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Recovering energy biomass from sustainable forestry using local labor resources

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ABSTRACT

Logging residues from sustainable forest operations can be recovered as biomass feedstock for renewable energy generation. Under the conditions of developing economies, residue recovery is best performed with manual techniques, because labour cost is still low, whereas capital availability is limited. Furthermore, manual recovery minimizes fossil inputs and creates employment opportunity for self-employed forest villagers in disadvantaged rural areas, and it may help contrasting landscape neglect and rampant urbanization. This study offers the example of residue recovery from the regeneration cut of mature Turkish pine (*Pinus brutia* Ten.). Even after all stem and branch portions are recovered to a minimum small-end diameter of 4 cm for the production of conventional firewood logs, residues amount to 15–30 fresh t ha^{-1} and require windrowing before replanting. Approximately 50% of the residue can be recovered as energy biomass, after separating the fibre rich portion from twigs and leaves. This operation allows additional recovery, while minimizing nutrient removal. Productivity was estimated between 0.3 and 0.7 fresh t h^{-1}, for a three-men crew. Manual extraction of processed residues to the roadside proceeded at a pace between 0.8 and 1.7 fresh t h^{-1} for the same crew. Best results were obtained when processing was performed after removing all conventional product, and before windrowing the residues. The most effective extraction method was throwing the biomass sticks downhill to the roadside. Processing and extraction cost amounted to 27 € fresh t^{-1}, or 8.3 € MWh^{-1}. After accounting for delay time, for chipping, transportation and all other indirect cost, total delivered cost amounted to 14.3 € MWh^{-1}. That was over the 10 € MWh^{-1} target, indicating the need for increased efficiency, possibly obtained through better mechanization. The results of this study might be generalized and extended to many other developing economies, where the rational recovery of logging residues may offer significant economic, environmental and social benefits.

1. Introduction

Increased use of renewable energy sources is a strategic goal for both industrialized and developing economies, which have a strong interest in decoupling economic growth and environmental pressure (Schandl et al., 2016). In particular, biomass energy allows for the clean disposal of byproducts and the efficient use of natural resources. Furthermore, biomass energy offers the benefit of small-scale decentralized generation, which may overcome the limits of the obsolete and expanding distribution networks that characterize developing economies (Bazmi et al., 2015). Under these conditions, residue recovery is best performed with manual techniques, because labour cost is still low, whereas capital availability is the limiting factor. An interesting example may come from Turkey, where a changing forestry practice and the new renewable energy act have encouraged the use of renewable energy resources such as woody biomass (McKay, 2006). One instrument for supporting energy generation from biomass is represented by subsidized feed-in tariffs guaranteed by the national government, like is already done in many other countries (Eker, 2014). Turkish forests may supply large amount of biomass, because they cover 22 million hectares and have an annual increment of 46 million m^3. However, the country hosts only two biomass plants with a fuel consumption of ca. 17 t h^{-1}, or ca. 140,000 t per year (Saraçoğlu, 2015). On the other hand, firewood is a popular energy vector used by traditional

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households and is obtained from any tree portion capable of offering a log with a minimum small end diameter of 4 cm and a minimum length of 1 m. However, firewood consumption has decreased sharply in recent years, and a major part of the firewood stream has been diverted towards the particle-board industry (Eker, 2014). Taken together, the forest industry and the residential sector (heating and cooking) use about 29 million m^3 of wood material per year (GDF, 2015), which precludes the utilization of merchantable wood as fuel for the growing bio-energy sector. Therefore, the most readily available source of biomass fuel is represented by logging residues (Eker et al., 2013). The General Directorate of Forestry (GDF) has decided that the logging residues derived from the harvesting of Turkish pine (*Pinus brutia* Ten.) forests should be used as biomass fuel (GDF, 2009), in order to promote renewable energy, to decrease regeneration cost and to reduce fire hazard.

Unutilized logging residues have attracted increasing attention among fuel wood suppliers, bio-energy producers, and the chipboard industry (Saraçoğlu, 2010). However, locals also target the firewood portion of these residues for meeting their heating and cooking needs (Alkan et al., 2014). Therefore, the tree portion available for an eventual biomass plant is the low value by-product obtained from unmerchantable branches and tree tops with a diameter between 1.5 and 4 cm and a length of at least 1 m. This material should be clean of twigs, cones, and needles, and is defined as "residual woody biomass" (RWB) for the purpose for this study.

As a first step, it is essential to quantify the recoverable amount of RWB, in order to predict the contribution of recovery operations to biomass supply (Kizha and Han, 2015). The theoretical potential of logging residues derived from all Turkish forest has already been estimated at 5–7 million fresh t (Kaygusuz and Turker, 2002; Demirbaş, 2008; GDF, 2009). Previous studies have indicated that the amount of logging residues from Turkish pine forests could range between 8 t ha^{-1} and 32 t ha^{-1} (Sun et al., 1980; Durkaya et al., 2009; GDF, 2010). Eker (2011), and Çoban and Eker (2014) have estimated that the woody parts of these logging residues may represent between 4.4 t ha^{-1} and 11.7 t ha^{-1}, depending on stand conditions. However, actual recovery depends on many factors (Smeets and Faaij, 2007; Ralevic et al., 2010; Spinelli et al., 2016), and therefore the amount of available logging residues should be determined case-by-case based on site-specific conditions. A critical stage is to determine the financial viability of RWB recovery, depending on site conditions and technology.

As a second step, one should determine if residue recovery is financially viable under the specific work conditions offered by Turkish forestry. There, motor-manual cut-to-length harvesting system (CTL) is the most common work system used for wood harvesting in Turkey. Motor-manual CTL harvesting affects the recoverable amount of logging residues and leads to an increase of harvesting cost between 40 and 50% compared with whole tree harvesting, but it guarantees that the nutrient-rich tree components are left in the stand (Hacker, 2005). In Turkey, unfavourable terrain conditions, low product yield per ha and the need to support employment within the rural population impose to use of motor-manual timber harvesting and of low-investment extraction techniques (gravity sliding), in general. For the same reasons, manual techniques are the only option for RWB recovery. Unfortunately, very few studies have been conducted about the viability of residue recovery using manual techniques, despite the very large potential for these methods in developing economies across the world. Furthermore, the same motor-manual techniques can be applied in a variety of different ways. The manufacturing of RWB involves always the same processes (i.e. crosscutting, delimbing and piling), but it can be carried out at different moments, and namely: during tree processing in a single pass, or after timber processing in a second pass. Similarly, manual extraction can be obtained by throwing or by carrying. Obviously, different possibilities may offer different productive and financial results.

Therefore, the purpose of this study was: (1) to determine the quantity of RWB recovered from the logging residues generated from regeneration felling using motor-manual CTL harvesting and (2) to determine work productivity and unit costs for a range of manual recovery techniques. This was an initial feasibility study to assess the techno-economic viability of manual recovery of RWB, with the ultimate objective of informing forest managers, energy investors, and all parties potentially interested in biomass recovery for energy generation.

2. Material and methods

2.1. Study site

The study site was located in the state-owned forests managed by the Isparta Regional Directorate of Forestry, which grow in the mountainous and karstic terrain characterizing the Mediterranean Region of Turkey (Fig. 1). The natural Turkish pine-dominated stands are managed according to multi-functional close-to-nature forestry practice. All study compartments were clearfelled between 2011 and 2014, within the context of ordinary silvicultural prescriptions for natural regeneration. These study sites were randomly selected among mature stands with different site index and located in different compartments, so that the survey might be taken as generally representative of the Mediterranean Region of Turkey, and of other zones offering similar climate and forest conditions.

The experimental plan included 22 sample stands representing different conditions (tree size, slope gradient, site index, ground etc.) and distributed according to a randomized, balanced design. Each sample stand was divided into three plots, one for each of three RWB processing treatments (Table 1). Manual extraction trials were also performed on 12 different stands, each divided in two plots in order to test three alternative extraction methods or treatments, since one of the extraction method was not applicable to all sites. Mean plot size was ca. 1000 m^2, and the total surface of all test plots amounted to 9.30 ha.

2.2. Systems and treatments

The main harvesting was performed according to the conventional motor-manual CTL system. After tree felling, the stem was processed into various wood products, using a medium-size chainsaw. Thick branches and tree tops were turned into firewood and therefore were not available as RWB. When felling and

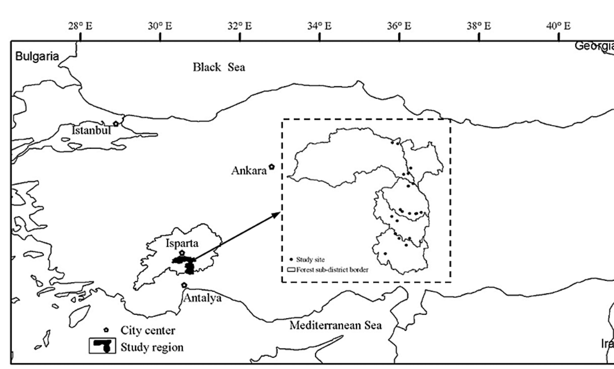

Fig. 1. Location of the study sites (the dark-colored polygon includes sampling sites).