Preliminary evaluation of a short rotation forestry poplar biomass supply chain in Emilia Romagna Region

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Abstract

Woody Biomasses (from agriculture and forestry activities) are among the most promising renewable energy sources. Current literature describes woody biomass feedstock supply chains supporting biofuels and utilities industries: the potentially productive land area overheads required for biomass production may results in a complex logistic within the whole chain. Its effective enhancement requires significant changes in the logistics environment of energy plants for sustainable energy production and the sequence-dependent procurement chains for biomasses furthermore complicate these changes. According to this, optimizing harvesting and supplying operations turns out to be strategic within the framework of the current energy policy. In this work we present a case study carried out monitoring 57 short rotation forestry (SRF) production sites placed in Emilia Romagna Region, Northern Italy, all supplying the harvested biomass to the same biomass power plant placed in the province of Ravenna (Italy). The overall average yield of these sites was 55 t/ha, the site surfaces ranged from 0.3 to 20 hectares and the distance from the power plant ranged between 8.2 to 102 km with one production site only within 10 km from the power plant. Harvest and transport costs were calculated according to two different harvesting scenarios: *i)* single phase harvesting (one cutting/chopping machine + tractors and trailers); *ii)* double phase harvesting (cutting/mowing machine followed after 80 days by chopping machine + tractors and trailers). Results show that, according to the first scenario, at increasing distances overall harvesting and transport costs ranged from 8.9 to 21.0 ± 1.3 €/t (average ± standard deviation), while, with reference to the second scenario, they increased from 10.3 to 23.8 ± 1.5 €/t with the transportation costs accounting from 16 to almost 70% of the total costs.

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Introduction

The rises of fossil fuel derived energy prices, and the increasing environmental concern, encourage the use of alternative and renewable energy sources as woody biomasses (Goldstein, 2006): low carbon power sources whose energy exploitation has the advantage that the emitted greenhouse gases (GHG) amounts are the same of those absorbed during the growth phase (Dubuisson and Sintzoff, 1998; Walle *et al.*, 2007; Djomo *et al.*, 2011).

Short rotation forestry (SRF) programs, made these woody fuel sources widely available allowing increases in production quality maintaining the competitiveness of the production costs: as far as woody fuel quality is concerned studies pointed out the importance of proper storage and handling of these biomasses (Lehtikangas, 2000; Jirjis, 2001; Lehtikangas, 2001; Pettersson and Nordfjell, 2007; Noll *et al.*, 2010) and production management criteria were addressed as way to maintain and increase the sustainability of this production (Cherubini and Strømman, 2011; Stolarski *et al.*, 2011; González-García *et al.*, 2012). With particular reference to harvesting operations, one recent study of Fiala and Bacenetti (2012) pointed out, with reference to poplar trees, how plantation characteristics strongly influence machine productivity together with biomass transport system efficiency introducing a big tricky point of this energetic sector: biomass production and transportation account for a significant part of the whole bioenergy costs (Zhang *et al.*, 2005) affecting plants' profitability, which is known to be highly geographically dependent (Noon and Daly, 1996). Transporting loose comminuted biomass is, at the moment, the most effective method for biomass supplying provided that close coordination of the transportation fleet is arranged (Spinelli and Hartsough, 2006).

Transportation costs from the sources to the energy plants take a significant proportion of the overall production costs of woody biomasses: hauling distance, load bulk density and delivered material moisture content can accounting up to 50 per cent of delivered costs (Angus-Hankin *et al.*, 1995; Zhan *et al.*, 2005; Pan *et al.*, 2008). Increasing the transportation efficiency of woody biomass should significantly reduce overall production costs as well as environmental impacts (Palmgren *et al.*, 2004). To achieve this, many models and decision systems relying on GIS approach have been developed to define planning and management strategies for the optimal logistics for energy production from woody biomass, such as forest biomass, agricultural scraps and industrial and urban untreated wood residues (Andersson *et al.*, 1995; Frombo *et al.*, 2008; Sang-Kyun *et al.*, 2012). These decision support systems have been set up to select least-cost bioenergy locations when more than one bioenergy plant is present in the region and there is significant variability in biomass farm-gate price or in supply costs (Ranta, 2005; Panichelli and Gnansounou, 2008) or to facilitate the definition of sound policies and strategies based on a comprehensive perspective of the whole energy system (Mitchell, 2000; Masera *et al.*, 2006).

Within this framework, with the final aim to assess the effective account of delivery costs on woody biomass price, we present a case study carried out monitoring short rotation forestry (SRF) production sites placed in Emilia Romagna Region, Northern Italy, all supplying the harvested biomass to the same biomass power plant placed in the province of Ravenna (Italy).

Material and methods

Fifty seven short rotation forestry biomass production sites (Figure 1) growing poplar tree (*Populus spp*.) or locust tree (*Robinia pseudoacacia*) were monitored with reference to biomass production and transport to the power plant site. According to the distance from the centralized power plant, biomass production units were divided in the following groups: *i*) within 10 km; *ii*) from 10 to 30 km; *iii*) from 30 to 40 km; *iv*) from 40 to 60 km; *v*) from 60 to 70 km; *vi*) more than 70 km.

For this production site characterization, two different scenarios (namely, "single phase harvesting" and "double phase harvesting" procedures) have been taken into account.

According to single phase harvesting scenario, biomass was harvested and chopped with a CLAAS forager (Jaguar series, CLAAS KGaA mbH, Germany) powered by an engine rated at 372 kW. The unit, fitted with one "GBE-1" header for SRF crop harvesting (Figure 2) cuts the stems and moves them toward the horizontal in feed rollers built into the forager unit. This harvesting-chipping machine enters the field followed by tractors with trailers or by lorries providing for chopped biomass transport to the plant site.

The double phase harvesting scenario considers two separate passes. In the first pass, a semi-trailed cut-windrower (applied to a 60 kW tractor at least), cuts the stems and lays them in the inter-row parallel with the advancing direction of the tractor while, in the second pass, a forage harvester equipped with a pick up head collects and chip the windrowed stems. The pick-up gathers the plants from the ground and the concomitant action of the forward moving of the tractor and of the conveyor device allows for the loading of the trees towards the feeding rolls of the chipping device and the offloading of the chips into the trailers. While the first pass is conducted in winter and during the dormant season, the second pass occurs in late spring, after the stems have been partially dehydrated. Information about production rates and costs of each of these scenario are reported in Tables 1 and 2. For each production unit, the distance from the centralized power plant was determined and according to this, harvesting and transporting costs were calculated as follows:

$$Harvesting\ Costs\ (€/t) = \frac{Produced\ Biomass\ (t)}{Machine\ operative\ capacity\ (ha/h)} \ x\ hourly\ Costs\ (€/h)$$

$$Transport\ Costs\ (€/t) = \frac{Time\ required\ (h)}{Lorry\ hourly\ cost\ (€/h)} \ x\ Number\ of\ required\ trips\ x\ 2$$

$$Overall\ Costs\ (€/t) = Harvesting\ costs\ (€/t) + Transport\ Costs\ (€\ /\ t)$$

The obtained data underwent statistical analysis by means of *Minitab® 16 Statistical Software* (2010) to perform descriptive statistics and analysis of variance (P<0.05).

Results

Biomass production units of the considered scenario turn out to be quite unevenly distributed among the considered distance ranges (Figure 3), nevertheless the average surface used for biomass production turned out not to be significantly different (Figure 4) at P < 0.05: as a matter of fact only one production site (whose production accounts for

Figure 1. Geographical distribution of the biomass production sites (green markers) and of the power plant (red marker). Image from Google Earth®.

Figure 2. Particular of the GBE-1 header for SRF harvesting.

1.3% of the total produced biomass) is located within 10 km from the power plant and 4 plants only (7.0% of the total) are placed from 10 to 30 km of distance while great part of them are placed more than 40 km far (Figure 3).

The comparison carried out on overall costs and on the per cent weight of transport costs (Table 3) shows that overall costs range from 8.92 – 10.26 € t^{-1} to 20.97 – 23.79 € t^{-1} increasing, as expected, at increasing distances from the power plant with similar percentage incidences of the transport costs.

If, on one hand, generally speaking, the costs related to the double phase harvesting procedure are always higher than those related to the one phase harvesting, on the other the one way ANOVA shows that in three cases only this difference turns out to be significant.

The same analysis carried out on the incidence of transport costs, shows that for production sites placed from 40 to 60 km and from 60 to

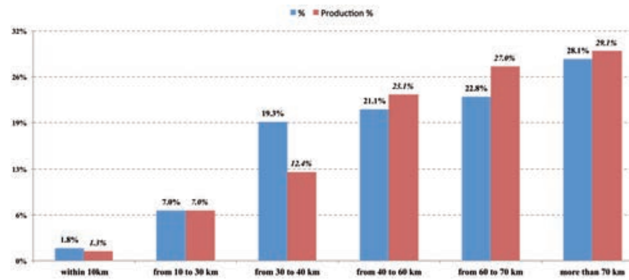

Figure 3. Distribution of the biomass production units in the distance range as percentage of their number (blue columns) and of the whole produced biomass (red columns).

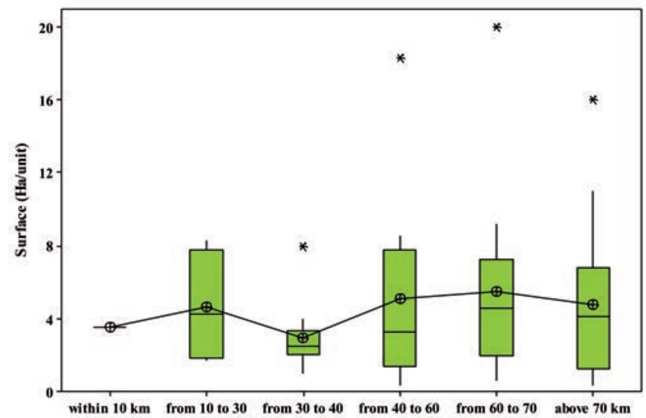

Figure 4. Boxplot chart of the average unit surface (Ha/unit) for the considered distance ranges.

Table 1. Main economic and technical features of the *single phase harvesting procedure*.

Cutting/Chopping machine hourly cost (€/h)	411.00
Productivity (Ha/h)	1.0
Woody Biomass Yield (Mg/ha)	55.0
Tractor + trailer hourly cost (€/h)	42.00
Trailer maximum capacity (t)	0.37
Tractor average speed (km/h)	35.0
Lorry hourly cost (€/h)	65.00
Maximum capacity of the lorry (t)	21.00
Average speed of the lorry (km/h)	50.0

Table 2. Main economic and technical features of the *double phase harvesting procedure*.

1st phase: cutting and mowing		2nd phase: chipping and transporting	
Cutting hourly cost (€/h)	67.00	Pick-up Hourly Cost (€/h)	308.50
Operative Capacity (Ha/h)	1.40	Operative capacity (Ha/h)	0.85
Biomass Yield (Mg/ha)	55.0	Biomass Yield (Mg/ha)	46.7
Tractor + trailer hourly cost (€/h)	42.00	Tractor + trailer hourly cost (€/h)	42.00
		Maximum trailer capacity (Mg)	0.70
		Lorry for biomass transport (€/ha)	73.00

Table 3. Average harvesting and transporting overall costs as well as average per cent accounting of transport costs on the total costs. Uppercase letters indicate significant differences among mean values along the same column (p<0.05), lowercase letters indicate significant differences (p<0.05) between values belonging to different harvesting procedures.

Distance ranges from the power plant	N. of units	Single phase harvesting Overall costs (€/t)	Single phase harvesting Transport costs (%)	Double phase harvesting Overall costs (€/t)	Double phase harvesting Transport costs (%)
Within 10 km	1	8.92 A	16.3 A	10.26 A	15.8 A
From 10 to 30 km	4	10.91±0.90 (B, a)	31.2±5.62 (B, a)	12.49±1.01 (B, a)	30.6±5.60 (B, a)
From 30 to 40 km	11	13.56±0.46 (C, a)	44.8±1.84 (C, a)	15.47±0.52 (C, b)	44.1±1.80 (C, a)
From 40 to 60 km	12	17.66±0.28 (D, a)	57.7±0.69 (D, b)	20.08±0.31 (D, a)	56.9±0.69 (D, a)
From 60 to 70 km	13	18.37±0.23 (E, a)	59.3±0.50 (E, b)	20.87±0.26 (E, b)	58.6±0.54 (E, a)
More than 70 km	16	20.97±1.34 (F, a)	64.2±2.00 (F, a)	23.79±1.51 (F, b)	63.5±2.02 (F, a)

70 km from the power plant, the incidence of these is significantly, despite slightly, lower when harvesting is carried out according to the double phase system.

With reference to transport costs incidence on overall costs, these results fully comply with the finding of Spinelli *et al.* (2006), who assessed that transportation accounts for 30-50% of the total costs on the short haul, and 60-70% of the costs on the long one when SRF poplar for pulpwood is concerned. Nevertheless, when transport cost values are concerned, according with Sultana and Kumar (2011), both fixed costs and distance related variable should be considered with the latter depending on the type of biomass being transported, on the form of biomass, on the equipment used for loading–unloading and any existing contractual agreement (Searcy *et al.*, 2007). Mahmudi and Flynn (2006) assessed the fixed costs of woody chips transport at 4.07 € t^{-1} and the variable component at 0.06 € t^{-1}. Transport costs recalculation with these values (converted into euros) give rise to an great overestimation of transport costs for the production unit closer to the power plant, while for the other groups of biomass production sites the predicted values are 24% higher than ours in case of units ranging from, 10 to 30 km from the plant, while for all the others the estimated values are from 29 to 60 % lower. This trend is confirmed also by comparing overall costs with those of 49.46 € t^{-1} for 16 km distance and 36.33 € t^{-1} for 27 km distance presented by Perrin (2012) who worked on corn-stover biomass supply of ethanol production facility. The reason of this can be ascribed, on one hand, to the costs of the fuel for transport which, has high impact on transport costs in the European context, while on the other to the high variability of duty trucks which can differ substantially around the world and even in the same country (Widerberg *et al.*, 2006). Moreover, with reference to data provided by Perrin *et al.* (2012) their value is unavoidably affected by the higher value of fixed and variable components that, according to Kumar and Sokhansanj (2007),are quite higher than those provided by Mahmudi and Flynn (2006).

Conclusions

A case study on the effective costs related to biomass supply chain in the Emilia Romagna region was carried out considering a number of SRF production sites within 70 km of distance from the power plant. At increasing of the distance, overall cost can almost double passing, at varying of the hypothesized scenario, from 8.92 – 10.26 € t^{-1} to 20.97 – 23.79 € t^{-1} where transport costs incidence varies from 31 to 64%.

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