# Development of automated pipeline for time-resolved link-wise vehicular energy consumption in the Chattanooga, TN road network

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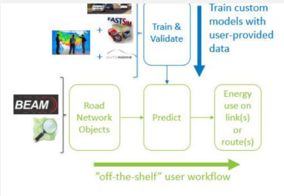
**Abstract**

*The Department of Energy (DOE) has shown strong interest in detecting energy inefficiencies in regional road networks, so as to derive energy consumed at a high spatial temporal resolution. We have developed a workflow to automate the estimation of time-resolved vehicular energy consumption over each link in a road network of interest. The road network used in the current work is centered around the city of Chattanooga, Tennessee and its bordering regions. Utilizing the most mature road network for the Chattanooga, TN region, vehicle speed & count data from TomTom in conjunction with machine learning methods, we have developed an automated pipeline to estimate energy consumption for every link in the network. The first step in the pipeline is ingesting vehicle probe counts and speed estimates from TomTom API. In the next step, the probe counts, speed profiles and other exogenous data (i.e. road types, weather data, ground-truth volume counts and more) were used as input to a supervised learning algorithm to estimate the number of vehicles throughout the entire region for each road segment. These volume estimates were then mapped to a unified road network that contained additional important information such as percentage change in gradient across a link, number of lanes and link lengths that are features in pre-trained single vehicle energy-consumption models available with the RouteE software developed at NREL. The per vehicle energy consumption on each road link predicted using appropriate RouteE vehicular models were multiplied by the volume estimate for the corresponding link over a given time period to predict energy consumed per link for the time interval of interest. Currently, work is underway to improve both the RouteE per vehicle energy estimate and the volume estimates derived from TomTom probe counts. We have also explored the correlation of the link-wise energy estimates with the features of the pre-trained RouteE machine learning model in order to gain insight into what factors contribute most to the link-wise energy consumption.*

## Link-wise Energy Estimation Using RouteE

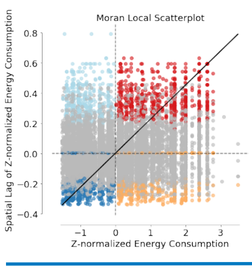


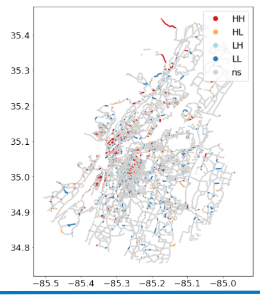

**RouteE:**
*Python package for route energy estimation developed under ARPA-e TRANSNET and SMART Mobility - CAVs*

- Users can train own models; pre-trained models also available
- Multiple existing pre-trained passenger vehicle models appropriate for Chattanooga, TN
- Features of these predictive models are:
  - -speed during the trip,
  - -% change in grade across the trip,
  - -number of lanes during the trip and,
  - -distance of the trip (in miles)
- For link-wise energy estimation, each trip traverses a link in the Chattanooga road network
- RouteE based per vehicle energy estimation can be multiplied by the link-wise estimated volume

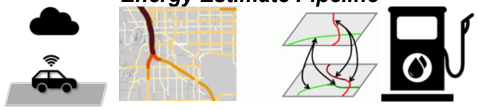
## Local Spatial Autocorrelation Analysis of Estimated Energy

- Local Moran's I statistic calculated using queen contiguity weights
- Local Moran's I measures how similar a geographical entity is to its neighbors
- LISA (Local Indicators of Spatial Association) implementation of the Moran's I statistic
- Implemented using PySAL python package
- Moran Local Scatterplot and LISA clustering based on estimated energy (AB) direction for p value of 0.05 also
- obtained using PySAL package



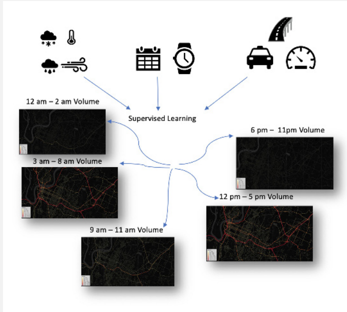




## Energy Estimate Pipeline



| TomTom | Volume Estimation | Map Matching | Energy Estimate |
|---|---|---|---|
| • Historical probe volume counts & speeds at road links<br>• Near real-time speeds | • ML-based volume estimate from<br>- Weather conditions<br>- Time of day<br>- Day of week<br>- Road type<br>- Average speeds<br>- Probe counts | • TomTom road network matched to TPO network<br>• Grid partitioning networks decreased computation time from 2 weeks to 2h | Energy Estimated using pre-trained RouteE explicit binning model developed at NREL |

## Volume Estimation



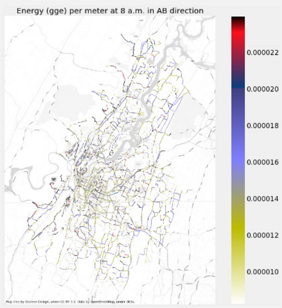

**ML modeling Details**

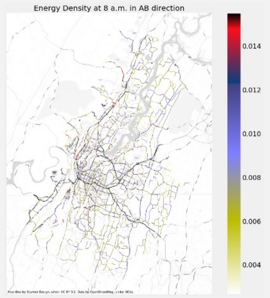
**Algorithm:** Xgboost

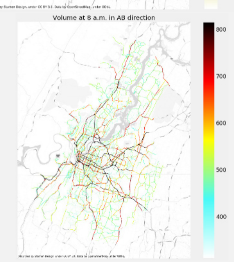
**Features:**
- Precipitation (Rain/Snow)
- Temperature
- Wind Speed & Direction
- Day of Week
- Hour of Day
- Average Speed
- Speed Limits
- Road Types
- Probe Volume Counts

**Training Data:**
Tube Count Data throughout Chattanooga, TN region

## Results



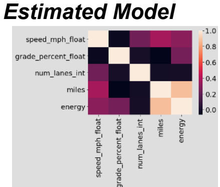



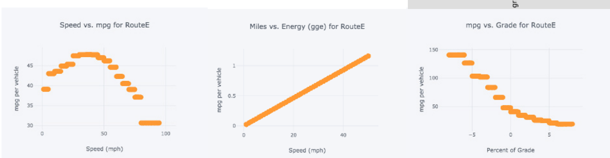




- Per vehicle energy consumption shows strongest correlation with the link length among the different features of RouteE model
- Energy density is obtained by taking the product of the per vehicle energy consumption across a link.
- Occurrences of high values of the energy density consistent with the high traffic volumes through highways and arterials
- Aggregation of energy density (in gge) over 24 hours shows peaking at both morning and evening rush hours.

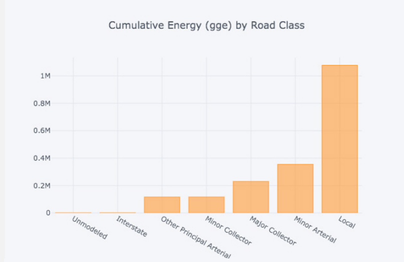
## Scatter Plots and Correlation Plot of Estimated Model

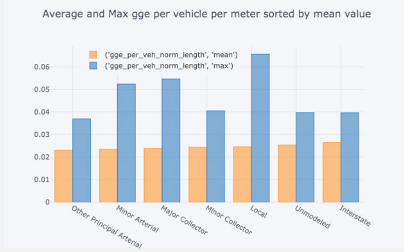
- RouteE uses 4 inputs to the model for calculating energy (gge) per link:
  - Length in miles, grade on segment, average speed on segment and number of lanes
- Length of road segment has positive linear relationship to gge
- % Grade has negative impact on mpg
- Speed has concave down parabolic relation to mpg




## Key Findings




- Over 50% of the total energy on the network is found on local streets
- Local streets comprise over 58% of the network in miles.
- After normalizing road segments by length and volume, interstates on average consume the most amount of fuel and other principle arterials comprise the least on average

## Next Steps

- Improve volume estimate training data in region given GridSmart volume counts at intersections and Radar Detection System (RDS ) data along the highways
- Run estimates with updated RouteE model (i.e. Random Forest)
- Add truck vehicle classes to RouteE model for freight energy estimates.
- Leverage existing RouteE energy estimate model that captures acceleration and/or variation of speeds between adjoining segments.
- Build surrogate volume estimate model based on real-time speed profiles from TomTom.

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