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Evaluation of alternative fuels for light-duty vehicles in Iran using a multi-criteria approach

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ABSTRACT

The diversification and optimization of the fuel portfolio for the transportation sector in Iran are subject to evaluation of a variety of alternative fuels. Currently, fossil fuels, especially gasoline, have the greatest share in supplying the light-duty vehicles' fuel demand in Iran; this has led to numerous environmentally and strategically unfavorable consequences. Through a multi-criteria approach, this paper evaluates various alternative fuels for light-duty vehicles in Iran, considering a midterm horizon. For this purpose, eight different alternative fuels with both fossil and renewable bases were evaluated: compressed natural gas, liquid petroleum gas, petroleum diesel, biodiesel, biogas, two mixtures of ethanol and methanol with gasoline called E85 and M85, and hydrogen. A comprehensive literature review was performed and the key metrics of cost-, technical-, social- and policy-related aspects were identified. Each alternative was scored against the aforementioned criteria in six alternative scenarios, including one base scenario and five scenarios with different weight settings of criteria. The results showed that compressed natural gas and liquid petroleum gas are the most suitable alternative fuels for light-duty vehicles in Iran, and that biogas has the highest priority, as compared with other alternative renewable fuels.

1. Introduction

Energy consumption is known as one of the performance measurement components in various countries. This index assesses two different sides of one aspect. First, the volume and value of the consumed energy in the country's total production units represent the number of active units as well as the manufacturing operation volume with certain approximations, and implicate the investments volume. Another side of energy consumption could be a criterion for judging the macro-level economic situation of the country's firms. Thus, the productivity level in industry and economy and the consumption patterns of a country can be identified by comparing of the consumed energy volume and the number of such consumers as the manufacturing machinery or vehicles; the greater the proportion between consumption and consumers is, the less efficient the sector and vice versa will be [1–3]. In 2013, consumption of oil products in Iranian transportation sector was more than 48% of the total consumption of all sectors. Moreover, the road transport was in charge of more than 97% of the total gasoline consumption in the transportation sector in that year. The gasoline consumption in the transportation sector had an average annual growth of 2.78% from 2001 to 2013 [4]. Given the number of light-duty vehicles in 2011, the average daily consumption of gasoline for each car was 10.5 liters, which is approximately 5.2 and 2.6 times greater than the same index in Europe and the United States, respectively [5]. Basically, the problem associated with Iranian road transportation sector, particularly light-duty vehicles (LDVs), is not only the fuel consumption inefficiency but also an excessive reliance on gasoline.

Currently, Iran holds the world's fourth largest proved crude oil reserves and the world's second largest natural gas reserves [6]. Although the vast resources of fossil fuels, and subsequently, their low prices in Iran make them attractive and the dominant family of the fuels in road transportation, the environmental considerations are indispensable. In 2013, the largest share of the emission of pollutants like carbon monoxide (CO), nitrogen oxides (NO_x), unburned hydrocarbons and suspended particulate matters (SPMs) was related to the transportation sector. Besides, carbon dioxide (CO_2) emission from LDVs in that year with a 3.12% annual growth reached the amount of 25.59 million tons [4].

Regarding the finite natural resources and environmental concerns, the modification of the fuel consumption pattern and the use of alternative fuels are two crucial issues [7]. In order to restrain the

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wasteful energy use and to limit the domestic demand growth, Iran has embarked on an energy subsidy reform to raise the prices of the domestic petroleum, natural gas, and electricity. The first phase of the reform was enacted in late 2010, and the second phase was initiated in early 2014 [6]. At the primary stages, this reform did not have a tangible impact on the fuel consumption. Considering the inflationary effects, moving away from the highly subsidized fuel through a multi-stage plan can be effective in a mid-term horizon.

Now, LDVs are mainly utilizing the internal combustion engines (ICEs) emitting harmful pollutants like CO, CO_2, NO_x, SPMs, smoke and so forth. Therefore, the simultaneous power production and reduction in engine emissions are the most important research aspects in ICEs, implying that the deployment of clean and new alternative fuels would be an available approach [8]. Many countries have amplified their investigation budget and developed incentive policies like fuel tax exemptions and production subsidies to generalize alternative fuels, especially biofuels [9–11]. Some fossil gas fuels and biofuels such as compressed natural gas (CNG), ethanol and biodiesel have significant attractive characteristics, making them more prevalent. For instance, by using the same amount of heat, the combustion of natural gas produces about 30% less CO_2 than petroleum. Correspondingly, liquid natural gas (LPG), a low-carbon-emitting hydrocarbon fuel, emits 19% less CO_2 per kWh than oil [8,12–15]. Research has shown that the released CO_2 from the combustion of renewable fuels like ethanol and biodiesel is balanced by the CO_2 captured when the crops are grown to make them. On a life cycle analysis basis, the corn-based and cellulosic ethanol production and use reduce the greenhouse gases (GHGs) emissions by up to 52% and 86%, respectively, as compared to the petroleum gasoline production and use. Similarly, the combustion of bio-diesel at different ratios reduces CO_2 emissions [8,16,17].

1.1. Decision support systems and multi-criteria decision-making

Comparison of fuels with regard to a wide range of attentions and different attitudes of decision-makers has a high level of complexity. To deal with such an ambiguous problem, multi-attribute decision-making (MCDM) is highly recommended. As one of the major parts of the decision theory, it delivers an innovative idea that is able to combine a wide variety of variables evaluated in different ways, thereby offering a clear aid to the decision-makers [18,19]. More importantly, replacing the decision-maker is not the purpose of a decision support system; rather it supports the decision-making process by offering complex and interlinked data in a way that allows the influences of different choices to be more clearly understood [20].

This study aims to develop a multi-criteria evaluation model in order to rank different alternative fuels for LDVs by joining both qualitative and quantitative criteria. A recognized multi-criteria evaluation method named the Preference Ranking Organization Method for Enrichment and Evaluations (PROMETHEE) was applied to rank the alternatives based on various criteria, including the cost, technical and social aspects, and policy. This technique tends to be employed for the ranking of alternatives in various energy sectors, such as power plants and electricity generation [21–25], transportation investigations [26–31], geothermal systems [32,33], and residential sector energy planning [18,34]. The methodology is based on the pair-wise comparison of the alternatives against certain criteria. This research work includes the detailed assessment of one base scenario and five alternative scenarios to inspect the stability of the outcomes. The final result of this study is in the form of ranking various alternative fuels in regard to the selected criteria.

Along with international efforts and studies and regarding to the definite need of modification of Iran's fueling policy in the transportation sector, assessing the potential fuels is inevitable, the very task that this study carries away innovatively. Taking into account the current and midterm Iran's natural resources' condition, technological situation, and environmental and sustainability issues, the solution of this work could provide helpful insight toward diversification and substitution of fuels in the transportation sector and bridge the research and policy gaps in this regard in Iran.

2. Literature review

Environmental and sustainability problems caused by the excessive use of petroleum products in the transportation sector have intensified the need for cleaner fuels. Accordingly, several studies have been conducted focusing on different aspects of fuel substitution in the transportation sector. For instance, Salvi et al. [8] compiled a holistic scenario of different resources, production technologies, and properties of alternative fuels for transportation vehicles. Detailed descriptions of production technologies and fuel properties were presented using the findings of studies carried out globally by scientists according to their local socio-cultural and economic situations. In a comprehensive research work, Sangeeta et al. [35] reviewed the prospects and opportunities for using alternative fuels like vegetable oils, bio-ethanol, glycerol, biodiesel and hydrogen in different applications. Based on the analysis provided to bipartisan National Commission on Energy Policy, Romm [36] reviewed the technical literature on alternative fuel vehicles and discussions with experts in vehicle technology and energy analysis. In 2010, Arslan et al. [11] took a look at the history of alternative fuels and investigated the alternative engine fuel potential of Turkey. Possible future policies based on experience were also introduced. Considering the environmental and sustainability concerns, Hosseini et al. [37] conducted a study to evaluate renewable energy potentials from various resources in Iran. The role of biofuels in supplying the US transportation fuel demands was considered by Akinci et al. [38]. They evaluated the production capacities of ethanol and biodiesel for their potential impact on the US energy market and concluded that ethanol or biodiesel production does not seem to be scalable to make a significant difference on the US fossil fuel demand for transportation. Using a supply chain approach, Mansson et al. [39] analyzed Sweden's supply and use of biogas, bioethanol and biodiesel as biofuels for road transportation. Potential synergies between climate change mitigation and energy security were also inspected, and it was concluded that biofuels can provide these synergies. In a thorough study, Ben-Iwo et al. [40] assessed the biomass resources (agricultural, forest, urban, and other wastes) available in Nigeria, as well as the potential for biofuel (as transportation fuels) production from different kinds of biomass feed stocks. Similarly, prospect of biofuels as an alternative transportation fuel in Australia was reviewed and discussed by Azad et al. [41]. In addition, taking alternative vehicle technologies into account, Baptista et al. [42] evaluated the energy and environmental impacts of alternative pathways for the Portuguese road transportation sector. On the other hand, barriers to the deployment of alternative fuels and technologies, as well as potential policies and actions that may be implemented to overcome such barriers were investigated [43–45]. As a significant concern of development and a barrier toward popularity of cleaner fuels, related infrastructures and refueling stations have also been discussed and inspected as well [46–51].

Generally, transit operations and public transportation play important roles in greenhouse gas reductions and air quality improvements. In this regard, numerous researches have been done concentrating on alternative fueled transit and urban buses [50,52–58]. More specifically, many surveys have been dedicated to investigate particular alternative fuels including CNG [59–62], LPG [63,64], Biogas [65–68], ethanol [16,69,70], methanol [71–73], biodiesel [74–77] and hydrogen [78–82].

Over the last decade, MCDM methods have been widely applied in the field of the selection and evaluation of all kinds of vehicle propulsion power including fuel and technology. Tsita and Pilavachi [83] applied analytic hierarchy process (AHP) to evaluate alternative