

# A Theoretical Approach to Determine the Best Alternative as the Dominant Fuel Type of a Megacity's Light Duty Vehicles

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**ABSTRACT:** Global Warming and other related environmental issues are some of the most important concerns of the 21st century. Consumption of fossil fuels, particularly by light duty vehicles, is recognized as the most important and significant reason of environmental issues due to its considerable amount of pollutant emissions. Different alternative fuels are available in urban areas with different levels of environmental impacts and prices which should be chosen by citizens. In this study, alternative fuels were ranked using two widely accepted methods to solve a multi-criteria decision making problem. Results showed that fossil fuels and particularly gasoline, despite their environmental impacts, can be preferred by citizens.

**KEYWORDS:** Multi criteria decision making, TOPSIS, SAW, Alternative Fuel.

## I. INTRODUCTION

Global Warming and other related environmental issues are some of the most important concerns of the 21st century [1,2]. The built environment and the construction industry will be impacted by climate change in many ways [3,4]. Consumption of fossil fuels, due to its considerable amount of pollutant emissions is recognized as the most important and significant reason of aforementioned environmental issues [5]. According to various implemented studies around the world, vehicles are responsible for most of the pollutant emissions in the urban environments, so their emission control is crucial for improving urban air quality [6,7].

Vehicular emissions depend on various factors related to the vehicle's condition, its quality, and operating state [8]. Such factors include powertrain technology, type, and quality of utilized fuel, emission control technology, vehicle model and age, driving cycles and traveling speeds [9]. It has been proved that vehicles' powertrain and fuel type have a significant effect on the level of pollutant emissions and associated exposure [10,11]. In this regard, developing alternative fuels and evaluating the resulted emissions are problems that pioneer academic centers and government agencies are currently working on [12].

Another reason for studying renewable energy is the decreasing trend of world fossil resources. In this regard, energy generated by fossil fuels will become more expensive. Hence, developing alternative fuels has some dominant economic and political aspects which decision makers around the world would not let it be ignored. Considering above mentioned reasons, introducing new alternative fuels is inevitable and numerous studies are being done in this area [13].

It should be considered that there is a trade-off between expenditures and obtained results in any topic including vehicles usage. In other words, people should spend money to purchase a car with specific characteristics including its powertrain, fuel type, environmental effects and other characteristics that may matter to them. In almost all cases, to reach a better set of results, the responsible party should accept the related costs. In this regard, the study of various available options considering people's interests and the level of their interest to spend money to achieve their intention is extremely determinant. This study was performed to obtain the best alternative as dominant fuel type of a megacity's light duty vehicles (LDVs) [14].

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To this end, a list of Stakeholders who might have some relevant interest in the final decision was prepared. A list of demonstrative criteria that should be used to evaluate alternatives in decision making was defined. Weighting criteria was implemented using Paired Comparison with the magnitude of preference. In this regard, questionnaires were prepared and distributed to 6 subject-matter experts. After that, alternative scores were defined for each criterion. Finally, alternatives were ranked considering two widely accepted methods. Compensatory Method (Simple Additive Weights: SAW) and Outranking Method (TOPSIS) were used in this project to rank alternatives, based on recent pioneer studies in this area. It should be noted that these have been done as a sample survey in this area and a multi-criteria decision making example and can be implemented using more reliable values based a large dataset to evaluate alternatives with a higher level of accuracy [15].

## II. RELATED WORK

Different types of vehicles' fuels and also the consequences of their use have been topics of numerous studies in recent decade. It should be noted that a focus has been on electric vehicles in their studies. Noori et al. studied different environmental and economic aspects of using electric vehicles [16,17]. Different fuel types are also studied in terms of technological advancement, energy security, and policy [18,19]. As earlier mentioned different fuel types are studied from different aspects especially with focus on environmental issues [20], but customers behaviour and the effect of their preference on their decision making needs more study. In other words, the environmental and financial aspects of selecting a fuel type might be clear, but what matter is final option chosen by customers. In this regard, a fuel alternative with higher level of environmental impacts might be selected by customers. In this study the priorities of customers to make a decision on their light duty vehicle's fuel type is investigated.

## III. METHODOLOGY

### Stakeholders:

There are various parties that will be influenced by going toward the distribution of one or several types of fuels. First of all, citizens will be affected regarding direct and indirect costs and environmental aspects of vehicular emissions [21]. Manufacturers that should keep their products up-to-date considering community interests and market situations are among the stakeholders. Government interests in this area depend on their national economic policies including their roles in the production of vehicles and fuels as well as the distribution of fuels. In government subsets, ministries or organizations related to energy, environmental and industries account for who have interests in this issue.

### Criteria:

To obtain the best alternative as dominant fuel type of a megacity's LDVs, some representative criteria should be defined first. In this regard, considering various aspects of driving which serve as one of the requirements of nowadays life and might be affected by different fuel options is inevitable. In this regard, the main focus was on considering various aspects of driving that have some effects on choosing an option as vehicles fuel type. Finally, four main criteria were defined that each of them may cover some other criteria.

### Costs:

"Costs" criterion mainly focuses on peoples' payment regarding the option that they have chosen. The price of the car, fuel consumption, and maintenance are the main related costs people should consider. In this regard, the price of fuel and the fuel efficiency should be considered as fuel costs. It should be noted that the price of fuel is directly or indirectly related to the level of accessibility to resources, amount and distribution of facilities and infrastructures and in some cases political or market situations. The price of a car includes the money that should be paid for the car including net price, tax and all of the related costs. Vehicles' powertrain technologies which are extremely related to fuel type and related issues may have significant effects on this part. Maintenance related costs generally refer to all of the expenditures incurred to keep a car in a good condition or working order [22]. It is clear that the type of

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powertrain technologies is extremely determinant in maintenance expenditures. It should be noted that for the sake of technologic improvement various options are generally available to achieve to human desires and each one has related costs [23,24].

### Environmental Parameters:

We all know that consumption of various types of fuels leads to the main 21st century Environmental concerns such as Global Warming, Climate Change, and Human Health. In this regard, clean fuels issue versus fossil ones is among the most significant issues that academic and industrial communities are working on [25]. Environmental Parameters refer to all of the effects that consumption of a certain type of fuel may have on the environment. In this regard, environmental aspects of production, distribution, and consumption of each of fuels should be considered.

### Vehicles Power and Acceleration:

According to implemented surveys, various powertrain technologies provide different levels of propulsion power [26], [27]. In this regard, choosing a certain type of fuel and related powertrain technology leads to some vehicles' power specifications such as acceleration. Some car owners consider driving as a hobby and they prefer to pay more to have a powerful car or ignore environmental issues. For this reason, vehicles power and acceleration is considered as a criterion.

### Waiting Time in the queue:

The time that car owners should spend to recharge their cars in related stations is considered in this part. Mentioned time is related to the number of stations around the city and infrastructures are available to be used in the distribution network. Waiting time in queue is a trade-off related to the time that car owners should consider and finally come up with a decision about it.

To obtain a ranking for vehicles' fuel type, first criteria were weighted using paired-comparison with the magnitude of preference. To this end, questionnaires were distributed for judgments and obtained judgments consistencies were checked. Next Step was scoring of alternatives for each criterion. In this regard, alternatives were ranked non-dimensionally according to the consensus of subject matter experts for each criterion. After that, non-dimensional scores were quantified using linear value functions. Finally, alternatives were ranked according to weighted additive scores obtained via Simple Additive Weights (SAW) and TOPSIS. Above mentioned procedure and final results are explained by details in the following.

## IV. RESULTS

To obtain weighting of criteria, questionnaires were prepared and distributed to six subject-matter experts. Participants completed questionnaires based on quantitative paired-comparative importance. One of the completed questionnaires is illustrated in Table 1. In this table, criteria A refers to Costs, criteria B refers to Environmental Issues, criteria C refers to Vehicles' Power and Acceleration, and criteria D refers to Waiting Time in the queue. For instance, according to what this participant has mentioned, Costs and vehicle's Power are more important rather than Environmental issues and Waiting time in the queue.

Table 1-One of Completed Questionnaires

Criteria A- Costs	Criteria B- Environmental Impacts	Criteria C- Vehicle Power & Acceleration	Criteria D- Waiting Time in Queue
5	1		
1		1	
3			1
	1	3	
	1		1
		3	1

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Consistency check of judgments revealed that all of the questionnaires were completed consistently. To check consistency, “Judgment Matrices” were prepared. In the following, “Consistency Index and Ratio” were calculated via “Eigen values”. All of calculated “Consistency Ratios” were smaller than the value of 0.015 which indicate the consistency of judgments.

To obtain weights of criteria, “Eigen Vector” was calculated through normalizing “Geometric Mean” of each row of “Integrated Judgment Matrix”. According to what is mentioned in references, each array of “Integrated Judgment Matrix” is equal to geometric mean of similar arrays in each of “Judgment matrices”. As the result of abovementioned procedure, weights of criteria were calculated as shown in Table 2. Table 2 shows the importance level of criteria according to participants’ points of view.

Table 2- Weights of Criteria

Criteria	Weight
Costs	0.35
Environmental Impacts	0.18
Vehicle Power & Acceleration	0.34
Waiting Time in Queue	0.13

A solid background and comprehensive survey are extremely required to achieve a reliable databank through which absolute values that are applicable to rank alternatives for each criterion can be achieved. Implementation of such a vast survey just to obtain related values for this specific part is beyond this project. Hence, using relative states of alternatives considering each criterion according to the consensus of subject matter experts suffices. In this regard, relative states of alternatives categorized in a 5 level classification which is presented in Table 3. It is clear that to obtain reliable results in a comprehensive study, this part requires a great amount of data gathering, data mining, and related calculations that may be extremely in final results.

Table 3- Relative States and Values that are assigned to each level

Relative State	Value
Low	1
Low Moderate	2
Moderate	3
High Moderate	4
High	5

Using above mentioned table, each alternative was scored on the non-dimensional scale of 0 to 1. Up to now activities lead to obtaining weighted criteria and scored alternatives for each criterion. Mentioned data are presented in Table 4.

Table 4- Criteria weights and non-dimensional scores alternatives

	Costs	Environmental Impacts	Vehicle Power & Acceleration	Waiting Time in Queue
Weights	0.35	0.18	0.34	0.13
Gasoline	1	0	1	0.5
Diesel	0.75	0	0.5	0.25
Gas	0.75	0	0.25	0
Hybrid	0	0.75	0.5	0.75
Electric	0	1	0	1

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Table 4 shows weighted criteria and also scored alternatives for each criterion. In a Multi-Criteria Decision Analysis procedure at this stage, there are various methods to achieve the final ranking. In this project, alternatives were ranked according to Simple Additive Weights (SAW) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which will be explained briefly.

To obtain a ranking of alternatives via SAW, it is enough to calculate the summation of alternative's score for each criteria times the relevant weights. This summation leads to obtain Weighted Additive Scores for each alternative. Mentioned scores are presented in Table 5 for each alternative.

Table 5- Alternatives Scores According to SAW

Alternative	Simple Additive Weighted Score
Gasoline	0.75
Diesel	0.46
Gas	0.35
Hybrid	0.41
Electric	0.31

Through this way, all of the alternatives can be ranked according to calculated weighted scores. Mentioned ranking for alternatives is presented in Table 6. According to these results, although Hybrid and Electric vehicles have less environmental impacts, Gasoline and diesel vehicles due to their lower prices and a higher level of vehicle's power are more preferred.

Table 6- Alternatives Ranking According to SAW

Alternative	Saw Ranking
Gasoline	1
Diesel	2
Gas	4
Hybrid	3
Electric	5

As it has mentioned previously, alternatives can be ranked using TOPSIS. To this end, alternatives' score for each criterion should be normalized via "Vector Normalization". In this regard,  $r_{ij}$  which is equal to value of each score divided by square root of the sum of the square of all score was defined and calculated.

Table 7- Calculation of square root of sum of square of all scores in each column

	Costs	Environmental Impacts	Vehicle Power & Acceleration	Waiting Time in Queue
Weights	0.35	0.18	0.34	0.13
Gasoline	1	0	1	0.5
Diesel	0.75	0	0.5	0.25
Gas	0.75	0	0.25	0
Hybrid	0	0.75	0.5	0.75
Electric	0	1	0	1
	1.46	1.25	1.25	1.37

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Table 7 shows explained vector normalization procedure for different types of fuels and the different criteria table. The  $r_{ij}$  which is equal to value of each score divided by square root of the sum of the square of all scores required for TOPSIS procedure is calculated and presented in Table 8. In Table 8 the scores for each fuel type and criteria (presented in Table 7) is normalized. In other words, Table 8 contains the comparative weight of each fuel type considering different aspects.

Table 8- Calculation of  $r_{ij}$  (Normalized Score) for each score

	Costs	Environmental Impacts	Vehicle Power & Acceleration	Waiting Time in Queue
Weights	0.35	0.18	0.34	0.13
Gasoline	0.69	0	0.8	0.37
Diesel	0.51	0	0.4	0.18
Gas	0.51	0	0.2	0
Hybrid	0	0.6	0.4	0.55
Electric	0	0.8	0	0.73

In the next step, the weight of each criterion should be applied to each normalized score, which is done and obtained values are presented in Table 9. In other words, values in Table 9 illustrates the relative weights of each effective elements in TOPSIS calculation. In this regard, the values presented in Table 9 are final global weights to add to together the get the final weights.

Table 9- Weighted Normalized Scores

	Costs	Environmental Impacts	Vehicle Power & Acceleration	Waiting Time in Queue
Gasoline	0.24	0	0.27	0.05
Diesel	0.18	0	0.13	0.02
Gas	0.18	0	0.07	0
Hybrid	0	0.11	0.13	0.07
Electric	0	0.15	0	0.1

Moreover, maximum and minimum scores for each criterion should be recognized which will be used in the next step to calculate the distance of each alternative to Positive Ideal and Negative Ideal solutions. In Table 10, the distance of each alternative from positive and also negative ideal solutions are presented as well as TOPSIS scores which are equal to  $D^-$  divided by the summation of  $D^+$  and  $D^-$  for each alternative.

Table 10- Distance of Alternatives from Positive and Negative Ideal Solutions and TOPSIS Scores

	D+	D-	TOPSIS Score
Gasoline	0.15	0.36	0.7
Diesel	0.22	0.22	0.51
Gas	0.27	0.19	0.41
Hybrid	0.27	0.19	0.4
Electric	0.36	0.18	0.33

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The final step is to rank alternatives according to obtained scores which are done and presented in Table 11. According to TOPSIS ranking, the best alternatives are gasoline and diesel vehicles the same as what was obtained from SAW but the story is different for other alternatives. According to TOPSIS ranking hybrid and electric vehicles have the least preference among alternatives.

Table 11- TOPSIS Ranking

Alternative	TOPSIS Ranking
Gasoline	1
Diesel	2
Gas	3
Hybrid	4
Electric	5

The two most preferred and also the least preferred alternatives through both methods are similar. The difference between obtained rankings is in ranking of gas and hybrid vehicles. As it can be seen, a ranking of gas vehicles in TOPSIS is three while the one in SAW is four. Moreover, ranking of hybrid vehicles in TOPSIS is four while the one in SAW is three.

## V. CONCLUSION

It is widely accepted that using different fuel alternatives for light duty vehicles in a megacity will have different levels of environmental consequences. Different tools are developed to evaluate utilizing different kinds of fuels in terms of emission and energy, but it totally depends on choices of customers to use a specific fuel alternative. In this regard, determination of an alternative fuel can be considered as a multi-criteria decision making problem. In this study, alternative fuels were ranked according to weighted additive scores obtained via Simple Additive Weights (SAW) and TOPSIS. Results showed that fossil fuels and particularly gasoline can be preferred by citizens although they know about considerable effects of using fossil fuels. It revealed that green fuels may not necessarily be preferred by people because they are more willing to pay for their convenience rather than the clean air.

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