Improvement of Residential Wood Combustion Emissions in the Southeastern U.S.

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ABSTRACT

The Southeastern Modeling, Analysis, and Planning (SEMAP) project is continuing the efforts of ten states in the southeastern U.S. to address the next phase of ozone, fine particle, and regional haze assessment obligations required by the Clean Air Act. As part of the SEMAP project, emissions from residential wood combustion were initially estimated with U.S. Environmental Protection Agency's Residential Wood Combustion (RWC) Tool. After reviewing the preliminary results with GIS tools and other published information, however, SEMAP states decided to revise the underlying input data to better reflect local characteristics. Two major components revised in this study were the number of wood-burning appliances and cords of wood burned per appliance. To incorporate these input changes into the RWC Tool, wood-burning appliance profiles and burn rate profiles were updated, and a series of decision algorithms were developed to assign revised profiles to each county in the SEMAP region. The revised RWC Tool resulted in the following SEMAP region-wide reductions of emissions compared with the preliminary estimates with original RWC Tool inputs: 74 % reduction in NOx, 62 % reduction in VOCs, and 59 % reduction in primary PM2.5. The resulting estimates are considered to more closely reflect actual southeastern U.S. RWC emissions. This paper describes details of the methodology, results, and conclusions, as well as recommendations for future work.

INTRODUCTION

Residential wood combustion (RWC) is a major emission source in the southeastern U.S. In the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) 2002 emission inventory, 77,501 tons per year of primary PM2.5 emissions were estimated to come from RWC, accounting for 15 % of the total anthropogenic non-point source PM2.5 emissions in the region.

The Southeastern Modeling, Analysis, and Planning (SEMAP) project is the successor of VISTAS where ten states (AL, FL, GA, KY, MS, NC, SC, TN, VA, and WV) in the southeastern U.S. make collaborative efforts to address the next phase of ozone, fine particle, and regional haze assessment obligations required by the Clean Air Act. As part of the SEMAP project, emissions from residential wood combustion were initially estimated based on the National Emission Inventory (NEI) 2008 methodology which uses U.S. Environmental Protection Agency's (EPA) Residential Wood Combustion (RWC) Tool (hereafter, The Tool).[1] The Tool is software utilizing various data such as the number of wood-burning appliances (i.e., appliance populations) and cords of wood burned per appliance (i.e., burn rate). Review of the preliminary results showed that the Tool estimated a reduction in PM2.5 emissions of about 50% compared with the VISTAS 2002 emissions inventory. However, further reviews with GIS tools raised an issue about unreasonable spatial distribution of RWC emissions in the SEMAP region. In addition, a 2009 study showed a potentially large (~ 90 %) overestimation of RWC emissions in VISTAS' 2002 emissions inventory.[2] Therefore, SEMAP states decided to perform a review of the initial RWC emissions for refinements. This paper details how SEMAP states made revisions to the initial RWC emission estimates.

METHODS

NEI 2008 Methodology

The initial version of SEMAP's residential wood combustion emission inventory was built with EPA's Tool which uses the following equation to estimate RWC emissions:

Equations (1) $E = N \times BR \times D \times F$

where

- E = Emissions
- N = Number of wood-burning appliances (i.e., appliance population)
- BR = Cords of wood burned per appliance (i.e., burn rate)
- D = Density of wood burned
- F = Emission factor

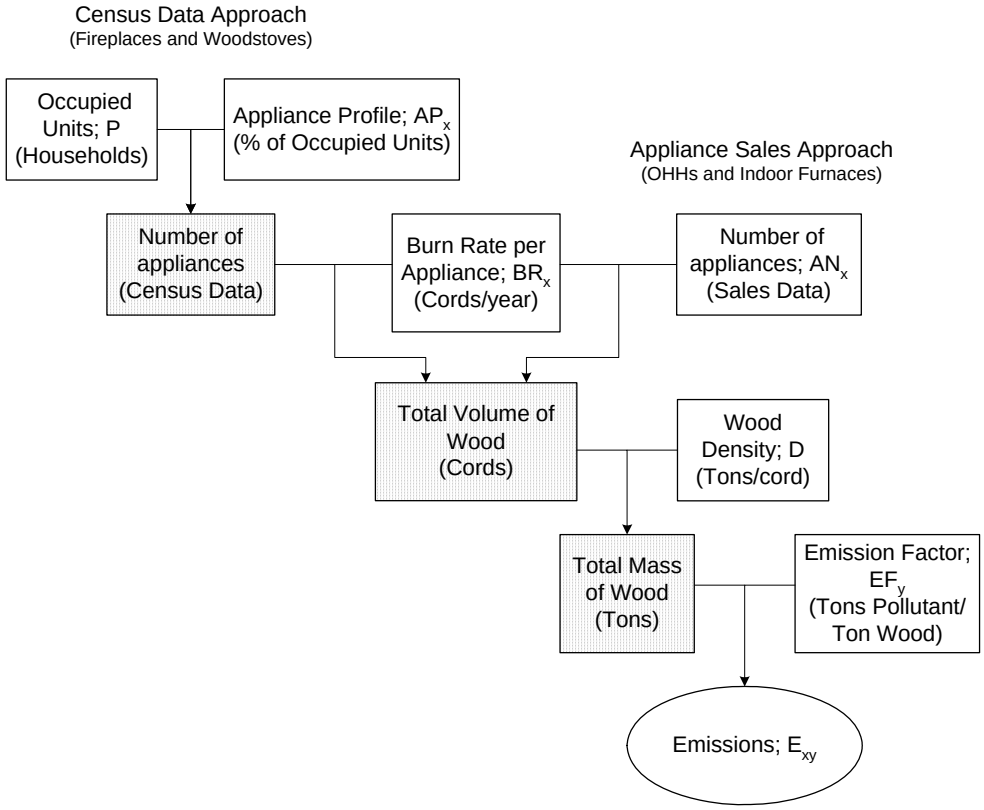
Detailed information about how the Tool estimates emissions can be found in the Tool documentation.[1] Here, we summarize the most critical parts of the Tool that are relevant to our study: appliance population and burn rate.

Different approaches were used to estimate appliance populations and burn rates for different types of appliances. For fireplaces, fireplaces burning wax logs, fireplaces with inserts, and woodstoves, the number of occupied housing units was multiplied by percentages of occupied housing units with a given appliance (i.e. appliance profiles) to estimate the actual appliance population in each county. The county-level number of occupied housing units was derived from the percentage of total housing units that were occupied as computed from 2000 U.S. Census data and the 2007 U.S. Census intercensal estimates of total number of housing units. The appliance profiles were developed from the number of wood burning appliances and number of occupied housing units data compiled from the U.S. Census Bureau's "American Housing

Survey" (AHS). Regional and metropolitan statistical area (MSA) level profiles were developed using the same algorithm applied to the specific geographic areas reported in the survey. The product of these appliance profile percentages with the number of occupied units in a county was used to estimate the total number of appliances in the county for the majority of appliance types. For pellet stoves and hydronic heaters, regional or state sales data was allocated to the county level based on the number of woodstoves calculated to be in each county. The Tool estimates the number of wood-burning indoor furnaces by multiplying the estimated number of woodstoves in each county by a factor (0.53) calculated from available data.

Burn rates were estimated by applying climate zone-based adjustment factors to the national average burn rates obtained from U.S. Department of Agriculture (USDA) Forest Service documents describing Midwest or Great Plain state residential wood consumption surveys performed in the 1990s. Two major factors affected the burn rate estimates: appliance type (woodstove, fireplace, fireplace with insert, furnace/boiler, and firepit) and burning purpose (Main Heating, Secondary Heating, and Pleasure). Appliance types determined the efficiency of fuel use. Burning purpose also greatly affects the burn rates. Climate zone was also considered to estimate the burn rates. Figure 1 shows the overall data flow of EPA's RWC Tool.

Figure 1. RWC Tool Data Flow Diagram

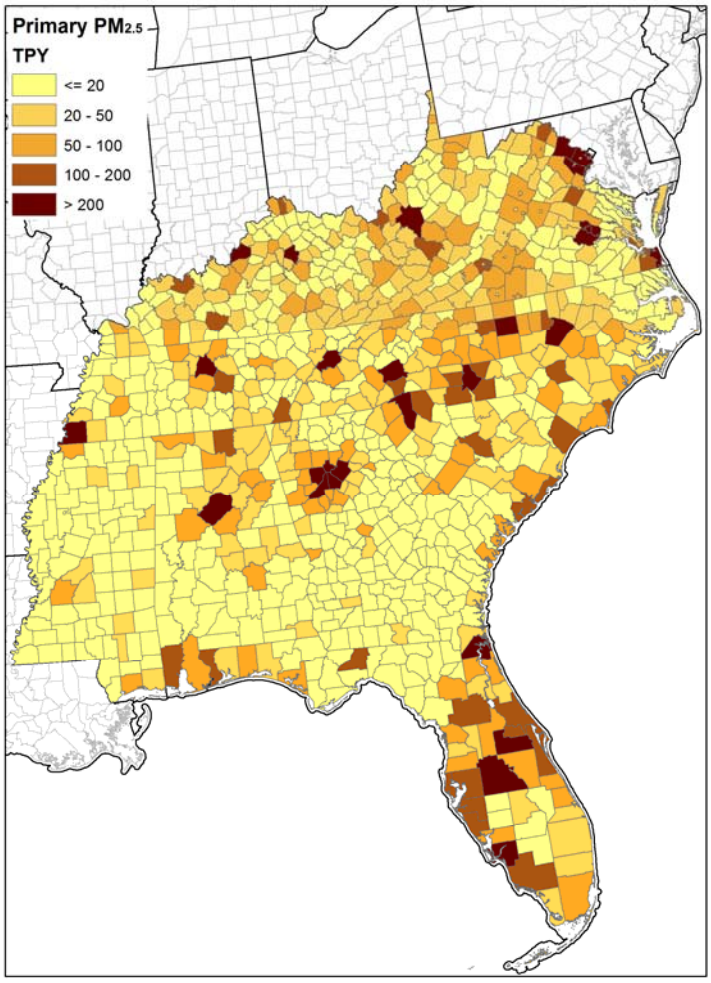


SEMAP 2007 Methodology

A review of the spatial distribution of initial $PM_{2.5}$ emission estimates from the Tool for the SEMAP region indicated much higher emissions in urbanized areas than rural areas (Figure 2).

Although there is reason to expect some correlation between the number of occupied housing units and residential wood combustion emissions, this correlation would be expected to be fairly weak because of at least two factors. The first factor is that housing units in urbanized areas generally have greater access to natural gas as a heating fuel, and therefore, would be expected to have a greater penetration of natural gas fireplaces than rural areas. The second factor is that the access to inexpensive wood supplies would be expected to be much greater in rural areas (and related to this, the proportion of housing units with wood-burning appliances that are used as primary heating units – i.e., woodstoves, outdoor hydronic heaters, pellet stoves – would also be expected to be greater in rural areas). Review of several wood consumption surveys, including the latest survey from Minnesota, also showed a clear trend in households in urbanized areas consuming less wood than their counterparts in rural areas.[3] The following describes the specific refinements that SEMAP states incorporated into the revised Tool.

Figure 2. Initial 2007 PM2.5 emission estimates in tons per year from residential wood combustion for SEMAP states with the Tool



Appliance Population

SEMAP states incorporated the U.S. Census' American Community Survey (ACS) estimates of the 2007 year number of occupied housing units where these values were available (primarily

counties with large populations). This allowed areas which had ACS data available to use 2007-specific occupation rates rather than assuming the occupation rates remained the same as the 2000 Census.

The algorithm EPA used to calculate appliances profiles used Table 2-4 of AHS which reports the total number of stoves, fireplaces with inserts, and fireplaces without inserts used for heating in occupied housing units. These data were used, in combination with AHS occupied housing unit counts, to estimate the percentage of occupied housing units in a given region/MSA that have each of these types of heating equipment. Discussions with the Bureau of the Census confirmed that these equipment types are not restricted to wood-burning equipment. Therefore, SEMAP states used AHS Table 2-5 data that reports the number of occupied housing units using wood as a Main Heating fuel and the number of occupied housing units using wood for Other Heating to estimate the proportions of Table 2-4 Main Heating equipment burning wood and Other Heating equipment burning wood. Because Table 2-5 does not report data by equipment type, this approach assumes that the proportions are the same for each of the three equipment types. Since Table 2-5 in the 2007 and 2009 AHS no longer reports the number of occupied housing units using wood for Other Heating, for the regional appliance profiles, SEMAP states relied on proportions computed from 2005 AHS data. Because the algorithm for calculating appliance quantities for pleasure burning takes main and secondary heating into account, the adjustment for non-wood heating may actually result in a net increase in number of appliances. The end result of these calculations results in a shift to pleasure burning appliances whose emissions are considerably smaller than main or secondary heating resulting in an overall drop in emissions.

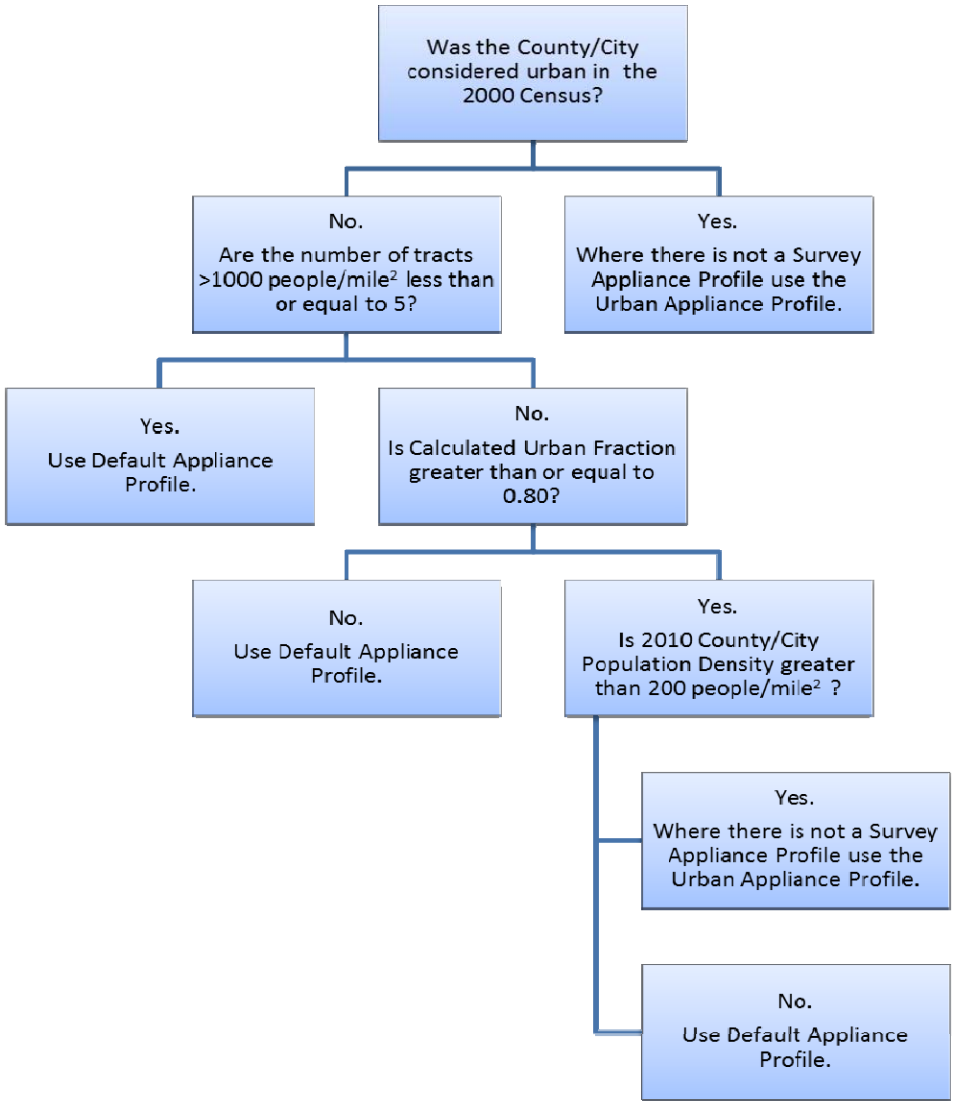
To improve upon EPA's use of MSA-level data, sub-MSA appliance profiles were developed using the "sub-area" sections of the original Metropolitan Areas AHS used in the Tool. In keeping with EPA's MSA appliance profile assignment approach, SEMAP states assigned the sub-MSA profiles only to the counties to which they applied:

- Birmingham, AL;
- Miami-Dade County, FL;
- Urban Atlanta, GA;
- Kenton County, KY;
- De Soto County, MS;
- Gaston County, NC;
- Mecklenburg County, NC;
- York County, SC;
- Shelby County, TN;
- Fairfax County, VA;
- Urban Norfolk-Virginia Beach-Newport News area, VA.

Using the same algorithm as the EPA, SEMAP states also developed a default urban appliance profile in an attempt to better characterize wood-burning equipment populations in urbanized areas for which the AHS does not report MSA-specific data. Places such as Greensboro NC, Knoxville TN, and Richmond VA do not have MSA-specific profiles, however the regional profile did not seem to reflect proportions seen in the nearby MSA profiles. The urban profile reflects national average wood-burning appliance information from the 2005 National AHS.

SESARM then developed a set of criteria for determining which counties should be assigned the applicable regional average appliance profile (South), and which would be assigned the new national urban appliance profile. Figure 3 shows the decision tree that SEMAP states developed to assign each of these two appliance profiles.

Figure 3. Decision Tree for Assigning Regional Average (Default) or National Urban Appliance Profile



The estimates for pellet stoves, indoor furnaces, and hydronic heaters (also known as outdoor wood boilers) are hard-coded into the Tool. After review of the EPA's appliance count estimation methods for these units, SEMAP states decided that the estimates for these appliances should also be updated. In the case of pellet stoves and hydronic heaters, the Tool allocates regional (pellet stoves) or state-level (hydronic heater) counts of each appliance type. The Tool utilizes estimates of the number of each type of equipment as calculated from cumulative sales data. The Tool then allocates these regional/state estimates to counties based on the proportion

of regional/state number of woodstoves in each county. Because the revised Tool includes updated county-level woodstove population estimates, consistency with EPA's methodology requires re-allocating the estimated number of regional/state pellet stoves and hydronic heaters to each county using the updated woodstove data incorporated into the revised Tool. The Tool estimates the number of wood-burning indoor furnaces by multiplying the estimated number of woodstoves in each county by a factor. The EPA calculated this factor (0.53) from data on the number of woodstoves and indoor furnaces used for main heating in climate zones 1-3. To be consistent with the Tool methods for estimating indoor furnaces, SEMAP states updated the indoor furnace appliance counts by multiplying the revised number of woodstoves in each county by the 0.53 factor.

Burn Rate

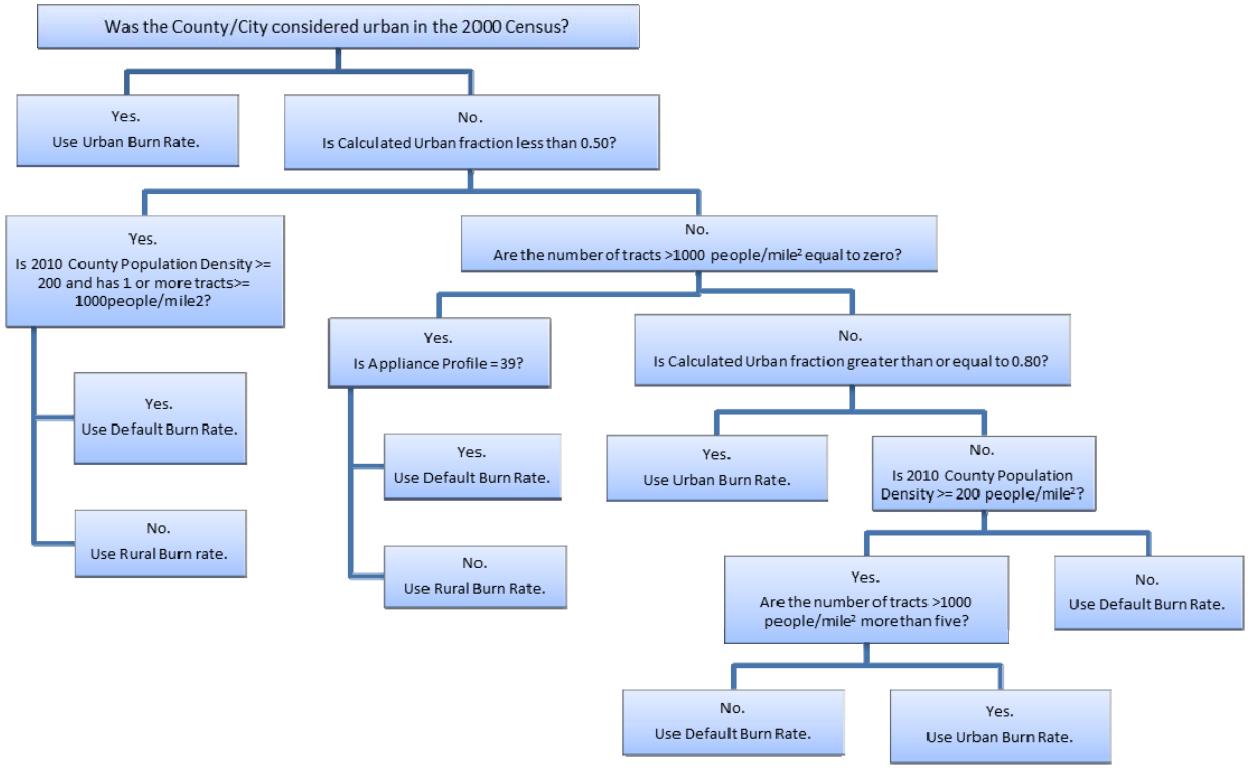
SEMAP states also incorporated new burn rate profiles that characterize the amount of wood burned in each type of appliance. As with the appliance profiles, burn rate profiles can be assigned to one or more geographical areas. The Tool included burn rate profiles that were developed and refined by EPA using survey data from the U.S. Forest Service's North Central region as the starting point. The EPA adjusted these data based on the ratio of energy consumption in the surveyed climate to energy consumption in other areas of the country. For example, if the energy consumption in climate zone 5 (the warmest climate zone) was half of the energy consumption in climate zone 1 (the surveyed climate zone), burn rates in climate zone 5 were estimated to be 50 percent of the burn rates in climate zone 1. The energy consumption data for these adjustments were obtained from the Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS).

SEMAP states compiled 2005 RECS data to refine the EPA's burn rates, by computing the average cords of wood burned per household for each of three categories: Rural, Urban (sum of cities, towns, and suburbs), and Total. SEMAP states then calculated two ratios: Rural to Total wood consumption per household (1.563); and Urban to Total wood consumption per household (0.537). These ratios were then applied to the existing burn rate profiles to create new Rural and Urban burn rate profiles for each of the SEMAP region climate zones—2, 3, 4, and 5. After the appropriate calculations were performed, the new burn rate profiles were developed by adding either an "r" for Rural or "u" for urban to the Tool's original default burn rate profile number. They are as follows:

- Climate zone 2: Nu and Nr;
- Climate zone 3: 3Au and 3Ar;
- Climate zone 4: 4u and 4r; and
- Climate zone 5: 5u and 5r.

The next step in refining the burn rate information was to identify the criteria for assigning the Rural, Urban, and overall average burn rates (the original burn rate for a given climate zone) to each county within a climate zone. SEMAP states developed these criteria, which are represented in Figure 4. With a few exceptions, these updated burn rates were applied to most of the counties in SEMAP states.

Figure 4. Decision Tree for Assigning Average (Default), Urban, or Rural Burn Profiles



RESULTS AND CONCLUSIONS

SEMAP states reviewed the initial RWC emissions estimates in the region calculated with the Tool. Based on this review, SEMAP states decided to revise two major inputs of the Tools, appliance population and burn rate, and to develop decision trees to assign appropriate updated input data to each county in the region.

The updates related to appliance population were:

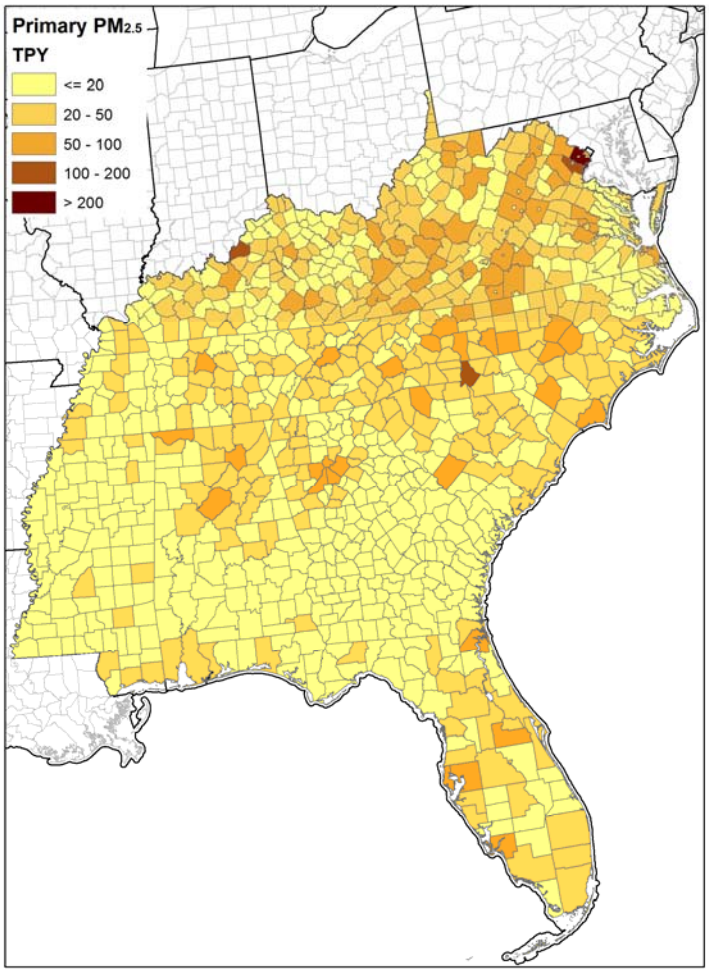
- Revising the occupied unit calculations;
- Incorporating region-specific appliance profile adjustments based on the estimated proportion of Main Heating and Other Heating appliances that do not burn wood;
- Integrating "sub-MSA" area profiles for the 11 MSAs;
- Including a default urban appliance profile based on national urban values reported by the 2005 AHS; and
- Revising estimated pellet stove, indoor furnace, and hydronic heater counts based on the updated woodstove counts developed in the revised Tool.

The burn rate updates required the following steps: (1) calculating two wood consumption per household ratios for Rural to Total (1.563) and Urban to Total (0.537), (2) revising the Tool's default burn rates profiles for the SEMAP region climate zones based on these ratios, and (3)

identifying the criteria for assigning the Rural, Urban, and overall average burn rates (the original burn rate for a given climate zone) to each county within a climate zone.

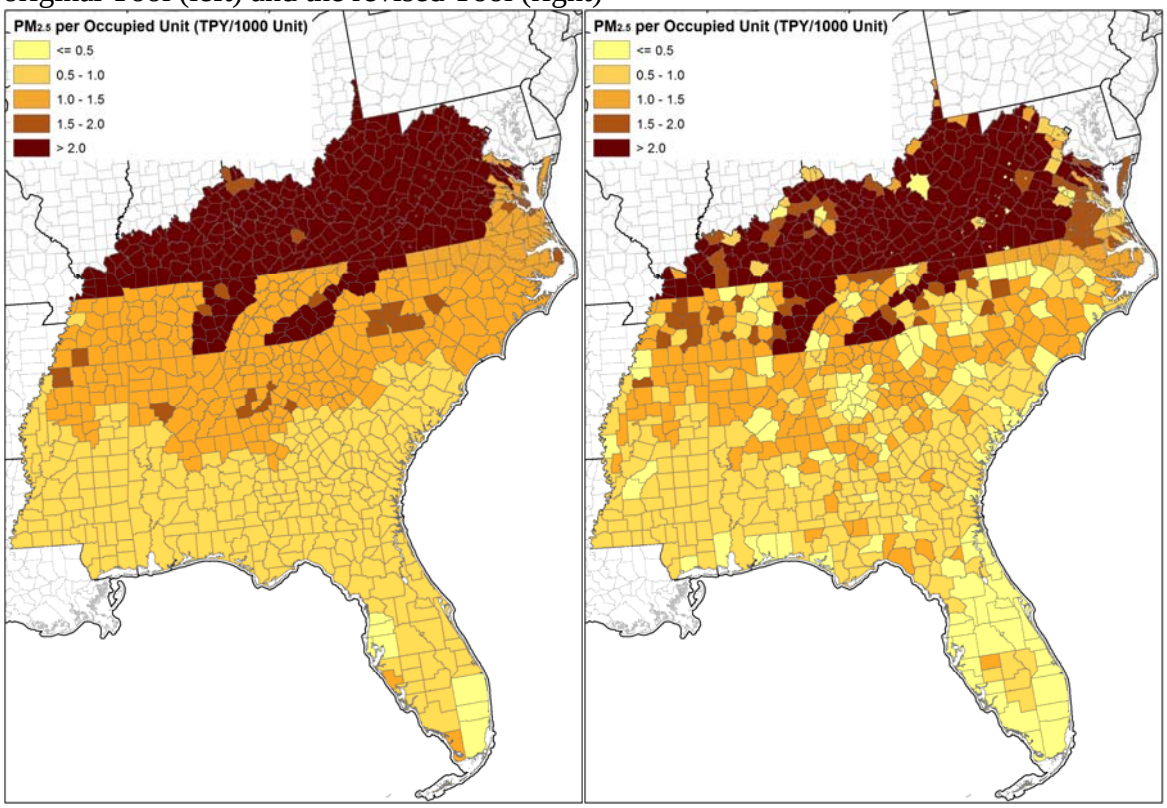
The revised Tool resulted in SEMAP region-wide reductions of emissions compared with initial estimates from EPA's original Tool inputs as follows: 74 % reduction in NOx, 62 % reduction in VOCs, and 59 % reduction in primary $PM_{2.5}$. Figure 5 shows the total PM2.5 emission estimates with the revised Tool. Compared with Figure 2, it depicts great reduction of PM2.5 emissions, especially in urban areas and warm regions such as southern Florida. The revised RWC Tool resulted in the following SEMAP region-wide reductions of emissions compared with the preliminary estimates with original RWC Tool inputs: 74 % reduction in NOx, 62 % reduction in VOCs, and 59 % reduction in primary PM2.5.

Figure 5. Final 2007 PM2.5 emission estimates in tons per year from residential wood combustion for SEMAP states with the revised Tool



As shown in Figure 6, the revised Tool also often estimated less emissions per occupied housing unit, especially in urban and sub-urban areas. The resulting estimates are considered to more closely reflect actual SEMAP states' RWC emissions. Eventually, SEMAP's efforts to refine the Tool will be incorporated in the next version of the Tool for NEI 2011.[4]

Figure 6. Comparison of PM2.5 emission estimates per 1000 occupied housing units from the original Tool (left) and the revised Tool (right)



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KEY WORDS

Residential wood combustion
Stationary area source
Southeast