Gateway Blueprint Model Workshop 2005

Air Emissions Model for the St. Louis Region

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Abstract:

Linking an air quality model with the LEAM land use model will allow us to estimate, allocate and locate emissions by land use and across space and time in order to provide answers to the following questions:

- Where will be emission hotspots in the future?
- How sensitive is the spatial and temporal distribution of emissions to the driving forces such as land-use change, technology, and planning policies?
- How do emission patterns vary among different pollutants?

A “bottom-up” approach based on Geographic Information System (GIS) is proposed and evaluated using data of St. Louis Metropolitan Area (SLMA). We began by validating the 2000 residential emission estimates. It was determined that there are many inaccuracies in the National Emissions Inventory data, and that our approach provides more accurate estimates of most pollutants.

The next step will involve predictions of future emissions of residential combustion emissions of CO, NO_x, SO_2, VOCs, PM-10, and PM-2.5 using simulated land-use maps of SLMA between 2005 and 2050.

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Introduction

Air pollution is one of the most important human impacts resulting from urbanization. It not only causes harm to human health but also has other negative effects such as reducing crop production, disturbing or ruining ecosystem, and damaging material, and some air pollutants also contribute to climate change. Therefore, changes in regional air quality associated with urbanization has been a major concern to urban planners.

Linking an air quality model with the LEAM land use model will allow us to estimate, allocate and locate emissions by land use and across space and time in order to provide answers to the following questions:

- Where will be emission hotspots in the future?
- How sensitive is the spatial and temporal distribution of emissions to the driving forces such as land-use change, technology, and planning policies?
- How do emission patterns vary among different pollutants?

The ability to answer such questions is particularly important for areas that are near the border of compliance with the National Ambient Air Quality Standards. Based on the results of such an analysis, control polices and mitigation strategies can be more specific and effective. Unfortunately, the current state-of-the-art for predicting future emissions simply increases emissions from existing locations at the regional level and distributes the emissions across space using surrogate variables like population. This approach does not take into account a common phenomenon accompanying urbanization: the changing amount and location of emission sources as new areas develop. In addition, because primary pollutant concentrations govern chemical reaction rates and hence subsequent human exposure, models that assume increased future emissions without capturing their spatial distribution over time would tend to overestimate the resulting consequences at some locations and underestimate them at others.

A “bottom-up” approach based on Geographic Information System (GIS) is proposed and evaluated using data of St. Louis Metropolitan Area (SLMA). For validation purposes, emission factors together with control measures adopted in creating the 1999 National Emission Inventory (1999 NEI) are assigned to residential land use identified on the 2000 land-use map and a spatial emission map is then generated for each pollutant (CO, NO_x, SO_2, VOCs, PM-10, and PM-2.5). The aggregated total residential combustion emissions by pollutant type at county level and over the study region are compared to the corresponding data from the 1999 NEI. The next step will involve predictions of future emissions of residential combustion emissions of CO, NO_x, SO_2, VOCs, PM-10, and PM-2.5 using simulated land-use maps of SLMA between 2005 and 2050. Technology-based emission factors provided by Speciated Pollutant Emission Wizard (SPEW) will replace the emission factors used for validation. A similar analysis will also be done to estimate air emissions from commercial/industrial land use. Various scenarios reflecting land development, technology advancement, and emission control policies will be assessed to support regional decision-making.

Methodology

1.1. Validation of Residential Emissions

The analysis begins with differentiating between city, town, suburb, and rural area because the energy consumption behavior differs a lot in different locations. Then city, town, suburb, and rural area boundary maps are created (Figure 1). Weights for city, town, suburb, and rural respectively by fuel type are estimated using the following formula:

$$W_i = \frac{E_i}{\sum_{i=1}^{n} E_i}$$

Here i is type of fuel, W is weight, and E_i is national energy consumption for that fuel type (Data source: 2001 American Housing Survey). Note that coal is assumed to be only consumed in rural area and therefore the weight of coal for rural area is 1 and 0 for the other 3 regions.

Energy consumption per household (HH) in 2000 is calculated based on this formula:

$$E_i / HH = RTE / RTHH$$

Here E_i is energy consumption for each fuel type, RTE is regional (climate zone or state) total energy consumption, and $RTHH$ is regional (climate zone or state) total households. This was done for MO and IL separately using energy data from Energy Information Agency (EIA) and household data from the 2000 Census.

Next, we calculated the number of households per block group from the 2000 census (Figure 2).

After obtaining emission factors from 1999 NEI instructions with certain modification based on data availability, the emissions are calculated for each pollutant and Census BKP

$$E_i / BKP = HH / BKP * NE\% * W_i * (E_i / HH)$$

$$EMS / BKP = \sum_{i}^{n} E_i / BKP * EF_i$$

Here E_i is energy consumption for a specific fuel, *BKP* is block group, W_i is the weighting factor for city, or town, or suburb, or rural area, *NE%* is the percentage of households which do not use fuels (electricity, solar, wind, etc) except the ones under study, EF_i is the emission factor for a specific fuel, and *EMS* is emissions for a BKP. Now a map can be created for each pollutant showing annual emissions at BKP level

1.1.1. Validation results

The estimated emissions per census block group are compared to 1999 NEI emissions data at the county level and region level. At the regional level, the data provided by 1999 NEI gave unreasonable values for certain pollutants, particularly NO_x. According to the 1999 NEI instruction, we recalculated emission values at the regional level for all the pollutants and could not obtain similar results.

Using the recalculated results, we found that using state average per HH energy consumption in the method gave closer estimation for all the pollutants except CO and SO_2 (where using climate zone average per HH energy consumption led to closer estimation) (Table 1). We found similar results when we added emission estimates from wood combustion (Table 2).

At the county level, without wood combustion, the distribution of regional total emissions to each county for the two methods were different only for CO and SO_2. The other pollutants showed similar distribution patterns (Figure 3). With wood combustion, there are apparent distribution differences for all the pollutants except for NO_x (Figure 4).

Figure 5 shows the spatial distribution of residential emissions at block group level based on the approach outlined in this report.

1.2. Next Step: Prediction of Future Emissions

The next step in this analysis is to estimate future air emissions as a result of the land use change projected in LEAM for various scenarios.

1.2.1. Energy consumption projections

To project future emissions, energy consumption projections must be forecasted. Energy consumption data can either be obtained from DOE projections or from projected Gross Regional Production (GRP) data calculated in the LEAM economic model. Energy projection results from these two sources will be compared.

1.2.2. Residential area source emissions (Figure 6)

The changes in future emissions from residential area sources can be linked to the changes in residential development. LEAM provides future land-use maps with projections of where low-density residential development may occur. It is currently assumed that only 1 person lives in each new residential land-use cell. Overlaying the Census urban and rural map with the future land-use map, we can estimate new population in each block group, redefine urban and rural areas, and redefine the boundary of the city, town, municipal boundary map for each year of the LEAM simulation results. Finally, block group level emissions for future years can be spatially estimated using emission factors from SPEW and energy projection data from either LEAMecon or DOE.

1.2.3. Commercial/industrial area source emissions (Figure 7)

With the land-use map projections that result from a LEAM simulation, the locations of future commercial/industrial cells for each time step are estimated. With emission factors from SPEW and energy projection data from either LEAMecon or DOE, future emissions from each newly developed commercial/industrial cell can be estimated spatially. Based on the needs, the emissions can be aggregated up to any spatial scale greater than 30 by 30 meters.

Figure 1. Boundary map of city, town, suburb, and rural region of St. Louis Metropolitan Area

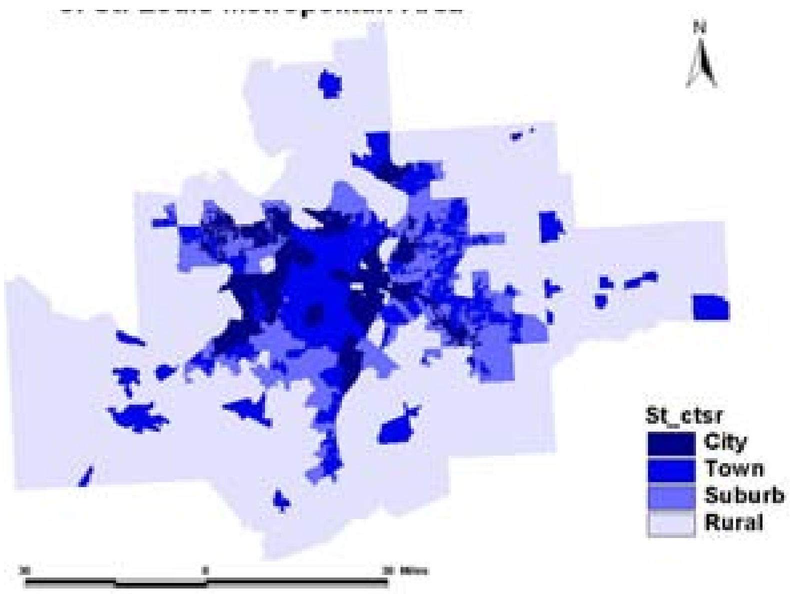


Figure 2. Census 2000 number of households at block-group level for St. Louis Metropolitan Area

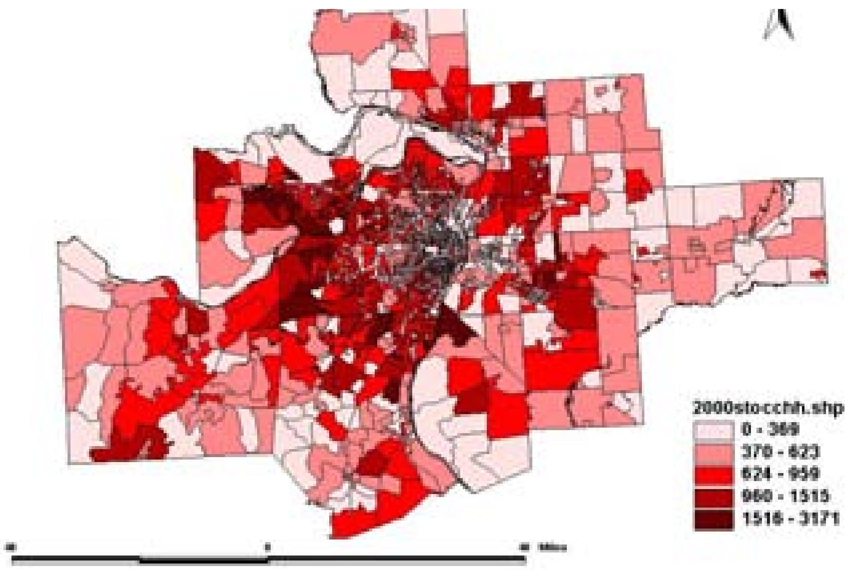


Figure 3. Percentage share of county emissions (without wood combustion) of 4 selected pollutants within St. Louis Metropolitan Area: comparisons between recalculated 1999 NEI and LEAM results

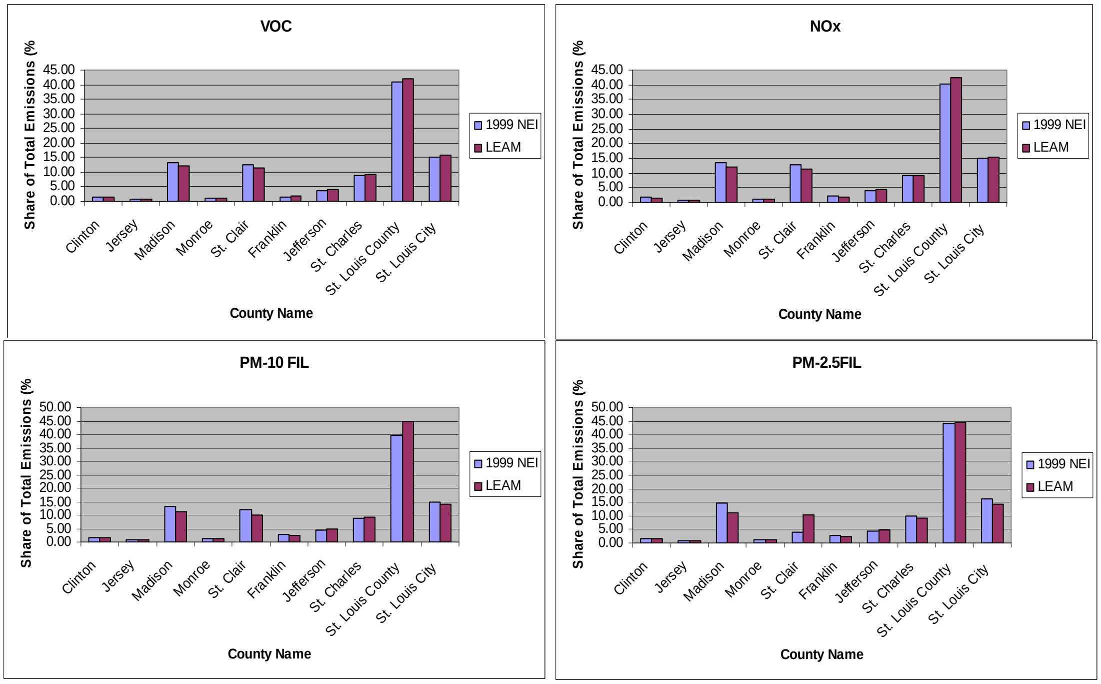


Figure 4. Percentage share of county emissions (with wood combustion) of 4 selected pollutants within St. Louis Metropolitan Area: comparisons between recalculated 1999 NEI and LEAM results

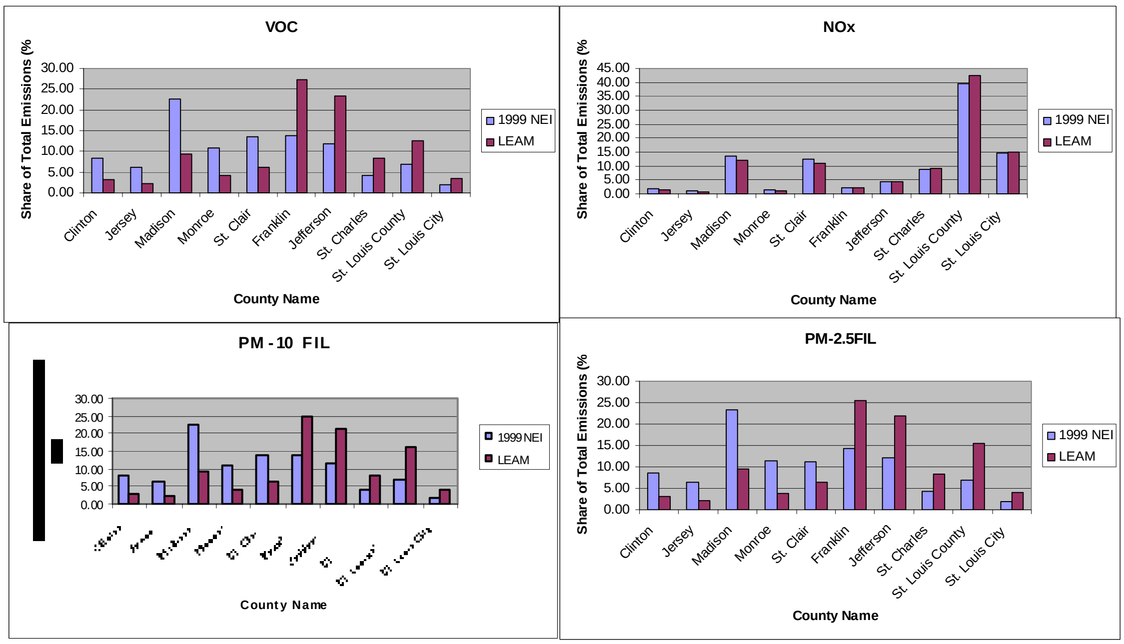
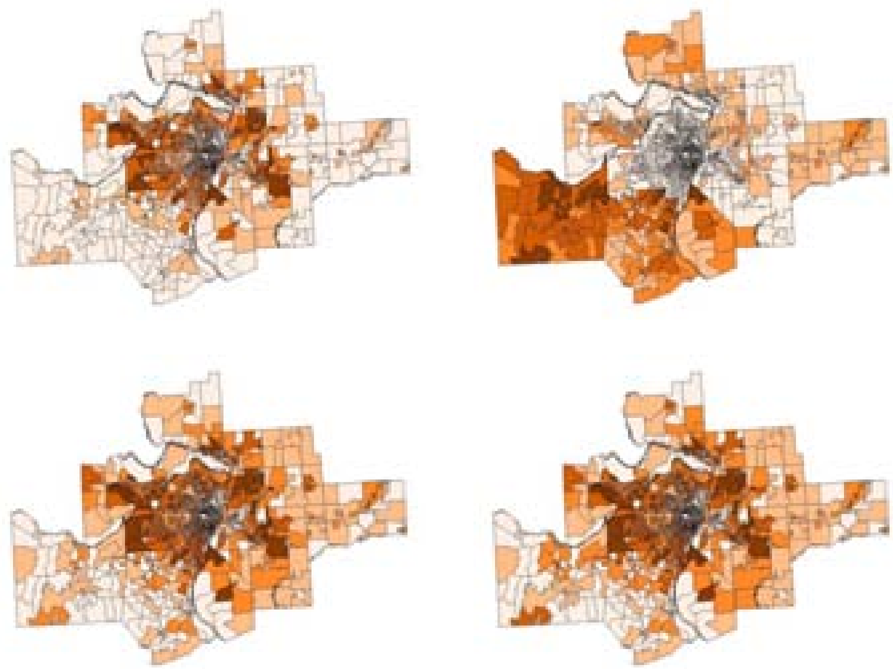


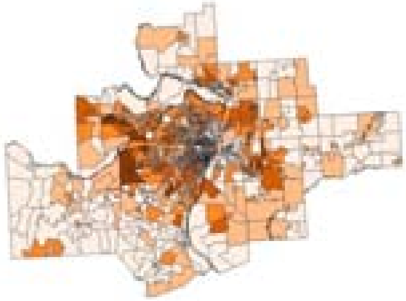
Figure 5. Spatial distribution of 2000 residential emissions (without and with wood combustion) within St. Louis Metropolitan Area for 4 selected pollutants (the darker the color in the census block the higher the level of emissions)

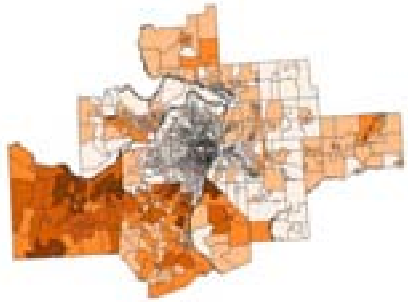
VOC

NO_X

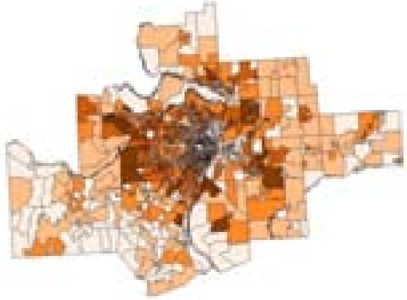


PM-10 FIL





PM-2.5 FIL



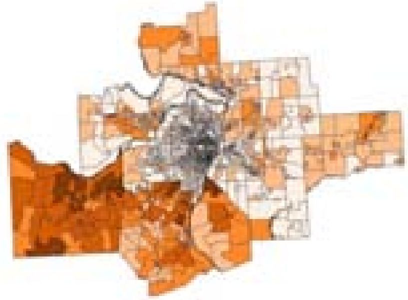


Figure 6. Proposed method for predicting residential area source emissions

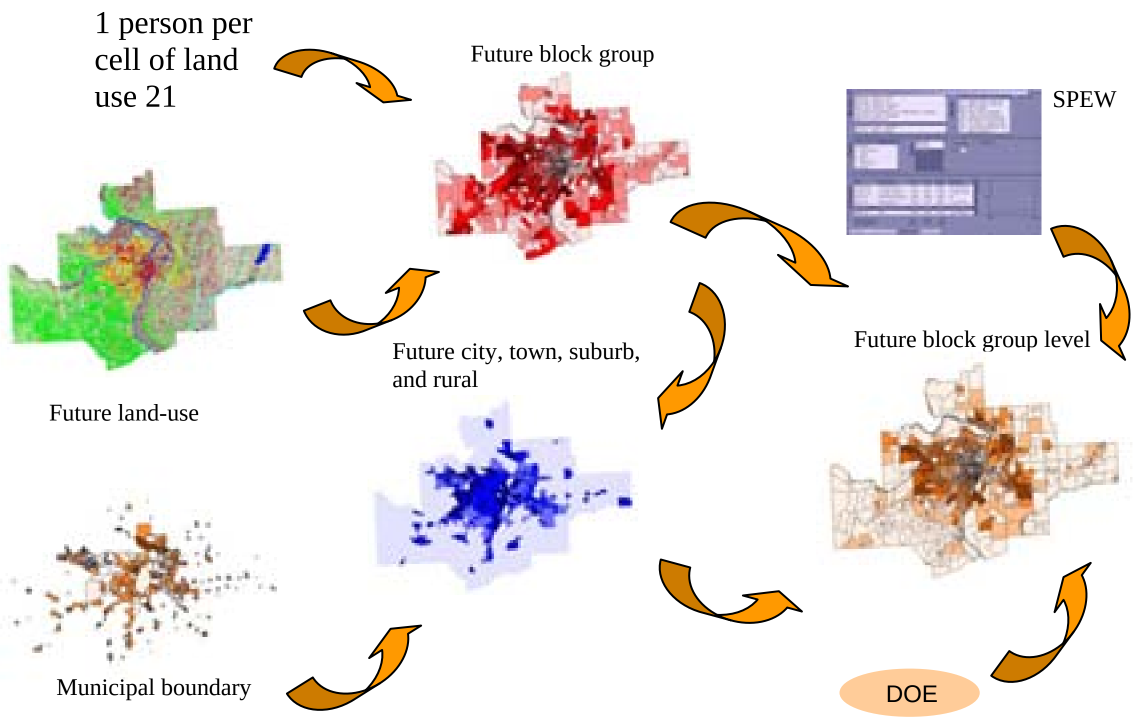


Figure 7. Proposed method for predicting commercial/industrial area source emissions