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Full Length Research Paper

Assessment of procurement systems for unutilized logging residues for Brutian pine forest of Turkey

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This study examined the possibilities and feasibility of increasing the procurement of logging residues intended for bioenergy from forests in Turkey. The state of the art of potential procurement technology of logging residues was investigated to examine the purposes of configuring a supply system to harvest residues. The costs of wood chip production generated from logging residues were calculated applying economic simulation and estimation method with actual data. Three system scenarios were modeled for the procurement of logging residues left in the forest after clear-cutting operation with cut-to-length harvesting method. The first and second systems were the roadside chipping with small and middle sized chipper and the third was the terminal chipping. The results showed that coarse logging residues can be available as firewood in traditional utilization manner, but a thin material is left in the forest because of high collection and extraction costs. However, it was found that the increasing demand for forest biomass as a bioenergy resource encouraged the use of logging residues. The lack of feasibility research and uncertainty on the supply system cost caused the refraining of state owned and private entrepreneurs. The feasibility study suggests that, roadside chipping with mid-sized chipper named as system-2 can be preferable for the initial supply chain configuration in Turkey. The procurement cost of forest chips varied from 47.99 to 76.80 $/t for the sample area. The utilization of logging residues could support energy resource, fuel reduction in forest floor, employment and site preparation.

Key words: logging residue, forest biomass, chipping, supply cost, biomass procurement, Turkish Forestry.

INTRODUCTION

The forestry and also the energy sector has recently focused on the use of woody biomass for green energy, fuels and materials for reducing the dependency on fossil fuels and petroleum, because of many factors such as exhaustion of renewable natural resources, global warming, carbon sequestration, sustainable development, etc. Forest biomass includes trees, shrubs, herbs, grasses and all waste biomass such as logging residues compiled from thin branches, damaged or unmerchantable stem sections, tops, barks, needles and stumps (Roser et al., 2008). Logging residues are the most challenging bioenergy resource and a raw material for forest products industry. For the fact that utilization of logging residues as a forest biomass is affordable, it creates business opportunities and employments, generates profit from residual material, provides energy self-sufficiency for forest industry and rural communities and enables the reduction of fire and insect attack due to the removal of fuel material (Eker et al., 2009). However, this is cost prohibitive due to the absence of efficient handling, harvesting and transportation methods for the logging residues within a supply chain structure. For this reason, it is necessary to set up a low cost procurement system based on harvesting and transportation operations for logging residues in order to improve utilization of the residues.

Currently, although the potential of available logging residues is 5 to 7 Mt (million tonnes) for Turkey (GDF, 2009a, b, c), the supply and utilization of logging residues is very poor because of the indefiniteness on cost and system components such as where chipping is to be done, which chipper types are used, how many logging residues are left in the stand to supply the organic matter needed, how it can be collected, etc. In Turkey, the experiment progress for chip production from logging residues recently began procurement (Eker et al., 2010).

Logging residues are being closely examined nationwide and particularly in Brutian pine forests. The region between southern and eastern Turkey, with over 5 million hectares of the total land dedicated to managed pine forest, have the potential to play a major role in producing biomass feedstock for various industries.

In this concept, the aim of the study was to: (1) do a feasibility analysis on the unstructured logging residue supply chain, (2) develop alternative system scenarios for procurement of residues, (3) analyze and evaluate the simulated chipping systems and (4) select an appropriate residue procurement system. Alternative systems based on chipping technologies have previously not been introduced for the procurement of logging residues for use as a raw material in Turkish cut-to-length (CTL) timber harvesting method. The simulated systems to be tested use a methodology for calculating the extent of the regional logging residue potential and the costs of realizing it. The study's methodology was based on the information content of existing stand databases and estimated cost structures. Furthermore, it is possible to calculate the economically harvestable residual potential for any existing stand by actual data. The usefulness of the logging residue procurement system was tested by the derived data in which the average values of stand-level were calculated using the stand characteristics of forest management plans and harvesting program.

MATERIALS AND METHODS

The study was based on both simulated and realistic data. Simulated data were derived from existing study's results and some prediction models, which were time consumption of the systems for productivity and cost analysis. The realistic data were obtained from a forest planning unit. The conceptual framework and data flows of the study were described in the form of a process step labeled as: (1) determination of a study site as a sample, (2) data derivation, (3) setting up procurement system scenario for logging residue, (4) modeling of logging residue quantity and (5) estimation of the system costs.

The material consisted of the following datasets: (1) multi-objective functional forest management plans, maps and stand attribute tables which were used to derive the stand estimates (2) annual stand harvesting records for the last year; (3) biomass calculation module, yield tables and productivity models to estimate potential logging residues (4) machine cost analysis procedures and calculation equations and (5) digital elevation model and forest road map with raster and vector format to calculate extraction and transportation costs thoroughly via hauling routes. The required map layers such as roads, stands and industry center were selected for map analysis. The ArcGIS software was used for database management, spatial and network analysis. Furthermore, Microsoft excel spreadsheet was improved and used for the modeling of logging residuals and cost analysis.

Study site

For the test and analysis, the procurement systems generated a dataset from the material which consisted primarily of information covering a geographical region in Çamlik Forest Planning Unit of Isparta Regional Directorate of Forestry located in the West Mediterranean region of Turkey, of latitude 37°32'08" to 37°23'45'' N and longitude 30°39'22" to 30°50'55" E. The elevation ranges from 260 to 1395 m. The planning unit had a great potential stand types with first site index. The total area of the concerned planning unit was about 15723.5 ha, 74% of which is forest land. This area is dominated by stands of brutian pine (*Pinus brutia Ten.*), that is, they occupy about 96.6% of the total area. According to the multi-functional forest management planning concept, the stands allocated for wood production function is 54% of the total planning unit. Total standing tree volume was 1344387 m^3 and the increment was 38100 m^3 (FMP, 2009).

Data

The data were derived from only clear-cutting operations that will be realized in 2011. The stand database was analytically used as a sample and the average calculation for potential logging residues was used to fill the gaps. The stand data were used to determine the diameter distributions and to simulate productivity and cost variables of the alternative harvesting systems for logging residue procurement. For this purpose, information about 11 clear-cutting stands was used in the study in order to better understand the cost concept in logging residue procurement system with roadside and terminal chipping technology and CTL harvesting method (Table 1). The stands were located in the high fire hazard area. Therefore, removing the fuel material (at least, 70% of the total) from the forest floor will be very fitting in the point of fire hazard reduction for forest health.

Considering the stands in Table 1, it would be seen that the cut volume, as a merchantable timber, is the standing tree's volume. The commercial volume portion of the stand will be merchandized into products. Non-merchantable portion of the stand, including branches, tops and thin materials (diameters less than 8 cm) were collected and chipped for utilization.

Furthermore, round and fuel wood supply from state owned forests and consumption were analyzed using annually statistical data (GDF, 2010) to put forward and support the trend on wood chips in the forest industry. The reports including results of some trials about wood chipping operations in small and local scale realized by GDF were manipulated in calculation of logging residue potential on the sample stands (GDF, 2009a, b, c).

In the cost analysis of the supply system, selling guides and technical brochures of some machines/equipments were used to calculate the fixed and operational cost. Furthermore, the existing results of the trials were taken into account (GDF, 2009b) and literature review (Athanassiadis, 2000; Yoshioka et al., 2002; Van Belle et al., 2003; Mizaraite et al., 2007; Spinelli et al., 2007; Röser et al., 2008; Liska et al., 2010) was done for the time and motion analysis to estimate system productivity.

System background

Wood supply chain has been managed by the General Directorate of Forestry (GDF) in Turkey. Traditionally, cut-to-length harvesting method has been used in Turkish forestry (Eker et al., 2009). Cutting, delimbing and bucking activities are realized in the forest stand by means of chainsaw. Debarking with axe and/or log wizard is mostly operated in stand and rarely on roadside (Eker and Acar, 2006). The logging residues comprising thin branches, tops, barks and other waste materials are left in the stand.

For the chipping operations, three different chipping system scenarios were installed for comparison. The supply and/or chipping systems for forest biomass have been classified according to comminuting and chipping place, where chipper characteristics act as an important role (Bjorheden and Eriksson, 1989; Hakkila, 2003; Talbot and Suadicani, 2005). The alternative systems have been

Table 1. The stand characteristics used in prognosis of logging residue potential.

Stand no.	Stand type*	Site index	Area (ha)	Cut volume (m^3)	Slope (%)	Skidding distance (m)	Hauling distance (km)
1	Çzcd2	2	12	2260	29	175	47.7
2	Çzcd2	2	2.2	200	50	150	23
3	Çzcd2	1	9.8	1376	46	140	24
4	Çzcd2	2	10.8	1769	34	170	45
5	Çzcd3	2	8	1559	39	200	53.5
6	Çzcd3	2	12	2182	33	150	52
7	Çzd1	1	6.5	921	22	150	56.7
8	Çzd3	1	5.5	2320	39	130	56.7
9	Çzcd2	2	3	380	37	150	42
10	Çzcd3	2	2.8	428	31	250	42
11	Çzd2	2	3	201	15	300	52

*Çzcd2 symbolizes that *Çz* is Brutian pine, *c* is thin sawtimber, *d* is sawtimber and *1/2/3* is variable closure degree as 11 to 40, 41 to 70 and 70% < -, respectively.

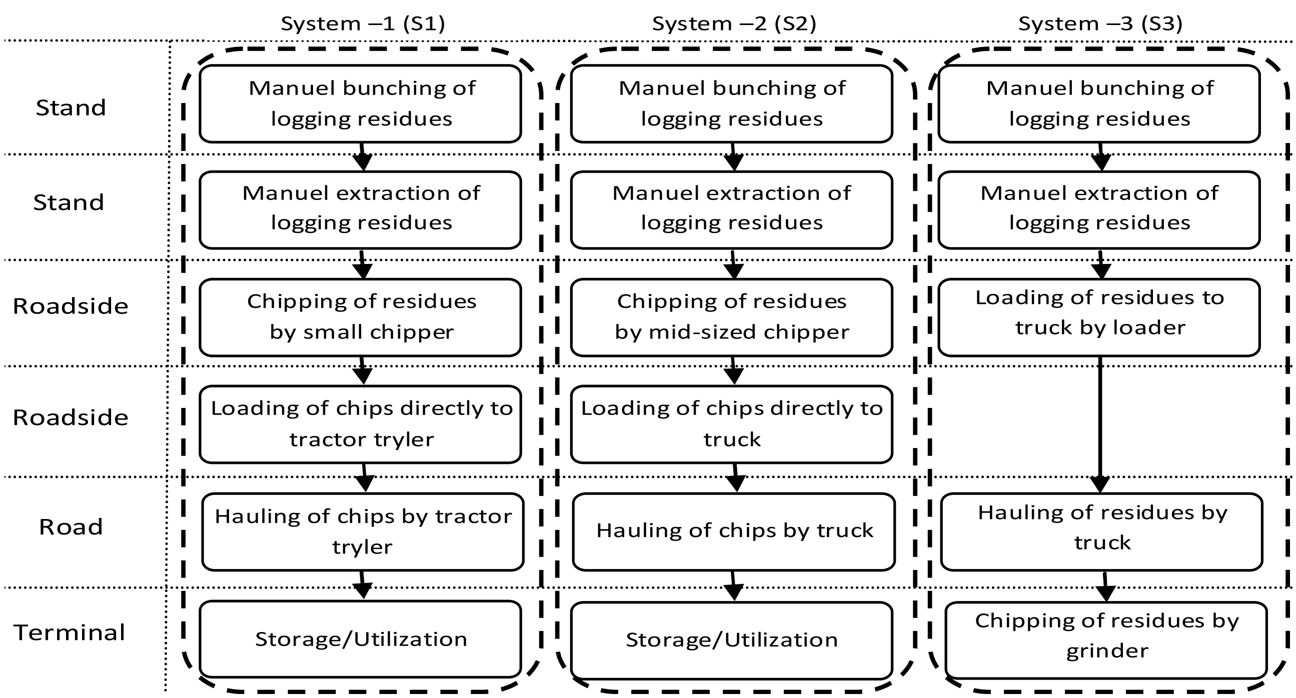

Figure 1. System configuration of the logging residue supply system.

grouped in literature, that is: (i) terrain, (ii) roadside, (iii) intermediate landing and (iv) terminal chipping (Ranta, 2002; Cuchet et al., 2004; Junginger et al., 2005; Johansson et al., 2006; Stampfer and Kanzian, 2006). In this study, the chipper types were decisive in the alternative system structure. The system choices were summarized in Figure 1. It was possible to produce numerous system matrixes for logging residue supply system including also chipping operations, but the available and reasonable systems for Turkish forestry (Eker, 2004) was preferred to simulate an initial structuring for feasibility analysis.

In the simulated systems, logging residues from clear cutting was piled at the forest road nearly 8 to 9 weeks after the cutting process. For the three procurement systems, the forest workers manually collect and bunch the logging residues at the same time with the site preparation for regeneration of clear felled stand. Manual extraction method with auxiliary hand tools were used to remove residues from stand to roadside by way of skidding, gradually pulling-pushing, humping, and/or rolling from up to down. The crew, who at the same time can be the same worker, removed the logging residues allocated by the roadside manually to feed the chipper. The small sized mobile chipper usage was modeled for System-1 (S1), while the middle sized mobile chipper was modeled for System-2 (S2). The technical specifications of the chippers were given in Table 2. The chipper automatically sprayed and loaded the chip onto a tractor trailer or truck case in S1 and S2, as well. The chip material was transported from the forest to the terminal by

Table 2. Technical data of the mobile chippers.

Type of chipper	Small sized chipper (System - 1)	Mid-sized chipper (System - 2)
Cutting system	Disc	Drum
Gross horsepower (hp)	50	85
Engine speed (rpm)	1200	2600
Number of chipping knives	4	2
Inlet opening dimensions (cm)	22x30	50.8x43.2
Max. diameter of chipped wood (cm)	12 - 15	30.5
Weight of chipper (kg)	450	2091
Engine make and model	Dependent on tractor	Cummins B3.3 Turbo Tier 3
Fuel type	Dependent on tractor	Diesel
Carriage	Wheeled	Trailer chassis
Feed roller style	Horizontal	Horizontal
Capacity (m^3/hour in SMH*)	20 (maximum)	60 (average)

SMH, Scheduled machine hours.

track trailers in S1 and trucks in S2 through forest, public and main roads. The terminals were the conversion unit of chips to energy raw material, where they can be converted into wood fibre-chip fabrics, pellet or briquette production, or combining heating plant, etc. In this study, to calculate the hauling distance, the central forest storage was located in the city centre including the forest industry, accepted as a terminal point. The System-3 (S3) was designed as a control system for comparing the other systems. In this system, the loose residue material removed from the roadside was loaded to trucks by hydraulic crane or grapple loader and then transported to the terminal. In the terminal, the portable or stationary grinders were chipped into the loose residue material.

Here, System-1 operates a disc chipper for processing logging residues with a diameter to 15 cm. The chipper was manufactured in Turkey and is used in the agricultural and newly forestry sector, as well. It runs as mobile equipment mounted on tractors by three point suspension or it can be driven by wheeled self-trailer. The chipper with four knifes produces chips that are 3 to 6 mm long, suitable for the direct combustion or industrial purposes. In the second system scenario, the drum chipper was simulated for chipping operations and was equipped with 85 hp diesel engines. This is an imported chipper and is self powered. The third system was a stationary, as well as a terminal, including drum grinder with conveyor feeding. The system was operated by electrical energy in the forest industry. The system consumed 7.89 kWh electricity energy with 3 workers for chipping one air dried tonne slash material for Brutian pine (Bayir, 2008).

In addition, it modeled the use of the farm and/or forest tractor for carrying small chippers into the logging residue supply systems. The use of pick-up or tractors was planned for pulling mid-sized chippers. Tractor trailer as a bin and truck was the transportation equipment used in the scenarios to carry out chips and loose material with 4 tonnes capacity. A truck for the transportation of residuals or chips was with 10 to 15 solid tonnes load limit.

Modeling of logging residues quantity

Estimation of the potential logging residues in a stand was done using a standing tree measurement table designed for each stand before timber harvesting operations (Table 1). Standing tree volumes that were the annual allowable cut for clear-cutting before regeneration were used to create models for estimating the amount of residual material. A linear regression model generated from Sun et al. (1980), Durkaya et al. (2009), standard yield tables (FMP, 2009) and GDF reports (2009c) was used to estimate the potential volume of the logging residue in a given area for each tree based on the stand-level information available in the data tables. These models, using the diameter at breast height (dbh1.3 in cm) as an independent variable, tried to calculate the amount of logging residues per tree and hectare as green and oven dry tonnes. The data necessary for the modeling amount of logging residues included median tree diameters (cm), lengths (m), age, volumes in cubic meters (m^3/ha) and other stand characteristics. The stand's data were used to create models for estimating the amount of logging residual in each stand separately.

In this study, only branch biomass was preferred as the available logging residues for biomass supply chain; therefore, all calculations were carried out according to the branch biomass ratio to stem biomass. In addition to the forest management database, yield tables developed by Alemdağ (1962), Firat (1973) and Kalipsiz (1984), including median tree diameters (cm), lengths (m), tree number per hectare, calculated standing tree volumes in cubic meters (m^3/ha), site index and other stand characteristic was used in the calculation of tree biomass. To estimate the green and/or dry weight of the single tree biomass (kg/tree) and stand biomass (t/ha), equations developed by Sun et al. (1980), Durkaya et al. (2009), and Saraçoğlu (2008) were preferred. The models that were considered in the calculation were summarized in Table 3.

The data created for clear cutting treatment planned for 2011 budget year, were applied in the models to estimate the total biomass as theoretical. The system's residual wood in a forest stand could be estimated by dividing the trees into biomass components using given theoretical and empirical diameter distributions (Vainio et al., 2009). In this study, theoretical approach was applied to estimate logging residue. These models guided the determination of the total biomass and proportional biomass of tree components such as stem, branch, etc.

After a series of calculation process, according to the mentioned models, it was found that branch biomass ratio to stem biomass was average; 17% in per cubic meter as empirical. The standing tree volume symbolizes the stem volume; therefore, the standing tree volume tables were proportionally used in the calculation of the residues. The measurement unit translation into stere (stacked cubic meter) and kilogram from cubic meters was realized by using the methodology of Firat (1973) and Kalipsiz (1984). However, the branch section of a falling tree was traditionally used in fuel wood utilization. It was orientated by GDF that 55% of the total branch

Table 3. Single tree and stand biomass equations.

Resource	Characteristic	Model	Model number
Durkaya et al.	Single tree biomass and oven dry weight in kg	lnBB = -4.99881+2.558273lnd (f:1.476)	1
	Stand biomass and oven dry weight in tonnes/ha	lnBB = 3.525959+1.872978lnd (f:1.19)	2
Sun et al.	Single tree biomass and green or oven dry weight in kg	Log (TBg/TBod) = Loga+b*Log(dbh) a= -55536 b=2.213187 for green weight a= -88492 b=2.26720 for od weight	3
	Stand biomass and oven dry in tonnes/ha	Log BB = Loga+b*Log(dbh) a= 0.06458 b=0.81952	4

BB = Branch biomass; TB = total above-ground biomass; dbh: diameter at breast height (cm).

Table 4. The available quantity of calculated logging residue biomass.

Stand number	Standing tree volume (m^3)	Branch biomass (m^3)	Branch biomass (Stere)	Available logging residue		
				(Stere)	Air dry tonnes	Green tonnes
1	2260	384.2	768.4	345.78	82.99	155.60
2	200	34	68	30.6	7.34	13.77
3	1376	233.92	467.84	210.53	50.53	94.74
4	1769	300.73	601.46	270.66	64.96	121.79
5	1559	265.03	530.06	238.53	57.25	107.34
6	2182	370.94	741.88	333.85	80.12	150.23
7	921	156.57	313.14	140.91	33.82	63.41
8	2320	394.4	788.8	354.96	85.19	159.73
9	380	64.6	129.2	58.14	13.95	26.16
10	428	72.76	145.52	65.48	15.72	29.47
11	201	34.17	68.34	30.75	7.38	13.84
Total	13596	2311.32	4622.64	2080.18	499.25	936.08

biomass should be assigned for fuel wood supply (GDF, 2009c); therefore, it was accepted and estimated that the amount of logging residues was 45% of the total branch biomass. When the weight estimation of logging residues (LR, kg) was used as slash per tree or total biomass, it was considered proportional to the volume of the standing tree (ST_{vol}, m^3) expressed as:

$$BB = k * ST_{vol} \quad (1)$$

Where, *BB* is branch biomass as green in m^3 per stand, ST_{vol} is the standing tree volume in m^3 per stand and *k* is a proportional coefficient as 0.17 for Brutian pine. Since *k* was interpreted as the biomass weight of slash materials per unit volume of standing trees, it was regarded as a value particular to the Brutian pine. The calculation in quantity of logging residues for this study was, "branches" only which were considered as the slash generated from clear cutting harvesting, so *k* was obtained from the models mentioned in Table 3. To convert the branches as slash from cubic meter to stere, the following equation was used:

$$BB_{stere} = c * BB \quad (2)$$

Where BB_{stere} is branch biomass as green in stere and *c* is a converting factor for branch wood in the fuel wood conditions. In this study, it was agreed that one cubic meter of green branch wood was two stere like that in Firat (1973). On the other hand, only 45% of all branch biomass could be used as logging residue, so the reduction factor (*rf; 0.45*) was treated as:

$$LR_{stere} = rf * BB_{stere} \quad (3)$$

Where, LR_{stere} is the amount of logging residue produced from the branches in stere. The logging residues that were left in the forest stand floor after round wood harvesting and fuel wood collection were generally thin branches with 5 to 6 cm in diameters. Since the harvesting operations were normally processed through 8 weeks, until the collection of residues, the residues in the sun could lose the water content. Therefore, the weight of the slash residue material was reduced. To calculate the green and air dry weight of slash logging residue in kg, it was used the correction factors (*cf*) derived from Kalipsiz (1984) and GDF (2009c):

$$LR_{kg} = cf_{green/dry} * LR_{stere} \quad (4)$$

Where, LR_{kg} is the weight of logging residues biomass in kg, *cf* is a correction factor, that is 450 kg for green weight and 240 kg for air dry weight of slash residues with 45 to 55% water content in Brutian pine stands. The available logging residue quantity in the sample stands for simulation was summarized in Table 4.

Estimating procurement system costs

The procurement of logging residues as chips was studied by the use of an economic simulation method based on fixed and variable cost. In this study, the cost was calculated for logging residue chips from only clear cutting operations. The cost structure of residue depends on chip production technology and site conditions (Mizaraite et al., 2007). Nowadays, in Turkish forestry, some chipping systems, small sized mobile chippers with tractor aided and truck mounted drum chipper have been generally used in field trial (GDF, 2009c). These chipping organizations were based on comminution of logging residues at landing, alongside a forest road. Furthermore, in Turkish forest industry sector, terminal chipping method was also chosen for analysis in addition to roadside chipping, because some forestry enterprise which processes wood fiber and chips has a grinder owned factory,.

Procurement cost and productivity estimation of logging residue with the chipping systems were projected from existing studies, catalogue of chipper manufacturer, literature cited, personal communication and field observation without any time and motion study. However, cost and productivity were calculated for harvesting and chipping of the logging residues and transportation of the chips or loose material.

Cost models were also created for various harvesting and transportation schemes or scenarios/systems. An actual transportation cost per stand was calculated using a cost-distance relation between landing and destination point via network and spatial analyst modules of the geographical information system's environment.

The cost estimation of a procurement system was based on the sum, residue handling in the stand, extraction from stand to roadside, chipper feeding and chipping, chip or slash loading and chip or slash hauling costs. The cost of an operation was a function of the multiplication of unit time consumption by unit cost. The operation costs were calculated with the usual accounting methods adapted to forestry operations by Miyata (1980), FAO (1992), Bayoğlu et al. (1996), Eker (2004), Akay et al. (2009), GDF (2009c) and Liska et al. (2010) (Table 5).

In the cost calculation for small chippers mounted on tractor (when the total cost of tractor were not included), the cost analysis which was only the fuel cost was added to the chipper cost, and then the total cost of the chipper was found to be 17.37 $ in SMH and 24.81 $ in PMH without workmanship costs. It was pointed out that two cost components were used in order to calculate the total machine costs. One of them was the calculated value from the cost analysis procedure in the table symbolizing the setting up of machine cost. The other was the machine rental costs determined by GDF because in the realization of the operations, the forest co-operatives or contractors have rented out the forestry machines to GDF. Therefore, machine rental cost including fuel and lubricant cost mentioned in the last line of the table was added to the operating cost of the system.

In this study, manual handling and comminuting operation of the slash logging residues were combined with the manual extraction process. In steep and sloping forest area, collection and accumulation of residuals could be carried out from upstairs by simple hand tools through throwing, pushing, pulling and rolling. In this process, the residuals could be moved in a direction from stump to roadside. Consequently, the processes were merged one after the other. On the other hand, comminuting and extraction of slash material for all procurement systems from the stand to roadside were connected with site preparation in order to determine the calculation of the realistic operation costs. The complex calculation methods based on the cost assumptions, personal communication and site trial (GDF, 2009c) were used in the study and the only abstracted table (Table 6) was given for the description of the system's productivity and costs.

Productivity of collection and forwarding costs were calculated for the special characteristics of each stand such as slope and skidding distance. Chippers' productivities were predicted by means of the existing field trial by GDF (2009b), personal communication and catalogue of machine manufacturer, and the formula of Spinelli and Hartsough (2001) to optimize worker delays and unproductiveness for computation:

$$Chip_{min/t} = 0.02 + 13.1/(Piece\ Size*Power) + 566/\ Power \quad (5)$$

Where, *piece size* is the chipped weight per piece (tonnes) (0.240 air dry tonnes for the study) and *power* is the chipper engine or tractor PTO power (kW). However, the relocation cost of the chippers was neglected.

Furthermore, the records of the enterprise including unit cost and work time were taken into consideration to predict the productivity of manual comminuting and extraction, loading and transportation of logging residues or slash. Extraction distances for each sample stand were determined by ArcGIS spatial analysis modules according to the procedure of Eker (2004) as the mean real skidding distance. Transportation distance was measured by network analysis module for each segment of the dirt, in a stabilized and asphalted road separately.

RESULTS

The brief feasibility study based on the simulated system structure and calculated data indicated that some questions could be answered in the following ways: (i) quantity of logging residues in a given stand with the standing tree volume, (ii) cost analysis for the system configuration, (iii) productivity and cost for manual handling and extraction of slash logging residues, (iv) productivity and cost of small and mid-sized chippers, (v) transportation cost of chips, and (vi) appropriate system selection for initial organization.

The logging residues comprised branches, thin stems, tops, bark and stumps. In the study, the branches biomass was only used to calculate logging residue potential. The amount of logging residue was calculated by a series of calculation processes after determining the branch biomass in clear cutting operations. The quantity of logging residues for the studied area was 499.25 air dry tonnes was obtained from 11 stands having 13596 m^3 standing tree volume in the suitable site index of 75.6 ha. The available logging residue ratio was 3.67% for the total volume (Table 4), while the average potential of residues was 6.6 tonnes, air dried per hectare for the studied stands. The differences in logging residues volume among stands were mainly caused by the amount of the standing tree volume per hectare.

Three procurement systems were created for the supply chain of logging residues (Figure 1). The System-1 symbolized the small scale residue biomass production with lower technology including manual extraction, small mobile chipper and tractor hauling. When the mid-sized mobile chipper and truck hauling were added to the system, it was upgraded to System-2, which was the mid-scale technology. Both systems were based on the road-side chipping method. In System-3, the position and type of chipping operation was shifted in the system structure

Table 5. The summarized cost analysis for machines.

Machine description	Chipper without tractor	Farm tractor	Mid sized chipper	Forest tractor	Truck	Tractor trailer	Loader
Input data							
Purchase price ($)*	4000	40000	60000	90000	100000	4000	85000
Machine horsepower rating (hp)	50	50	85	95	240	-	95
Machine life (years)	5	10	5	10	10	5	10
Utilization rate (%)	70	70	70	70	100	50	65
Fuel consumption rate (gal/hp-PMH**)	-	0.022	0.026	0.029	0.04	-	0.026
Scheduled machine hours (SMH/year)	2000	2000	2000	2000	2000	2000	2000
Calculations							
Average yearly investment ($)	2720	25600	40800	57600	68500	2720	58225
Productive machine hours (PMH/year)	1400	1400	1400	1400	2000	1000	1300
Ownership costs							
Yearly ownership cost ($/year)	994	6528	14904	14688	15905	994	14684
Ownership cost ($/SMH)	0.50	3.26	7.45	7.34	7.95	0.50	7.34
Ownership cost ($/PMH)	0.71	4.66	10.65	10.49	7.95	0.99	11.30
Operating costs							
Fuel cost ($/ph)	-	11.00	22.10	27.55	96.00	-	19.76
Lube cost ($/ph)	-	4.07	8.18	10.19	9.60	-	7.31
Repair and maintenance cost ($/PMH)	0.46	2.06	6.17	4.63	3.50	0.64	4.12
Operator labor and benefit cost ($/PMH)	8.57	8.57	8.57	8.57	6.00	-	9.23
Operating cost ($/SMH)	6.32	17.99	31.51	35.66	115.10	0.32	26.27
Operating cost ($/PMH)	9.03	25.70	45.02	50.94	115.10	0.64	40.42
Total costs							
Total cost ($/SMH)	6.82	21.25	38.97	43.00	123.05	0.82	33.62
Total cost ($/PMH)	9.74	30.36	55.67	61.43	123.05	1.63	51.72
Worker (4 person) $/PMH	10.00	-	10.00	-	-	-	-
Available total cost ($/PMH)	19.74	30.36	65.67	61.43	123.05	1.63	51.72
Machine rental cost $/PMH	-	31.81	-	63.41	123.8	-	53.71

*In this study. 1 TL equals the average of 0.666 US$, according to data of Turkish Central Bank. ** PMH, Productive machine hour.

as a terminal chipping and truck hauling as a slash material.

For all systems, the comminuting process of slash residuals within the stand was operated manually with the aid of the forest villagers. The extraction of the material from stand to roadside through ground-based techniques was also carried out manually, together with the site preparation process. The extraction cost ranged from 21.67 to 51.21 $/t and the weighted average cost was 36.7 $/t (Table 7).

Productivity on manual collection and extraction of logging residues was 0.218 $/t by a crew with two workers. There were three chipping scenarios with two chipping system as roadside and terminal. Chipping cost with small sized chipper was found to be 7.46 and 2.71 $/t with mid-sized chipper in roadside, and 5.66 $/t with portable grinder for terminal chipping, respectively. Transportation cost of chips with truck hauling varied from 13.10 to 23.61 $/t. The chip hauling cost with tractor was found between 35.29 and 86.99 $/t.

Given the procurement cost of logging residue among alternative systems in Table 7, the most suitable was economically System-2, while the total cost was 47.99 to 76.80 $ per tonnes. The procurement costs by System-3 was calculated as 89.76 to 124.66 $/t, while the cost of System-1 ranged from 86.56 to 140.76 $/t.

DISCUSSION

After silvicultural interventions of thin branches (2 to 8

Table 6. Cost and productivity assumptions with weighted average values.

Process and work name	Productivity and cost		Statement
Site preparation cost	306.66	$/ha	After clear-cutting
Manual collection and extraction	6.604	t/ha	Weighted average values for stands
Working hour	8	h/day	
Worker cost	20	$/day	Daily piecework
Crew with 2 workers	0.218	t/h	Collecting and forwarding with 35% slope gradient and 100 m skidding distance
	36.77	$/t	
Chipping at roadside	6.72	t/h	Small sized chipper, manual feeding, crew with 4 persons and chipper with farm tractor
	7.46	$/t	
	24.2	t/h	Mid-sized chipper, manual feeding, crew with 4 persons and self machine
	2.71	$/t	
Terminal chipping	1.72	t/h	Drum grinder, manual feeding to conveyor, crew with 3 persons and electric machine
	5.66	$/t	
Manual loading	2.378	t/h	
	4.55	$/t	
Mechanical loading	4.725	t/h	The average of the overall grapple and crane loader
	5.02	$/t	
Hauling distance	23 - 56.7	Km	Average distance of all stands
Hauling cost	13.10-23.61	$/t	Truck transportation of chips
	6.86	t/cycle	Truck transportation of chips
	2.5	t/cycle	Truck transportation of slash
	123.05	$/h	Truck transportation
	47.72–65.87	$/t	Tractor-trailer transportation of chips
	2.74	t/cycle	Tractor-trailer transportation of chips
	1.0	t/cycle	Tractor-trailer transportation of slash
	63.06	$/h	Tractor-trailer transportation

cm), tops and wood residuals are abandoned in the forest stands as non-useable materials (GDF, 2010), which are sparsely distributed at a forest level, thereby restricting their economic accessibility (Borjesson and Gustavsson, 1996). Leaving unmerchantable logging residuals in forest stands result to infested insects in production forests (Bolding and Landford, 2001). Furthermore, logging residues can hinder reforestation and increase flammable materials density on the forest ground and fire hazard (Spinelli and Hartsough, 2001). Thus, this is the most effective way to use the logging residues as bioenergy resource or/and raw material for fiber-chip industry.

Total biomass was 1633 million tonnes in only the productive forest and 160.5 tonnes per hectare for Turkey having 21.2 million hectares forest area. In addition, the annual biomass potential of Turkey was 32 million tons, while the utilizable bio-energy potential was 17.2 million tonnes (FAO, 2007) and the total biomass requirements was 7.41 MToe in 2010. However, a small portion of the potential woody biomass could be used in bioenergy production. Recently, utilization of forest biomass including logging residues for bioenergy resource started in Turkey (Eker et al., 2009). It was found that approximately four percent of the annual production volume could be available as residual material, that is, 551 thousand tonnes for 15 million cubic meters. The ratio is 1 TWh energy equivalent, whereas the residues after timber harvesting operations are expensive for energy raw material in terms of the costs of harvesting and transportation. Indefiniteness or high cost on procurement of logging residues has delayed the utilization of the forest materials for various goals. Therefore, the reason is one

Table 7. Outline of the procurement cost of the study site.

Stand number	Logging residues	Extraction cost	Chipping cost small sized	Chipping cost mid-sized	Chipping cost at terminal	Manual loading	Machinery loading	Truck hauling cost of chips	Truck hauling cost of slash	Tractor hauling cost of chips	Tractor hauling cost of slash	System -1 (S1)	System -2 (S2)	System -3 (S3)
	t	$/t												
1	82.98	33.32	7.46	2.71	5.66	4.55	5.02	21.75	59.67	73.18	200.53	113.97	57.78	103.67
2	7.34	49.24	7.46	2.71	5.66	4.55	5.02	13.10	35.95	35.29	96.69	91.99	65.05	95.87
3	50.52	42.28	7.46	2.71	5.66	4.55	5.02	13.41	36.80	36.82	100.89	86.56	58.40	89.76
4	64.95	37.95	7.46	2.71	5.66	4.55	5.02	20.72	56.85	69.04	189.19	114.45	61.38	105.48
5	57.24	51.21	7.46	2.71	5.66	4.55	5.02	22.88	62.77	82.08	224.91	140.76	76.80	124.66
6	80.12	32.50	7.46	2.71	5.66	4.55	5.02	23.19	63.64	79.78	218.61	119.74	58.40	106.82
7	33.81	21.67	7.46	2.71	5.66	4.55	5.02	23.61	64.79	86.99	238.36	116.13	47.99	97.14
8	85.19	33.29	7.46	2.71	5.66	4.55	5.02	23.61	64.79	86.99	238.36	127.75	59.61	108.76
9	13.95	36.44	7.46	2.71	5.66	4.55	5.02	18.85	51.71	64.44	176.57	108.34	58.00	98.83
10	15.71	50.88	7.46	2.71	5.66	4.55	5.02	18.85	51.71	64.44	176.57	122.78	72.44	113.27
11	7.380	29.55	7.46	2.71	5.66	4.55	5.02	22.86	62.72	79.78	218.61	116.79	55.12	102.95

of the major aspects of any feasibility analysis.

The primary purpose of the study was to evaluate the proposed/simulated procurement system for logging residues by which residue supply system could be taken into account in the local level. It focused on calculation and analysis of procurement cost of the modeled system rather than a discussion of the integration of the used estimation modules. The estimation of logging residues, extraction, chipping and transportation costs were treated to a more detailed study than other studies realized in Turkey (Bayir, 2008; Ateş et al., 2007; GDF, 2009a).

The conceptual framework was found to be a useful approach for selection logging residue procurement system, because it can easily take account of the fixed and variable cost analysis criteria for the Turkish cut-to-length timber harvesting method. The result showed that the analysis modules for logging residues were a predictable tool that would be suitable for further feasibility analysis in relation to residual procurement.

An economically feasible and utilizable logging residue potential is required for a planning effort, in the same way timber harvesting is required in local bases. A calculation model was developed for the simulated procurement system in the study for providing a more realistic prognosis of the volumes of logging residue and for combining these with extraction, chipping and transportation cost estimates. The amounts of residue potentials and cost factors were estimated for 11 stands separately. Here, the residue potential of clear-cutting operations was also calculated and it was found that the output of logging residue from clear-cutting was low per hectare (6.6 tonnes/ha). The quantity of logging residue, which would be obtained from the forest with wood production function, was taken into consideration only. Furthermore, it is possible to gain the residual biomass from another stand with ecological and societal function. In this way, the procurement cost decreases as the volume of logging residues per hectare increases (Malinen et al., 2001).

The results gave lower estimates for the residual material that was obtained by Sun et al. (1980), Saraçoğlu (2008) and Durkaya et al. (2009). The general diameter distribution models gave much lower estimates for residual energy wood in general. The parametric models have underestimated biomass resources in cases of a heterogeneous stand structure. Therefore, it was very difficult to calculate the precise logging residuals and biomass estimates with parametric models (Vainio et al., 2009). In this respect, a ratio coefficient of the standing tree volume for the heterogeneous stand area and cut volume was determined using the parametric models mentioned in the context. The calculation strategy was the worst scenario model, thus it was accepted as

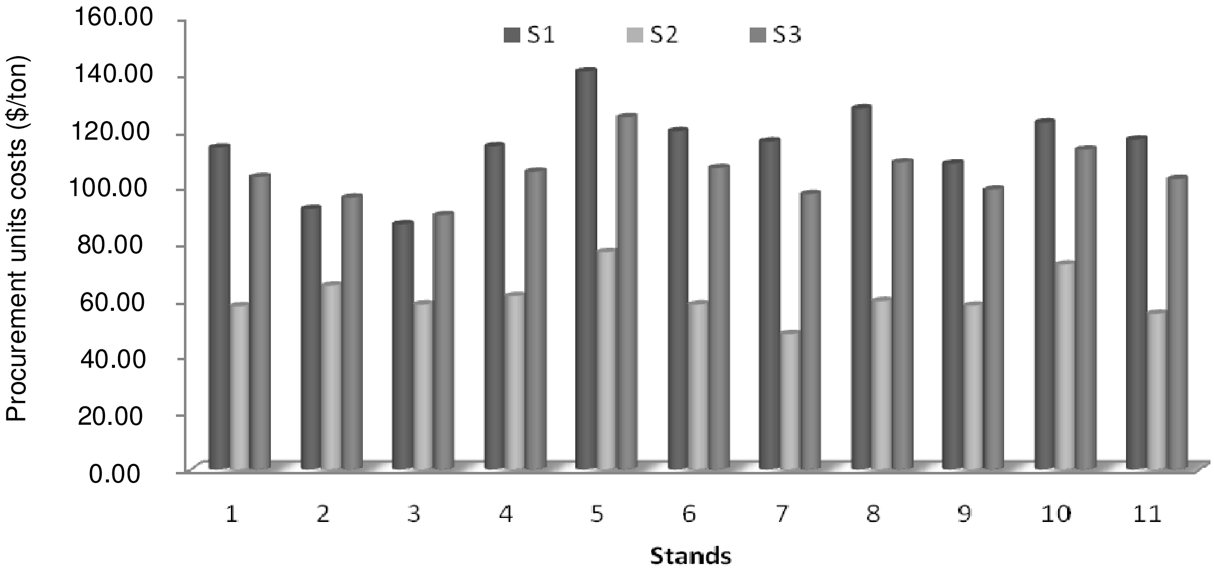

Figure 2. Procurement unit cost of the sample stands.

a consistent ratio.

This study contained only logging residues after clear-cutting, thus the available residues quantity was found to be lower per hectare. This could put entrepreneurs and investor off from biomass utilization. However, the residuals from thinning and tending operations have several effects in supporting the utilizable forest biomass amount. On the other hand, the essential discourager is the total supply cost of the system because of harvesting and transportation cost.

Manual handling was used to collect and carry the logging residues and real skidding distances were calculated for each stand to remove also uncertainties in the calculation procedures. The collection of logging residues is dependent on harvesting operations and how intensively the actual harvesting is carried out (Vainio et al., 2009). The size of the area and the volume to be harvested greatly influences the profitability and total cost of the operation (Nurminen et al., 2006). The cost of procurement can be reduced if the logging residue collection is integrated into timber harvesting operations, this being especially the case in stands having appropriate topographic conditions. The costs of procurement systems can be calculated under stand conditions using time consumption data for different stand structures, harvesting methods, transportation distances, chipping techniques and total harvestable volumes (Ranta, 2002; Vainio et al., 2009).

The cost components of the modeled systems comprise extraction, chipping, loading and hauling/road transportation costs. With respect to procurement cost per unit weight of logging residues in each of the three systems modeled in the study, System-2 was the lowest cost and System-1 was the highest, although both systems were the roadside chipping systems (Figure 2). The main reason for the diversity was based on hauling of chips by the tractor trailer in System-1 because cycle time increased and the transported material quantity decreased in each cycle within the same hauling distance. However, the procurement cost of System-3 (that is, terminal chipping and logging residues, transported by truck as slash material) was higher than the function of System-2 in roadside chipping, so the margin of chips to slashes was larger than that in truck hauling. When the hauling was carried out by truck instead of tractor trailer in System-1, the differences in system costs between System-1 and System-2 decreased to only 8%, depending on the chipping costs in the same extraction distance condition.

Furthermore, the cost of System-1 was lower than that of System-3 in only stand numbers two and three. This results from the transportation distance because the distance was 23 and 24 km for stands 2 and 3, respectively. This shows that in the short distances less than 25 to 30 km, transportation of chips by tractor trailer is preferable than the transportation of the slash material by trucks. Thus, it is possible to say that the chips can be economically hauled by tractor trailer for short distances, as parallel to the work of (Pelkonen et al., 2001). That is, the tractor trailer can be suitable for transportation in a short transportation distance. Meanwhile, the transportation efficiency of slashes was less than one fourth of the efficiency of transportation solid material (Yoshioka et al., 2000).

Although, the extraction methods were the same for the three systems in all stands, the ground slope and skidding distances varied for each. The extraction cost of the distances between 130 and 300 m (weighted average,

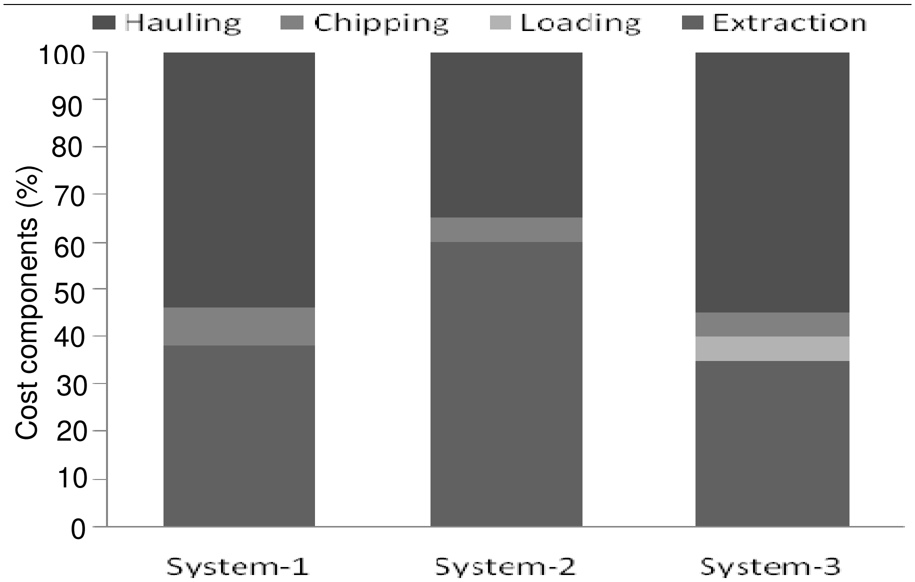

Figure 3. The variation on cost components of the procurement systems.

163 m) constituted 60% of the total system cost for System-2, 32% for System-1 and 35% for System-3 (Figure 3). The difference in System-2 resulted from the low transportation cost (35%) because hauling of chips by truck was the most economical transportation mode in the study.

The chipping is a key process for the study. As such, three chipper technologies were introduced. Productivity, chip quality, cost, energy requirements, workmanship, etc can affect the selection of the chipping system. The study revealed low chipping cost for logging residues. Consequently, the cost of chips from System-2 with mid-sized chipper was lower than that of the other small sized chippers and portable grinder. The reason for these differences is that the mid-sized chipper was more suitable for chipping of collected slashes in the roadside. Small sized chipper was less expensive (4000 $), but the productivity was lower (6.72 t/h) than the mid-sized chipper (24.2 t/h), as well. Therefore, chipping of logging residues with small sized chippers was costly (7.46 $/t) compared with mid-sized chippers (2.71 $/t). The low productivity and high cost of chipping operations in the study was based on the manual feeding system with inexperienced workers and bulk density of thin residual material in addition to chipper type. Due to the fact that the chipper is more suitable for chipping of stems or the whole trees than for chipping of residuals, the mechanical feeding systems and full mechanized chipper or grinder is more effective (Stoke et al., 1987; Spinelli and Hartsough, 2001; Mizaraite et al., 2007; Roser et al., 2008; Karha et al., 2009; Spinelli and Magagnotti, 2010).

The logging residues mentioned assume only thin branches that will be seen economically as feasible residual. In practical forestry, a large part of this wood is left in the forest (GDF, 2009c). It was assumed that 70% of the theoretical volume of logging residues can actually be collected. According to the study, logging residues could be transported from stands to central point at a cost level between 13.10 and 238.36 $/t for various system configuration (Table 7). The linear correlation between road transportation cost and distance has an effect of 0.46 $/t/km for truck hauling of chips and 1.53 $/t/km for tractor (with trailer) hauling of chips. Moreover, transportation cost in this study was too high for Systems-1 and 3. The systems were sensitive to hauling vehicle capacity based on truck or tractor trailer usage (Figure 4). Thus, the utilization of trucks with the heavy load capacity within national road and traffic standards could bring about the greatest savings for residual biomass procurement.

The literature summarized in Table 8 shows that, there is similarity and differences between Turkey (nationwide) and some countries in terms of procurement cost. Accordingly, the procurement cost of the 10 $/MWh (46.68 $/t) level can be accepted as a target of the systems for Turkish forestry competition with other countries. For example, Mizaraite et al. (2007) quoted that the chip cost was 13.33 to 37.33 $/t (1 m^3 = 0.5 dry tonnes) from logging residues in final cuttings in Lithuania. In Belgium, the average procurement cost of residues was found to be 77.33 $/t with mid-scale system components (Van Belle et al., 2003).

There are various procurement systems having both advantages and disadvantages in literature for harvesting and transportation of logging residues (Cuchet et al., 2004; Junginger et al., 2005; Stampfer and Kanzian, 2006; Roser et al., 2008). System selection point of comminution has an infrastructural impact on the material

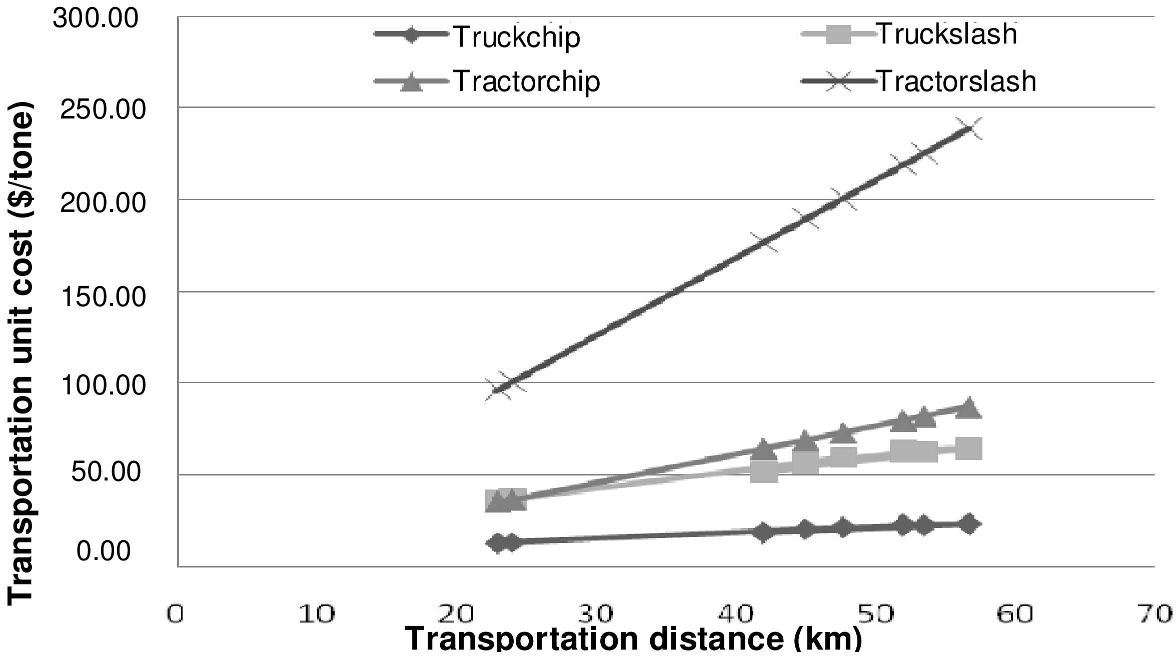

Figure 4. Delivered material cost for increasing transportation distances for all hauling types.

Table 8. The comparison of procurement costs of some countries.

Country	Distance		Procurement cost ($/MWh[4])	
	Extraction (m)	Transportation (km)	Roadside type	Terminal type
Turkey*	130-300	23-57	10.28 – 16.45	19.23 – 26.70
Turkey[1]	-	-	62.96	-
Turkey[2]	-	40	25.80	-
Turkey[3]	-	-	-	20.43
Japan[5]	100-1000	20-80	72.7- 133	127 – 254
U.Kingdom[5]	-	20-80	10.2 – 14.1	8.35 – 11.2
Sweden[5]	-	60	14.1 – 15.5	12.4 – 13.8
Finland[5]	250	60	9.67	-
Lithuania[6]	100-1250	10-100	13.33-18.66	-

*This study [1], Aladağ enterprise (GDF, 2009c); [2,] Gölyaka enterprise (GDF, 2009c); [3,] Eskere enterprise (Bayir, 2008); [4,]1 Tonnes= 4.668 MWh; [5,] Yoshioaka et al., 2002; [6,] Mizaraite et al. (2007).

handling chain, and a procurement system is likely to be superior within a region or supply channel (Allen et al., 1998). Although techno-economically founded, the choice of a supply system is also influenced by the legislative, ecological (Talbot and Suadicani, 2005) and societal constraints. The most common system of procurement forest residuals in Denmark is in-field (terrain) chipping (Talbot and Suadicani, 2005), whereas in Italy, it is generally roadside and in-stand chipping (Spinelli and Hartsough, 2001; Spinelli et al., 2007), in Austria, it is roadside and terminal chipping (Stampfer and Kanzian, 2006) and in Scandinavian country, it is terminal chipping with baling techniques (Karha et al., 2009). In the beginning stage, it was found that System-2 depending on roadside chipping operations with mid-scale drum chipper could be viable for Turkish forestry. The result of our study showed a similarity with the study of Van Belle et al. (2003) on the chosen system.

Furthermore, Turkish forestry is in the machine selection stage in point of forest operations management paradigms (Heinimann, 2007). The result of the study proposes the use of mobile chipper (middle or small sized) because of their low purchase price and flexible use; they allow the prime mover. Chipping at the roadside is technically the most influential method, but it needs close coordination in terms of transportation logistics. The chipper capacity is a determiner for decision making on chipping system (Spinelli and Hartsough, 2001).

Conclusıons

The study dealt with the local cost centre of a portion of Turkish forest area, but the findings could also be applicable to the forestry inside and outside the region if the operational information requirements were given.

The technology and applications for logging residue procurement are developing, and the number of technically and economically feasible harvestable stands is increasing. The environmental pressures and technological development on the various utilization of woody biomass as energy sources has progressed during the last five years in Turkey. The outlook for the realization of the procurement system for residues in Turkey is doubtful from the standpoint of total supply cost contrary to fossil fuel as energy sources. Therefore, the entire cost such as purchase cost of residues from forest and selling price of chips and slashes to chip board industry or energy conversion plants should be calculated. There is also a continuing requirement to improve the procurement process, which means that for realizing the utilization of logging residues and also woody biomass, it is essential to apply low cost harvesting and transportation techniques.

Mobile and less expensive chippers can allow operations to stay small, but more efficient for supply chain of logging residues. Productivity and cost results showed the system to be capable of harvesting logging residues as wood chips, which in the past have been normally left unutilized in the forest. The gain from the value of residual chips can make the system economically attractive and can alter the forest fire behavior in future by the fuel reduction potential.

The extraction and hauling costs were higher due to lower load volume of logging residues. The procurement cost of residue chips can be decreased by improving technology, planning and training, use of mechanical extraction with high load capacity, use of chippers that are more suitable for chipping of residues, instruction of workers and better planning.

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