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NATIONAL ESTIMATES OF RESIDENTIAL FIREWOOD AND AIR POLLUTION EMISSIONS

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ABSTRACT

Estimates are presented for the distribution and quantity of recent (1978-1979) use of residential firewood in the United States, based on a correlation of survey data from 64 New England counties. The available survey data from other states are in agreement with the relationship derived from New England; no constraints due to wood supply are apparent. This relationship indicates that the highest density of wood usage (Kg/ha) occurs in urban areas; thus exacerbation of urban air quality problems is a matter of some concern. The data presentation used here gives an upper limit to this density of firewood usage which will allow realistic estimates of air quality impact to be made.

1. INTRODUCTION

One of the results of the oil embargo of 1974 and the subsequent steep price increases in petroleum and natural gas has been the increasing use of alternative fuels for home heating. Wood is perhaps foremost among these, as evidenced by increasing sales of wood stoves and efficient fireplaces, now estimated at nearing a million units per year.

Previous estimates of the extent of residential firewood usage have tended to be varied and unreliable, perhaps since the distribution is non-uniform and scattered. The Census Bureau's Annual Housing Survey [1] is limited to fuels used as the primary heat source, whereas most firewood users rely on it as supplementary fuel. The Department of Energy's State Energy Data Report [2] does not list wood as a residential fuel. Other surveys have given only the number or percentage of households using some wood, without providing data on the amount of usage. DOE's Technology Assessment of Solar Energy Systems (TASE) [3] was based on 0.1 quads of "wood stove" use in 1975, growing to 0.3 quads by the year 2000 in the high solar growth scenario. Fireplace use was not specifically considered in TASE.

EPA estimated about 0.3 quads of wood heating energy for the year 1976,[4] and computed environmental impacts on the basis of either a single, isolated source or an agglomeration of 100 such sources is a dense array. Neither of these extremes will provide a realistic estimate of ambient air quality impacts.

Although wood smoke is generally regarded as benign by the public, concern has been expressed about the effects on ambient air quality resulting from widespread use of wood fuel. In addition, there are accident hazards involved in harvesting the wood. Data on the extent of firewood usage are needed to assess these effects; in addition, estimates of the spatial density of wood use (cords/sq. mile or kg/ha) are needed in order to assess air quality impacts.

DISCLAIMER

2. CORRELATION OF WOOD USAGE SURVEY DATA

In recent years, a number of agencies have undertaken consumer surveys of the use of firewood for space heating (Table 1). Most of these have been at the state level, with occasional breakdown to regions of a state. The New England Fuelwood Survey, [5] however, provided county level data for 64 New England counties for the 1977-78 heating season. These survey data were used to develop the following empirical equation:

$$\text{Cords used per household per } 10^4 \text{ degree days} = 3.087 - 0.322 \log (\text{population density}) \quad (1)$$

with population density expressed as persons per square mile.* Equation (1) was then applied to all counties in the conterminous United States to develop estimates of wood usage, by multiplying by the number of households in the county (1970 census) and the 30-year average heating degree days.** Figure 1 displays the spatial patterns of usage throughout the country on the basis of Air Quality Control Regions;† concentrations in northern urban areas are apparent. The U.S. national total on this basis was 34.7×10^6 cords per year (in the 1977-1979 period) or about 0.8 quad of energy (1 quad = 10^{15} Btu). This is about 10% of space heating energy input, although the percentage of delivered heat will be substantially less because of the relatively lower thermal efficiencies of stoves and fireplaces. This national total is substantially higher than previous estimates,[4] but somewhat lower than a recent Gallup poll.[6]

As a check on the validity of this extrapolation of New England data to the rest of the country, state totals were compared to the available survey data from 12 other states, 18 in all. This comparison is given in Figure 2, and agreement is seen to be generally quite good (correlation coefficient = 0.78), with the exception of three outliers. Oregon uses substantially more wood than Eq. (1) would predict; this may have to do with the ready availability of waste from the logging and forest products industries. Montana and Minnesota use less wood than expected; no reasons are readily apparent.†† However, the essential message from Figure 2 is that the states surveyed use firewood in the same manner as New England; no supply constraints are apparent at this level of usage.

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*The data used to develop equation (1) could also support a number of alternate relationships, since many other attributes of New England counties are reasonably collinear with population density. These may include percent urbanization, percentage of land in forest, retail price of wood, and perhaps even family income. But since the main purpose of this inquiry is to be able to realistically examine air quality problems, population density is the preferred parameter.

**It is recognized that use of 1970 data for the number and distribution of households and for the population density introduces error when used in conjunction with 1977-9 survey data. The 1980 census indicates the rural non-farm population has grown in many areas, often at the expense of urban areas. However, given the nature of the sampling data being used here, this error is not believed to be serious. Similarly, the error introduced through the use of 30 year average heating demands will tend to average out across the nation - 1978-9 was colder than normal in some areas and warmer than normal in others, for example. The error involved in basing fuel usage on degree-days referenced to 65°F may be more important, since it is doubtful that homeowners in climates where only occasional space heating is required would make the investment required for wood heating systems.

†There are 238 Air Quality Control Regions in the conterminous U.S., designated by the U.S. Environmental Protection Agency for the purpose of administering air pollution regulations. They are usually groups of counties, and vary considerably in size and population. Figure 1 is based on aggregated county data, i.e. total cords burned in the county divided by total land area.

††Survey data from Missoula County, MT[7], agree quite well with eq. (1): 0.8×10^{12} Btu vs 0.87×10^{12} Btu. This could indicate that the statewide survey is not representative.

Table 1
Wood Energy Surveys

Area	Date of Survey	Geog. Level of Data	no. of house-holds sampled	Method of Survey	Other Information Gathered			
					Type of Equip.	Subst Fuel	Wood Source	Other
6 New England States	Fall 1979 77-78	Co.	5600	phone	X	X		Socio-economic data
Upstate New York	Feb-March 1979	Co.	2200	phone mail	X	X	X	Sources of info.
Maine	Spring 1978	Co.	156	phone	X	X		education, income
Vermont	Jan. 1978	State	519	phone	X	X	X	insulation, demography
Georgia	Summer, 1979	3 regions of state	2055	phone	X	X	X	
Washington Oregon Idaho Montana	Nov 1979-Jan 80	State	4030	Interviews	X	X	X	demography, characteristics
TVA service territory	1979	TVA districts	8554	mail		X	X	housing, income
NW Wash state	1980	region	338	phone	X	X	X	
N. Carolina	1979	state	(ad hoc estimate)		X	X		
Kansas	1979	5 Metropolitan areas	2374	phone	X		X	
Minnesota	1978-79	Region	2042	phone	X			
Wisconsin	1979-80	Region	2232	phone	X			
Missouri	1979-80	Region	2370	phone	X			
Upper Michigan	1979-80	Region	398	phone	X			
California	1980	State	(ad hoc estimate)					
Virginia	1980	State	(ad hoc estimate)					

Many of the surveys provided demographic data on wood fuel users, which indicate that the use of wood for space heating is no longer concentrated among the rural poor.* Even in a wood-scarce state like Kansas, nearly 31% of households in the five largest cities burned some wood, [8] as compared to 33% in rural farm and rural suburban households in 3 counties in upstate New York, for example.[9] Clearly, wood-burning has acquired an urban dimension.

There is also interest in projecting future usage of residential firewood and to do so requires attention to the economics of wood use. Future use will depend on supply factors, i.e. the availability of wood, and demand factors which are driven primarily by the price differential with respect to alternate fuels. Convenience factors will also enter. The extant data are much too limited for a realistic examination of these factors, which vary greatly among the states shown in Figure 2. However, inspection of the deviations about the 1:1 line on Figure 2 gives no consistent indication that these factors are playing an important role at present. For example, there are states with predominantly oil, gas, and electric heating grouped together below the line. Thus, there are no indications that wood is being used preferentially to displace a particular conventional fuel. And all three outlier states, on both sides of the line, have plentiful wood supplies. It appears that development of a trend-forecasting model will require more and better quality data.

3. NATIONAL AIR POLLUTION EMISSIONS ESTIMATES

The emissions per unit of wood burned vary widely, depending on the types of equipment used, draft setting, type and dryness of wood, etc. Typical ranges were given in Reference 10 which have been reproduced in Table 2. These values were then multipled by the estimated national total firewood use (34.7×10^6 cords). In order to compare to national emissions totals from all sources, data from References 11 and 12 were consulted. In both cases, the values used for residential wood were much lower than the present analysis indicates, and therefore the national totals from all sources were revised to reflect the new estimates for residential firewood.

As shown in Table 2, firewood emissions dominate for phenols, acetic acid, acetaldehyde, and POM's (using the upper range of estimates); firewood emissions are important for formaldehyde , particulates, and carbon monoxide; and unimportant for volatile hydrocarbons, sulfur oxides, and nitrogen oxides. Obviously, on a local scale there will be exceptions to these findings.

4. AIR QUALITY IMPACTS

From an air quality impact point of view, the important parameter is the density of usage, so that air pollutant emissions may be estimated per unit area for use with an atmospheric dispersion model. Eq. (1) may be differentiated with respect to population density to display the sensitivity of usage density to

*The assumption that only the rural population burns wood was shown in the New York State estimates (Ref. 10), in which the urban/suburban population was totally neglected. The correlation with poverty was shown in a factor analysis of 1970 census data for Standard Metropolitan Statistical Areas (SMSA), "% of population that is non-white," "% of population with family incomes below the poverty leve," and "% of households using wood heat x annual degree-days" were associated. The wood heating variable was also associated negatively with SMSA population density.

Table 2
National Air Pollution Emission Burdens

	g/kg	lb/cord	total from residential wood 10^6 tons	National* total, all sources (1978)	% of total
Particulate	2-15	8-60	0.14-1.04	11.2	1.2-9.3
Carbon monoxide	60-130	240-520	4.16-9.02	109	3.7-8.2
Hydrocarbons (assumed to be volatile)	2-9	8-40	0.14-0.71	28.0	0.4-3.5
SO_x	0.2	0.8	0.014	26.7	0.05
NO_x	2	8	0.14	25.0	0.56
Formaldehyde	1.6	6.4	0.11	0.32	34
Acetaldehyde	0.7	3	0.05	0.058	86.
Phenols	1	4	0.07	0.0705	99.0
Acetic acid	6.4	26	0.45	0.478	94.0
Polycyclic organic matter	$5x10^{-4}$ - 0.2	$2x10^{-3}$ -0.8	35-13,900*	76000-21400**	0.5-65

*Including residential wood from this analysis.
**Figures are in tons.

Table 3
Estimates of Wood Use in the
15 Highest Usage-Density Counties

Major City and State	County Name	Cords / Year	Cords / Household	Cords / Sq. Mile
Milwaukee, WI	Milwaukee	99475.	.2845	419.7
St. Paul, MN	Ramsey	62785.	.4090	405.1
Denver, CO	Denver	33979.	.1754	357.7
Chicago, IL	Cook	339826.	.1834	356.2
Detroit, MI	Wayne	208596.	.2398	344.8
Cleveland, OH	Cuyahoga	155095.	.2686	340.1
Minneapolis, MN	Hennepin	180950.	.5655	319.1
Elizabeth, NJ	Union	28727.	.1648	278.9
Newark, NJ	Essex	35937.	.1153	276.4
Staten Island, NY	Richmond	15214.	.1704	262.3
(suburban NY City)	Nassau	73554.	.1805	254.5
Patterson, NJ	Bergen	59068.	.2083	252.4
Indianapolis, IN	Marion	95392.	.3548	243.3
Pittsburgh, PA	Allegheny	171139.	.3210	235.1
(suburban Philadelphia)	Delaware	43240.	.2345	235.0

population density, as shown in Figure 3.* Wood usage density peaks at a population density of about 5360 persons per square mile (2.5 houses per acre or about 4% wood users). Population exposure (the product of population times air pollution) would peak at an even higher density, about 8800 persons per square mile. These are urban population densities, and Table 3, listing the 15 highest usage density counties, includes major cities in the Northern United States.

This emphasis on urban firewood usage is a direct result of the regression analysis leading to Eq (1), which is not very sensitive to low values of cords per household. Small changes in the coefficients of Eq (1) can result in relatively larger changes in wood usage, since the cords per household figures for urban areas are multiplied by such large population bases.

Figure 3 indicates an upper limit to the density of firewood use and thus to the resulting air pollution emission density. This is an important finding, since it will allow realistic simulation of the resulting air quality impact through the use of conventional dispersion models. Previous assessments [5] have employed hypothetical situations, which can be quite misleading.

The air quality impacts of these findings are currently being investigated. It appears that emissions of particulate matter from wood burning in Northern cities may now comprise the major portion of all space heating particulate emissions.**

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*Figure 3 is based on an arbitrary average number of persons per household (3.1) and 6500 heating degree-days per year.

**Particulate emissions from wood burning are 20-60 times higher per input Btu than from liquid or gaseous fuels. The substitution of wood fuel for 10% of the heat input can thus result in doubling or tripling the total emissions of particulate matter. In addition, more recent surveys indicate still further penetration of wood heat into the residential market.

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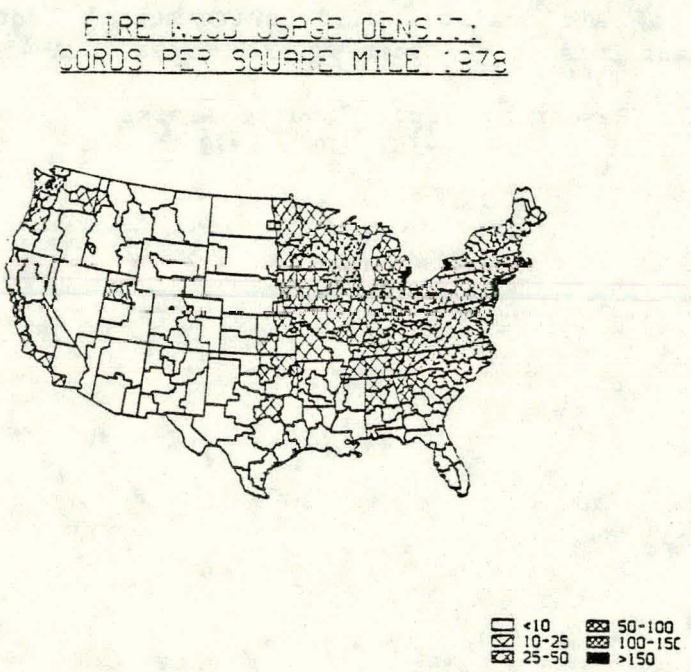

Figure 1. Fire Wood Usage Density

Cords Per Square Mile 1978

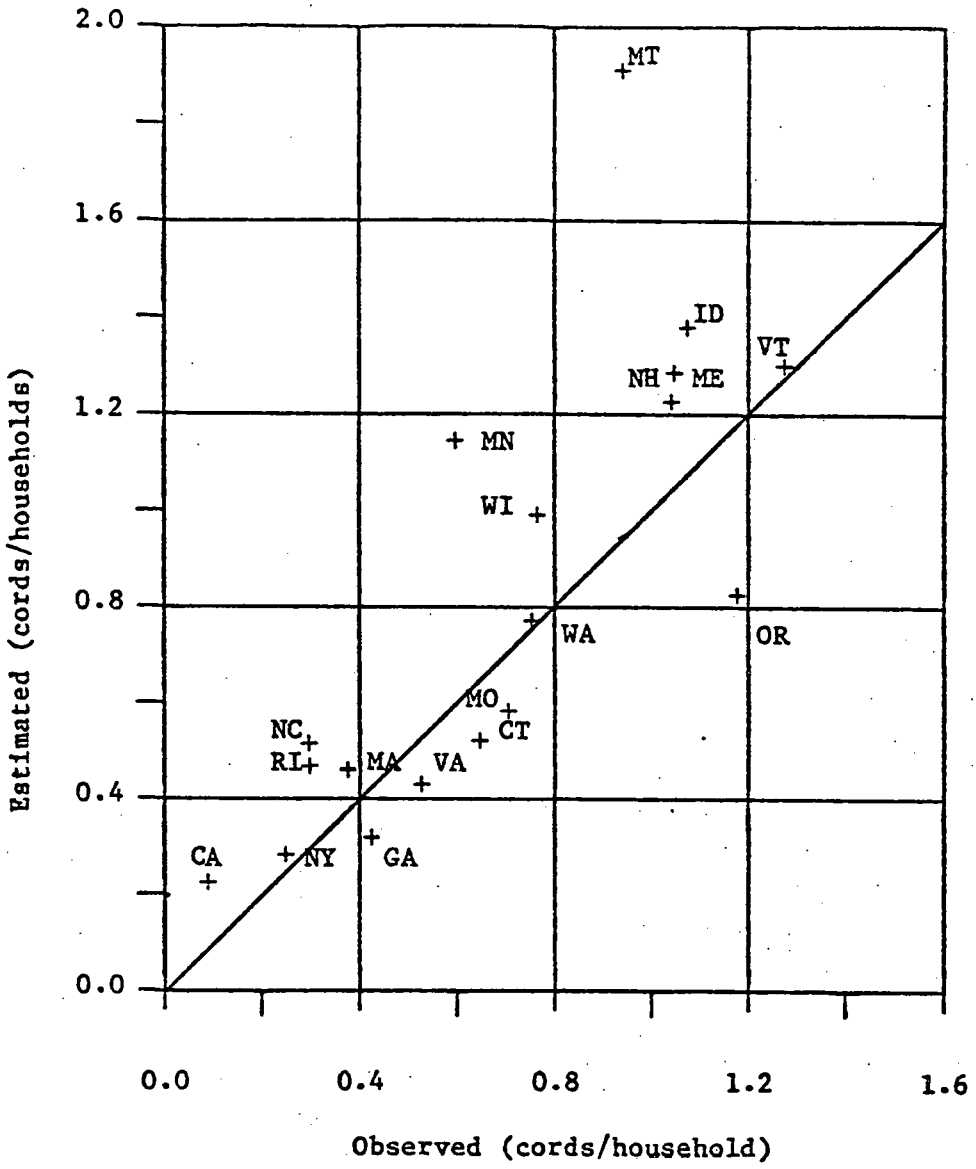

Figure 2. State Level Wood Use Correlation

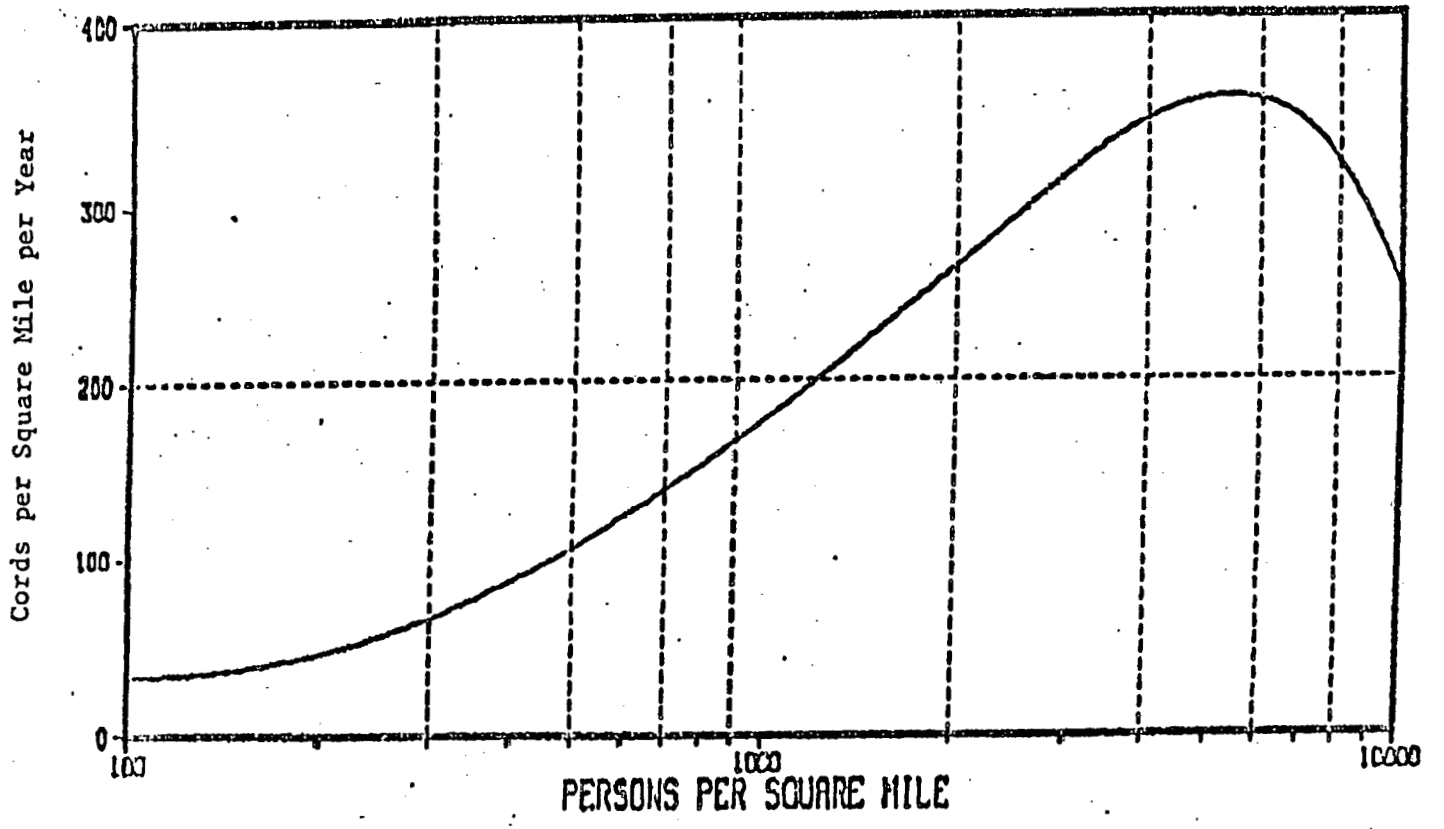

Figure 3. Annual Wood Fuel Use in the Norhteast (1978-79)