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Sustainable fuel portfolio optimization: Integrated fuzzy multi-objective programming and multi-criteria decision making

Mohammad-Hadi Sehatpour, Aliyeh Kazemi*

Department of Industrial Management, Faculty of Management, University of Tehran, Tehran, Iran

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ABSTRACT

The chronic illness of transportation sector is its excessive dependence on petroleum products that necessitates immediate actions to mitigate negative externalities. Developing an environmentally benign, economically feasible, and socially acceptable fuel portfolio can generally, improve the sustainability of future transportation systems. This study aims to predict an optimal fuel portfolio based on different concerns for light-duty vehicles of Iran in the light of alternative fuels until 2025. Six potential fossil and renewable fuels including gasoline, diesel, compressed natural gas (CNG), liquid petroleum gas (LPG), a mixture of 85% ethanol and 15% gasoline (E85) and biodiesel, and one gasoline-electric hybrid technology competed through an integrated fuzzy multi-objective programming. Seven goals with environmental, cost, social and policy nature, as well as systematic constraints and fuel priority (obtained by the application of a multi-criteria decision making (MCDM) method) had to be met in the model. The solution of the model along with the sensitivity analysis of weights and aspiration levels indicated that with an acceptable possibility of achieving the goals, CNG had the greatest share in the optimal fuel portfolio followed by gasoline, LPG and diesel. Through the intended horizon, the fossil fuels' share has declined such that 13.5% of the optimal portfolio was replaced by hybrid technology, biodiesel and E85 in 2025, and more importantly, carbon dioxide emission and fuel cost could be mitigated by 11% and 18%, respectively in the same year. Two scenarios focusing on environmental and cost goals were defined through assigning 70% and 80% of the weights to the related goals, respectively; the results revealed that the main characteristics of the optimal portfolio were stable. Likewise, the analysis of the aspiration and tolerance levels of the goals proved the stability of the model and revealed that these parameters play a sensitive role in the model and could affect the optimality and feasibility of the solutions.

1. Introduction

The importance of transportation as a fundamental part of the economy of any country is such that it is introduced as an indicator of development. Having a significant contribution in the production of national value-added, the transportation sector, basically affects the production growth in any society (Achour and Belloumi, 2016). During the past two decades, Iran's transportation sector had accounted for a high proportion of energy consumption so that, after the residential and commercial sectors, this sector is the second largest final energy and the first petroleum products consumer. According to the statistics of National Iranian Oil Refining and Distribution Company (NIORDC) in 2014, road transport and more specifically light-duty vehicles (LDVs) have been in charge of more than 99% of the total gasoline consumption in the transportation sector (IFCO, 2012; MOE, 2014; NIORDC, 2014). Consequently, considerable amount of greenhouse gases (GHGs) is emitted every year in Iran such that it has put this country among the ten first carbon dioxide (CO_2) producers in the world in 2014.

Moreover, around 31% of the overall energy consumption (158.7 million barrels of oil equivalent (MBOE)) was assigned to the transportation sector in 2014, making it responsible for 49.69%, 79.76%, 24.93%, 97%, and 45% of total NO_x, SPM, CO_2, CO and SO_x emissions (MOE, 2014; NIORDC, 2014; Statistics, 2015). In terms of quantity, energy consumption in Iran released around 602 million tons of CO_2 in 2014 of which approximately 150 million tons were emitted by the transportation sector.

Air pollution, especially in the mega cities of Iran, figures prominently among the main environmental causes, which affect

* Corresponding author. Nasr Bridge, Chamran Highway, PO Box: 14155–6311, Tehran, Iran.
E-mail address: aliyehkazemi@ut.ac.ir (A. Kazemi).

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Nomenclatures

X	n-vector with components $x_1, x_2, \ldots, x_n$ (decision variables)
μ	Membership function (MF)
$BX \leq b$	System constraints
G	Number of goals
w_i	Relative weight of the ith goal
$f_i(X)$	Value of the ith goal
f_i^*	Aspiration level (AL)
f_i^{min}	Lower tolerance limit
f_i^{max}	Upper tolerance limit
FV	Future value
PV	Present value
IR	Inflation rate
n	Number of periods
A	Alternative
$g_j(.)$	Level of performance for each alternative against each criterion
d	Difference between the alternatives' performances against each criterion
p	Preference level
q	Indifference level
S	Superiority matrix
I	Inferiority matrix
$\phi^{>}(.)$	Superiority flow
$\phi^{<}(.)$	Inferiority flow
ϕ_n	Net flow
ϕ_r	Relative flow
$\mathbb{R}_n$	Complete ranking based on net flow
$\mathbb{R}_r$	Complete ranking based on relative flow

human health. A study on air quality in Tehran (capital of Iran) revealed the mortality risk associated with particulates as being at 4000 deaths per year due to this pollutant (Shafie-Pour et al., 2007). Beside the transportation's exclusive dependency on fossil fuels, energy consumption in all sectors of Iran, especially transportation sector does not follow basically an appropriate pattern. While about 10% of the country's production resources are spent on transportation, the value-added coming from this sector is about 8% (MOE, 2014). Consequently, the modification of energy consuming pattern has a great matter of importance in this sector, which can be investigated to several sub-sectors such as transportation navigation, infrastructures, road transport structure and new fuels and technologies (Sehatpour et al., 2017). Currently, LDVs compose around 90% of Iran's road transportation navigation, and about 65% of the fuel demand of this type of vehicles is supplied by gasoline while diesel, compressed natural gas (CNG) and liquid petroleum gas (LPG) contribute by 9%, 22% and 4%, respectively to supply the rest of the demand (IFCO, 2012). One cannot help but notice that such layout is not only inefficient but also does not satisfy the preliminary concerns of sustainability. Moreover, absence of biofuels should be addressed by evaluating and considering this family of fuels to let the road transport navigation utilize their numerous favorable characteristics. On a life cycle analysis basis, the corn-based and cellulosic ethanol production and use reduce the emission of GHGs by up to 52% and 86%, respectively, as compared to the petroleum gasoline production and use. Similarly, the combustion of biodiesel at different ratios reduces CO_2 emissions (Sadeghinezhad et al., 2014). Moreover, by using the same amount of heat, the combustion of natural gas produces about 30% less CO_2 than petroleum, and as a low-carbon-emitting hydrocarbon fuel, LPG emits 19% less CO_2 than oil (Salvi et al., 2013). On the other hand, hybrid vehicles, which utilize both electrical and internal combustion engines for propulsion, are presently providing solution for the problem of dependence on traditional fuels, emissions of growing CO_2, and other environmental concerns (Adnan et al., 2017).

Over the last decades, energy planning has entirely changed from the almost sole concern with the cost minimization of the supply-side choices to the need for explicitly multiple and potentially conflicting objectives, involving different groups of actors. This complex environment indicates the multi-objective nature of the issue (San Cristóbal, 2012).

Determining the arrangement of various fuels in the transport fuel portfolio and the realization of their supply in the intended horizon require comprehensive studies on the development of the energy supply system in this sector. In this regard, via a fuzzy goal programming (GP) and considering the 2025 horizon it has been tried to develop the Iran's road transportation fuel portfolio, while taking into account several concerns including environmental, cost, social and policy as the objectives. Moreover, evaluation of current fuels is done using a multi-criteria approach, and the results as well as the systematic limitations will be applied to the model as crisp constraints. Two different weighted scenarios are defined to test the stability of the model and address the differences in the decision-makers' priorities, including one with more focus on the environmental concerns and a cost-oriented scenario.

The rest of the paper is structured as follows: Section 2 presents a comprehensive literature survey of the applied methodology to provide an insight about the research gap in the related scope. Section 3 introduces the integrated approach and the details of the model employed in this study. In Sections 4, the results of the optimization model along with sensitivity analysis of the results, review of the future demand through the optimal portfolios, and related policy regarding the implications of the optimal fuel portfolios are presented. Finally, Sections 5 presents concluding remarks, limitations, and recommendations for future works in accordance with the findings of this research. Definition of the goals considered in the model is presented in Appendix A.

2. Literature review and research motivation

Developing and optimization of an energy portfolio is a multi-actor and sophisticated problem due to the need for incorporating conflicting quantitative and qualitative considerations. Evidently, multi-criteria decision making (MCDM) framework is proposed highly in the literature to deal with such a problem effectively. Multi-attribute decision making (MADM) and multi-objective decision making (MODM) represent two main categories of MCDM methods. MODM approaches are, generally, employed to design by considering trade-off relationships among design constraints, while MADM models focus on solving problems involving selection from different sets of decision alternatives (Onat et al., 2016). As a branch of MODM, goal programming is used to handle multiple and normally conflicting objectives. Although the setting of appropriate weights in a GP model and Pareto-optimality of the solutions has raised debate, effectiveness of this approach, especially in problems with relatively large number of both quantitative and qualitative variables, constraints and objectives is quite considerable (Chiandussi et al., 2012).

Being used frequently by many researchers in energy portfolio