A Comparison of Harvesting Residue Yield and Recovery Rates For Energy Policy Development

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Master Thesis no. 164
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BIOGRAPHY

Arnis Jurevics is a student from Latvia. His undergraduate studies were in Wood-processing Engineering. After successfully finished one year studies of EUROFORESTER Master Program at Swedish University of Agricultural Sciences (SLU), he continued in the two year Dual Master's degree (ATLANTIS) program.

Environmental issues do not respect countries' borders and forestry businesses are increasingly globalized. As a graduate of the Transatlantic Master's Degree Program in Forest Resources he possessed professional knowledge, language and intercultural communication skills invaluable for successful career in international environments.

He has work experinece in private company and in government institution.

He studied one semester at University of Helsinki and two semesters at North Carolina State University (NCSU). While studying in the USA, he learned a lot about the local culture, society and habits.

There was joint supervision of this thesis work from the SLU and NCSU.

ABSTRACT

This study assessed and compared the importance of residue yield rate ρ and recovery rate η. Literature and a North Carolina field study data suggest that residue yield rate ρ range from 20-50% whereas recovery rate η can range from 60-80%. Reported values for the US and EU were similar. The FIA data were slightly overestimated in comparison to data reported in literature. Estimates of available residues for energy differed by a factor of three, if optimistic or conservative values of ρ and η for residue estimates were applied. Projections for a 30-year time span did not appreciably change the estimates of residues. If all harvesting residues were used for electricity production in North Carolina, it would displace from 2.8% to 9.3% of current production from other sources. If residues were used for ethanol production, it would displace 2.4% to 8.1% of current production from fossil fuels. I concluded that for residue availability estimates and policy-based goals, conservative values of these rates should be used (ρ=20% and η=60%).

Keywords: Forest residues; residue ratio; recovery rates; woody biomass

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INTRODUCTION

Many factors including concerns about climate change have led many countries to pursue development of renewable energy (Ladanai 2009). The United States is experiencing unprecedented interest in developing renewable energy including that from woody biomass. As an example, North Carolina has set an energy goal to increase renewable electricity production up to 12.5 % by the year 2021[1] (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 harvest are expected to play a pivotal role in meeting national renewable energy goals.

There is a debate about the potential size of contribution of logging residues (Abt et al. 2009, Asikainen et al. 2008, Liepa and Blija 2008). Unfortunately, the viability of using residues for energy production is not well documented (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 recoverable (current recovery rate or η (Gan and Smith 2006)). Current recovery rates are affected by available technology, costs, environmental constraints and other factors. Therefore, total logging residues (LR) can be calculated by $LR=VTotal*\rho*\eta$, where VTotal is the amount of total harvested volume, drawn from the US Forest Service Inventory and

[1] Senate Bill 3 (S-3), 2007, The Renewable Energy and Energy Efficiency Portfolio Standard (REPS).

Analysis Program (FIA) data (US Department of Agriculture (USDA) Forest Service 2009); ρ – the residue yield rate; and η – the recovery rate of logging residues. The ρ and η are an important component of many biomass availability studies. Values used for these components and their source should be but often are not stated for these estimates.

The goal of this study was to estimate optimistic and conservative ranges of available logging residues through use of carefully considered ρ and η. Logging residues consist of branches and tops (Figure 1). The amount of logging residues yielded from harvested timber depends on tree form, stand quality, and utilization limits. 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. The decurrent tree has a weak central leader that eventually produces a rounded tree crown (most hardwood trees: oak, hickory, maple, etc.), but the excurrent tree has a single and strong central trunk with lateral branches, as in spruce trees (Oliver and Larson 1996). Species with persistent limbs will have higher values of ρ than self-pruning species. Higher utilization standards where roundwood is utilized by traditional timber industry to a smaller top diameter will have lower values of ρ than with larger top-of-log diameters. A comparison of ρ and η in the US and European Union (EU) was done.

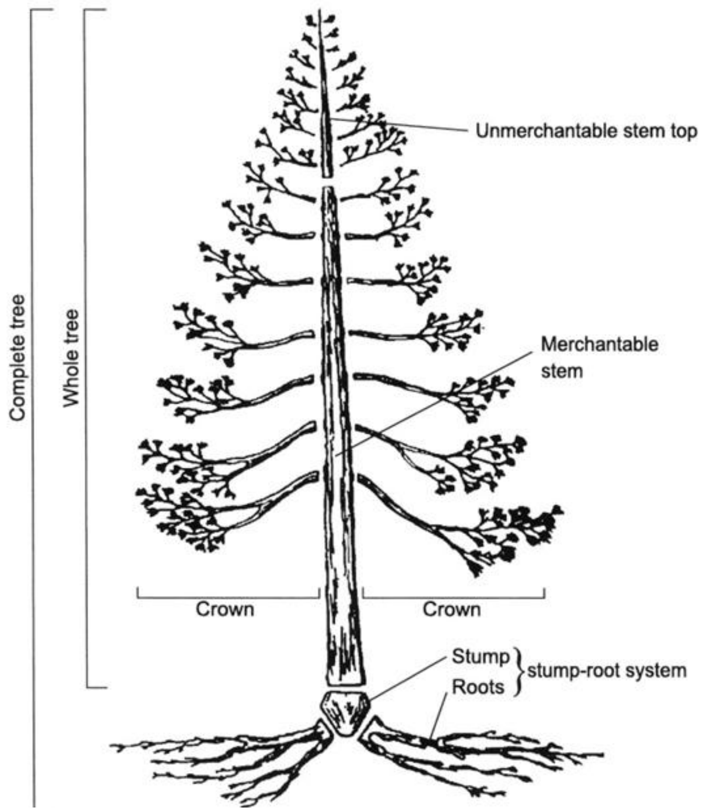

Figure 1. The biomass components of tree
(redrawn from Young et al. 1964).

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 forests and harvesting systems, and (2) use these rates to estimate ranges of annually available biomass in North Carolina and discuss impacts of the selection of these values on policy development. Specific objectives are: conduct a meta-analysis to determine influences in archetypal ρ and η; determine which ρ and η are appropriate representatives of the southeastern US; apply ρ and η to the current harvest data to estimate logging residual potential; project estimates for a 30-year time span with the Sub-Regional Timber Supply (SRTS) model[2]; and compare

[2] A detailed description of the SRTS model can be found in Abt et al., 2009

results with policy-based goals and evaluate their reasonableness. Recoverable amount of biomass can vary greatly depending on what ρ and η were used (Somogyi et al. 2006, Gan and Smith 2006). In this study I will develop reasonable ranges of ρ and η for the southeastern US and show the impact to Renewable Energy and Energy Efficiency Portfolio Standard (REPS) and Renewable Fuel Standard (RFS) (Project Co-conveners and Steering Committee 2007) goals in North Carolina.

METHODS

Assessing residue yield rate ρ and recovery rate η

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. Average ρ and η were estimated for each region to show the importance of good estimates for policy-based goals.

Computer databases including (1) Web of Science, (2) Agricola and (3) Google Scholar were used to conduct the study. Six search terms were used: (1) Residue recovery rate, (2) Recovery rate, (3) Forest residues, (4) Woody biomass, (5) Logging residues and (6) Logging residues utilization.

Initially, all studies with titles that included one of the search terms were selected. Further selection of studies was based on relevancy criteria. For example, residue harvesting technology studies (Patterson et al. 2008, Aulakh 2008, Hartsough et al. 2000, Stokes et al. 1989) were not included, because no ρ and η were published. Many studies provided residue biomass estimates (Līpiņš 2004, Xu and Carraway 2007). A vast majority of studies dealt with economic issues (E&IC 2009, Creech et al. 2009, Biomass Research and Development Technical Advisory Committee 2007, Kerstetter and Lyons 2001) or were focused on environmental impacts (Berglund and Åström 2007, Adamovičs et al. 2009, Eggers 2002, Kirschbaum 2002), which were not relevant to this study. Therefore, data were collected solely from the US or EU studies that included data source for ρ and η. Some relevant studies provided equations for biomass calculations (Lehtonen et al. 2003, Repola et al. 2007, Muukkonen and Mäkipää 2006).

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, Westbrook and Green et al. (2007) used the approach that defines η as the difference between estimated residues and actually recovered residues. My approach as defined above was different. The η as used here is a rate based on actual reported rates, where the residue percentage recovered reflected the real-world logging chance that the logger faced including economical, ecological, political and technological aspects. And indeed, recovery rates may change in time depending on political goals, technical feasibility and associated costs. Graudums and Lazdāns (2005) reported yield model estimates for ρ, whereas Asikainen et al. (2008) used FAO Global Forest Resources Assessment (FRA) 2005 report (FAO 2006) data and applied Marklund's (1988) equation. In many sources, ρ and η were only discussed, but no values were disclosed.

In addition, following Gan and Smith (2006), average ρ and η were derived from the USDA Forest Service's FIA *Timber Product Output* (*TPO*) database[3]. "Logging residues" data columns were divided by "all removals" columns (growing stock and non-growing stock inclusive). Tree biomass estimates in the FIA database are minimally supported by empirical data (Roesch et al.). For example, there is only one sample plot per 6000 acres (USDA Forest Service). Therefore, the complexity of those data leads to an inconsistency of estimates from state-to-state (Chojnacky).

[3] Table 10 (year 2002, 2005 and 2007 databases from North Carolina, South Carolina and Virginia)

Finally, average ρ and η from a recent North Carolina field study data were assessed (Hazel et al. unpublished). 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.

The importance of ρ and η for policy development

Optimistic and conservative values for ρ and η 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 to current consumption in North Carolina (U.S. Energy Information Administartion 2008) and expressed as percentages. Potential ethanol production was compared to North Carolina's RFS goal (Project Co-conveners and Steering Committee 2007). The reported results were compiled and summarized in graphs.

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. This model (Abt et al. 2000), is used by many forest companies and consultants (Abt et al. 2010) for timber supply analyses. The SRTS model analyses data sets with the area, inventory, growth, and removals classified into the age class, management type, and species group categories. Input data for this model are inventory, growth and removal data from the FIA database. This model has three modules: (a) market module – price and demand function; (b) inventory module – inventory, ownership and forest type; (c) goal programming module – allocate harvest to forest types and age classes (Abt et al. 2009). Demand assumptions (increase or decrease) are set in the market module. In this study, constant demand was assumed for residual projections. The starting data were collected in 2006 by Forest Service Forest Inventory and Analysis (FIA) Group in the Southern Research Station. The model produced projections for North Carolina over the 30-year projection time span, based on current harvesting patterns and management methods.

RESULTS AND DISCUSSION

Assessing residue yield rate ρ

Average ρ are 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 are based on derived data rather than empirical data. For FIA, there is an assumption that stump height is one foot and it is considered to be biomass and is included in the FIA residues estimates. A North Carolina field study based on 39 harvested sites in the Piedmont and Coastal Plain show higher values than all other sources. All these results are from scattered single studies with localized data.

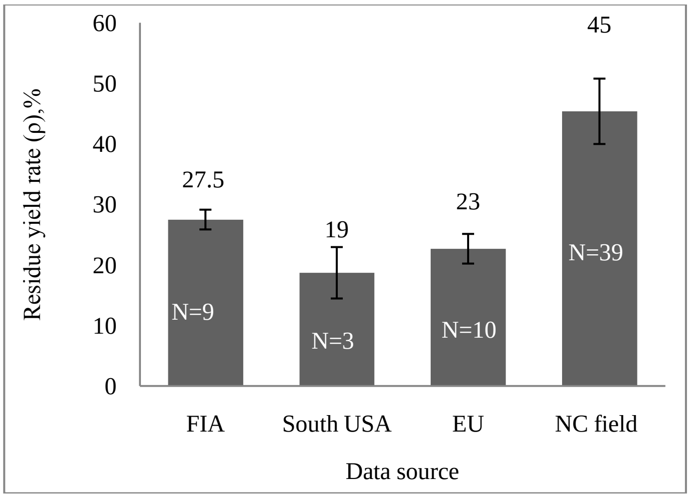

Figure 2. Distribution of average residue yield rates (ρ) derived from literature (the southern US including the US Forest Service Inventory and Analysis Program (FIA) and European Union (EU)) and North Carolina field data with confidence interval (α=0.05). Numbers of observations (N) are shown (a) inside the bars. The average values are shown above each bar in chart.

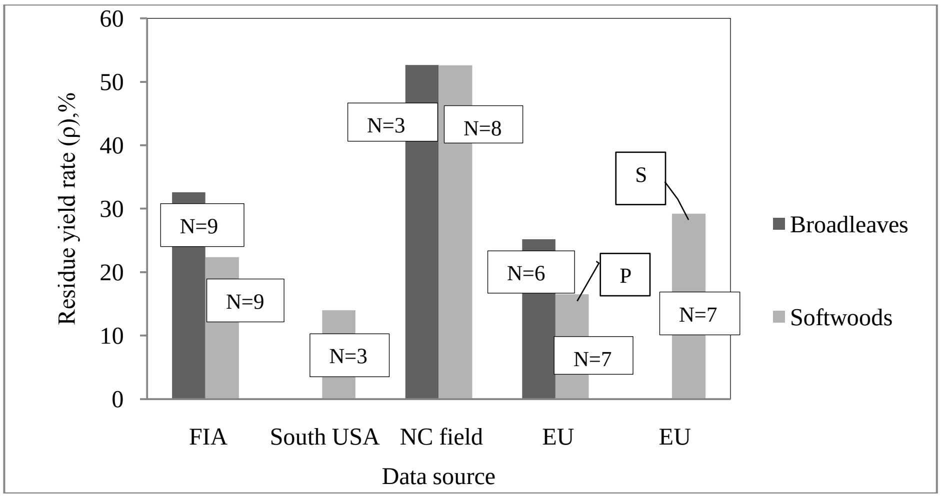

Figure 3. Distribution of average residue yield rates (*ρ*) derived from literature (the southern US including the US Forest Service Inventory and Analysis Program (FIA) and European Union (EU)) and North Carolina field data grouped by broadleaves and softwoods with confidence interval (α=0.05). Numbers of observations (N) are shown above the bars. Acronyms: S – spruce, P – pine.

The value of *ρ* is a function of species composition and regional variation (Figure 2 and 3). 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%). Explanations may include the fact that trees in the EU are harvested with log-length harvesting systems rather than the tree-length systems typically used for southern yellow pines.

With many EU log-length systems, biomass left in the stand is later retrieved for chipping resulting in relatively high recovery rates. Differences in recovery rates reported are not only partly explained by differences among harvesting systems such as log-length systems used in the EU and steeper hardwood-dominated mountain regions of the southeast, but also differences in specific equipment used by a logger or even how it is used. In tree-length systems in the southeast, some loggers harvesting large pine sawtimber will strip most limbs from stems in the stand by straddling stems with skidders while other loggers will remove limbs only at the logging deck with delimbers. Skidder-stripped limbs usually remain on the site and never reach the deck for chipping. However, when stroke delimbers are used throughout the stand, relatively compact piles of limbs and tops are created that can easily be moved to the deck-located chipper with grapple skidders.

The ρ from the NC field study were about twice the value than reported from other sources and more variable (Figures 2). "Other Removals" from TPO database[4] were not included in the FIA calculated residue yield rates. "Other Removals" are thinning, land use change and other removals (USDA Forest Service's FIA Timber Product Output (TPO)).

Data in Figure 4 from Virginia show that ρ values are relative higher in the Mountain region than in the Coastal and Piedmont regions (Parhizkar and Smith 2008). Explanations may include the fact that hardwood forests are dominant in the Mountains of Virginia, but softwoods are dominant in Coastal Plain (Parhizkar and Smith 2008). In addition, due to limited accessibility, less mechanized harvesting technologies are used in mountain region.

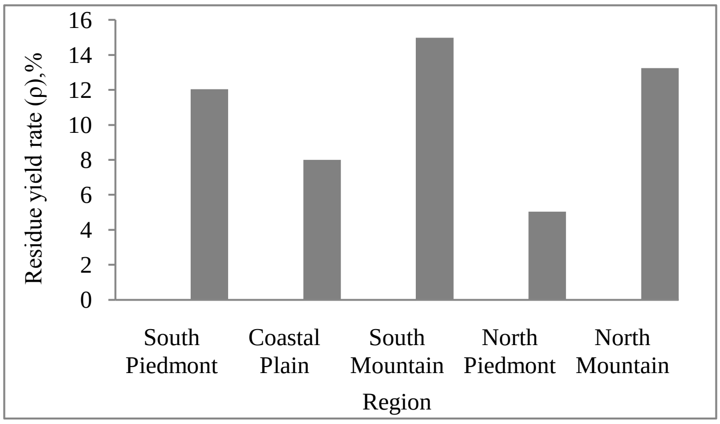

Figure 4. Distribution of residue yield rates (ρ) in regions of Virginia derived from literature.

[4] Table 10 (year 2002, 2005 and 2007 databases from North Carolina, South Carolina and Virginia)

Values for ρ for FIA for North Carolina, South Carolina and Virginia increased gradually from 2002 to 2007 (Figure 5). Staff from FIA explained that there was a refinement in estimates of logging residue between 2001 and 2005 (T. G. Johnson, personal communication October 1, 2010). They believe that FIA has been underestimating potential logging residues prior to the refinements (between 2001 and 2005). The TPO data highlight variations between states and time (Figure 5).

Figure 5. Distribution of residue yield rates (ρ) derived from FIA.
Graph highlights ρ differences in North Carolina (NC), South Carolina (SC) and Virginia (VA).
There are data from year 2002, 2005 and 2007.

The reported optimistic values of ρ for residue estimates were around 50%, but the conservative values – around 20 %. 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. The range of values was selected to compare optimistic and conservative scenarios. Those values were then used for residue biomass estimates, because that includes both current situation with minimal biomass markets and the potential of residues in robust markets. An optimistic value 50% for residue estimates is reasonable since the average of all species in NC field study was 45%, but for broadleaves and softwoods separately it was 52% (Figure 3). Average for the US was 18.7% however for the FIA data it was 27%.

Assessing recovery rate η

Results (Figure 6) show 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 are slightly higher than those 60% reported previously (Stokes B. J. 1992).

The explanation for differences may be the fact that in the northern Europe harvested stands on average are smaller and have well-maintained forest roads and appropriate sized harvesting machines. Therefore, dispersed location of small biomass utilities (local district heating, electricity and combustion power plants) diminish residue transportation distances and increase η. The assumed EU increased efficiency in recovering residues follows the findings of Gan and Smith whereby small electricity power plants can produce sufficient amount of electricity with lower costs (Gan and Smith 2006).

The North Carolina field data of η (83%) are 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 6).

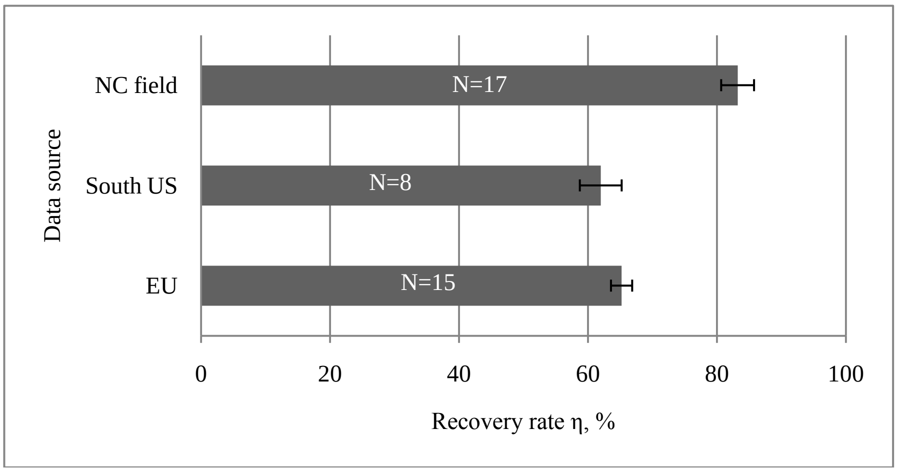

Figure 6. Distribution of recovery rates (η)
derived from literature (the southern US and European Union (EU)) and North Carolina field data with confidence interval (α=0.05). Numbers of observations (N) are shown inside the bars.

Harvesting technology impacts recovery rate

According to Asikainen et al. (2008) η is 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 increase to 65% and may be 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 values of ρ and η directly relate to the estimates of potentially available residues. Residue recovery estimates increase proportionately as ρ and η increase. There are benefits to high levels of recovery of harvesting residues: (1) reduces the need for site preparation, (2) decreasing site preparation costs, (3) planting becomes easier, (4) better seedling survival, (5) improves aesthetics, (6) efficiencies for forest machine contractors (Koistinen and Äijälä 2005). Drawbacks from increased residue recovery includes: (1) nutrient loss and (2) reduced humus growth (Koistinen and Äijälä 2005). However, the result may be significant nutrient loss and reduced humus growth. One study suggested that the growth of the next tree generation can decrease, especially in spruce stands (Koistinen and Äijälä 2005).

The optimistic value of η for residue estimates was around 80%, but the conservative value was about 60%. Those values were used for the residue biomass estimates, because that includes current situation and the potential with the improved harvesting technologies. Based on results, it was assumed 60% to be conservative η. The η 80% and 60% were chosen for further analysis, because they represent current situation and future potential. Optimistic value (η=80%) for residue estimates represents future potential in light of sustainability concerns and technology constraint.

Importance of residue yield rate ρ and recovery rate η for policy development

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. Results from four scenarios show that the most optimistic result is about three times higher than the conservative one. Potential electricity and ethanol production from logging residues varies depending on ρ and η (Figure 7). 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 7a). The Renewable Energy and Energy Efficiency Portfolio Standard (REPS) require 12.5% electricity produced from renewable sources by 2021. Therefore, harvesting residues could play major role, but ρ and η are affecting results of residue estimates more than three fold.

If all recoverable logging residues from logging operations were used for ethanol production, it would account for about 8.1% (scenario 1) and 2.4% (scenario 4) of all currently consumed liquid fuels in North Carolina (Figure 7b). The Renewable Fuel Standard (RFS) goal for North Carolina is to increase biofuel production to 600 million gallons (10% of all liquid fuels consumed) by the year 2017 (Biofuels Center of North Carolina). This means that 81% of RFS goal for North Carolina could be met with logging residues with the optimistic scenario 1 for residue estimates, because it would account for about 8.1% of all currently consumed liquid fuels in North Carolina. These results indicate importance of ρ and η for availability estimates of residuals. Therefore, policymakers will need to consider different scenarios based on assumptions of harvesting system's efficiency. I assumed that all logging residues will be used either for electricity or liquid fuel production. The REPS and RFS goals are not attainable concurrently.

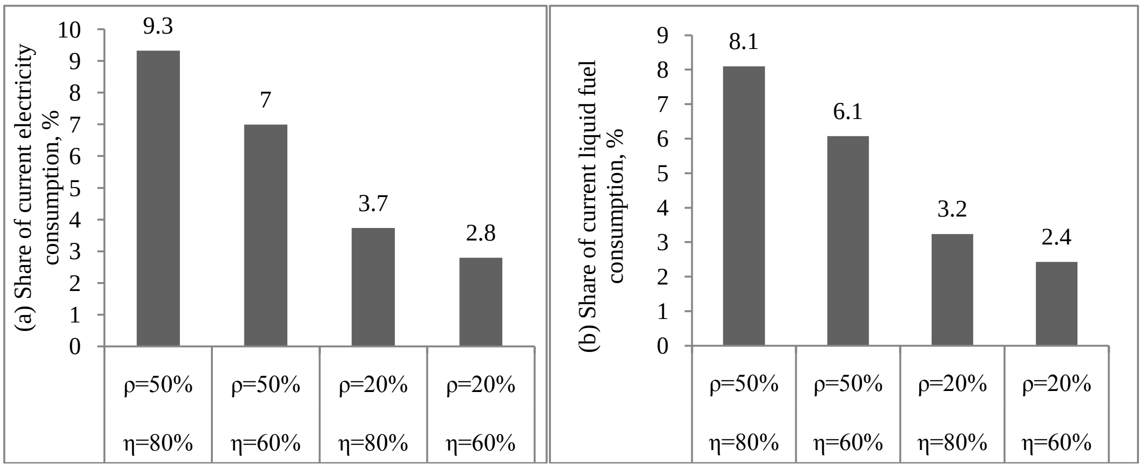

Figure 7. Residue biomass energy potential compared to current consumption of (a) electricity and (b) liquid fuels scenarios with different values of ρ and η were applied.

Residues from meta-analysis estimates are three times higher than those from Gan and Smith (2006). Results from Sub-Regional Timber Supply (SRTS) model runs are shown in Figure 8. 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 are simply a constant factor applied to removals, the residual trend follows the harvest trend. However, Gan and Smith (2006) projections showed increased levels of harvest and logging residue by 2030 in 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 is 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.

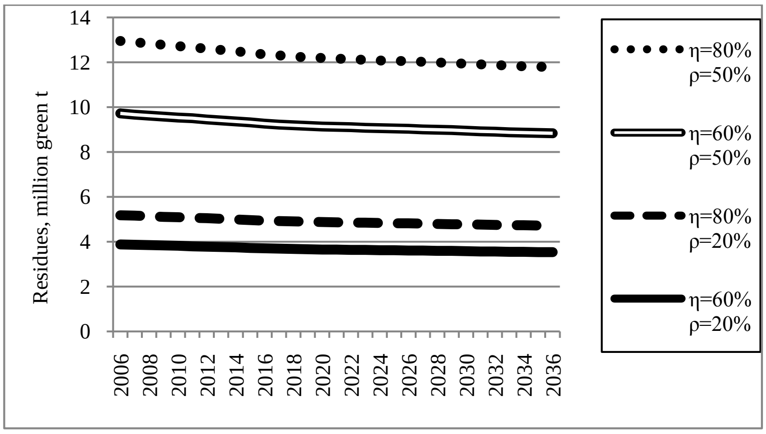

Figure 8. Available volumes of residue projected by SRTS model in North Carolina with optimistic and conservative ρ and η values for residue estimates. Time span is from 2006 to 2036.

The optimistic or conservative ρ and η values affect logging residue availability estimates. 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 is 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 has minor impacts on forest ecological sustainability. In addition, more effective logistics will increase recovery rate η (Furness-Linden et al. 2008).

If scenarios with high ρ and η are to be adopted for policy planning purposes, appropriate regulatory instruments should be developed to ensure reliability and sustainability for those plans (Löfgren 2008). Tax incentives, subsidies and government investments should increase the demand for logging residues, followed by the increase volumes of harvested logging residues. Therefore, if no government support is planned, conservative values (scenario 4) are more appropriate. For example, if incentives for residue harvest are applied and appropriate industries benefit, η will increase and change market responses. These instruments may affect ρ and η to favor biomass production, but sound choices should be made. Kåberger (2008) reported that new industries will develop, when political and economical instruments are applied wisely.

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. Based on the results from literature it can be concluded that FIA data overestimate volumes of residues. The ρ are affected by species composition and harvesting technologies, where pine has the lowest values. Overall, there was not considerable difference between recovery rates η in the US and EU (around 60%), but in North Carolina – 80% (from unpublished field study). It is problematic to state a single reasonable rate for North Carolina, because it depends from species, form of species and logging technology. Even FIA data showed variation between states and time.

I concluded that for residue availability estimates and policy-based goals conservative values of these rates should be used (ρ=20% and η=60%). Optimistic rates are realistic, but more accurate small scale regional studies and data are needed. If residues were used for electricity production in North Carolina, that would displace current consumption by 9.3% with optimistic rates and 2.8% with conservative rates. If residues were used for ethanol production, that would displace current consumption by 8.1% and 2.4%, respectively. This suggests that ρ and η change the availability estimates three fold.

It is possible to expand further this work including residues from thinning and fuel-reduction treatments, since this study does not reflect that. It would be important to include more factors than ρ and η for estimates of residues. For example, minimum required spatial density (Gan and Smith 2006), available road systems etc. It would be interesting to find correlation between *η, ρ* and volume of residues on one hectare. Westbrook et al. (2007) did estimate costs depending on *ρ,* which could be incorporated in this study. This study was focused mainly on North Carolina with data collection from the US and EU. However, it would be helpful to apply this study to other regions. Finally, despite the potential significance of logging residues, literature dealing with the amount of recoverable logging residues is limited (Biomass Research and Development Board, 2008). Even less literature have available empirical residue data. Therefore, new empirical field studies on forest sites would be favorable and induced.

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