Fuel 154 (2015) 9–16

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Assessment of alternative fuels for transportation using a hybrid graph theory and analytic hierarchy process method

Pramod B. Lanjewar [a,*], R.V. Rao [b], A.V. Kale [c]

[a] Department of Mechanical Engineering, St. Vincent Pallotti College of Engineering and Technology, Nagpur 441108, Maharashtra, India
[b] Department of Mechanical Engineering, S. V. National Institute of Technology, Surat 395007, Gujrat, India
[c] Department of Mechanical Engineering, Yeshwantrao Chavan College of Engineering, Nagpur 441110, Maharashtra, India

HIGHLIGHTS

- A hybrid multicriteria methodology is developed for the performance assessment of transportation fuels.
- Graph theory and AHP methods are combined to develop the hybrid multicriteria methodology.
- Three examples are presented to demonstrate the effectiveness of the proposed methodology.

ARTICLE INFO

Article history:
Received 2 February 2015
Received in revised form 24 March 2015
Accepted 24 March 2015
Available online 2 April 2015

Keywords:
Alternative fuels
Greenhouse gases
Multicriteria decision making
Digraph
Analytic hierarchy process

ABSTRACT

The release of large amounts of greenhouse gases due to fossil fuel combustion contributes to global warming causing a serious environmental problem. The transportation technologies based on cleaner and renewable alternative fuels can play a major role in mitigating the green house effect and improving the urban air quality. In the present work, a hybrid multicriteria methodology is developed using graph theory and analytic hierarchy process methods for the performance assessment of conventional and non-conventional transportation fuels on the basis of multiple criteria. The proposed fuel suitability digraph presents a graphical visualization of alternative fuel selection attributes and their interrelations. The fuel preference index obtained from matrix permanent function provides a total objective value for comparison of alternative fuel options. Analytic hierarchy process is employed to assign the relative weights to the fuel selection attributes. Three examples are considered in order to demonstrate the effectiveness and flexibility of the proposed methodology.

1. Introduction

The present surface transportation technologies are based on fossil fuels (petrol and diesel) which are in limited supply. The increase in per capita energy use and improved living standard in both, developed and developing countries has led to increase in fossil fuel consumption, much of that increase is from the transportation sector. The release of large amounts of greenhouse gases (GHG) due to fossil fuel combustion contributes to global warming causing a serious environmental problem and has attracted the attention of researchers world-wide. Factors such as increasing oil demand, rising fuel prices and alarming GHG emissions have triggered extensive research and development efforts for alternative fuels that are renewable, produce less harmful emissions and can help nations to become more energy independent. Promotion of alternative automotive fuels as a clean and safe energy resource can be expected to play a major role in improving the urban air quality and dependency on conventional fuels.

The vehicles that run on fuel other than the conventional petroleum fuels are called alternative fuel vehicles (AFVs). In recent years significant progress has been made in the development of AFVs with the research primarily focusing to address the GHG emissions and climate change issues. Various types of AFVs based on methanol, ethanol, bio-diesel, natural gas, hydrogen, electric vehicles and hybrid electric vehicles are being developed and tested for transportation sector.

The development and deployment of AFVs involves economic factors such as the costs of vehicle, operation and maintenance, environmental factors such as levels of GHG emissions and other atmospheric pollutants, technical factors such as availability of the technologies required for the alternative fuels, levels of vehicle safety, performance, and reliability and infrastructural

* Corresponding author. Tel.: +91 9975549133.
E-mail addresses: lanjewarpb@gmail.com (P.B. Lanjewar), ravipudirao@gmail.com (R.V. Rao), svssngp@gmail.com (A.V. Kale).

http://dx.doi.org/10.1016/j.fuel.2015.03.062
0016-2361/

Nomenclature

AFV	alternative fuel vehicles
AHP	analytic hierarchy process
AP	air pollution
B100	100% biodiesel
CD	conventional diesel
CG	conventional gasoline
CNG	compressed natural gas
DEA	data envelopment analysis
DEC	direct electric charging
DS	distance between refueling stations
E85	mixture of 85% ethanol and 15% gasoline by volume
EE	energy efficiency
ES	energy supply
EEB	electric bus with exchangeable batteries
FC	fuel cost
FPI	fuel priority index
GE	green house gas emissions
GEH	gasoline-electric hybrid
GHG	greenhouse gases
GWP	global warming potential
GTMA	graph theory and matrix approach
HECNG	hybrid electric bus with CNG engine
HED	hybrid electric bus with diesel engine
HEG	hybrid electric bus with gasoline engine
HELPG	hybrid electric bus with LPG engine
IC	cost of implementation
IR	industrial relationship
LCA	life cycle assessment
LCC	life cycle cost
LPG	liquid propane gas
M85	mixture of 85% methanol and 15% gasoline by volume
MC	cost of maintenance
MCDM	multicriteria decision making
NE	net energy yield
NP	noise pollution
NRDP	non-renewable resource depletion potential
OCEV	electric vehicle – opportunity charging
PROMETHEE	preference ranking organisation method for enrichment and evaluation
RF	road facility
SC	sense of comfort
ST	speed of traffic flow
TOPSIS	technique for order of preference by similarity to ideal solution
VC	vehicle cost
VCa	vehicle capability
VIKOR	visekriterijumsko kompromisno rangiranje (compromise ranking)
VO	number of vehicle options available to consumer

requirements to support the technology, and government support such as subsidies, tax incentives, and research grants. Assessment of alternative fuels for transport vehicles is therefore, a multidisciplinary challenge that requires participation of experts from different fields including technical, economic and social. This is why the multi-criteria assessment can be of help to decision makers and governments to take decisions concerning promotion of alternative fuel and propulsion technologies for transportation sector.

In the literatures, several different approaches were introduced to the assessment of alternative fuel technologies, including life cycle analysis and multi-criteria analysis. Streimikiene et al. [1] employed Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to develop a multi-criteria framework for comparative assessment of energy technologies in road transport. The assessment was based on environmental and economic parameters. They also presented the effect of transportation infrastructure on the energy consumption and greenhouse gases emissions by vehicles. Shelton and Medina [2] presented an integrated Analytic hierarchy process (AHP) – TOPSIS methodology for ranking the transportation projects. The AHP was used to decide weights of criteria by pair-wise comparisons, and TOPSIS was used to obtain final rankings of projects. Tzeng et al. [3] presented a composite decision making model for the selection of alternate fuel buses for urban areas of Taiwan. They considered buses fuelled with diesel, compressed natural gas, liquid propane gas, methanol, hydrogen fuel cell bus, electric buses and hybrid electric buses for assessment and comparison based on eleven different criteria. AHP was adopted to determine the criteria weights and TOPSIS and compromise ranking method (VIKOR) methods were applied to assess and rank the alternative fuel mode buses.

Aydın and Kahraman [4] addressed the problem of bus selection for public transportation for Ankara using a hybrid multicriteria decision making (MCDM) method. The weights of the economic, social, and technological factors were determined by fuzzy AHP and then the alternatives were ranked by fuzzy VIKOR. A sensitivity analysis was also performed to check the effect of variation in criteria weights on the final ranking of the buses. The fuzzy methodologies employed involve complex computations. Tsita and Pilavachi [5] evaluated seven alternative fuels for the Greek road transport sector using AHP. Internal combustion engine, blends of gasoline and 1st and 2nd generation biofuels, fuel cells, hybrid vehicles, plug-in hybrids and electric vehicles were evaluated according to cost and policy aspects. Fazeli et al. [6] presented a multi-criteria evaluation framework for the choice of alternative fuel options of light-duty vehicle fleets. They identified user's acceptance, emissions of pollutants to atmosphere, risk of the technology development, transition costs, and availability of fuel supply as evaluation criteria and employed Pareto optimal (PO) approach, and data envelopment analysis (DEA) method to identify the most preferred alternative fuel option. Brey et al. [7] utilised DEA method to analyse and compare the fuel cell vehicles with conventional internal combustion engine vehicles and hybrid vehicles on the basis of technical, economic and environmental aspects. DEA requires more computation and familiarity with the concepts of linear programming.

Mohamadabadi et al. [8] illustrated the application of Preference Ranking Organisation Method for Enrichment and Evaluation (PROMETHEE) for ranking renewable and non-renewable fuel vehicles for road transportation. In their study, vehicles based on gasoline, gasoline-electric (hybrid), diesel, compressed natural gas, B100 biodiesel and E85 ethanol were evaluated with respect to vehicle cost, fuel cost, distance between refueling stations, number of vehicle options available to the consumer, and greenhouse gas emissions. Sensitivity analysis was also performed to investigate the effect of criteria weight changes on final ranking of vehicles.

Zhou et al. [9] carried out multicriteria assessment of fuels to compare the conventional fuels with new and renewable fuels. Conventional gasoline, conventional diesel, compressed natural gas, blend of 15% gasoline and 85% methanol by volume, blend of 15% gasoline and 85% ethanol by volume, and pure ethanol were assessed with respect to life cycle cost, global warming potential,