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Short communication

A Python toolkit for visualizing greenhouse gas emissions at sub-county scales

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ABSTRACT

This short communication describes a package written in the Python language that facilitates analysis and visualization of transportation-related greenhouse gas emissions at sub-county scales. Known as the Small Area Greenhouse Gas Estimation Tool (SAGGET), the toolkit uses outputs from the Motor Vehicle Emission Simulator (MOVES) emission model to create emissions estimates and projections for user-defined geographies. The Python scripts issue calls to third party geoprocessing libraries; separate versions of the toolkit are available for use in conjunction with the ArcGIS library produced by ESRI, and for the open-source SpatiaLite extension to the SQLite database engine. We demonstrate the capacity of the toolkit by presenting small-area emissions estimates for the St. Louis region as a whole, and for a specific transportation corridor. The package is freely available from the East-West Gateway Council of Governments.

Software availability

Name of software: Small Area Greenhouse Gas Estimation Tool (SAGGET)
Version: 1.1
Developers: M. Wohlstadter and L. Shoaib
Contact email: Michael.wohlstadter@ewgateway.org
Available from: Request a ZIP file containing scripts and documentation from the East-West Gateway Council of Governments at the contact email above. Users who request the software via email will receive updates.

1. Introduction

A growing awareness of harms caused by greenhouse gas (GHG) emissions has spurred an interest among policy makers in refining estimates of GHG emissions in different sectors, including agriculture (Perez-Minana et al., 2012; Howden and O'Leary, 1997), energy (DeCarolis et al., 2016) and water distribution systems (Stokes et al., 2015). The analysis of future emissions under alternative scenarios and at multiple scales is increasingly recognized as an urgent priority (Schweizer and Kurniawan, 2016; Guivarch et al., 2016).

Transportation accounts for 27% of U.S. greenhouse gas emissions (U.S. EPA, 2015a), and nearly a quarter of global emissions (Sims et al., 2014). The transportation sector, therefore, has a significant role to play in any plan for reducing greenhouse gas emissions. Accordingly, measuring transportation's contribution to greenhouse gas emissions has become a key concern for policy makers interested in greenhouse gas mitigation.

In the United States, the Motor Vehicle Emission Simulator (MOVES) model has become a commonly used model for estimating greenhouse gas emissions (U.S. EPA, 2015b). The model, created by the U.S. Environmental Protection Agency (EPA), can estimate transportation-related emissions for several pollutants, including oxides of nitrogen, volatile organic compounds, carbon dioxide (CO_2), and other greenhouse gases. MOVES is used by many state and metropolitan transportation planning agencies for the purpose of demonstrating conformity with the Clean Air Act. The model has also been used to estimate greenhouse gas production in several places, including New Jersey (Kall et al., 2012) and Atlanta (Liu et al., 2015).

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Key inputs to MOVES include files containing the distribution of vehicle types and the age of vehicles in the area. These files are provided by agencies of state government, which is responsible for motor vehicle registration in the United States. An additional input is a meteorology file, which comes from the National Weather service. Data on time of travel and speed distributions for different road types are provided by EPA.

MOVES offers an inventory mode that allows estimation of emissions for a user-specified geography. While this is a useful tool, it does not contain a batch mode. Thus, if a user wished to estimate emissions for one square mile grid cells over a 5000 square mile region, this would require running the MOVES model 5000 times, which is not a feasible option. Another tool for estimating GHG emissions at sub-county scales is the Clean Air and Climate Protection (CACP) software produced by ICLEI (City of St. Louis, 2012). This software converts estimates of Vehicle Miles of Travel (VMT) from a Travel Demand Model (TDM) using national averages to convert VMT into emissions. Again, while this is a useful and respected tool, it does not make use of the full emissions modeling capabilities of the MOVES model.

MOVES is one of several emissions models used throughout the world. Fujita et al. (2012) compare MOVES with its predecessor, MOBILE6. Using emission measurements from North Carolina, Fujita et al. determine that MOVES is in “reasonable agreement” with measured data with respect to CO and NOx emissions, although MOVES was reported to underestimate non-methane hydrocarbons in periods of high ambient temperature. Park et al. (2016) compare MOVES with several other models including COPERT, the most widely used model in Europe. One key difference between MOVES and COPERT is that MOVES relies upon speed distribution estimates, while COPERT uses only average speeds. Park, Lee, and Lee find the MOVES approach preferable on this count.

The ability to downscale MOVES outputs has the potential to inform decision making. There is a significant interest among municipal decision makers in measuring and mitigating greenhouse gases (Guerra et al., 2015). More than 1000 mayors in the United States who have signed the U.S. Conference of Mayors Climate Protection Agreement, which commits signatories to reducing emissions within their jurisdictions. Moreover, many state and regional transportation planning agencies are seeking to incorporate greenhouse gas emissions into planning activities (Kenney et al., 2014). Identifying emissions at sub-county scales has the potential to contribute to these types of policy and planning applications.

While the small area analysis of greenhouse gas emissions was the primary motivation for the development of this tool, the software may also be used to analyze other types of emissions that can be estimated using the MOVES model. A command line argument allows the user to specify the type of pollutant for which analysis is desired.

The software introduced in this article provides the capacity to downscale projections of regional emissions to user-defined sub-county geographic units. The emissions analyzed are those that occur while the vehicle is in motion, and are attributed to polygons containing roadway segments on which the emissions occur.

2. Software characteristics and capabilities

2.1. Software environment

We sought to make the software easy to obtain, use and manipulate, to make it available to a community of potential users, particularly among state and metropolitan agencies that already use the MOVES model for demonstrating air quality conformity. We use the Python programming language, which runs on all major platforms and is freely available from the Python Software Foundation (PSF, 2016). Many programmers and modelers use Python because its libraries (packages developed by the Python user community) hold thousands of functions for implementing a wide range of data manipulation techniques. There are also packages and add-ons designed specifically for the processing of geographic data. For these reasons, Python has been used for many environmental modeling and software applications (e.g., Zhang et al., 2013; Marta-Almeida et al., 2011). This software uses Python v. 2.7.

2.2. Required inputs

SAGGET is a downscaling tool that relies upon outputs from two other modeling systems commonly used in transportation planning.

2.2.1. Travel Demand Model

Outputs from a Travel Demand Model (TDM) constitute one set of inputs. A TDM is a tool used by Metropolitan Planning Organizations (MPOs) and state departments of transportation to create estimates and projections of traffic volume for each of the individual road segments in a transportation network (McNally, 2007). TDMs operate at a level of geography called the Transportation Analysis Zone (TAZ). TAZs are defined locally. The output produced by the TDM is a file referred to as the “loaded network,” and can be exported as a Geographic Information Systems (GIS) file. The loaded network contains an estimate of traffic volume for each functionally classified road segment in the region.

2.2.2. Motor Vehicle Emission Simulator (MOVES)

The loaded network is a principal input of the MOVES emission model. MOVES uses VMT from the loaded network, along with other inputs such as a meteorology data file, files specifying the temporal distribution of traffic volume and data files containing estimates of vehicle types to create projections of emission rates. The output file relevant to SAGGET is the “Rate per Distance” file, which is a lookup table of emission rates as emission per distance, e.g., grams per mile. Rate per distance shows estimated emission rates broken down by vehicle type, road type, time of day, day of week, month of year, and speed. Hours with hotter temperatures (mid-day, mid-year) have elevated emission rates due to increased use of air conditioning. Road types affect emission rates mainly through stop signs, traffic signals and speed. Thus, freeways and major arterials tend to have lower emission rates at given speeds than local roads or collectors. Emission rates decline steeply as

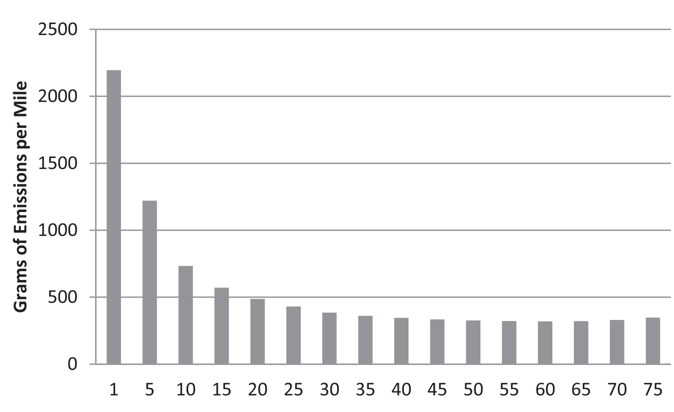

Fig. 1. Relationship between speed and emissions.