REGIONALLY SPECIFIC HARVESTING RESIDUE YIELD AND RECOVERY RATES USED FOR ENERGY POLICY DEVELOPMENT

Arnis Jurevics[1], Dennis Hazel[1], Robert Abt[1], Mark Megalos[1], Ola Sallnas[2]
[1] North Carolina State University
[2] Swedish University of Agricultural Sciences
Arnis.Jurevics@gmail.com; Dennis.Hazel@ncsu.edu; Robert.Abt@ncsu.edu; Mark.Megalos@ncsu.edu; Ola.Sallnas@slu.se

Abstract

We assessed the importance of residue yield rate ρ and recovery rate η for forest biomass recovery. Studies indicate that ρ ranges from 20-50% and η from 60-80%. Estimates of available residues for energy use a combination of both factors. By using reported ranges, we obtained estimates of available biomass for given areas that varied by a factor of three. Yet, energy policies are being developed that use single values of these two factors over large geographic areas.

We concluded that the wide range of reported rate values is a function of the combinations of tree form, harvesting systems, and current markets that influence utilization. Thus, more precise estimates of energy from logging residues will require development and use of regionally specific yield and recovery rates. Until rates are developed that are specific for species groups and harvesting systems, conservative values of these rates should be used (ρ=20% and η=60%).

Key words: residue yield rate, recovery rate, biomass.

Introduction

Many factors including concerns about climate change have led many countries to pursue development of renewable energy (Ladanai 2009). The United States (US) is experiencing unprecedented interest in developing renewable energy including that from woody biomass. As an example, the state of North Carolina has set an energy goal to increase renewable electricity production up to 12.5 % by the year 2021, according to Senate Bill 3 (S-3), 2007, The Renewable Energy and Energy Efficiency Portfolio Standard (REPS). (Abt et al. in press, General Assembly of North Carolina Session 2007). Perlack et al. (2005) concluded that biomass in general and especially logging residues from final harvests are expected to play a pivotal role in meeting national renewable energy goals. Unfortunately, the viability of using residues for large-scale energy production is inadequately documented from a sustainability perspective (Gan and Smith 2006). Therefore, studies are needed to determine sustainable levels of residues realistically available for renewable energy.

Estimates of potential available residues require knowing what percentage of total harvested tree volume can be expected to be left on site as logging residues following harvesting (residue yield rate or ρ) and the proportion of logging residues which is typically recovered (current recovery rate or η) (Gan and Smith 2006)). Current recovery rates are affected by available technology, costs, environmental constraints and other factors. Total logging residues (LR) can be calculated by multiplying the amount of total harvested volume, ρ – the residue yield rate and η – the recovery rate of logging residues. LR for this study were calculated from inventory data as reported by the US Forest Service Inventory and Analysis Program (FIA) data (US Department of Agriculture (USDA) Forest Service, 2009). Many studies on available biomass do not discuss ρ and η values while others state their values but do not discuss where those values were obtained.

Logging residues consist of branches, tops above the merchantable stem for traditional forest products, and non-merchantable stems. The amount of logging residues yielded from harvested timber depends on tree form, stand quality, and utilization limits – a function of equipment used and decisions by the logger based on markets. Trees with a decurrent tree form have a weak central leader that eventually produces a rounded tree crown (most hardwood trees: oak, hickory, maple, etc.), whereas excurrent trees have a single and strong central trunk with lateral branches, as in spruce trees (Oliver and Larson 1996). Trees with decurrent growth habit or large branches from sparse stands will have larger values of ρ, whereas dense stands or stands with excurrent species will have lower values. Species with persistent limbs will have higher values of ρ than self-pruning species. Higher utilization standards where logs are utilized by timber industry to a smaller top diameter will have lower values of ρ than with larger top-of-log diameters.

The two principal objectives of this study were to (1) evaluate reported ρ and η and to postulate a reasonable range of values typical for southeastern US forests and harvesting systems, and (2) use these rates to estimate ranges of annually available biomass in North Carolina as a sample region and discuss impacts of the selection of these values on policy development.

Methods

To achieve our objectives we: (1) conducted a meta-analysis to determine influences in archetypal ρ and η; (2) determined which ρ and η are appropriate representatives of the southeastern US; (3) applied ρ and η to the current harvest data to estimate logging residual potential; (4) projected estimates for a 30-year time span with the Sub-Regional Timber Supply (SRTS) model (Abt et al., 2009); and then (5) compared results with policy-based goals and evaluate their reasonableness with respect to two policies – the North Carolina REPS (North Carolina general Assembly 2007) and the Renewable Fuel Standard (RFS) (Project Co-conveners and Steering Committee 2007) goals in North Carolina.

Estimates of ρ and η for the US including the FIA, EU, and an unpublished North Carolina field study data were compared to assess reasonable ρ and η for North Carolina. An extensive literature review was done to summarize and interpret more than 40 studies with a focus on ρ and η. Only studies from the EU and US that discussed both ρ and η and cited the data source for ρ and η were selected.

Data were then sorted and categorized into ρ and η groups for the US and EU based on tree species, region and harvesting technology. Average values of ρ and η were summarized in graphs. Not all ρ and η data were directly comparable because of different research methodologies used. For example, Green and Westbrook et al. (2007) used the approach that defines η as the difference between estimated residues and actually recovered residues. In our approach, however, η is a rate based on actual reported rates, where the residue percentage recovered reflected the real-world logging chance that the logger faced including economic, ecological, political and technological aspects. And indeed, recovery rates may change in time depending on political goals, technical feasibility and associated costs. In many sources, ρ and η were only discussed, but no values were disclosed.

Gan and Smith (2006) calculated an average ρ and η using USDA Forest Service's FIA *Timber Product Output* (*TPO*) database. "Logging residues" data columns were divided by "all removals" columns (growing stock and non-growing stock inclusive); however biomass estimates in the FIA database were minimally supported by empirical data (Roesch et al.). For example, there was only one sample plot per 6000 acres (USDA Forest Service). Therefore, the complexity of those data led to an inconsistency of estimates from state-to-state (Chojnacky unpublished).

Finally, average ρ and η from a recent North Carolina field study data were also assessed (Hazel et al. unpublished). In this study, field measurements were made using prism sweep (Bebber and Thomas 2003) and line intercept methods (Van Wagner 1968) to measure post-harvest residual woody debris on 39 sites for which harvest records of all products including fuel chips were available.

Optimistic (high values of ρ and η in the reported range) and conservative values (low values for ρ and η in the reported range) were selected from obtained data and used as input data to estimate available logging residues for biomass production in North Carolina. These estimated residue volumes were converted to electricity energy equivalent (1.86 GWh per 1 dry kilo metric ton residues) derived from Gan and Smith (2006) and ethanol (70 gallons per 1 dry metric ton residues) based on USDA (2010). Assumptions were made that power plant efficiency was 35% and 1 dry ton biomass equals 2 green tons. Estimates of electricity from residues were compared with current consumption in North Carolina (U.S. Energy Information Administartion 2008) and expressed as percentages. Potential ethanol production was compared with North Carolina's RFS goal (Project Co-conveners and Steering Committee 2007).

The SRTS model was used to model how the availability of residues may change over a 30-year time span using different values for ρ and η, based on current harvesting patterns and management methods (Abt et al. 2000).

Results and Discussion

Average ρ were slightly higher (Figure 2) in the EU (23%) than in the southern US (19%). The ρ used by FIA were somewhat higher than those reported for the EU and elsewhere for the southeastern US (Figure 2). For FIA, ρ were based on derived data rather than empirical data. For FIA, there was an assumption that stump height is one foot and it was considered to be biomass and was included in the FIA residues estimates. A North Carolina field study based on 39 harvested sites in the Piedmont and Coastal Plain showed higher values than all other sources. All these results were from scattered single studies with localized data.

The value of ρ is a function of species composition and regional variation (Figure 2). As an example, ρ in the EU for spruce stands (29%) and broadleaf stands (25%) were higher than those from pine stands (16.5%). Explanations may include the fact that many hardwoods have a form that has much top and branch volume. As a comparison, ρ for pine stands in the EU (16.5%) were slightly higher than in the US (14%).

Data in Figure 3 from Virginia showed that ρ values were relatively higher in the Mountain region than in the Coastal and Piedmont regions (Parhizkar and Smith 2008). Explanations may include the fact that hardwood forests have been dominant in the Mountains of Virginia, but softwoods have been dominant in Coastal Plain (Parhizkar and Smith 2008). In addition,

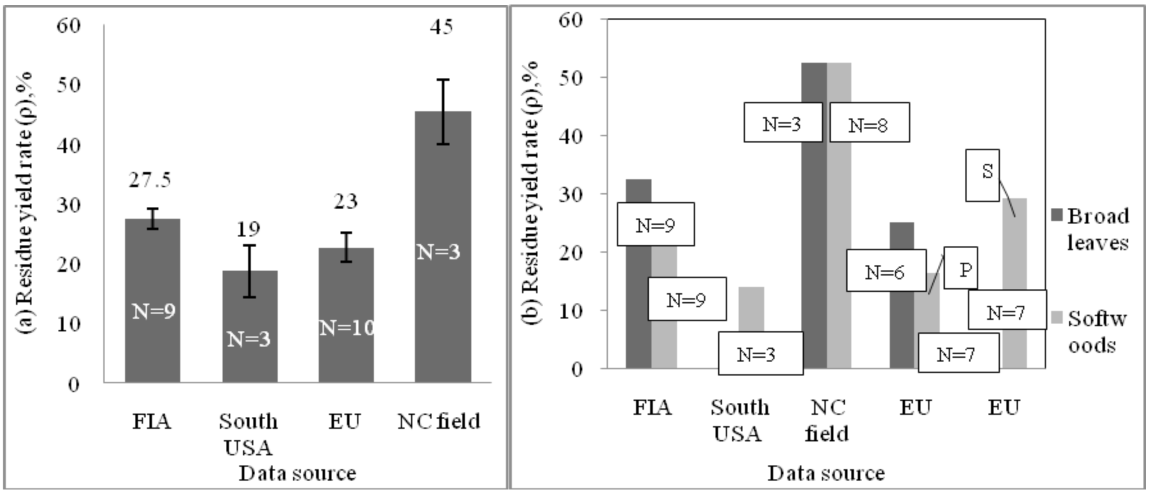

Figure 2. Distribution of average residue yield rates (ρ) derived from literature (the southern US including the US Forest Service Inventory and Analysis Program (FIA) and European Union (EU)) and North Carolina field data grouped by (a) all species and by (b) broadleaves and softwoods with confidence interval (α=0.05). Numbers of observations (N) are shown (a) inside and (b) above the bars. The average values are shown above each bar in chart (a). Acronyms: S – spruce, P – pine.

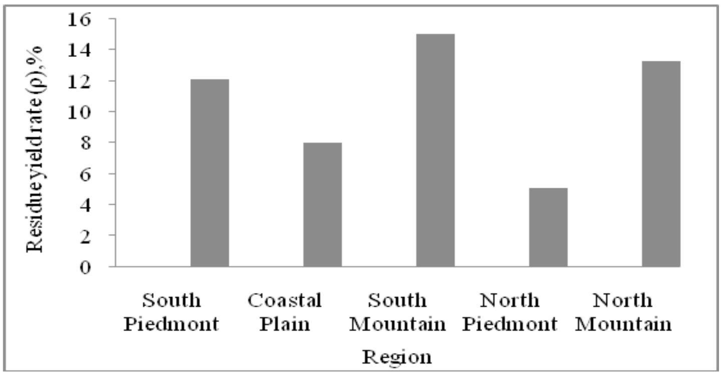

Figure 3. Distribution of residue yield rates (ρ) in regions of Virginia derived from literature.

due to limited accessibility, less mechanized harvesting technologies have been used in mountain region.

Based on the results, the conservative value for ρ was chosen as 20%, but the most optimistic was 50%. These rates were the most reasonable range that represented all values. Those values were then used for residue biomass estimates, because that included current situation with minimal biomass markets and the potential of residues in robust markets. An optimistic value 50% could be reasonable since the average of all species in NC field study was 45%, but for broadleaves and softwoods separately it was 52% (Figure 2). Average for the US was 18.7%, however, for the FIA data it was 27%.

For example, distribution of crown biomass and complete tree in final felling according to the National Technology Agency (2004) was 16% for Scots Pine and 27% for Norway Spruce. This was a study in Finland based on current harvesting practices (cut to length). According to FIA data for the US, residue rate for Hardwoods was 33%, but for Pine – 23%. We made the conclusion that even the same species composition had different rates. This was due to log-length technology used in the southern US and cut-to-length technology in Finland. The maturity of timber market changes the residue rate, because with developed markets and increased efficiency of timber industry more tree biomass can be utilized by traditional timber industry. In Finland smaller dimensions' trees were utilized, which reduced residue rate for Scots Pine compared with southern Pine.

Results (Figure 5) showed that there are similar recovery rates η in the southern US (62%) and in the EU (65%) with reported values from 46% to 80%. Results from meta-analysis were slightly higher than those 60% reported previously (Stokes, 1989).

The North Carolina field data of η (83%) were higher than reported elsewhere in literature; however, they reflect the increased recovery rates η in the Coastal Plain and Piedmont, where most of the data were collected (Figure 5).

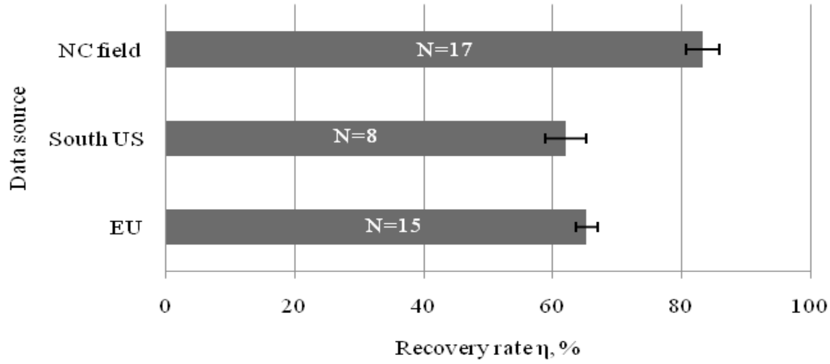

Figure 5. Distribution of recovery rates (η) derived from literature (the southern US and European Union (EU)) and North Carolina field data with confidence interval (α=0.05). Numbers of observations (N) are shown inside the bars.

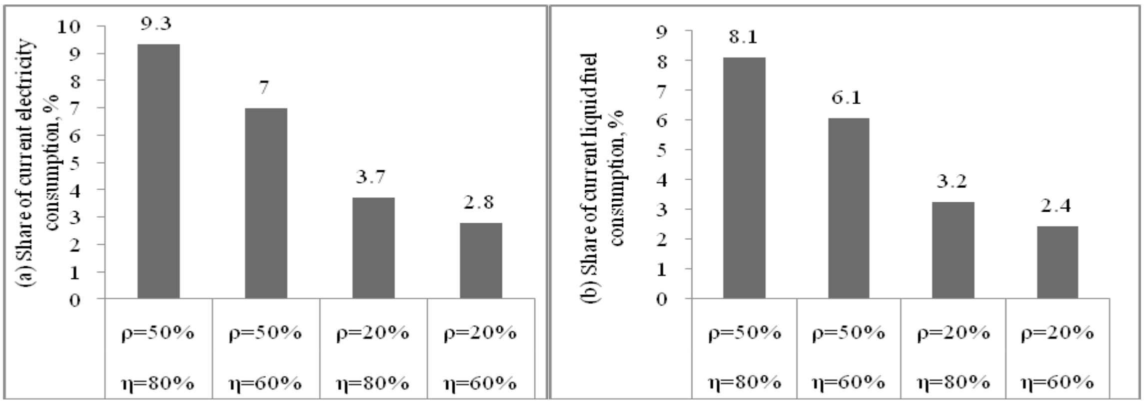

Figure 6. Residue biomass energy potential compared with current consumption of (a) electricity and (b) liquid fuels scenarios with different values of ρ and η applied.

According to Asikainen et al. (2008) η was 65% for mechanized cutting and – 50% for manual cutting. Residues consist of small pieces of tops, branches, limbs, needles and leaves (Perlack et al. 2005), making recovery difficult after manual cuttings. However, with the improved harvesting technology, the η increased to 65% and may be as high as 94%, when special integrated harvesting systems are applied and biomass markets are mature (Perlack et al. 2005). Despite the ability to attain high recovery rates, it is widely assumed that a substantial share of the residues should remain on site for environmental sustainability (Perlack et al. 2005). The η 80% and 60% were chosen for further analysis, because they represented current situation and future potential.

Based on our obtained data, the following values were applied to current FIA harvest data – 20% and 50% for ρ, and 60% and 80% for η. This resulted in four scenarios based on combinations of the two values for each variable: (1) ρ=50% and η=80% for scenario 1, (2) ρ=50% and η=60% for scenario 2 and etc. Logging residue estimates with scenario 1 were most optimistic, but scenario 4 was the most conservative.

To explore the potential impact of improved recovery estimates and efficiencies on policy development in North Carolina, residue estimates were converted to electricity and ethanol measures (Figure 6). For example, if the recoverable logging residues from logging operations were all used for electricity generation, it would displace coal-generated electricity and account for about 9.3% (scenario 1) and 2.8% (scenario 4) of current electricity consumption in North Carolina (Figure 6a).

These results indicated importance of ρ and η for availability estimates of residuals. Therefore, policymakers would need to consider different scenarios based on assumptions of harvesting system's efficiency. We assumed that all logging residues will be used either for electricity or liquid fuel production.

Residues from meta-analysis estimates were three times higher than those from Gan and Smith (2006). Results from Sub-Regional Timber Supply (SRTS) model runs were shown in Figure 7. Potential availability of residues in North Carolina was slightly decreasing for projections from year 2006 to 2036. Harvest in the SRTS projection were declining in the northern Coastal Plain and steady to increasing in the other regions. Overall there was a slight decline in harvest statewide over time. Since residuals were simply a constant factor applied to removals, the residual trend

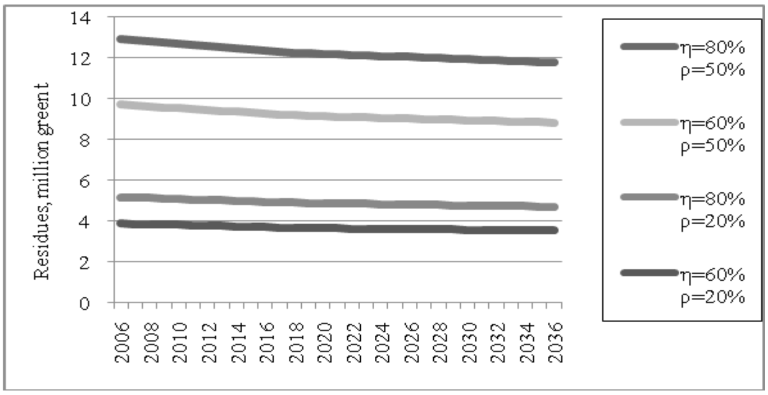

Figure 7. Available volumes of residue projected by SRTS model in North Carolina with optimistic and conservative ρ and η values. Time span was from 2006 to 2036.

followed the harvest trend. However, Gan and Smith (2006) projections showed increased levels of harvest and logging residue by 2030 in the southeastern US. They used 2002 Forest and Rangeland Renewable Resources Planning Act (RPA) assessment (Haynes 2003). They assumed a 70% recovery rate and an 18% increase in softwood harvest from 1997 to 2010 and an additional 26% from 2010 to 2020. For hardwoods they assumed a 23% increase in the first period and an additional 6.5% in the second period. They assumed a decline in residue yield rate ρ over time, but this was more than offset by the increased harvest. For SRTS constant demand was assumed which led to a 9% drop in harvest statewide from 2006 to 2036. There were increases in the Mountain and Piedmont regions, the southern coastal plain remained fairly constant, but there was a 35% drop in the northern coastal plain.

Estimates and projections with conservative values resulted in lower residue availability, which should be considered by policy makers. The potential volume of harvest residues in North Carolina was not sufficient to fully support policy-based goals for REPS and RFS, even with scenario 1 (optimistic). To meet these goals, additional biomass sources will be required. One way to increase residue availability is increased annual forest growth through fertilization (Linder et al. 2008). An additional source of bioenergy is stump harvesting. According to Melin et al. (2010) stump removal had minor impacts on forest ecological sustainability. In addition, more effective logistics would increase recovery rate η (Furness-Linden et al. 2008).

Conclusions

This paper assessed the residue yield rate ρ and recovery rate η for the southeastern US including that from FIA and North Carolina field study as well as for the EU. Average ρ were slightly higher in the EU (23%) than those in the southern US (19%). For FIA, ρ was higher and for North Carolina field study – even double the values found in the literature. The ρ were affected by species composition and harvesting technologies, where pine had the lowest values. It was problematic to state a single reasonable rate for North Carolina, because it depended on species, form of species and logging technology. Even FIA data showed variation between states and time.

We concluded that the wide range of values of these rates as reported in the literature is largely a function of the combination of tree forms, harvesting systems, and markets at time of harvest. Differences in forest stands change residue and recovery rates leading to inaccurate large-scale national estimates. Therefore, large-scale national residue estimates should be summed up from estimates from separate sub-regional forest stand estimates. We concluded that until rates are developed that are specific for species groups and typical harvesting systems, for residue availability estimates and policy-based goals, conservative values of these rates should be use (ρ=20% and η=60%).

Uncertainty regarding correct estimates of ρ and η can lead to imprecise estimates of potential renewable energy from logging residues. Ideally, studies should be conducted to empirically determine reasonable values of ρ and η.

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