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A Fuzzy and a Monte Carlo simulation approach to assess sustainability and rank vehicles in urban environment

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Abstract

The selection and assessment of new vehicle technologies and mobility solutions to stimulate sustainable transportation planning becomes challenging, due to lack of frameworks and tools that are capable of considering the features of new solutions. The objective of this paper is to present a method that combines Fuzzy Logic and Monte Carlo Simulation (MCS) for the sustainability assessment of urban transportation vehicles and evaluate the applicability of the method to selected indicators for ranking the sustainability performance of vehicles. The fuzzy method has been chosen for its ability to incorporate imprecise and vague information in a decision-making process and the MCS for its ability to generate many scenarios by considering the random sampling of each probability distribution of uncertain input values. The results revealed that by using the fuzzy method alone or with MCS provide similar rankings. The MCS added value to the sustainability assessment by presenting the distribution characteristics of each sustainability index for the five vehicle types and added a layer of statistical confidence in interpreting and comparing the advantages and disadvantages between vehicle types.

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1. Introduction

Transportation planning in urban areas is a complex process due to the multiple components of a transportation system that need to be taken into consideration. These components generate many and potentially large impacts because they affect travel patterns, commuting, travel behaviors, land uses etc. Selection and assessment of new vehicle technologies and mobility solutions in transportation planning to promote sustainability becomes challenging, due to lack of frameworks and tools that are capable of considering the features of new solutions.

New vehicle technologies and fuel types, with no long term data and only limited short term data, introduce uncertainty in the evaluation of new transportation modes and in the formation of environmental and transportation strategies. New vehicle and fuel features, with an unexplored impact on sustainability and transportation planning, necessitate that uncertainty should be incorporated in sustainability assessments. Additionally, the complexity of transportation systems and the numerous indicators that are developed for the assessment per se invite uncertainty

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because required data may be incomplete. Uncertainty can be treated with probabilistic methods that require data to have a statistical basis. However, some input variables in a decision making process do not have a statistical basis, therefore other methods such as the fuzzy logic are required. Fuzzy logic methods may combine vague and uncertain criteria with well-defined and/or quantitative criteria to obtain the best alternative (Hardy 1995).

In fuzzy logic, imprecise information can be represented by linguistic values that through an inference system can provide precise conclusions. Fuzzy methods are recommended for application in sustainability oriented problems because such problems include non-uniform quantities and data, uncertain information, imprecise data and interrelations between sustainability dimensions (Pislaru and Trandabat 2012; Rossi et al. 2013). The objectives of this paper are to develop and present a fuzzy and a Monte Carlo Simulation approach for the sustainability assessment of urban transportation vehicles and evaluate the applicability of the method to selected indicators for ranking the sustainability performance of vehicles. The fuzzy method has been chosen for its ability to incorporate imprecise and vague information in decision making process. A Monte Carlo Simulation is also used in the calculation of the distribution percentiles of the sustainability indices for the five vehicle types by taking into account the uncertainty in of the input indicators. A recent study by Mitropoulos and Prevedouros (2013) developed a sustainability framework for assessing the sustainability performance of urban transportation vehicles using several powerplants and fuels under various scenarios. The study herein develops a fuzzy logic and Monte Carlo based method for incorporating uncertainty into sustainable transportation planning and uses the results from Mitropoulos and Prevedouros (2013) to test the method.

2. Sustainability Assessment Framework of Urban Vehicles

The proposed sustainability framework consists of five dimensions that are captured by the goals for governing transportation systems: Environment, Technology performance, Energy, Economy, and Users. The goals of the framework are to help a community meet its needs by: 1) Minimizing environmental impact and energy consumption; and 2) Maximizing its economy, user and community satisfaction, and technology performance. (Technology performance refers to the features of modes that support community livability, enhance public health, safety and comfort for all their users.) A set of indicators was developed for assessing the sustainability performance of five urban transportation vehicles based on the framework's five dimensions. The indicators address objectives by identifying individual vehicle features that contribute towards maximization of sustainability. When the impacts (i.e., positive or negative) of those features of sustainability are aggregated for all vehicles on the network, their value determines goal achievement and ways to move a transportation system towards sustainability. The sustainability framework was the methodological guide for developing a sustainability assessment tool.

All vehicles were assumed to use the same highway infrastructure; roads and related traffic infrastructure were not part of the assessment. The five urban vehicles examined were: Internal Combustion Engine Vehicle (ICEV), Hybrid Electric Vehicle (HEV), Electric Vehicle (EV), Diesel Bus (DB), Hybrid Diesel Electric Bus (HDEB). Vehicle specifications were necessary for estimating their impact on the five sustainability dimensions (i.e., Environment, Technology performance, Energy, Economy and Users) that capture the goals of a transportation system. For vehicle types, such as the ICEV, the HEV and the EV, the most representative vehicles were selected based on their sales volume (Edmunds 2012). Vehicle type refers to vehicle propulsion technology (e.g., internal combustion engine, electric motor or hybrid), and basic functionality (e.g., car/van, light-truck, bus, etc.) In summary, the assumption for modelling emissions and energy indicators per life cycle stage are described below.

Manufacturing. Manufacturing emissions and energy were modeled in The Greenhouse Gases, Regulated Emissions and Energy Use in Transportation GREET (CTR 1998; CTR 2005; CTR 2006) including vehicle materials, batteries, fluids and vehicle assembly. Specific input assumptions related to each vehicle and its components are extracted from the official specifications sheet of each vehicle (e.g., vehicle weight, battery weight, fluid weight, other material percentage by weight).

Fueling. GREET is used for the fuel life cycle ("well to wheel"). The model estimates the emissions and energy associated with primary energy production (feedstock recovery), transportation and storage, and with fuel production, transportation, storage and distribution. The fuel production option for conventional gasoline and low sulfur diesel is petroleum. For electricity generation the following mix is assumed: Coal 50.4%, nuclear power 20.0%, natural gas 18.3, residual oil 1.1%, biomass 0.7%, other 9.5% (i.e., hydro, solar, wind and geothermal).

Operation and Idling. For the operation stage, MOBILE6.2 (EPA 2003) was used to estimate the emissions generated