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Potential and supply costs of wood chips from forests in Soria, Spain

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Abstract

Soria is a forested province in Northern Spain. The utilization level of the forests in Soria is low at present, but it is predicted to rise in the future. Because of the high altitude, heating is also needed. These form a good basis for increasing the use of wood chips in energy production. In this study, a procedure to estimate the potential of wood chip from forests and their procurement costs was adapted to Spanish conditions. The harvesting potential was estimated to be between 140,000 m^3 and 280,000 m^3 in 2010, and to double by 2030. Cost-supply curves were provided to aid in the planning of heating plant investments. Compared to European cost levels, the procurement costs in Soria are not high.
Key words: GIS, forest biomass; forest residues; forest chips; transport costs; availability; fuel wood.

Resumen

Potencial energético de los bosques y costes de suministro para Soria, España

Soria es una provincia con gran tradición forestal situada en la mitad norte de España. Actualmente el nivel de cortas en los bosques de Soria es bajo aunque se prevé que aumente en el futuro. Al ser una provincia montañosa, de clima frío en invierno, el uso de calefacción es necesario durante bastantes meses al año. Esto hace que sea interesante incrementar el uso de astillas de madera para producir energía. En este estudio, se adaptó a las condiciones españolas un procedimiento para estimar fuentes de biomasa leñosa y sus costes de suministro. Se ha estimado un potencial de aprovechamientos para 2010 que oscila entre los 140.000 y 280.000 m^3, y el doble para 2030. Se han utilizado curvas de coste de suministro para ayudar a planificar las inversiones en plantas de producción de calor. Los costes de suministro en Soria no son altos comparados con el nivel de costes europeo.
Palabras clave: SIG; biomasa forestal; residuos forestales; astillas; costes de transporte; disponibilidad; biomasa leñosa.

Introduction

The need to develop and increase the use of renewable energy has been emphasized in the European Union for over a decade. The most recent and legally binding roadmap for renewables was published in April 2009 (COM, 2009). The Member States of the EU have committed by 2020 to produce 20% of their energy with renewable sources, and 10% of traffic fuels should also be derived from renewables by that year. The Commission suggests that the EU countries reduce emissions further so that by 2020 they would be 20% lower than in 1990. If a broader global agreement were to be signed, the EU countries may reduce their levels of greenhouse gas (GHG) emissions as much as 30% compared against emissions in 1990. In 2005, 6.7% of gross inland energy consumption in the EU27 was produced with renewables (Anon, 2006). Of that, 67.9% was produced from biomass. Although the share of forest residues, on average, was only 12% (Alakangas *et al.,* 2007), there is still plenty of unutilized potential (Asikainen *et al.,* 2008).

In Spain the share of renewables based on gross final energy consumption in 2005 was 8.7%, and the target for 2020 is 20% (COM, 2009). Among the renewable energy sources, the bioenergy consumption was 4.6 Mtoe (80% for heat generation and 20% for power generation) (PBCyL, 2009). Owing to the good availability of biomass and the high annual heat load, especially

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the forested areas of Northern Spain and also high altitude areas in other parts of the country, are favorable for renewable heat production based on woody biomass. Asikainen *et al.* (2008) estimated that the technical potential of logging residues in Spain would be 6.1 million m^3 (c. 1 Mtoe) and that, in addition, 25% of roundwood balance equaling 6.0 million m^3 would be available.

The consumption of renewable energies in Castile and León in 2006 represented 6% of the total consumption of energy, with 0.278 Mtoe of bioenergy consumed, of which 0.081 Mtoe was derived from forestry sources (PBCyL, 2009). This was just 2% of the estimated potential of the region. Castile and León has planned to reach a bioenergy consumption of 0.893 Mtoe (around 5.8% of its potential) by 2013, with the intention of increasing the consumption to 1.6 Mtoe in 2020 (around 10% of its potential).

Soria is a province in central-north central Spain, located in the Eastern area of Castile and León. The population density in Soria is around 9 inhabitants per km^2, one of the lowest in the European Union. Thus, its wealth is based on natural resources and forest products. The province of Soria has approximately 600,000 ha of forest, with outstanding conifers such as Scots pine (*Pinus sylvestris* L.) and Mediterranean maritime pine (*Pinus pinaster* Ait.) and hardwoods such as holm oak (*Quercus ilex* L.).

Nationwide potential and cost estimates give only a general overview of the situation, and are not generally detailed enough for local or regional planning. Variation in forest resources and infrastructures can be very great from one region to the next. Therefore, techniques have been developed to estimate local or regional volumes and costs for selected biomass plant locations. Stand data of logging companies have been used to estimate the spatial distribution and cost-supply curves of logging residues (*e.g.* Asikainen *et al.,* 2001; Ranta, 2002; Ranta *et al.,* 2007). In addition, multi-source national forest inventory data (Tomppo *et al.*, 1998) have been used to estimate the potential especially in young forests (Laitila *et al.*, 2004; Heikkilä *et al.*, 2005; Ranta *et al.*, 2007; Laitila *et al.*, 2010). Based on land cover maps and a digital road network, Möller and Nielsen (2007) analyzed the costs of transporting wood chips from forests to energy plants for four bioenergy plants in Denmark. A study in New York State is another example where land cover and land use data were utilized (Castellano *et al.*, 2009). In Wallonia, Van Belle *et al.* (2003) estimated the availability of forest residues based on forest inventory data from permanent plots and a survey on harvested amounts. The costs of different procurement systems were also estimated. All in all, the estimation procedure depends on the available data sources and the constraints that limit the availability of biomass.

The available data sources and their inventory principles vary markedly within Europe. This study established a procedure for estimating potential of wood chips from forests and their procurement costs. The aims of the study were: 1) to estimate the amount of wood chips available from forests in Soria, Spain; and 2) to determine a feasible procurement system for wood chips. Wood chip potentials were based on a timber harvesting prediction by local experts. Four possible supply chains were compared in terms of the total cost of procuring wood chips. The costs were calculated for National Forest Inventory (NFI) plots. As no local productivity models were available, Finnish models were used instead. In addition, Finnish parameter values were applied when local ones did not exist or could not be estimated.

Material and methods

Data

NFI data including altogether 2,321 sample plots on forested land were measured in 2003 (Fig. 1). The most common and economically important species are *Pinus sylvestris* L. and *Pinus pinaster* Ait. (Table 1). The forests are of good growing age. On average, *Pinus sylvestris* L. grows at higher altitudes and on steeper slopes than the other species. According to the NFI data, the total conifer stem volume in Soria is nearly 20 million m^3, reaching around 30 million m^3 when all the species in the forest are taken into account. All of the volumes presented in this study are in solid cubic meters, unless otherwise is stated.

Road network data were used to calculate transportation costs. The data consisted of all the roads drivable by truck. The average driving speed was known for each road section. Furthermore, an existing terminal (in the City of Soria) and two possible plant locations were digitized using GIS. Cabrejas del Pinar and Almazán were chosen as possible locations on the basis of their characteristics as typical forested lands, with the most common species composition and structure, and the towns' need for heat.

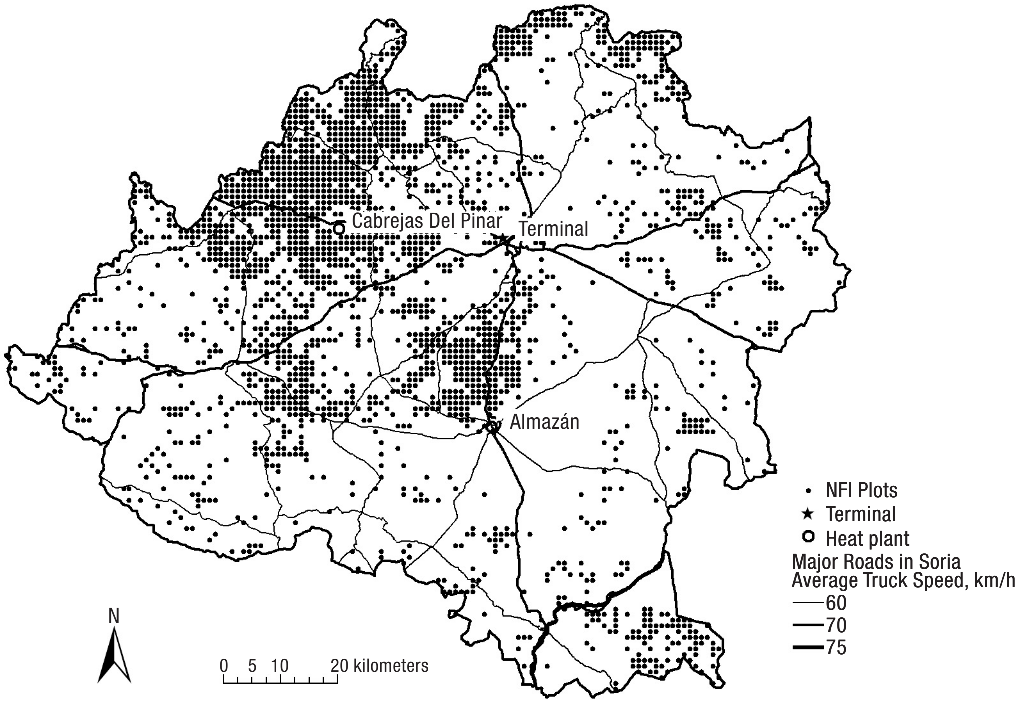

Figure 1. The main roads, planned heat plants, terminal and National Forest Inventory (NFI) plots in Soria province.

Wood chip potential

The technical potential of wood chips was based on a cutting scenario made public by the Regional Forest Service (JCyL, Parrado and Picardo, 2006). The potential was estimated as follows: First, based on cutting statistics from Soria for 2006, the total cutting volume was divided into three classes: clear fellings in softwood forests; clear fellings in hardwood forests; and thinnings in softwood forests (JCYL, 2006).

Second, expansion factors between removal of industrial roundwood and energy wood components were estimated. The factors were calculated separately for hardwoods and softwoods. The energy wood components considered in this study were 1) full trees (above-ground biomass) from thinnings, where the average diameter of removal was < 15 cm; 2) particle board wood (top diameter of a delimbed log 5-15 cm); and 3) logging residues (tree tops a having diameter of less than 5 cm, branches and foliage).

Table 1. National Forest Inventory data for Soria in 2003. D_{mean} = mean diameter at 1.3 m. TotVol = total stem volume

Species class		Age (a)	Altitude (m)	Slope (%)	D_{mean} (cm)	TotVol (m^3 ha^{-1})
P. sylvestris	Mean	43	1,307	17	27	163
n = 570	*Min*	*15*	*900*	*2*	*7*	*1*
	Max	*170*	*1,900*	*42*	*61*	*587*
P. pinaster	Mean	41	1,015	7	28	118
n = 533	*Min*	*15*	*800*	*2*	*7*	*1*
	Max	*123*	*1,300*	*28*	*55*	*457*
Other	Mean	30	1,063	11	20	35
n = 1,218	*Min*	*12*	*700*	*2*	*7*	*0*
	Max	*165*	*2,000*	*42*	*103*	*405*
Total	Mean	36	1,112	12	23	86
n = 2,321	*Min*	*12*	*700*	*2*	*7*	*0*
	Max	*170*	*2,000*	*42*	*103*	*587*

The volumes of different tree compartments were calculated from NFI plots. Subsequently, the expansion factors for all energy wood components could be estimated. In addition, it was assumed that 95% of the full tree volume, 100% of particle board wood and 70% of the volume of logging residues can be collected in practice. The reduction of 5% for full trees was based on the fact that the lowest branches are delimbed when felling is done with a single-grip harvester head. The recovery percentage for logging residues was based on the study by Asikainen *et al.* (2001).

Third, the potentials of different energy wood components were obtained by multiplying the predicted yield of stem wood by the corresponding expansion factor. Finally, the estimated use of firewood was deducted from the accumulation of logging residues. According to the statistics, collection of firewood in Soria amounted to 22,167 m^3 in 2006.

Energy densities (E_{ar}) of energy wood components were calculated for each NFI plot based on species-level lower heating values and wood densities. Wood moisture as received was assumed to be 40% (wet-basis). Subsequently, the following average values were used in estimating the energy contents: 2.60 $MWh \cdot m^{-3}$ for hardwood from final fellings; 2.33 $MWh \cdot m^{-3}$ for softwood from final fellings and softwood full trees from thinnings (dbh < 15cm); and 2.31 $MWh \cdot m^{-3}$ for softwood logging residues and particle board wood (dbh > 15cm) from thinnings.

Eventually, two different scenarios for energy wood accumulation were set. The first one, «Minimum», shows the minimum level of wood chips that would be available. This scenario includes full trees from thinnings where the mean diameter of removal is less than 15 cm and logging residues from final fellings. The other scenario, «Wood energy», demonstrates the maximum potential of wood chip harvesting. In addition to the components of the «Minimum» scenario, this scenario includes logging residues and particle board wood from thinnings where the mean diameter of removal is greater than 15 cm as well as particle board wood from final fellings.

Procurement systems for wood chips

Based on local conditions and knowledge of existing systems for wood chip procurement, four different procurement systems were considered (Fig. 2). According to the «Minimum» scenario, there are basically two sources of energy wood in Soria: full trees from first thinnings and logging residues from final fellings. Because these are the most important sources of energy wood, the procurement costs were calculated only for these two components. Both full trees and logging residues can be chipped either at a roadside landing or at a terminal. Owing to the risk of forest fires, logging residues were assumed to be collected when fresh.

Procurement costs of wood chips

Plot-level biomass and energy accumulations were needed for harvesting cost calculations. The NFI gives measures of tree-level attributes. Models were used to estimate the biomass or volume of a certain timber assortment. For this study, different biomass variables and volumes were calculated by ForEcoTechnologies Company (Anon, 2007). The attributes obtained for each plot are listed in Table 2. The data included descriptions of both growing stock and removal. Removal data were further used to calculate harvesting costs for wood chips.

In thinnings, the productivity of felling bunching was calculated with Finnish productivity functions (Kuitto *et al.*, 1994). Due to large tree volume it was assumed that the working technique in felling bunching would be single-tree handling, and that the work would be done by a normal harvester head for roundwood cutting. The function for harvester movement between working locations was as follows:

$$z = -0.07255 \cdot \ln(0.000414 \cdot y - 0.03039) \qquad [1]$$

Table 2. Attributes for National Forest Inventory plots

Attribute	Explanation	Unit
Prov_Plot	ProvinceNumber_PlotNumber	—
Spe	Main species	—
Age	Stand age (usually model prediction)	yr
X-coord	X coordinate	km
Y-coord	Y coordinate	km
Altitud	Elevation	m
Slope	Slope	%
GrowInd	Growth index (1 = average)	—
Dmean	Mean diameter	cm
Vmean	Mean tree volume	m^3
Bmean	Mean tree biomass (dry)	ton
TotVol	Total stem volume	$m^3\ ha^{-1}$
ThicLog	Total thick saw log volume	$m^3\ ha^{-1}$
ThinLog	Total saw log volume	$m^3\ ha^{-1}$
Particl	Total particle board assortment volume	$m^3\ ha^{-1}$
StemBM	Total stem biomass (dry)	$ton\ ha^{-1}$
BranchB	Total branch biomass without leaves (dry)	$ton\ ha^{-1}$
LeafBM	Total leaf biomass (dry)	$ton\ ha^{-1}$

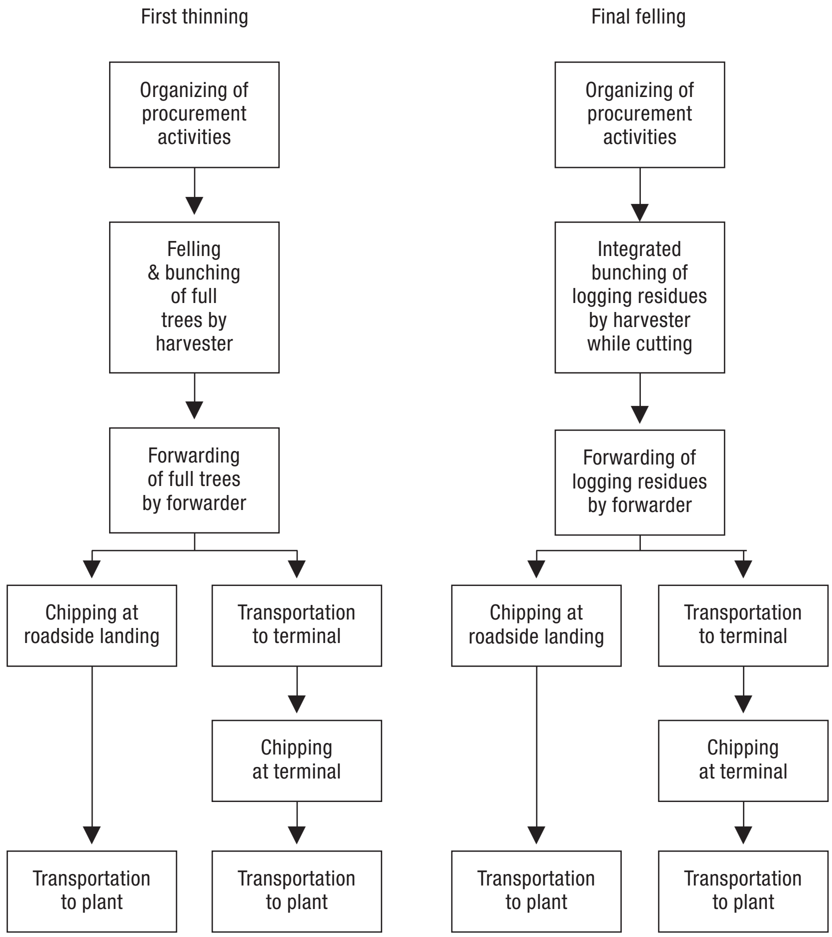

Figure 2. Systems for the procurement of wood chips in this study.

where z = movement time (min stem^{-1}) and y = number of stems removed (stems ha^{-1}). Processing time depends on stem size and species:

$$k = b_1 + b_2 \cdot x \cdot 1{,}000 + \frac{b_3}{x \cdot 1{,}000 - b_4} \qquad [2]$$

where k = processing time (min stem^{-1}), x = average stem size including branches (m^3) and b_i = parameters by species (Table 3). The parameter values of pine were used for all softwoods and hardwood values were used for all hardwoods.

Productivity was calculated with the following formula (modified from Kuitto *et al.*, 1994):

$$t = \frac{x \cdot 60}{(\frac{z}{m} + k) \cdot 1.35} \qquad [3]$$

where t = productivity (m^3 effective hour^{-1}) and m = terrain class factor (1, when slope < 20%; 0.765, when 20% ≤ slope < 40%; and 0.643, when slope ≥ 40%).

In final fellings, no direct cost is incurred for the felling of energy wood. However, for logging residues to be forwarded efficiently, they have to be bunched by the harvester during felling. The contractor may be paid a small compensation for bunching. Here, the Finnish value of €0.3 m^{-3} was used (Laitila, 2006).

The process of forwarding comprises loading the forwarder, driving during loading, driving when empty, driving when loaded and unloading the forwarder. The time consumed for the work phases in thinnings were

Table 3. Parameter values of the function for processing time. The pine species is *Pinus sylvestris* L. and hardwood mainly *Betula pendula* Roth and *Betula pubescens* Ehrh.

Parameter	Pine	Hardwood
b_1	0.65739	0.45624
b_2	0.00041	0.00064
b_3	–85.413	–17.078
b_4	–201.34	–73.34

calculated using the models presented by Laitila *et al.* (2007); the models of Ranta (2002) were used for time consumption for final felling. Because slopes make driving slower, the plots were classified into five slope categories and the productivities were reduced by correction factors (Brunberg, 2004; Ilavský *et al.,* 2007).

According to local data, the productivity of a drum chipper (Woodsman 20fx) when chipping whole trees from thinnings at a roadside landing was 90 loose-m^3 h^{-1}. Productivity was lowered by 20% to cover gross working time. Based on Finnish experiences, chipping is faster at a terminal than at the roadside because there are fewer stoppages caused by traffic, waiting, and other delays (*e.g.* Asikainen *et al.*, 2001). Consequently, productivity was estimated to increase by 30% when chipping at the terminal (Laitila, 2008). Chipping of whole trees was assumed to be 20% faster than chipping of logging residues, and chipping of hardwood was assumed to be 20% slower than chipping of softwood. The operating cost of the chipper per hour at a roadside landing was assumed to be €70 h^{-1}. The operating cost at the terminal was estimated to be 10% cheaper than chipping at a roadside landing because of the higher degree of the machine's utilization.

Transportation distances and times were calculated using GIS by finding the fastest routes for 1) transportation between the plots and the plants, 2) transportation between the plots and the terminal, and 3) transportation between the terminal and the plants.

Transportation was divided into driving without a load, loading, driving with a load, and unloading. The same distance was used for driving both with and without a load. Although a local contractor used a chip truck with a load space of 88 m^3, the maximum weight of load is 25 t, which equals 69 loose-m^3 and 28 solid-m^3 load size. The time it takes to load chips is directly dependent on the chipper's productivity per operating hour. The time for unloading was set at 0.7 h (Ilavský *et al.,* 2007). For loose residues, the figures used were: 18 solid-m^3 load size; 1.0 h for loading; and 1.3 h for unloading (Ilavský *et al.,* 2007).

The unit costs of working phases were calculated by dividing the hourly costs by the productivities. Furthermore, costs per MWh were derived by dividing the unit cost by the energy density. The parameter values used are listed in Table 4. Where Spanish values were not available, default values were used (Laitila, 2006). In the cost calculations, no VAT or stumpage value was added to the cost. Moreover, no subsidies were considered, either.

Results

Forest fuel resources

The cutting scenario that was applied indicated that there will be a considerable increase in the volume of commercial roundwood harvested annually in Soria, from an initial level of less than 400,000 m^3 in 2006 to over one million m^3 in 2030 (Fig. 3). Consequently, the amount of available wood chips will also increase. According to the «Minimum» scenario, a total of 88,000 m^3 of wood chips could be harvested in 2006. However, according to the «Wood energy» scenario, as much as 187,000 m^3 would be available. In 2030, the corresponding figures would be 322,000 m^3 and 647,000 m^3.

Figure 4 shows the potential of wood chips by energy wood components. The largest potential exists in full trees from early thinnings (26% of the whole potential), while the collection of logging residues from final fellings will be almost as important source in the future (24%). Moreover, particle board wood from later thinnings and final fellings presents huge potential (37% in 2006); so, too, do logging residues from later thinnings (17% in 2006).

Procurement costs

Because of the location of the forests, the total cost of wood chips is lower in Cabrejas del Pinar than in

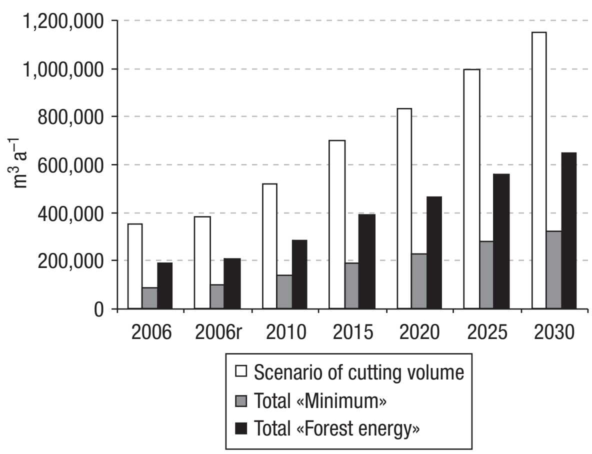

Figure 3. Predicted cuttings and corresponding potential of wood chips in five-year periods. 2006r means cutting volume according to the statistics and the corresponding wood chip potential.

Table 4. Parameter values used for the cost calculations

Work phase	Parameter	Value	Unit
Felling bunching	Gross effective/effective time coefficient	1.35	
	Hourly cost of a harvester	100	€ h^{-1}
Forwarding	Load volume of a forwarder	6.2	m^3
	Gross effective/effective time coefficient	1.2	
	Hourly cost of a forwarder	80	€ h^{-1}
	Forwarding distance	600	m
	Distance between strip roads	15	m
Comminution	Chipper's productivity per operating hour at the roadside landing, whole trees	72	loose-m^3 h^{-1}
	Chipper's productivity per operating hour at the roadside landing, logging residues	58	loose-m^3 h^{-1}
	Chipper's productivity per operating hour at the terminal, whole trees	93	loose-m^3 h^{-1}
	Chipper's productivity per operating hour at the terminal, logging residues	75	loose-m^3 h^{-1}
	Chipping cost per operating hour at the roadside landing	70	€ h^{-1}
	Chipping cost per operating hour at the terminal	63	€ h^{-1}
Transportation	Load volume	69	loose-m^3
	Size of a chip truck load	28	m^3
	Size of a loose residue truck load	18	m^3
	Truck cost when driving	70	€ h^{-1}
	Truck cost when loading/unloading	30	€ h^{-1}
	Loading time at the roadside landing, chips	1.0	h $load^{-1}$
	Loading time at the terminal, chips	0.7	h $load^{-1}$
	Loading time, loose residues	1.0	h $load^{-1}$
	Unloading time, chips	0.7	h $load^{-1}$
	Unloading time, loose residues	1.3	h $load^{-1}$
Other Costs	Compensation for piling logging residues into small heaps	0.3	€ m^{-3}
	Overhead costs	2	€ m^{-3}

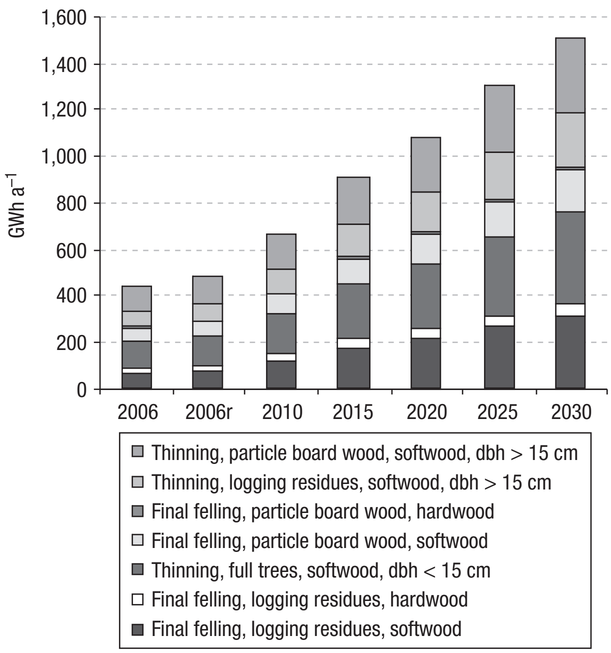

Figure 4. Wood chip potential in Soria. 2006r means wood chip yields corresponding to stem volume in cuttings.

Almazán (Fig. 5). The total procurement costs are lower with supply chains based on chipping at a roadside landing than with those based on chipping at the terminal. Although the chipping costs at the terminal are lower than those at a roadside landing, the higher transportation costs and extra handling costs raise the total costs of the former alternative (Fig. 6). In the following, only chipping at a roadside landing is considered. For logging residues from final fellings, the minimum total costs are about €6.5 MWh^{-1}, reaching a marginal cost of €10-11 MWh^{-1} at an annual consumption level of 300 GWh. For whole trees from thinnings, the respective costs are €9 and €13-14 MWh^{-1}. In terms of cubic meters, the procurement of one million cubic meters of logging residues directly to a plant would imply a marginal cost of €25-27 m^{-3}.

The total costs of procurement of full trees from thinnings are higher than those of logging residues from final fellings (Fig. 7). The felling of full trees is an extra cost compared to the harvesting of logging residues.

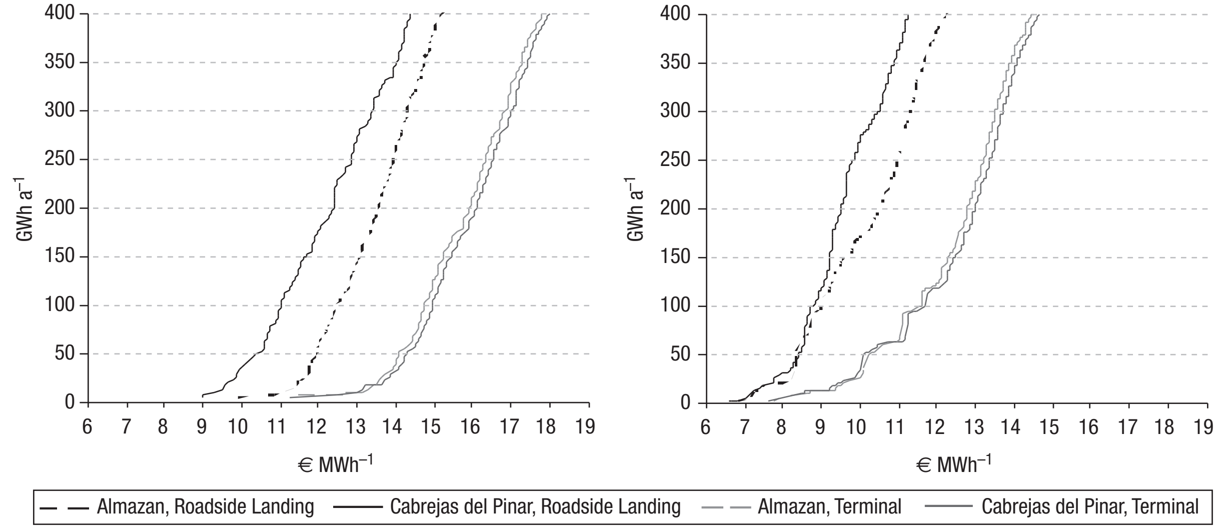

Figure 5. The effect of the annual procurement of wood chips from full trees from thinnings (left) and logging residues from final fellings (right) on the total cost of fuel at the plant.

Discussion

At the moment, the level of harvesting done at forests in Soria is low. In 2006, the harvested volume of timber was 383,000 m^3, which is less than one third of growth. In the future, the level of cuttings is expected to rise. Subsequently, this will also bring about an increase in the amount of wood chips available.

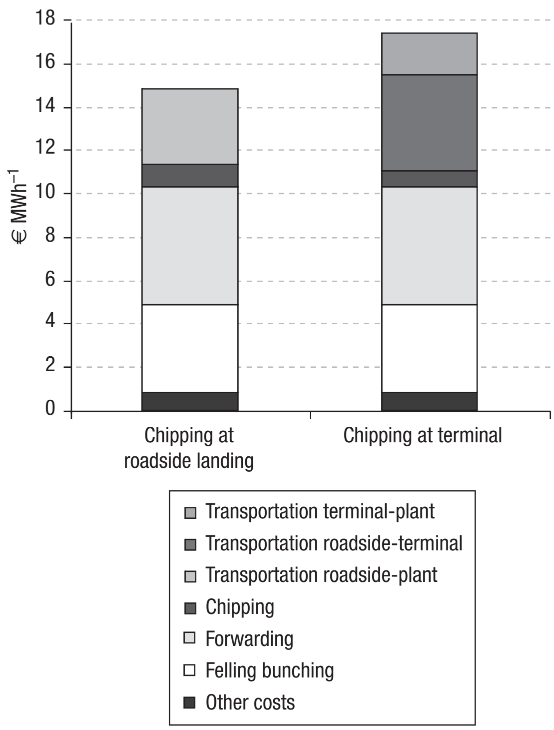

Figure 6. The effect of the site of chipping on the cost structure. Averages from Almazán when full trees from thinnings would be used. The average transportation distance was 65 km when chipping at the roadside landing and 79 km when chipping at the terminal.

However, even the current volumes would enable building more heating plants. It is assumed that only 300 GWh a^{-1} of wood chips would be technically and economically available. This implies that 35 plants of 2 MW could be run six months a year. Thus, the adequacy of forest resources poses no disincentives to the heat energy business.

Particle board wood holds a considerable reserve of wood chips. Although the price of particle board wood (€24 m^{-3}) at the roadside is considerably higher than the costs of bunching, forwarding and administration of felling (€7.92 m^{-3} when whole trees from thinnings would be used), there is not likely to be enough demand for increasing the amounts of particle board wood. Therefore, some of the particle board wood could be used for energy.

In the calculations, it was difficult to draw a line between first thinning and subsequent thinnings. The limit of 15 cm in mean diameter was chosen more or less arbitrarily. The limit influences the potential of full trees from thinnings. In fact, the limit may be smaller in reality, which means that the potential would be smaller.

As expected, the supply chains that included chipping at the terminal proved to be more expensive than those including chipping at a roadside landing. Where allowed by logistics and regulations, direct delivery of chips to

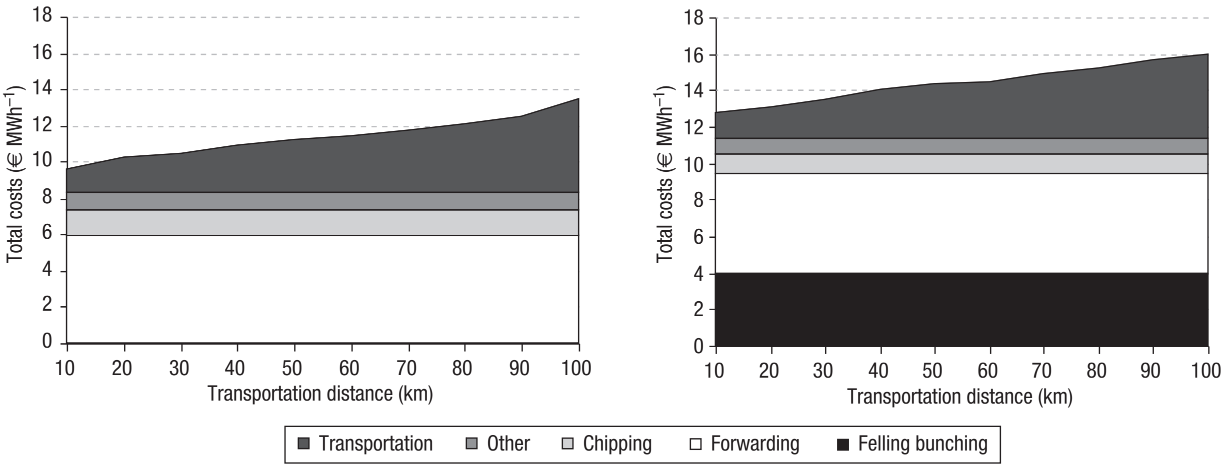

Figure 7. Cost structure for Almazán when logging residues from final fellings (left) and full trees from thinnings (right) are used and the supply is based on chipping at the roadside landing.

the end user, *i.e.,* chipping at a roadside landing, is the most cost efficient way to supply fuel. This is in good agreement both with the findings of studies conducted in the Nordic countries and with current practices (*e.g.,* Asikainen, 1998; Laitila, 2008).The role of a terminal is primarily to act as safety storage buffering against fluctuations in supply and demand.

Logging residues in final fellings are the cheapest source for wood chips. Collection of fire wood, however, may restrict the usage of logging residues in some areas. Full trees from first thinnings are another important resource. Although the total costs are higher than those of logging residues, preventing forest fires, increasing growth, and improving the quality of the remaining trees favor their use. If the consumption of wood chips should rise rapidly, logging residues from thinnings and particle board wood from thinnings and final fellings offer additional resources.

The procurement costs seem to be reasonably low compared to the general cost level in Europe. The costs for procurement of logging residues are similar to the country-level average costs in Finland and remarkably lower than the ones in Spain reported by a previous study (Asikainen *et al.*, 2008). This may partly stem from the fact that Soria is a more densely forested area than Spain on average.

The use of primary forest biomass (chips made of logging residues and trees small in diameter) as source of energy is just beginning in the Soria region. The solid wood fuel market is still largely based on residues from the mechanical wood processing industry. In the coming years, investments in expensive machinery for the fuel supply chain will pose greater risks than maximizing the use of the existing forest machinery (harvesters and forwarders) in the cutting and extracting of biomass to the roadside. Farm tractor driven chippers have sufficient capacity to meet the foreseen demand for wood chips to be used for energy. They can also operate in the terminals.

In order to improve the calculation of costs further, studies on the productivity of cutting, forwarding, and chipping local tree species with local chippers should be carried out in Spain. The driving speed in truck transportation should be modelled, and real load volumes with different material should be measured. For calculating the costs of machines, detailed data on variable and fixed costs should be collected as well. On the whole, a wood energy technology programme similar to the one conducted in Finland (Hakkila, 2004) would greatly enhance the business environment for new investments in wood energy in Spain.

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