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Wood Residue Distribution Simulator (WORDS)

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ABSTRACT

Successful development of woody biomass for energy will depend on the distribution of local supply and demand within subregions, rather than on the total inventory of residues. The Wood Residue Distribution Simulator (WORDS) attempts to find a least-cost allocation of residues from local sources of supply to local sources of demand, given the cost of the materials, their distribution, and the distribution of demand. The results are useful in evaluating the feasibility of developing wood energy either for a subregion in general or for specific locales. This paper describes WORDS and gives an example of its application to mill residues in the State of Georgia.

Keywords: Energy, supply, demand, Georgia.

Introduction

Interest in the development of wood energy remains high in the Southeast. Some States in the region maintain ongoiny programs to promote the use of noncommercial forest biomass for energy production. A substantial quantity of mill residues is generated, and there is a growing capability for recovering poor-quality material that previously has remained in the woods. Hence, residues for energy application are expected to be available for the long term with forest residues replacing mill residues as the latter decline in availability.

Much of the promotion to date has been based on the total inventory of potential wood fuels over fairly large geographical areas. Such totals are of limited value to the prospective user because they indicate only in a general way whether more precise assessments are justified. Successful development of many resources depends upon the distribution of local supply and demand within subregions. This is especially true of woody biomass used for energy because of its relatively low per unit heating value.

Our objective was to develop and evaluate methods for estimating the effective supply of wood residue fuels over a subregion given the cost of such materials, their distribution, and the distribution of the demand for them. The resulting Wood Residue Distribution Simulator (WORDS) attempts to find a least-cost wood residue allocation from local sources of supply to local points of demand. Simulation output may be used as a basis for evaluating whether or not wood residue is a viable energy source for either the subregion as a whole or for specific locales within the subregion. This paper describes the WORDS program and gives an example and evaluation of its use, with the State of Georgia as a pilot area.

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The Simulator

Two versions of WORDS have been developed, one for use in batch mode, the other for interactive mode on a computer TSO terminal. Both versions have three distinct segments. The first segment summarizes uncommitted wood residues and calculates average costs and energy values for those residues. The second computes cost-effective shipping distances as a function of a constant wood energy value, a schedule of shipping costs, and a variable wood residue purchase price. This segment also calculates the potential cost-effective supply available to each demand source. The third segment derives the allocation of wood residues from the sources of supply to the sources of demand, assuming that the demand sources compete for supply pools common to them.

Limitations on WORDS are inherent primarily in the dimensions of arrays. These can be readily altered to increase the simulator's capacity. "Supply unit" and "demand unit" are the terms used to denote locations from which and to which residues might be shipped. WORDS can accommodate up to 160 units for both supply and demand. Because a subregion may have many more actual supply and demand sources, it may be necessary to aggregate sources so that the total units of each is 160 or less. Thus, a particular demand or supply unit might be a composite of several. supply or demand sources. To calculate transportation distances, the weighted geographical center of the several sources would be the ideal location of the aggregate unit. In practice, however, it may be necessary to use some other location, such as city centers or county seats, so that transportation distance values can be derived at reasonable cost.

"Wood residues" denotes any of a number of similar materials, usually with different heating characteristics and different costs. WORDS can allocate any combination of residues up to eight. Data on each individual residue are inputs to the simulator, and the program calculates aggregate values for the user-specified combination.

A "cost-effective" wood fuel is defined as having a lower delivered cost per unit energy than an alternate energy source. We wish to emphasize strongly that an accurate estimate of the feasibility of using wood residues for energy must incorporate other costs in addition to the delivered cost of fuel. For example, storage and handling costs are inherently greater because wood residues are bulkier than fossil fuels. Some measure of conversion costs (such as capital cost amortized over the life of the wood-fueled system) must also be considered. Also, wood-fueled systems are more expensive to maintain than gas- or oil-fired systems.[1] Costs such as these must be included when estimating the overall feasibility of wood residues as an energy source. Currently, WORDS does not incorporate these costs, but it has been structured so that they can be easily added.

The three simulator segments are in the form of three computer programs, as follows:

Residue Summary Program

Because residue types vary in purchase price and energy value, it is important to be able to evaluate each type separately and in combination with others.

A description of each supply unit's wood residue inventory is required. This description consists of up to eight categories of wood residues (such as

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[1] Karchesy, Joseph; Koch, Peter. Energy production from hardwoods growing on southern pine sites. Gen. Tech. Rep. SO-24. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1979. 59 p.

hardwood bark, softwood chips, etc.), the quantity available in each category, the energy value of each type of residue in millions of Btu's per ton, and the cost of each residue type in dollars per ton. After the user specifies some desired combination of residue types, the program calculates, for each supply source, the total residue available, the average price of the residue, and the average heating value of the residue. These values are printed out in a report and stored in an external file for use in subsequent segments.

The program also calculates the maximum distance the given combination of residues can be shipped, with cost-effectiveness as a constraint. First, the user must develop a subroutine which, given a transport mileage, will return the cost of shipping 1 ton of residues that number of miles. The delivered cost of some alternate energy source (the "break-even" cost) must also be specified. By using the systemwide average heating value of residues, the program creates a table of the maximum cost-effective residue shipping distances as a function of purchase price, ranging from user-supplied minimum to maximum in 50-cent increments. Because shipping costs are likely'to be on a graduated scale, the computations are performed iteratively. For each price increment, delivered residue costs (in dollars per million Btu's) are calculated for transportation distance increments until the cost exceeds some user-supplied alternate fuel delivered cost. The last distance used before'the break-even cost is exceeded is considered the maximum cost-effective shipping distance for that particular residue cost. To give the user some reference values, both the average systemwide cost of residue and the average systemwide unit Btu content of the residue are reported.

Potential Supply Availability Program

The second segment uses calculations from the first segment to determine the supply of wood residue potentially available to each demand unit, with cost-effectiveness as a constraint and competition among demand units for common supply pools ignored.

With demand unit-supply unit distances and the transportation cost function, the program calculates a per million Btu transportation cost between every demand unit and every supply unit. It adds to this the purchase price of the residue at the supply unit, then compares that cost to the break-even cost at the demand source; every transfer that results in a cost lower than break-even is designated as cost-effective. The break-even cost may be different for each demand unit because a unique alternate fuel cost may be specified for each demand unit.

The program sums the total cost-effective supply for each demand source and prints out this sum as the supply potentially available to the demand source. At the discretion of the user, every cost-effective supply-demand transfer can be reported as well. The program also sums all supply and demand in the system, compares the two, and reports whether or not a deficit exists. Finally, supply and demand files are created for inputs to the Residue Allocation Program.

Residue Allocation Program

This program is adapted from a recreation distribution simulation model developed by Dress and Devine[2] and allocates wood residues from supply units to demand units, all of which are competing

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*Dress, Peter IE.; Devine, Hugh A., Jr. A simulation model for the estimation of unmet recreation facilities demand. Georgia Comprehensive Recreation Plan (GORP). Atlanta, GA: Georgia Department of Natural Resources; unpublished paper on file; 1978.

for the supply. The object is to approximate a least-cost allocation through a simulation procedure. Although linear programming could be used to find the optimal (i.e., the absolute least-cost) allocation, linear programming is expensive for large supply-demand systems. The simulation procedure approximates the optimal solution at a fraction of the cost. Dress and Devine[3] provide extensive documentation on the basic model, so our discussion is limited to its application to wood residue allocation. An optimal systemwide allocation is, in general, the one that satisfies as much demand as possible while minimizing the cost of doing so. In standard optimization terminology, our problem is to minimize total costs of allocating wood residues, subject to the constraints that either all demand is satisfied, or all supply is used, or both.

In the wood residue model each supply-demand transfer is assigned to a preference class, based on the delivered cost of fuel for the transfer. The user specifies the number of preference classes to be assigned and the cost range for each class. The program computes the purchase price plus transport cost for every potential supply-demand transfer and, based on the class boundaries, assigns each transfer to a preference class. Preference class 1 (the highest) will contain all the least expensive transfers; preference class 2, the next least expensive; and so forth.

Allocation is made in increments, the size of which are specified by the user. In general, smaller increments provide closer-to-optimal solutions but at a higher cost in computer time. The program allocates an increment of supply to a demand unit from every supply unit in the demand unit's preference class 1. It then proceeds to another demand unit, repeating the procedure. When all demand units have received their first increment allocations, the program returns to the first demand unit to allocate the second increment. This iterative process continues until all possible allocations in preference class 1 have been made. Normally this will occur either when demands have been satisfied or supplies exhausted along class 1 supply-demand transfer routes. If, after preference class 1 allocations are made, uncommitted supplies or unsatisfied demands still exist in the system, the program proceeds to repeat the above procedure for each successive preference class until all supply is allocated or all demand is satisfied. Allocating by preference class sequence results in a relatively low-cost overall allocation, because the lowest cost allocations (as a group) are made before more expensive allocations. Allocating within preference classes by increments simulates competition, because the supply is distributed, bit by bit, among demand units in the same preference class. When a supply source is exhausted or a demand source satisfied, no more allocations involving those units are made, although the procedure continues for the other units.

Inherent in this type of simulation is the fact that the quantity allocated to a given demand unit depends on the order of that demand unit in the sequence. If supply within a preference class is exhausted between the first increment allocation in a given iteration and the last, those demand units receiving the allocations first in the iteration will receive a larger supply at the lower cost. This is why a simulation will not necessarily result in the optimum allocation ensured by a linear program, which essentially makes simultaneous allocations to all demand units in the propor-

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[3] Dress, Peter E.; Devine, Hugh A., Jr. Decription of procedures, concepts and computation software for the estimation of unmet recreational demands. Georgia Comprehensive Recreation Plan (GORP). Atlanta, GA: Georgia Department of Natural Resources; unpublished paper on file; 1978.

tions that result in least cost. To reduce this effect, the demand units are randomly reordered before allocations within each preference class, eliminating a consistent automatic bias.

Finally, reports are generated by the program. The quantity of residue allocated from every supply unit to every demand unit as well as a list of the preference class assignment for each supply-demand transfer are produced as tables. Another report shows the satisfied and unsatisfied demand of each demand unit as well as the allocated and unallocated inventory of each supply unit.

A WORDS Example

Data from 1980 were used to test WORDS. The residue type consisted of unused mill residues in the State of Georgia. The residue production figures were from a survey conducted periodically by the Georgia Forestry Commission. Counties were used as supply units, with county seats taken as transportation nodes. Because of the confidential nature of these supply data, the county supply codes were randomized and reports listed only code numbers rather than county names. Supplies were aggregated by county and comprised eight residue types--softwood bark, hardwood bark, softwood shavings, hardwood shavings, softwood chips, hardwood chips, softwood dust, and hardwood dust.

For approximate energy value calculations, the residues were classified as either hardwoods or softwoods and as either bark or other wood fibers. Potential heating values were calculated by correcting for moisture content as given by Taras and Clark[4] and by estimating available heat according to Karchesy and Koch.[5] While burning efficiencies vary with equipment, a 70 percent efficiency was used to represent woodfired systems in general. The resulting available energy values were:

Residues	Million Btu/green ton
Softwood bark	7.482
Hardwood bark	6.056
Other softwood	5.789
Other hardwood	5.960

No explicit estimates of demand were available, so we formulated a hypothetical situation to represent a "real-world" problem. The assumption was that all nonelectrically heated public schools were to be converted to wood-fired heating systems. Estimates of countywide demand for each county were based on average annual heating energy use per student in three climatically stratified zones.

A schedule of approximate shipping rates was derived from confidential industry sources in the State:

Miles	Dollars/ton-mile
0- 40	0.245
41- 60	.205
61- 80	.195
81-100	.185
100+	.170

The following average residue prices were derived, again, from several confi-

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[4] Taras, Michael A.; Clark, Alexander, III. Aboveground biomass of loblolly pine in a natural, uneven-aged sawtimber stand in central Alabama. Tappi 58(2): 103-105; 1975.

[5] See footnote 1.

dential industry sources in the State:

Residue	Dollars/ton
Softwood and hardwood bark	5.50
Softwood chips	18.00
Hardwood chips	11.00
Softwood and hardwood dust	5.50
Softwood and hardwood shavings	11.00

Model Parameters

The following parameters were used for the example solution:

- Minimum and maximum wood residue purchase prices for calculating cost-effective shipping distances were $5 and $15 per ton, respectively.
- Three preference classes were used for supply-demand transfers; class 1, from $0 to $20; class 2, from $20.01 to $35; class 3, from $35.01 to $100 per delivered ton of residue.
- The allocation increment was 500 tons, with the maximum number of iterations set at 100. This would permit 50,000 (100x50) tons of residue to be shipped from any supply unit or to any demand unit in a given preference class. The object was to limit iterations but to base the limitations on a sufficiently large quantity so that either supply would be exhausted or demand met within a preference class before the maximum number of iterations was reached.

Results and Discussion

Although the problem addressed was hypothetical, the data enabled us to draw some useful conclusions about both the simulator's potential use and the development of wood residue as an energy source.

Cost-effective shipping distances for wood residues., With an inflated 1980 natural gas price of $0.48 per therm (100,000 Btu) and an assumed efficiency of 80 percent for gas-fired equipment, the estimated alternate fuel cost was about $6 per million Btu. For our data set, this resulted in cost-effective shipping mileages ranging from 137 miles at a residue price of $15 per ton to 196 miles at a residue purchase price of $5 per ton. As a general reference, the weighted cost of all residues in the State at that time was $6.66 per ton.

While transportation costs and wood residue prices are likely to increase, these will be offset at least partially by higher alternate fuel costs. The implication is that over the near term, mill residues could be a feasible source of energy even at transfer distances as great as 100 miles.

Residue availability. Wood residues, particularly mill residues, will become scarcer as the demand for less expensive energy increases. The large amount of residue existing in Georgia in 1980 suggests, however, that it may be several years before demand exceeds supply. By using natural gas as the alternate fuel source for all Georgia counties, the WORDS solution indicated that every county in the State has at least 47 other counties (out of a possible 158) from which it could potentially draw wood residue under the cost-effective constraint.

Under competition among counties, WORDS still indicated that, for the hypothetical problem, the total demand could be satisfied over the entire system and at a better than break-even cost. No county would have to pay more than an average of $4.50 per million Btu, and over 90 percent of the counties could obtain their residues at a delivered cost of under $3 per million Btu.

The model. WORDS appears to be a useful and inexpensive tool to aid in assessing the feasibility of large-scale use of wood residues for energy. Model parameters are easy to alter, hence sensitivity analyses to evaluate the effects of any changes in price or in the residue mix are easily made. The model is versatile enough for large or small residue supply-demand systems and with only minor changes can be adapted to other supply-demand systems as well.

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