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RESEARCH ARTICLE

Economics of forest biomass for bioenergy: potential site preparation savings from coarse woody harvesting residue removal in a short-rotation *Eucalyptus globulus* (Labill.) plantation

Martin Strandgard[1], Mathieu Béland[2]

[1] *Forest Industries Research Centre, University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, 4558 Queensland, Australia*
[2] *Nature Quebec, 870 avenue De Salaberry, Bureau 207 Québec, QC G1R 2T9, Canada*

Corresponding author: Martin Strandgard (mstrandg@usc.edu.au)

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Abstract
The study used time studies and cost analysis to assess potential economic benefits from site preparation cost reductions resulting from producing coarse woody harvesting residue (CWHR) for bioenergy. In contrast, previous studies have predominantly used anecdotal estimates of site preparation costs.
The study was performed in a recently clearfelled 15-year-old plantation of *Eucalyptus globulus* (Labill) in Tasmania, Australia. The study area consisted of the control area (0.51 ha), containing ~35 m^3 ha^{-1} of CWHR and the CWHR harvest area (2.47 ha), containing ≤12 m^3 ha^{-1} of CWHR. The control area had been harvested with a harvester – forwarder system, which left all harvesting residue (HR) onsite, whereas the CWHR harvest area had been harvested with a feller-buncher – skidder – processor system which removed most of the HR. The latter site was used to simulate an area where CWHR had been harvested. The study examined productivities and costs of machines performing site preparation in each area.
The preparation of the control area site was performed with an excavator that windrowed CWHR, followed by a skidder-mounted plough constructing planting furrows. Residual CWHR post-windrowing was <1 m^3 ha^{-1}. Productivities and costs were 0.53 ha PMH_0^{-1} and AUD$319 ha^{-1} for the excavator and 1.1 ha PMH_0^{-1} and AUD$139 PMH_0^{-1} for the skidder-mounted plough. The excavator was not required in the CWHR harvest area. In this area, skidder-mounted plough productivity and cost were 1.16 ha PMH_0^{-1} and AUD$109 ha^{-1} suggesting CWHR reduction to ≤12 m^3 ha^{-1} could reduce site preparation costs by AUD$319 ha^{-1}. Further studies on costs and revenues associated with CWHR removal and sale are re-

quired to determine net economic benefits and determine excavator cost and productivity for a range of CWHR quantities.

Keywords
Biofuel, *Eucalyptus globulus*, excavator, plough, site preparation, skidder, windrow

Introduction

Bioenergy provides the biggest share of the world's renewable energy (IPCC, 2011). However, economic studies of using forest biomass for bioenergy have frequently shown that profitability is hard to achieve when using harvesting residue (HR) as a primary feedstock (Sarkar, Kumar, 2009; Murphy et al., 2010; Kizha, Han, 2016; Berry et al., 2018; Béland et al., 2020), due mainly to its low bulk and spatial densities (Gan, Smith, 2006), which is a major obstacle for the establishment of a forest bioenergy industry. Currently, the use of HR as a bioenergy source is very limited in Australia. However, previous studies have estimated that large quantities of HR are available from Australian plantation harvesting operations (Ghaffariyan, 2013).

Costs to extract and use HR must be considered in the context of the costs associated with treating retained HR on site. HR left on site is typically burned or treated to facilitate site preparation prior to the establishment of the next rotation. HR treatments include pushing residues into long parallel piles (windrows) with an excavator or bulldozer and using a bulldozer-drawn heavy roller to knock down and chop residues (chopper-rolling) (Costantini et al., 1997). Treatment or burning of HR increases the costs of the next rotation and in the case of burning can reduce local air quality (Sifford et al., 2017) and remove a significant proportion of the site's post-harvest nutrients and organic matter, potentially reducing future tree growth (O'Hehir, Nambiar, 2010). Retaining HR in windrows can increase not only herbivore browsing damage to young trees (While, McArthur, 2006), but may also increase the availability of wildlife habitat (Lindenmayer, Hobbs, 2004).

Harvesting HR for bioenergy can reduce site preparation costs, particularly if no additional HR clearing is required to perform site preparation activities. However, there is a lack of published information about the magnitude of the cost savings from HR removal, especially in Australia. Published potential site preparation cost savings also cover a broad range: from US\$250 ha^{-1} (Gan, Smith, 2007) to US\$1100 ha^{-1} (Kizha, Han, 2016). Such cost estimates are frequently based on anecdotal evidence rather than on experimental findings (e.g. Ximenes et al., 2012; Kizha, Han, 2016).

Two methods are used to prepare eucalypt plantation sites for replanting in Tasmania: spot cultivation with an excavator or windrowing with an excavator followed by ploughing. Spot cultivation can be carried out with HR retained on site but has been found to be more expensive than windrowing and ploughing (Laffan et al., 2003). This study aimed to assess the potential economic benefits of harvesting coarse woody harvesting residue (CWHR) for bioenergy, in terms of site preparation cost reduction on a short-rotation plantation site of *Eucalyptus globulus* (Labill) in Tasmania.

Methods

The study was conducted from November 1st to 3rd, 2016 in a plantation of *Eucalyptus globulus* (Labill.), harvested for pulplogs in early 2016 at an age of approximately 15 years. The plantation was located ~30 kilometres northwest from Launceston, Tasmania (-41.26, 146.807). The study site consisted of two areas: a control area (0.51 ha) and a CWHR harvest area (2.47 ha).

The mean annual minimum and maximum temperatures at the site were 6° C and 21° C, respectively. The mean annual rainfall was 640 mm. The average slope in the control area was 6 degrees (10.5%) and in the CWHR harvest area was 0 degrees. The weather during the study was warm (~17-18°C) and sunny. The soil type was a dark brown silty clay loam. Rainfall had occurred prior to the trial but did not impact the machine performance.

Most of the plantation containing the study site had been harvested using a feller-buncher – skidder – processor harvest system and had low residual HR levels. The whole trees had been extracted to roadside for debarking – delimbing and processed to pulplogs. However, a section of the study site had been harvested using a harvester – forwarder harvest system processing and debarking trees at the stump to produce pulplogs, which resulted in large quantities of HR being left on site.

Two site preparation scenarios were evaluated in the study: a control scenario and a CWHR harvest scenario. The control scenario site was within the area harvested by the harvester – forwarder harvest system and was treated by windrowing and ploughing. The CWHR harvest scenario was tested for a site within the area harvested by the feller-buncher – skidder – processor harvest system and was treated using ploughing only. The low level of retained CWHR on this site enabled it to be used to emulate a site where CWHR had been harvested prior to site preparation.

In both the scenarios, the volume of CWHR before treatment was quantified, using the line transect method described by Van Wagner (1968). The quantity of CWHR retained after treatment of the control site by the excavator but before ploughing took place was also estimated using a line transect study. CWHR with a diameter at the point of contact with the line transect of <5 cm was excluded, since it appeared to have a lower impact on the productivity (Bérubé, 2011). The line transect method was preferred over the measurement of total HR volume because the volume of CWHR has been shown to be more relevant than total HR volume in predicting site preparation quality (Bérubé, 2011; Ximenes et al., 2012).

Site preparation on the control area was performed by two machines – an excavator (Komatsu 8 PC200-8 LC 2014 with 3575 engine hours) and a skidder (John Deere 648 H 2008 with 5165 engine hours) pulling a Savannah six-disc bedding plough. The excavator was used to pile CWHR into windrows approximately 12 – 14 m apart (Fig. 1). The skidder-mounted plough then ploughed the cleared area between the windrows in four or five continuous furrows (Fig. 2). Stumps were not removed prior to ploughing. Only four of the skidder-mounted plough's discs were required to produce a mound that met the plantation manager's requirements. Site preparation on the CWHR harvest site consisted solely of ploughing furrows with the skidder-mounted plough. The excavator operator had more than 18 months of experience with that machine and extensive experience operating excavator-based harvesters. The skidder operator had more than 30 years of experience operating skidders.

Machine productivity

Time studies were conducted to estimate the productivities of the excavator and skidder-mounted plough. Time study data for the skidder-mounted plough were collected using a Multidat data logger (Brown et al., 2002) installed in the skidder when working on the CWHR harvest site and from digital video recordings when on the control site. The Multidat has an onboard GPS receiver and a vibration sensor. The GPS receiver was set to record GPS points every 20 m and every minute to allow the travel distance and speed of the skidder-mounted plough to be determined. Delays were identified as periods of one minute or greater when the skidder-mounted plough was not moving. All delays were removed during data analysis to determine productive machine hours excluding delays (PMH_0). The productivity of the skidder-mounted plough was measured in ha PMH_0^{-1}.

The basic work pattern of the skidder-mounted plough was to: (1) plough a continuous planting furrow until the boundary of the area being treated was reached; (2) turn with the plough raised and then (3) lower the plough and continue ploughing in the opposite direction until the boundary on that side was reached. Cycle time elements for the plough were: plough, turn and delay (Table 1).

The excavator's productivity was determined from a time study conducted using digital video recordings. The excavator treated a smaller area than the skidder-mounted plough (0.45 ha) because 0.06 ha of the control area did not require HR removal by the

Figure 1. Excavator clearing harvesting residue into windrows

Figure 2. Skidder-mounted plough ploughing furrows

excavator prior to ploughing. We recorded the following excavator cycle elements: move, windrow, turn and delay (Table 2). Simultaneous moving or turning and windrowing was recorded as windrowing.

Machine costs

Machine costs were calculated using the method of Miyata (1980) based on the cost assumptions in Table 3. Based on data obtained from the Multidat for the study area and additional areas in the same plantation as the study, the utilisation rate for the skidder-mounted plough was determined to be 85%. As there were insufficient data to estimate the utilisation rate for the excavator, it was assigned the same utilisation rate as the skidder-mounted plough.

* At the time of the study, fuel for off-road use in Australia had an AUD 0.38 discount applied

[#] SMH is scheduled machine hours

Results

Harvesting residue volume

Mean and standard deviation of the CWHR quantities in each study area were: 35 m^3 ha^{-1} (SD 6.5 m^3 ha^{-1}) in the control area and 12 m^3 ha^{-1} (SD 5.4 m^3 ha^{-1}) in the CWHR harvest area. CWHR volume after the excavator had treated the control area was <1 m^3 ha^{-1}.

Table 1. Time element description for the plough

Time element	Description
Plough	Starts when the plough touches the ground and ends when the plough is lifted from the ground.
Turn	Starts when the plough is lifted from the ground and ends when the plough touches the ground
Delay	Any interruption to previous elements.

Table 2. Time element description for the excavator

Time element	Definition
Move	Starts when the tracks start moving. Ends when another element starts operating.
Windrow	Starts when the boom starts moving to windrow HR. Ends when another element starts operating.
Turn	Starts when the machine is at the end of the area being treated and commences turning to start the next windrow. Ends when another element starts operating.
Delay	Any interruption to previous elements.

Table 3. Excavator and skidder cost assumptions

Variable	Excavator	Skidder
Operating days per year	249	249
Shifts per day	1	1
Hours per shift	11	11
Purchase price (AUD$)	600000	450000
Machine life (yrs)	5	5
Salvage value (% of purchase price)	20	20
Utilisation rate, PMH/SMH (%)	85	85
Repair and maintenance (% of depreciation)	75	75
Interest rate (% of average yearly investment)	9	9
Insurance and tax rate (% of average yearly investment)	6	6
Fuel consumption (l PMH^{-1})	18	13
Fuel cost (AUD$ l^{-1})*	0.71	0.71
Oil & lubricant (% of fuel cost)	50%	50%
Labour costs (AUD$ SMH^{-1}) #	46.59	46.59
Supervision (% of labour costs)	10%	10%

Machine productivity

The productivity of the skidder-mounted plough in the control area and CWHR harvest area was 1.1 ha PMH_0^{-1} and 1.16 ha PMH_0^{-1}, respectively. The productivity of the excavator in the control area was 0.53 ha PMH_0^{-1}.

Elemental time proportions of the excavator's productive time were: move 0.08; windrow 0.86; turn 0.06. Elemental time proportions of the skidder-mounted plough's productive time were: control area plough 0.72; control area turn 0.28; CWHR harvest area plough 0.8 and CWHR harvest area turn 0.2.

Cost estimation

We estimated the machine costs for the skidder-mounted plough and excavator were AUD\$139 PMH_0^{-1} and AUD\$169 PMH_0^{-1}, respectively. The plough cost in the control area was AUD\$126 ha^{-1} and in the CWHR harvest area was AUD\$109 ha^{-1}. The excavator cost in the control area was AUD\$319 ha^{-1}. Therefore, the estimated site preparation saving resulting from the removal of the CWHR was AUD\$319 ha^{-1}.

Discussion

The productivity of the skidder-mounted plough in the current trial was similar to that reported by Saarinen (2006) for forwarder-mounted mounders (0.9–1.31 ha effective hour $(E_0)^{-1}$) and greater than that reported by Hämälainen, Kaila (1985) (0.74 ha PMH_{15}^{-1}), which included delays less than 15 minutes in duration accounting for 4.8% of the working time.

The higher productivity of the skidder-mounted plough in the CWHR harvest area compared with that in the control area was likely to be a result of the smaller size of the control area, which increased the proportion of time the skidder spent turning at the ends of the treated area. This concurs with the findings of Hämälainen, Kaila (1985) who reported that ploughing productivity increased as the size of the area being treated increased, as larger areas required less turning and reversing of the plough.

No published studies were found of excavator productivity or utilisation rate when clearing CWHR into windrows. The relative productivities of the two studied machines suggested that for sites with similar CWHR quantities to that in the studied control area (35 m^3 ha^{-1}), two excavators constructing windrows would be required to match the productivity of one skidder-mounted plough. This would increase the potential site preparation cost savings from CWHR removal.

The study found that approximately AUD\$319 ha^{-1} in site preparation costs could be saved by reducing CWHR to 12 m^3 ha^{-1} or less by removal of CWHR for use as a biofuel prior to the commencement of site preparation. This represented a saving of over 70% of the site preparation costs. To achieve this level of retained CWHR in the current study would have required the removal of at least 23 m^3 ha^{-1} of CWHR. The quantity of CWHR removed and the site preparation cost savings in the current study were similar to those reported by Wrobel-Tobiszewska et al. (2015) (20-29 t ha^{-1} and AUD\$300 ha^{-1}, respectively) in a study in a *E. nitens* plantation in the Florentine Valley, south-west Tasmania. Similarly, Gan, Smith (2007) reported that the removal of 70% of the HR would result in estimated site preparation cost savings of US\$250 ha^{-1} (~AUD\$350 ha^{-1}). site preparation savings from CWHR removal would be greater if it had been removed instead of being burnt on site, with estimates of burning costs ranging from AUD\$500 ha^{-1} (Ximenes et al., 2012) to US\$1000 ha^{-1} (~AUD\$1400 ha^{-1}) (Kizha, Han, 2016). Determination of the net economic benefit from CWHR reduction needs to consider the CWHR harvest, extraction and transport costs and revenue from CWHR sales. These costs and revenues were not determined in the current trial and should form part of a future trial. However, it is clear from previous studies harvesting and extracting similarly sized material in plantations of Australian *Pinus radiata* that the relatively low concentration of CWHR per hectare is a key factor in determining the cost of CWHR delivered to roadside (Ghaffariyan et al., 2014; Walsh, Strandgard, 2014; Ghaffariyan et al., 2015).

A frequent objection to the removal of HR for use as biofuel concerns the potential export of nutrients from the site in the biomass (e.g. O'Connell et al., 2004; Helmisaari et al., 2011), as these nutrients may need to be replaced using fertilisers to maintain tree growth creating an additional cost (Eisenbies et al., 2009). However, the current study was focussed on the removal of the coarse woody components of HR as it is these components that can impede the operation of the plough. CWHR components only contain a low proportion of site nutrients, thus reducing nutrient export from the site (Shammas et al., 2003; Rodríguez-Soalleiro et al., 2018). The current study also found that approximately one third of the CWHR (~12 m^3 ha^{-1}) could be left on site without impacting the productivity of the skidder-mounted plough.

Conclusion

The study found that substantial economic benefits (~AUD\$319 ha^{-1}) could be obtained by reducing the cost of site preparation through removal of a portion of the CWHR on a short-rotation pulplog plantation harvest site of *E. globulus*. Cost savings could be increased if two excavators were required to match the productivity of the skidder-mounted plough. However, the net economic benefit depends on the costs and revenues associated with CWHR removal and sale, which should be determined in future studies. The finding that up to 12 m^3 ha^{-1} of CWHR could be retained on site while still gaining the full economic benefits, combined with CWHR's relatively low nutrient content, suggested that a partial CWHR removal would have little impact on the site's nutrient stores, though this would need to be confirmed in subsequent studies.

A limitation of the study was that the excavator was only studied for one quantity of CWHR. Future studies could determine the excavator cost and productivity for a range of quantities of CWHR, as well as for sites with different soil types and slope classes. Combining this information with the cost of CWHR delivery to customers and the price and demand of CWHR as biofuel could also be used to assist forest managers to make decisions as to whether it is cheaper to extract CWHR for use as biofuel or windrow it on site.

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References

Béland, M., E. Thiffault, J. Barrette, W. Mabee. 2020. Degraded Trees from Spruce Budworm Epidemics as Bioenergy Feedstock: A Profitability Analysis of Forest Operations. – Energies, 13(18), 4609. DOI: https://doi.org/10.3390/en13184609

Berry, M.D., J. Sessions, R. Zamora-Cristales. 2018. Subregional comparison for forest-to-product biomass supply chains on the Pacific West Coast, USA. – Applied Engineering in Agriculture, 34(1), 157.

Bérubé, M.-A. 2011. Conditions de terrain affectant la qualité du travail des scarificateurs (Site conditions affecting the treatment quality of scarifiers). Point Clarie: FP Innovations Advantage report, 12(13), 8 pp.

Brown, M., D. Guimier, S. Mercier, Y. Provencher, P. Turcotte. 2002. MultiDAT and Opti-grade: Two knowledge-based electronic solutions for managing forestry operations more efficiently. Paper presented at the Woodfor Africa Forest Engineering Conference, Pietermaritzburg, South Africa, July 2-3: 45-49., Pietermaritzburg, South Africa.

Costantini, A., J. Grimmett, G. Dunn. 1997. Towards sustainable management of forest plantations in south-east Queensland. I: Logging and understorey residue management between rotations in steep country Araucaria cunninghamii plantations. – Australian Forestry, 60(4), 218-225. DOI: https://doi.org/10.1080/00049158.1997.10676147

Eisenbies, M.H., E.D. Vance, W.M. Aust, J.R. Seiler. 2009. Intensive utilization of harvest residues in southern pine plantations: quantities available and implications for nutrient budgets and sustainable site productivity. – BioEnergy Research, 2, 90-98. DOI: https://doi.org/10.1007/s12155-009-9036-z

Gan, J., C.T. Smith. 2006. Availability of logging residues and potential for electricity production and carbon displacement in the USA. – Biomass and Bioenergy, 30(12), 1011-1020. DOI: https://doi.org/10.1016/j.biombioe.2005.12.013

Gan, J., C.T. Smith. 2007. Co-benefits of utilizing logging residues for bioenergy production: The case for East Texas, USA. – Biomass and Bioenergy, 31(9), 623-630. DOI: https://doi.org/10.1016/j.biombioe.2007.06.027

Ghaffariyan, M.R. 2013. Remaining slash in different harvesting operation sites in Australian plantations. – Silva Balcanica, 14(1), 83-93.

Ghaffariyan, M.R., J. Sessions, M. Brown. 2014. Collecting harvesting residues in pine plantations using a mobile chipper in Victoria (Australia). – Silva Balcanica, 15(2), 81-95.

Ghaffariyan, M.R., R. Spinelli, N. Magagnotti, M. Brown. 2015. Integrated harvesting for conventional log and energy wood assortments: a case study in a pine plantation in Western Australia. – Southern Forests: a Journal of Forest Science, 77(4), 249-254. doi:10.2989/20702620.2015.1052946

Hämälainen, J., S. Kaila. 1985. Metsämaan äeastyksen ja aurauksen työvaikeustekijät, ajankäytön jakautuminen ja tuottavuus [Work difficulty factors, time distribution and productivity of forest site preparation with disc ploughs and wing ploughs]. (In Finnish, English summary), Metsäteho Report, 393, 16 pp.

Helmisaari, H.-S., K.H. Hanssen, S. Jacobson, M. Kukkola, J. Luiro, A. Saarsalmi, P. Tamminen, B. Tveite. 2011. Logging residue removal after thinning in nordic boreal forests: long-term impact on tree growth. – Forest Ecology and Management, 261, 1919-1927. DOI: https://doi.org/10.1016/j.foreco.2011.02.015

Kizha, A.R., H.-S. Han. 2016. Processing and sorting forest residues: Cost, productivity and managerial impacts. – Biomass and Bioenergy, 93, 97-106. DOI: https://doi.org/10.1016/j.biombioe.2016.06.021

Laffan, M., P. Naughton, S. Hetherington, S. Rees. 2003. Comparison of the effects of spot and strip cultivation on the early growth of *Eucalyptus nitens* and *Pinus radiata* in Tasmania. – Tasforests, 14, 137-143.

Lindenmayer, D., R.J. Hobbs. 2004. Fauna conservation in Australian plantation forests–a review. – Biological Conservation, 119(2), 151-168. DOI: https://doi.org/10.1016/j.biocon.2003.10.028

Miyata, E. S. 1980. Determining fixed and operating costs of logging equipment. General Technical Report NC-55. . Retrieved from St. Paul, MN.

Murphy, G., J. Lyons, M. O'Shea, G. Mullooly, E. Keane, G. Devlin. 2010. Management tools for optimal allocation of wood fibre to conventional log and bio-energy markets in Ireland: a case study. – European Journal of Forest Research, 129(6), 1057-1067. DOI: https://doi.org/10.1007/s10342-010-0390-3

O'Connell, A.M., T.S. Grove, D. Mendham, S.J. Rance. 2004. Impact of harvest residue management on soil nitrogen dynamics in *Eucalyptus globulus* plantations in South western Australia. – Soil Biology & Biochemistry, 36, 39-48. DOI: https://doi.org/10.1016/j.soilbio.2003.08.017

O'Hehir, J.F., E.K.S. Nambiar. 2010. Productivity of three successive rotations of *P. radiata* plantations in South Australia over a century. – Forest Ecology and Management, 259(10), 1857-1869. DOI: https://doi.org/10.1016/j.foreco.2009.12.004

Rodríguez-Soalleiro, R., C. Eimil-Fraga, E. Gómez-García, J.D. García-Villabrille, A. Rojo-Alboreca, F. Muñoz, N. Oliveira, H. Sixto, C. Pérez-Cruzado. 2018. Exploring the factors affecting carbon and nutrient concentrations in tree biomass components in natural forests, forest plantations and short rotation forestry. – Forest Ecosystems, 5(1), 35. DOI: https://doi.org/10.1186/s40663-018-0154-y

Saarinen, V.-M. 2006. The effects of slash and stump removal on productivity and quality of forest regeneration operations-preliminary results. – Biomass and Bioenergy, 30(4), 349-356. doi:https://doi.org/10.1016/j.biombioe.2005.07.014

Sarkar, S., A. Kumar. 2009. Techno-economic assessment of biohydrogen production from forest biomass in Western Canada. – Transactions of the ASABE, 52(2), 519-530.

Shammas, K., A.M. O'Connell, T.S. Grove, R. McMurtrie, P. Damon, S.J. Rance. 2003. Contribution of decomposing harvest residues to nutrient cycling in a second rotation *Eucalyptus globulus* plantation in south-western Australia. – Biology and Fertility of Soils, 38(4), 228-235. DOI: https://doi.org/10.1007/s00374-003-0654-x

Sifford, C.N., F. Pierobon, I. Ganguly, I. Eastin, E. Alvorado, L. Rogers. 2017. Developing an Impact Assessment of Local Air Quality as a Result of Biomass Burns. – Waste to Wisdom, Working Paper 128.

Van Wagner, C. 1968. The line intersect method in forest fuel sampling. – Forest Science, 14(1), 20-26. DOI:10.1093/forestscience/14.1.20

Walsh, D., M. Strandgard. 2014. Productivity and cost of harvesting a stemwood biomass product from integrated cut-to-length harvest operations in Australian *Pinus radiata* plantations. – Biomass, Bioenergy, 66, 93-102. DOI: https://doi.org/10.1016/j.biombioe.2014.01.017

While, G. M., C. McArthur. 2006. Distance from cover affects artificial food-patch depletion by macropod herbivores. – Wildlife Research, 33(7), 565-570. DOI: https://doi.org/10.1071/WR05063

Wrobel-Tobiszewska, A., M. Boersma, J. Sargison, P. Adams, S. Jarick. 2015. An economic analysis of biochar production using residues from Eucalypt plantations. – Biomass and Bioenergy, 81, 177-182. DOI: https://doi.org/10.1016/j.biombioe.2015.06.015

Ximenes, F., J. Ramos, H. Bi, N. Cameron, B.P. Singh, M. Blasi. 2012. Determining Biomass in Residues Following Harvest in *Pinus radiata* Forests in New South Wales. Canberra, Australia: Rural Industries Research and Development Corporation, Report 11/177, 78 pp.