of roundwood production in Slovenia is used to produce heat or electricity. Wood is mainly used for production of heat in households (nearly 80 % of all wood biomass is used in households). According to data from Statistical Office of the Republic of Slovenia (SORS, 2011) 1,314,000 t of wood fuels were used by households in 2010. In households wood logs are traditionally used, nearly 1,270,000 t were used in 2010 and only 12,690 t of wood chips were used. Wood chips are mainly used in district heating systems, CHP plants and in wood processing industry.

According to studies done by Slovenian Forestry Institute, the production of wood chips in Slovenia rose from 460,000 loose m^3 in 2007 to 850,000 loose m^3 in 2010. The number of wood chip producers in Slovenia recorded and included in the mentioned study was 62 in 2008 and 122 in 2011 (Krajnc and Premrl 2009, Krajnc and Čebul 2012). Inquire among all identified wood chip producers in Slovenia was performed by Slovenian Forestry Institute in 2008 and repeated in 2011. In both studied years wood chippers with the capacity up to 50 loose m^3/h prevail (Figure 1); in reality, the number of smaller wood chippers is higher but they are used only for self-supply on farms. These types of wood chippers were bought mainly by farmers and forest owners with the subsidies from Rural Development Programme 2007-2013.

Table 1: Use of wood for production of heat and electricity in Slovenia (SORS, 2010)

	Use of wood biomass [t]
Combined heat and power plants (CHP)	157,447
Wood biomass district heating systems	22,734
Industry (production of heat)	227,697
Households	1,610,505
Total	2,018,383

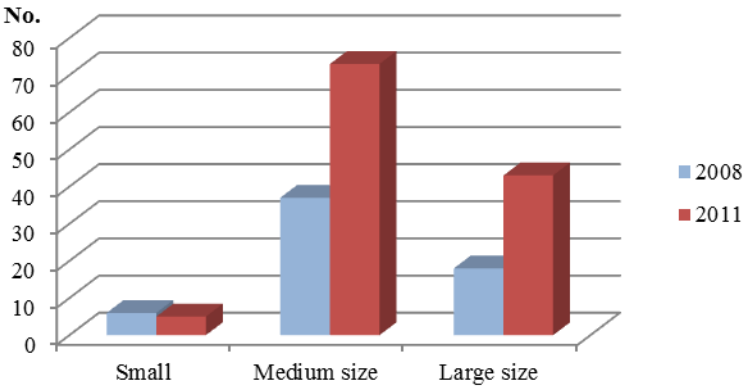

Figure 1: Number of wood chippers in 2008 and in 2011 in Slovenia

Data gathered through the mentioned study among identified wood chip producers showed that the share of roundwood originating from forests as raw material for wood chips decreased in absolute and relative terms between 2007 and 2010. In 2007, more than 20% of wood chips were produced from low quality roundwood, in 2010 roundwood represented 31% of raw material.

In Slovenian forests selective cutting and final cuttings with natural regeneration are mainly applied, forest residues stay in forest unused. With the development of wood biomass market and with higher demand for wood chips in Slovenia and also in neighbouring countries, the interest in green wood chips from forest residues arises. Interest in green wood chips is mainly shown by larger biomass users, while their technologies enable burning of chips with higher water content.

One of the first problems faced by extraction of forest residues is that cut to length harvesting system is mainly used. The whole tree system is used only with cable crane yarding in steep terrains in mountain regions. The predominant harvesting technology is chain saw followed by tractor (it is estimated that less than 10 % of felling is done by harvester followed by forwarder). With cut to length systems, selective cutting and predominate harvesting technology, the concentration of forest residues is rather small and the detailed economics of these operations has not been analyzed in detail yet. The concern for negative impacts on forest stands and soils became also an issue roused by the Ministry of Agriculture and the Environment and by some environmental organizations.

To address this new issue, Slovenian Forestry Institute set up a trail on selected test plots. The main aim is to study in detail different aspects of forest residue extraction. With data collected we would like to prepare generic guidelines for forest residue extraction with focus on thinning in stands with DBH between 10-19 cm, taking into account different technologies, stand and terrain characteristics and soil types.

This paper addresses only selected aspects of forest residue extraction in selected test plots. The main aim of this paper is to present the methodology used for longer-term studies of forest residue extraction and presentation of one case study in which production of green wood chips from forest residues was studied.

2 Material and methods

2.1 Description of the site

The study was conducted in Slovenian Dinarides, where Norway spruce (*Picea abies*) in the past was used for afforestation. The area of 16.31 ha presents one forest compartment and is owned by local forest common. The whole area was afforested 50 year ago on a pasture land. More detailed site characteristics are described in Table 2.

We have selected two 0.25 ha plots in similar conditions. At the end of the year 2010, marking of trees for cutting was conducted by a local forester. Both plots were selected in the same felling area, distance between plots was 0.5 km.

The aim of the study was to compare different systems of felling (bucking), using the same type of technology. On both plots production of roundwood and green wood chips was planned. Basically, "two pile cutting method" was used. Case study plots 1 and 2 differ in top minimum diameter of wood, 6-7 cm and 10 cm respectively. On the first plot, production of green wood chips was promoted, therefore the forest worker made only the quality part of the log (last cross cutting was done at diameter 10-15 cm, average top length was 594 cm), the rest was grinded up for wood chips. On the second plot, production of roundwood including the one with a smaller diameter (last cross cutting was done at diameter 6-7 cm, average top length was 114 cm) was promoted.

Table 2: Description of the test sites

	Plot 1 "Green wood chips"	Plot 2 "Roundwood"	Whole felling area
Locality	Flancovše - Nanos	Flancovše - Nanos	Flancovše - Nanos
Elevation (m.a.s.l.)	890 - 910	890 - 900	880-930*4
Felling area (ha)	0.25 ha	0.25 ha	16.31 ha*4
Average slope gradient (%)	18	17	15*4
Age (years)	51	51	51*4
Growing stock (m^3/ha)	-	-	341*4
Number of trees marked for cutting	121	114	6397*4
Intensity of thinning (%)	-	-	22.6
Removal (no. trees/ha)	484	456	392.2
Total removal (t/ha)*1	78.62	58.68	79.66
Share of green wood chips in total removal (%)	26	25	25
Average DBH of removed trees (cm)*2	17.1	15.9	17.6
Removal of roundwood (m^3, under bark)	18.81	14.37	1,188.98
Amount of green wood chips (loose m^3)	19.67	13.75	1,260
Water content (w %) for wood chips *3	40.4	44.4	43.2

*1 Total removal is the sum of roundwood and green chips calculated in green t/ha. *2 DBH: Arithmetic average of diameter at breast height. *3 Water content (w %) for wood chips was measured according to EN 14774-1:2010. *4 Data source Forest Unit Management Plan (GGN Podkraj – Nanos 2006 -201) and local forester.

2.2 Description of technologies and time studies

On both plots, trees were felled motor-manually with chain saw by two operators working at the same time. Roundwood was collected and transported to the landing site at forest road with farm tractor Zetor Proxima Plus 105 41 (79 KW) with trailer Palms 82 equipped with Palms 610T crane operated by third operator. Roundwood production and production of green wood chips was separated and performed by two different contractors. Collection of forest residues (branches and tops) with mini excavator (Yuchai YC35-8) followed felling and transportation of roundwood. Forest residues were transported to lending area with smaller size forwarder Novotny LVS 5000, where they were chipped by large-size chipping machine Starchl Mk 86 - 600 with Palfinger crane powered by tractor FENDT Vario 930. The transport of logs or wood chips from landing site to final buyer was not part of our time study.

In our case, forest owner selected the contractors to perform all described activities and we did not influence any decision taken regarding the technology selected. Operators were selected according to offered prices. In the case of roundwood costs of felling and skidding the price agreed amounted to €25/m^3, in the case of green wood chips selling price of wood chips at forest site (not at forest landing area) was negotiated and agreed on €0.3/loose m^3. During the negotiation the price for felling and skidding was lowered for €2/m^3 to €23/m^3, while forest workers did not have to collect branches and tops on stacks in the forest. According to Slovenian legislation, branches and tops of spruce should be gathered in stacks if there is danger of a bark beetle (*Ips typographus*) attack. These types of forests in Slovenia are particular endangered by these beetles; with green wood chips production the possibility for the attack was lowered, which can be considered as a positive side effect of wood chips production.

All forest operations were not performed at the same time. According to limited time and resources we decided that felling will not be studied in detail (studies for new Slovenian norms for felling with chain saw were performed in 2011 by the Slovenian Forestry Institute), time consumption and cost calculations of this operation was gained using new Slovenian norms. After felling and cross-cutting, all wood assortments were measured (middle diameter and length). For all other described operation detail, time studies were performed.

For studies of different technologies used for extraction of forest residues, we have set up and carried out time studies. All operations were recorded by using Trimble Nomad hand-held field computers with the time study software UMT-Plus. This instrument is able to capture the time elapsed between the start and the end of a previously defined operation. We have been focusing on cycle level of measurements, because in cycle level measurement, the observation unit is a single work cycle (e.g. the felling of a tree, the forwarding of a load etc.) This kind of measurement offers more detailed information and can help us describe the work process with much more accuracy (Spinelli, Visser, 2009). We have implicated every single working process, but generally they are all divided into three categories (such as productive time or supporting time, all remaining time was considered a delay). Productive time includes only effective time that is comparable among our plots. The time of forwarding (driving the full load from the site to the landing (Nurmi, 2007) and driving unloaded (the time from the moment when the forwarder leaves the standstill position at the landing until it stops for loading (Nurmi, 2007) was excluded from comparison of productivity at both plots because of different distances and different arrangement of the strip roads on our plots.

For further comparison of times we have calculated them to percentage of total scheduled time. Regarding all three categories, the total operating time can be defined as (Björheden, 1995):

$$WP = PW + SW + DT$$

whereby WP = Workplace time, PW = Productive work time, SW = Supportive work time, DT = Disturbance time.

The percentage for all categories can then be calculated:

$$PW (\%) = PW (hh:mm:ss) / WP (hh:mm:ss) *100$$

In presence of time study we have also measured all the outputs gained during work process. Outputs are both quantity and quality, which are equally important to evaluating work method (Spinelli, Visser, 2009). That is why the product quality was evaluated by comparing actual product characteristics with market specifications - in our case its moister content, particle size distribution and bulk density for wood chips or quality and quantity classification for logs. With product output data, we were able to calculate productivity of different technologies. In our case productivity is defined as:

Productivity = Product output / Time consumption

Most of our output data was gathered in the way of gaining information about solid volume of logs collected on the forest road (skidded) or loose volume for wood chips. One loose cubic meter corresponds approximately to 0.4 m^3 of solid volume. Roundwood volume was gained with field measurements of middle diameter and length using Huber's formula.

3 Results

3.1 Time studies

The analysis of results obtained by time study at two selected plots showed that the total operating time is affected by different delays and single events which cannot be compared. That is why we decided to compare and present in this stage only productive times of different operations. A more comprehensive study of total operating time will be prepared after the number of analysed plots will reach the threshold that will allow us to compare delays caused by different working methods. The structure of productive work time at both plots is presented in table 3.

Table 3: Consumption of productive work time

	Plot 1 [h/plot]	Plot 2 [h/plot]	Plot 1 [%]	Plot 2 [%]	Plot 1 [h/green t]*1	Plot 2 [h/green t]*1
Felling	10.31	8.46	38%	33%	0.71	0.76
Transport of logs with adapted farm tractor with trailer	4.31	5.92	16%	23%	0.30	0.53
Collection of forest residues with mini excavator	3.06	1.59	32%	19%	0.59	0.44
Transport of forest residues with forwarder	1.72	1.83	10%	22%	0.19	0.51
Chipping	0.65	0.31	4%	4%	0.07	0.09
Sum	20.05	18.11	100	100	1.85	2.33

Average bulk density of wood chips (measured according to EN 15150: 2011) at both plots was very similar with 263 kg/loose m^3 on plot 1 and 262 kg/loose m^3 on plot 2. For calculation of net solid m^3 (under bark, merchantable lengths) of spruce roundwood to green tons conversion factor 0.77 was applied.

The comparison of productive times has shown time savings (20%) in case of green wood chips production (top minimum diameter of wood 10 cm), mainly because of time savings for felling (cross cutting at larger diameter and less delimbing of tree tops), collecting and transporting of roundwood with tractor and a trailer (collecting and transporting of logs with larger diameter) and forwarding of forest residues (larger concentration of forest residues and tree tops in piles) to lending at forest road.

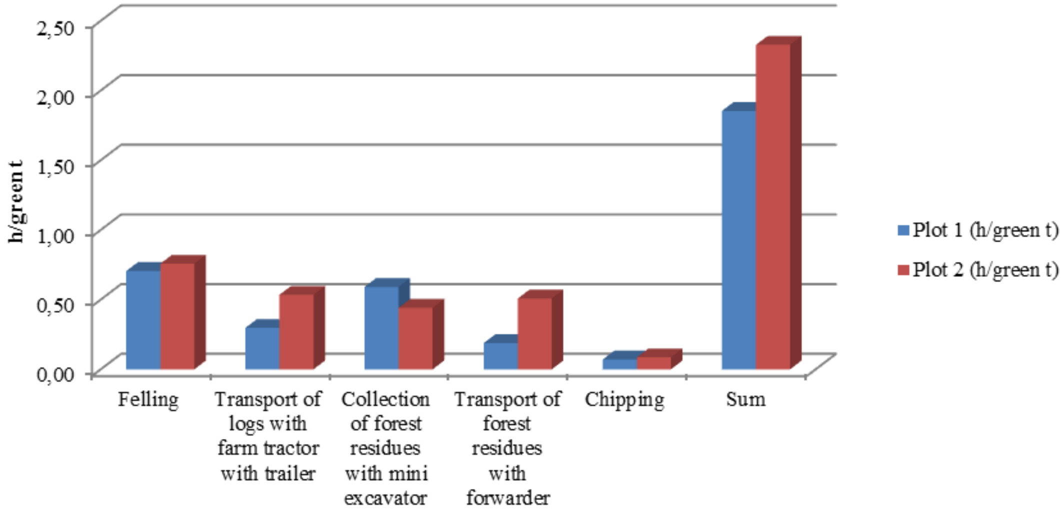

Figure 2: Comparison of productive time for production of roundwood and green wood chips at research plots

As presented in Table 4, the productivity was higher at plot 1 (24.6% higher). This can be explained also with average DBH distribution (average DBH in plot 1 was higher) and not only by selected harvesting system. The productivity for all operations together was 24.31 green t/h and 18.32 green t/h for plot 1 and 2 respectively. The highest differences are in productivity of forwarder (62.84% higher at plot 1) and chipper (17.07% higher at plot 1). The productivity of forwarder can be compared (3.97 green t/h and 1.40 green t/h for plot 1 and 2 respectively) to results obtained by Tolosana et.al (2011) for selected residual management methods.

Table 4: Productivity of different operations

	Plot 1 "green wood chips"	**Plot 2 "roundwood"**
Felling (m^3/h)	2.15	2.00
Transport of logs with adapted farm tractor with trailer (m^3/h)	4.36	2.43
Collection of forest residues with mini excavator (loose m^3/h)	6.43	8.65
Forwarding of forest residues (loose m^3/h)	20.21	7.51
Chipping (loose m^3/h)	53.48	44.35

For more certain and statistically proven conclusions, a more similar pair of plots should be selected and similar comparison of productivity should be performed. According to results obtained from this particular experiment we can conclude that in the case of even-aged spruce forests the optimisation of green wood chips (higher diameter of tops left for collecting, forwarding and chipping) can lead to higher productivity of all operations, except of collection of forest residues with mini excavator. The use of mini excavator can be justified at preparation of piles, for higher productivity of forwarding. The consumption of productive time in forwarding is mostly represented with the loading phase. Loading phase is the time from the moment when the forwarder stops on the strip road to the moment when the boom is back in transport position (Nurmi, 2007). In our case this working operation represents 47% of productive time on each plot. Similar results can be found in Finnish research, where the share of loading phase exceeds 50% (Nurmi, 2007). In case of manual cutting, the piles of wood are usually small and scattered over a larger area, that is why mini excavator is used for grasping the residues. Therefore the operator has to pick up one bunch of wood, paying attention to the standing trees, and then reposition the bunch on top of another pile, re-grapple both bunches, and place the grapple load on the bunk of the forwarder (Laitila, 2008). In case of mechanised felling with harvester, the operator can accumulate forest residues on the side of strip road, where they are eventually easily accessible for forwarding.

3.2 Assortments structure comparison between two production systems in selected DBH classes

According to differences in structure of plots regarding DBH (arithmetic average of diameter at breast height), distribution per number and per volume of the subclass with trees having DBH between 10 and 19 cm was selected. In that case both distributions had no significant statistical differences neither in DBH neither in volume distribution (p=0.93 and p = 0.67 respectively). In plot 1 and 2 the percentages of volume in selected DBH related to total volume of felling were 42% and 54% respectively. The percentage of number of trees with selected DBH (10-19 cm) related to all trees cut amounted in both plots to 70%. The differences between plots related to DBH structure of felled trees were in this way minimized. Additionally, this is in line with our assumption that the applied system might be most suitable for the first commercial thinning in coniferous even-aged stands with diameters between 10 and 19 cm. For trees in the DBH range from 10-19 cm, significant differences related to method of assortment bucking were found in RWE m^3 structure (Figure 3).

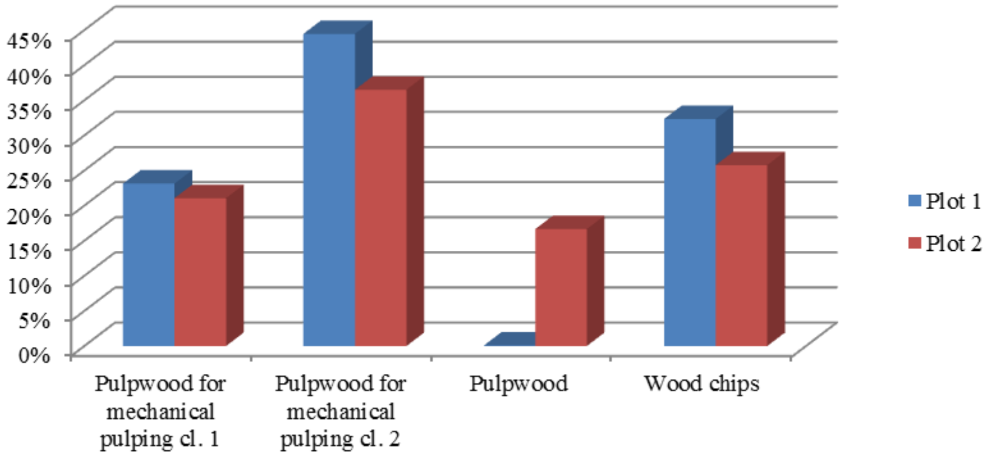

Figure 3: Assortments structure comparison for trees having DBH between 10 and 19 cm

Due to different methods applied in selected plots, the assortment structures differ significantly (Figure 3). Analyzing results from mechanic pulping industry perspective, we could favour the method used in plot 1, where production of green wood chips was promoted. However, the production of wood chips represents 32% and 26% of total production, for plot 1 and 2 respectively.

As the structure of aboveground dendromass was under high influence of DBH, the analysis of two DBH classes was performed in order to get deeper understanding of differences between plots. The results of analysis are presented in Table 5.

Table 5: Assortments structure of aboveground dendromass in two selected DBH classes

DBH class Plot number	10-14 cm Plot 1	10-14 cm Plot 2	15-19 cm Plot 1	15-19 cm Plot 2
Pulpwood for mechanical pulping cl. 1	0.00	0.00	0.39	0.34
Pulpwood for mechanical pulping cl. 2	0.61	0.47	0.33	0.30
Pulpwood for chemical pulping	0.00	0.22	0.00	0.13
Additional part of stemwood for green chips	0.11	0.00	0.06	0.00
Branches, needles and tops over 7 cm diameter	0.28	0.30	0.22	0.23
Total	1.00	1.00	1.00	1.00

Two effects could be identified as a direct consequence of green chips maximizing method (plot 1):

⇒ part of stemwood is additionally chipped,

⇒ the method influence bucking patterns which maximizes more valuable assortments (sawlogs and pulpwood for mechanical pulping).

These effects could be seen in Table 5. However, the volumes of additional stemwood for green chips production diminished when DBH overcome 20 cm. In DBH class 20-24 cm, the share of additional stemwood for production of green chips represented 3.0%. Other factors, such as tree height and quality as well as dimensional characteristics have greater effect on the aboveground structure of assortments than the method applied in our study which maximizes green chips production. The mentioned effects were more influent in thinner trees with DBH below 20 cm. With DBH increasing, both effects had diminished as other factors prevailed, such as height and falling percentage of tops, branches and needles in the aboveground dendromass.

Relative volume of tree tops, branches and needles differs between plots where different bucking operations were used, specifically different top minimum diameter of roundwood. Result is in line with the research of Raissanen and Nurmi (2011), where total residue was increasing according to minimum top diameter of roundwood. Additionally, differences were found between DBH classes 3 (10-14 cm) and 4 (15-19 cm) in both bucking patterns.

Gross revenue from thinning in selected plots in DBH range from 10 to 19 cm did not differ when compared on EUR/m^3 RWE o.b. (roundwood equivalent, over bark) basis. However, the average income per RWE m^3 o.b. was slightly higher in plot 1 in selected DBH classes 3 and 4, the ratio was 1.05 and 1.03 respectively.

Results from plots and in selected DBH classes signalize that the method with optimizing the volume of pulpwood for mechanical pulping and the volume of green chips might be an interesting and cost-efficient way for treatment of the first commercial thinning in even-aged spruce stands. Assortment structure has higher relative and absolute values of pulpwood for mechanical pulping compared to traditional method. This result indicates that workers change the way of crosscutting operations and are more effective in producing pulpwood for mechanical pulping. Mechanical pulping prevails in Slovenia as the two existing fully integrated pulp and paper plants produce mechanical pulp with a trend of increased production and consequently higher pulpwood for mechanical pulping volumes consumption. These circumstances could make the first commercial thinning in spruce even-aged stands more attractive in the near future.

Study reveals a need for comprehensive knowledge about conversion factors and wood science as a prerequisite for optimal decisions in wood supply chain management.

3.3 Costs of forest residues utilization

In this particular case economics of operations can be viewed from two different sides, the owner and contractors side. The aim of our study was a study of green wood chips production and not a detailed analysis of forest operations economics in private forests. That is why we will not go in details with the presentation of owners' point of view; we can just conclude that they benefited from two sides - lower costs for forest operations and income from green wood ships selling. The calculation of forest revenue (prices exclude VAT) for the whole harvesting area is presented in Table 6.

Table 6: Forest revenue (forest owner perspective)

in €	Total	Roundwood	Wood chips
1 Income	47,726.40		
Value of wood	45,426.40	45,048.40	378*1
Subsidy for commercial thinning operations	2,300		
2 Costs	22,788.20		
Felling and transport to lending side	22,032.00	22,032.00	
Manipulation costs (at landing side)	756.20	756.20	
3 Forest revenue	24,938.20	22,260.20	378

*1 wood chips were sold at forest site (€0.3/loose m^3) and not at plant.

The value of wood assortments was obtained from forest owner and consists of real data according to the selling price of wood from the whole production site.

Considering all felling area, data from forest residues utilizations reported by contractor are presented in Table 7.

Table 7: Costs of green wood chips production (recorded by contractor)

COSTS	Machinery hours spend [mh]	Machinery operating costs [€/mh]	Total costs [€]	Cost per unit [€/green t]
Forwarder	185	30	5,550.00	14.28
Mini excavator	205	22	4,510.00	11.60
Chipper	27	120	3,240.00	8.34
Total			13,300.00	34.22

The total costs of wood chips production (at landing site) reported by contractor were €10.56/loose m^3 or €34.22/green t, data from our test plots are only 6% lower (€9.88/loose m^3 or €37.54/green t). The selling price of wood chips delivered at plant site was €80/dry ton (€45.5/green t). Including the costs of transport (total costs of transport reported by contractor were €7,140 or €18.37/green t in average), the contractor had losses (€-7.09/green t). The main factor in our case was the transport distance which was 150 km in one direction. With development of the local market, the transport distance and consequently also transport costs would lower and in this case they should not exceed €8/green t.

The detailed calculation of costs of all operations showed that costs of roundwood production represent 71% of total costs. In the structure of green wood chips production, costs of forwarding forest residues with forwarder represent 48%, followed by mini excavator (38%), in roundwood production felling represents 52% of costs. Structure of costs for different operations is presented in Figure 4. Calculated costs (for our test plots) of felling and transport of logs to road site are €23.16/m^3, total costs of collecting, forwarding and chipping of forest residues are €9.88/loose m^3. Relation between costs of roundwood production (felling and transport of logs) and green wood chips production was 73:27 at plot 1 and 74:26 at plot 2, but the difference between income at plots 1 and 2 was not significant as the income per RWE m^3 o.b. relation between plots was 1.04:1.00. The basic reason for small difference in income per 1 RWE m^3 o.b. lies in price relation between pulpwood and green chips.

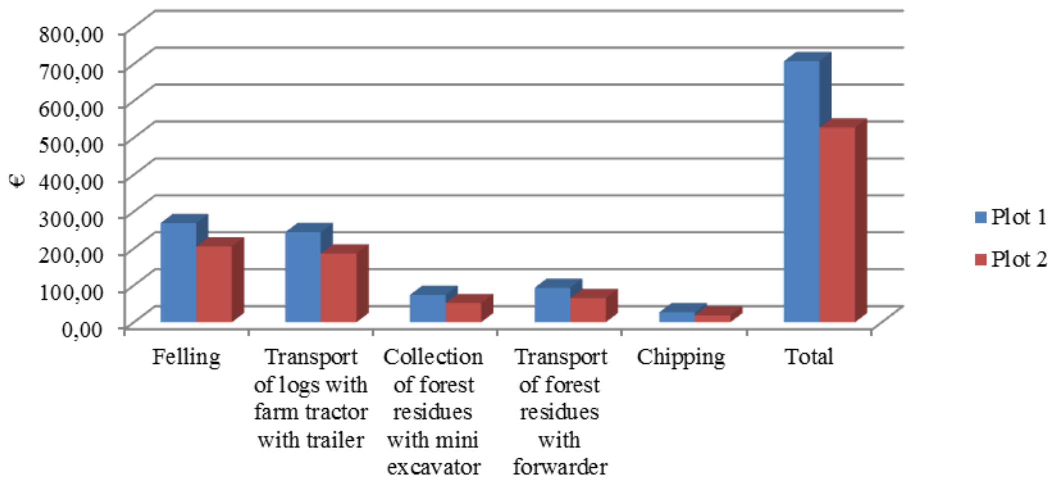

Figure 4: Structure of costs of round wood and wood chips production in selected plots

4 Discussion

Utilization of forest residues in Slovenia, where selective cutting and cut to length system prevails, is not considered common forest practice. After felling with chain saw and skidding with tractor, forest residues are commonly gathered in piles (to prevent beetle attack in coniferous stands) and left in the forest.

The natural conditions, stand characteristics and harvesting conditions can vary considerably even on small distance and in even-aged stands and can have influence on forest residues utilization. The amount of roundwood and wood chips at road site will be influenced not only by mentioned characteristics but also by harvesting system which was in our case determined by minimum diameter of tops left for chipping.

Recently, different studies about aspects of forest residues utilization were carried out but there are little studies done for selective cutting systems where intensity of thinning is from 15-20% and where the majority of felling is motor-manual with chain saw and trees are delimbed and cut to length in the forest. The main challenge with this technology is gathering of forest residues in strips or piles so that the forwarder can easily collect them and transport them to storage at forest road, where chipping can take place. According to the Finnish Forest Research Institute, the costs of forwarding residues to the forest road are almost twice higher in case of manually felled trees compared to mechanised felled trees (Laitila, 2008), but we have already mentioned that the selection of technology was not in our domain. Our hypothesis was that change in cross-cutting diameter and change in delimbing of tree tops can influence the productivity of main operations in roundwood and wood chips production as well as assortments structure and revenue. According to results obtained from this particular experiment we can conclude that in the case of even-aged spruce forests the optimisation of green wood chips (higher diameter of tops left for collecting, forwarding and chipping) can lead to higher productivity (in our case for 24.6% in case of green wood chips production). The direct comparison of results from two selected plots can be misleading while the number and dimension of trees felled at both plots are not exactly the same, so this hypothesis was tested only in selected DBH classes. A more comprehensive analysis of forest residues utilisation will be possible after several repetitions of the experiment. One of the most important results we are looking for are forest residues utilisation rates for different technologies and different amounts of trees marked for cutting. As we have represented earlier in results, production of wood fuel was higher on the plot 1, where production of woodchips has been promoted (the production of wood chips represents 32% and 26% of total production, for plot 1 and 2 respectively). Similar results were published in a Finnish study. Räisänen et.al have reported that the tree top mass was increased by 61-147% by every 2 cm increment in top diameter, and total residue by 13-28% (Räisänen and Nurmi, 2011).

Study done by Jylhä et al. (2010) revealed that pulp price had a strong effect on Wood Paying Capacity (WPC) in and the "Cut to length" system resulted in highest WPC per m^3 at stump. The highest residual value per m^3 was obtained in case of conventional pulpwood production chain. Gains in energy generation did not offset higher procurement costs. The gains in energy generation from additional raw material acquired with whole tree harvesting did not offset the losses in pulp production. As reported by Jylhä et al. (2010), the minimizing of top diameter did not offset higher production costs. The optimum top diameter in first thinnings was achieved with minimum pulpwood diameter of 6 cm. In our case, the difference between pulpwood prices and prices of green chips did not significantly influence income from wood, but there were considerable higher costs per unit of extracted wood biomass. From the forest revenue perspective, the method which optimizes tree bucking and produces more green chips was found considerably preferable.

Taking positive effect on bark beetle attack prevention, mechanization of manual work and negative consciences of utilization (damages on trees and soil and nutrias lost) into consideration, it is hard to conclude whether forest restudies utilisation should become a common practice in Slovenian situation or not. For more comprehensive conclusions about economical (additional revenue), environmental (fire and bark beetle attack prevention) and social (new jobs and new activities for forest entrepreneurs and forest owners) benefits, additional studies are required and will be carried out in near future within the framework of the national project (V4-1126) and international project PROFORMBIOMED (MED project).

Acknowledgments

Authors would like to thank the Forest common “Ravnik Orlovše” allowing carrying out the research in their forest. We also thank the entrepreneurs and foresters who participated in the presented study. The study was performed in the frame of national project “Possibilities and limitations of biomass production from forests” (V4-1126) and international project PROFORMBIOMED (IS-MED10-009).

5 References

(GGN) Gozdnogospodarski načrt gozdnogospodarske enote Podkraj – Nanos za obdobje 2006 – 2015 (Forest Unit Management Plan). 2006. Ljubljana, Zavod za gozdove republike Slovenije.

Björheden, R., 1995: An international nomenclature for forest work study. Jyväskylä : The Finish IUFRO World Congress Organizing Committee, 190 – 215.

Desrochers, L., Puttock, D., Ryans, M., 1993: The economics of chipping logging residues at roadside: A study of three systems. Biomass and Bioenergy 6(5), 401 - 411

Jylhä, P., Dahl, O., Laitila, J., Kärhä, K., 2010: The effect of supply system on the wood paying capability of a kraft pulp mill using Scots pine harvested from first thinnings. Silva Fennica 44(4): 695–714.

Krajnc, N., Čebul, T., 2012: Katalog proizvajalcev polen in sekancev v Sloveniji: 2011. Ljubljana: Slovenian forestry institute, Silva Slovenica, 2012, 59pp. ISBN 978-961-6425-59-9.

Krajnc, N., Premrl, T., 2009: Katalog proizvajalcev polen in sekancev v Sloveniji: 2008/2009. Ljubljana: Slovenian forestry institute, Silva Slovenica, 50 pp. ISBN 978-961-6425-41-4.

Laitila, J., 2008: Harvesting technology and the cost of fuel chips from early thinnings. Silva Fennica 42(2), 267 – 283

Nurmi, J., 2007: Recovery of logging residues for energy from spruce (*Picea abies*) dominated stands. Biomass and Bioenergy 31, 375 – 380

Räisänen, T., Nurmi, J., 2011: Impacts of changing the minimum diameter of roundwood on the accumulation of logging residue in first thinnings of Scots pine and Norway spruce. Biomass and Bioenergy 35, 2674-2682

Spinelli, R., Visser, R.J.M., 2009: Analyzing and estimating delays in wood chipping operations. Biomass and Bioenergy 33,429 – 433

Statistical Office of the Republic of Slovenia (SORS), SI-STAT Podatkovni portal available at: http://pxweb.stat.si/, 2011

Tolosan, E., Laina, R., Ambrosio, Y., Martin, M., 2011: Biomass Recovery from Spanish pine plantations mechanized thinning residue. Effects of biomass piling method and top diameters. Proceeding of FORMEC 2011 meeting, 9-13 October 2011, Graz, Austria. "Pushing the boundaries with research and innovation in forest engineering".