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A Decision Support System (DSS) to Select the Premier Fuel to Develop in the Value Chain of Natural Gas

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Abstract

A value chain is a series of events that takes a raw material and with each step adds value to it. Global interest in the application of natural gas (NG) in production and transportation has grown dramatically, representing a long-term, low-cost, domestic, and secure alternative to petroleum-based fuels. Many technological solutions are currently considered on the market or in development, which address the challenge and opportunity of NG. In this paper, a decision support system (DSS) is introduced for selecting the best fuel to develop in the value chain of NG through four options, namely compressed NG (CNG), liquefied NG (LNG), dimethyl ether (DME), and gas-to-liquids (GTL). The DSS includes a model which uses the technique for order performance by similarity to ideal solution (TOPSIS) to select the best fuel in the value chain of NG based on the attributes such as market situations, technology availability, and transportation infrastructure. The model recommends some key guidelines for two branches of countries, i.e. those which have NG resources and the others. We believe that applying the proposed DSS helps the oil and gas/energy ministries in a most effective and productive manner dealing with the complicated fuel-related production and transportation decision-making situations.

Keywords: Natural Gas, CNG, LNG, GTL, DME, DSS, TOPSIS, MADM

1. Introduction

As the world's population continues to grow and economies develop, the demand for energy also continues to grow significantly. This increased demand is also being strengthened by the quest for cleaner sources of energy to minimize impact on the environment. Demand for natural gas (NG) is likely to overtake other fossil fuels due to its availability, accessibility, versatility, and smaller environmental footprint (Wood et al., 2010).

NG has been recognized as a transportation fuel since the early twentieth century; advances in NG extraction technologies are enabling the delivery of abundant, affordable NG and the prospect of a shift to greater use of NG as a transportation fuel. While the price of NG per unit energy has historically been lower than liquid fossil fuels, this price differential must be large enough to overcome barriers to substantial market penetration by NG vehicles (NGV). These barriers include the capital expenses associated with infrastructure development for the storage of NG in compressed or

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liquefied form, and the cost premium for lower production vehicles with more expensive fuel tanks. The main problem of NG in its natural form is its low energy density. With the same amount of volume of fuel, it gives less energy than conventional fuels such as gasoline or diesel. The main idea behind compressing the NG is to make it provide sufficient energy to be able to be used in daily operations. Compressed NG (CNG) is a dense form of the NG in less than 1/100th of its volume at standard atmospheric pressure and temperature. In this form, it could give more energy to be considered as a candidate for a transportation sector replacement fuel (Uz, 2012). Transportation sector could benefit from expanding the use of lower emission technologies and fuels such as NG. Applying NG to transportation vehicle is possible in four types, which are presented in Figure 1. This figure indicates that NG may directly transport in pipelines. Moreover, it may be converted to CNG or liquefied NG (LNG). Furthermore, NG may be transformed to gas-to-liquid (GTL) or dimethyl ether (DME), which is one of the processed forms of methanol. It should be noted that DME could be considered as a substitute fuel for liquefied petroleum gas (LPG).

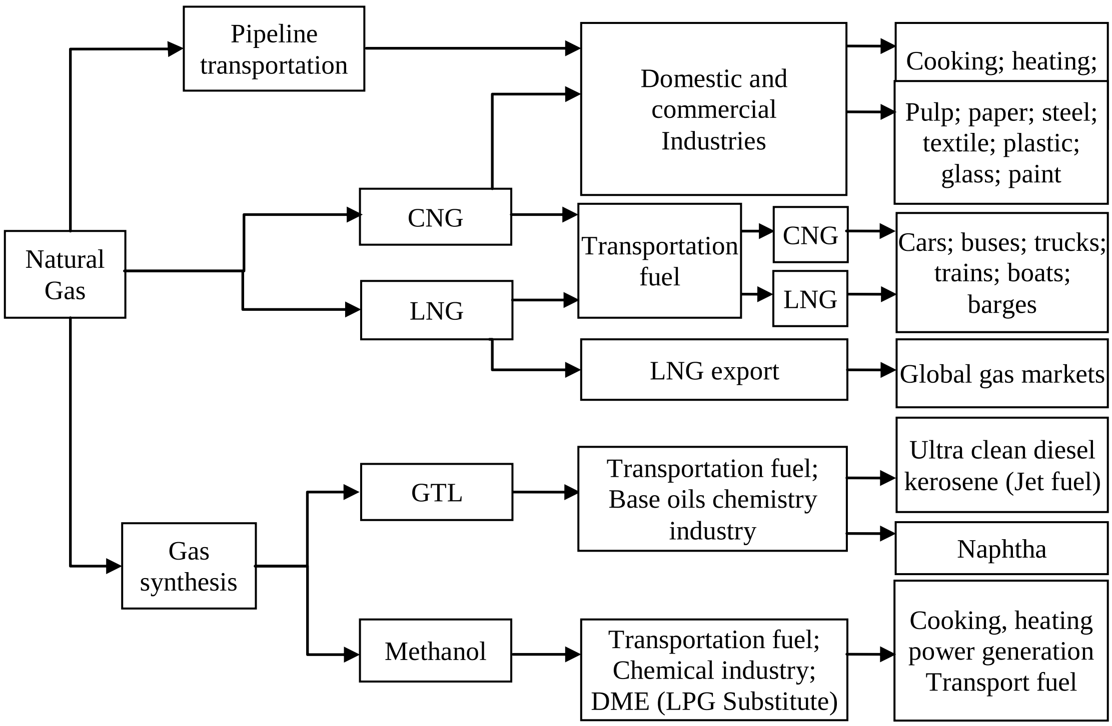

Figure 1
Gas monetization options.

The present article develops a decision support system (DSS) to select the best fuel to develop in the value chain of NG through the four options of CNG, LNG, DME, and GTL. The next section of the paper looks at the fuel options and describes them. The paper continues by addressing the application trend of four fuel options in transportation. Then, the DSS including a decision-making model will be proposed. Finally, for the purpose of the validity checking of our model, a numerical case will be analyzed.

2. Fuel options

NG is a gas primarily consisting of methane (CH_4), which can be used as a fuel after a refining process. This fossil fuel is extracted from the ground and burns relatively clean. We believe NG with its superior energy efficiency and environmental characteristics will be the main energy growth source in the next 5-10 years (of the major ones). Although this comes from suppressing further coal usage, it is more so into the liquid fuel segment. NG may have a relatively substantial impact on oil prices in the next few years. Over the next ten years, NG will play an increasingly important role in meeting the world's energy needs. Many technological solutions are currently on the market or in development which addresses the challenge and opportunity of NG without ready access to distribution infrastructure, know as stranded gas. These solutions include CNG, LNG, and a family of chemical conversion routes to produce methanol, DME, synthetic crude via Fischer-Tropsch (FT) synthesis, or other products; CNG is the simplest approach (Tonkovich et al., 2011). The mainstreaming of NG vehicles (NGV's) offers the potential to help diversify the primary energy used in our transportation sector and to provide attractive new markets for NG (SAIC, 2012). The economics of global vehicle manufacturing facilities lead to some delay or lag between when the market signals demand for a new vehicle type, and when manufacturers increase their supply. The rate of CNG and LNG vehicles will be increased (Graham and Smart, 2001).

2.1. CNG

CNG is made by compressing NG to less than 1/100th of its volume at standard atmospheric pressure and temperature. CNG has approximately 25% of the energy density of gasoline. CNG is stored in a steel or carbon fiber tank at approximately 200 atmospheres. CNG consists mostly of methane and is drawn from gas wells or in conjunction with crude oil production. CNG vehicles store NG in high-pressure fuel cylinders at 3,000 to 3,600 pounds per square inch. An odorant is normally added to CNG for safety reasons. In many cases, CNG vehicles generate fewer exhaust and greenhouse gas emissions than their gasoline- or diesel-powered counterparts. Two types of CNG fuel systems are on the market: dedicated vehicles, which operate exclusively on NG, and dual-fuel vehicles, which can use both NG and gasoline. CNG generally costs 15–40% percent less than gasoline or diesel. CNG requires more frequent refueling, however, because it contains only about a quarter of the energy by volume of gasoline. In addition, CNG vehicles cost between $3,500 and $6,000 more than their gasoline-powered counterparts, primarily because of the higher cost of the fuel cylinders. Easy conversion of current vehicles to CNG could make it appealing for various transportation applications such as daily use for residentially owned light vehicles or heavy vehicles such as commercial trucks, water vessels and trains, or governmental vehicles like buses and street sweepers (Uz, 2012). CNG advantages are reduction in fuel costs, reduction in greenhouse gases, reduction in operational and maintenance costs, using a domestic fuel source, ability to hedge pricing, and less volatile pricing.

2.2. LNG

LNG takes up about 1/600th the volume of NG in the gaseous state (Uz, 2012). LNG has a good safety record and is used widely across industry. It has a high ignition temperature; thus it is more difficult than diesel and many other common fuels to be set on fire. On release, LNG vaporizes into a lighter than- air gas, which quickly disperses into the atmosphere. LNG is nontoxic and non-corrosive and it will not pollute land or water resources in the event of a leak into the environment. The release of greenhouse gases such as carbon dioxide (CO_2) cannot be stopped overnight. However, by switching from diesel to NG, we can already achieve significant reductions in emissions as well as attractive financial savings (Power and Lowe, 2011). LNG is produced through the liquefaction process of NG, which can be used to power heavy-duty vehicles such as transit buses (IEA, 2011).

2.3. DME

DME is a fuel created from NG, coal, or biomass, which is noted for producing low levels of Nox emissions and low smoke levels when compared to petroleum-derived diesel fuels. Di-methyl ether does not have some of the transportation issues associated with other alternative fuels, such as ethanol, which causes corrosion in pipelines. Because DME is a gas at room temperature, it must be put under pressure in large tanks for transportation and storage, unlike ethanol. DME is clean-burning, sulfur-free, with extremely low particulate emissions. DME resembles LPG in many ways. DME, however, has good ignition quality and is therefore suited for diesel combustion (Nylund and Koponen, 2012). In the future, DME can be an alternative to conventional diesel fuel or a feed gas for power generation in gas turbines. Both applications are based on large-scale production facilities in order to achieve an economic fuel price. DME is as easy to handle as LPG and its calorific value per kilogram is close to coal, better than methanol, much better than hydrogen, and less than LPG, diesel, or methane. Per liter, it is close to methanol, methane, or propane and largely greater than hydrogen. In comparison with other fuels, DME rapidly decomposes into carbon dioxide (CO_2) and water in the atmosphere without forming ozone. Although the distribution of DME as fuel is easy due to the use of LPG infrastructure, it is required to integrate the special attention of the government, the fuel manufacturer, automobile manufacturer, and fuel consumers and to make the common effort together. The cetane number of DME is so high that it can be used in diesel engines (Semelsberger et al., 2006).

2.4. GTL

GTL technology converts NG into high-quality liquid petroleum products including diesel, naphtha, methanol, DME, and others. Liquid fuel produced through GTL is considered a clean source of energy with less environmental impact, since it does not contain sulfur and aromatic compounds and the diesel fuel has a high cetane number. A GTL facility has integrated value chain opportunities and synergies with upstream and chemical industries. GTL diesel is cleaner burning than conventional diesel, with virtually no sulfur or aromatic compounds. Life cycle greenhouse gas emissions are comparable to, or somewhat less than, conventional fuels. The low sulfur content and high cetane number of GTL diesel also make it a desirable blending component with conventional petroleum products. In this regard, it is an energy source that reflects the trends of the time. This technology could also become a source of new liquid fuels leading to a diversified energy supply because NG is used instead of crude oil as a feedstock (Gyetvay, 2012). GTL processes with FT technology first convert NG to synthesis gas, which is a mixture of carbon monoxide and hydrogen. The FT process then converts this synthesis gas into mainly long-chain paraffin hydrocarbons and distillates which are cracked into conventional transportation fuels. The process has a high distillate yield and also produces a lighter fraction, which can be used as a gasoline blending component or as a feedstock for chemicals production. The energy efficiency of the process in converting NG to liquid products is 58-65% (NPC, 2012).

3. Trend of applications in transportation

The year 2015 is an important year for the shipping industry. At that time, stricter requirements on fuel oil sulfur content will enter into force in the emission control areas (ECAs). From 2015, the maximum allowable sulfur content in fuel oils is 0.10% in the ECA’s. The confirmed ECA’s are Baltic Sea, North Sea, and the North American Coast together with the US Caribbean. From 2020, a global requirement of maximum 0.50% sulfur (outside ECA’s) will apply (Aagesen, 2012). The number of NG vehicles in Japan rose to 40,429 at the end of March 2011, with NG as the main fuel and diesel fuel as the auxiliary one.

3.1. CNG applications

The cost-benefit of using CNG as a vehicle fuel and feasible changes make CNG more cost effective. CNG is a good option for mid-sized gas resources less than 1,000 miles away from the market, but becomes economically unfeasible for more remote reserves (Tonkovich et al., 2011). If the entire light-duty vehicle fleet were to switch from gasoline/diesel to CNG, it would reduce total transportation emissions by 23% (IGU, 2012).

3.2. LNG applications

LNG is much like CNG, but uses a higher degree of compression and cooling to transform NG into a liquid. For transport applications, the most economic method of storage for NG is as a liquid. LNG has a much greater energy density than its compressed gaseous equivalent, CNG. This means a much greater range is achieved with LNG, which makes it a very attractive fuel for vehicles, especially for operators of heavy duty vehicles with high mileage. It is here that the greatest environmental and economic benefits can be gained (Power and Lowe, 2011). With steadily rising fuel costs and pressure to reduce emissions, the transport industry has been searching for alternative fuels which will address these two concerns. LNG is now establishing itself as the low carbon fuel of choice for heavy goods vehicles (Power and Lowe, 2011). All heavy goods vehicles and all shipping are switched over to LNG in line with the natural turnover of the capital stock. This reduces transportation emissions from these vehicles by at least 20%, and decreases overall transportation emissions by 6% (IGU, 2012).

3.3. DME applications

Significant commercial and regulatory developments worldwide are driving increases in DME production capacity, and demonstrating its remarkable potential as an ultra clean, renewable, low-carbon fuel (Oberon Fuels, 2012). The problems involved in the use of DME as fuel will not be difficult to solve in the consideration of the long experience gained by handling similar problems present in LPG, CNG, ethanol, methanol, GTL fuel distribution program (Semelsberger et al., 2006). DME can be used as fuel in diesel engines, gasoline engines (30% DME/70% LPG), and gas turbines. Only modest modifications are required to convert a diesel engine to run on DME, and engine and vehicle manufacturers, including Nissan and Volvo, have developed heavy vehicles running on diesel engines fuelled with DME (Oberon Fuels, 2012). Often described as “synthetic LPG”, DME can be blended with LPG (in a proportion of up to 20%) and used for domestic cooking and heating, without modifications to equipment or distribution networks (Oberon Fuels, 2012). In Japan, there were about 276,000 LPG vehicles as of June 2010. The amount of LPG demand has also decreased.

3.4. GTL applications

GTL is a clean burning and high performance diesel-type fuel, and it has the major advantage that it can be introduced to the existing current retail network and car engine technologies. However, the FT process entails significant losses of around 35%. Aviation is a sector, which may lend itself well to the adoption of GTL (IGU, 2012). There are GTL plants operating in Malaysia, South Africa, and Qatar, with additional plants under construction in Qatar and Nigeria (NPC, 2012).

4. The proposed DSS

Figure 2 portrays a schematic diagram showing the proposed DSS. It includes three major parts, including Data-Base subsystem (DB), Model-Base subsystem (MB), and user interface. The DB subsystem is connected to the important international and national industrial and scientific DB's to receive the online and real time information such as oil price, geographical distances, and big firms strategies. This connection could be applied using modern communication and telecommunication networks such as the Internet. In addition to the international and national DB's, the DB subsystem feeds from experts' opinions using the DELPHI technique. An MB subsystem received the whole inputted information to establish a decision-making matrix and solve it using a decision-making model. Consequently, the results of solving the model will be provided for the NG analysts to select the premier fuel.

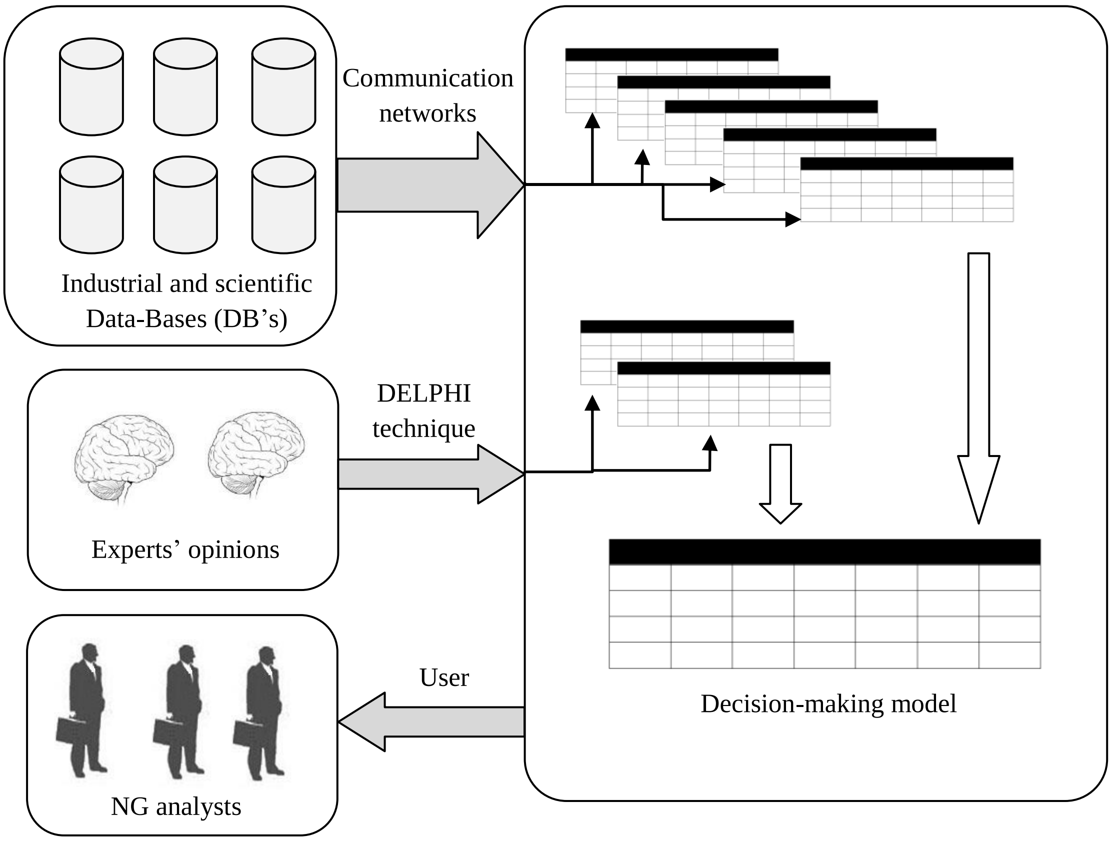

Figure 2
The schematic diagram showing the proposed DSS.

4.1. The decision-making model

The process of selecting NG options would be considered as a critical issue for countries. Typically, the multiple attribute decision-making (MADM) is a decision-making problem required to valuate several alternatives involved in a set of evaluation attributes. Hence NG selection can be formulated as a kind of MADM problem; it is better to employ MADM methods for reaching effective problem-solving. An MADM problem can be concisely expressed in an $m \times n$ tablet, namely MADM matrix, as given in Table 1 (Hwang, 1981; Lai, 1994).

Table 1
The MADM matrix.

	C_1	C_2	C_n
A_1	x_{11}	x_{12}	x_{1n}
A_2			
A_3			
.			
A_m	x_{m1}		x_{mn}

where, A_i $(i = 1, .., m_i)$ are possible alternatives among which decision makers have to choose; C_j $(j = 1, .., n_i)$ are attributes with which alternative performance is measured; x_{ij} stands for the rating of alternative A_i with respect to attribute C_j. Therefore, in the NG selection problem, $A_1 =$ CNG, $A_2 =$ LNG, $A_3 =$ DME, and $A_4 =$ GTL. Moreover, to analysis the options based on a DELPHI technique, 13 attributes are selected as follows:

$C_1 =$ Distance to market

$C_2 =$ Internal demand increment

$C_3 =$ Consumption trend

$C_4 =$ Big companies concentration

$C_5 =$ Impact on environment

$C_6 =$ Cleanness for gasoline type engines

$C_7 =$ Cleanness for diesel engines

$C_8 =$ Capital cost

$C_9 =$ Energy density

$C_{10} =$ Market price

$C_{11} =$ NG reserves

$C_{12} =$ Technology maturity

$C_{13} =$ Efficiency

All the above attributes should be valued in a 5-part bipolar scale of very low (VL), low (L), medium (M), high (H), and very high (VH). In the positive-aspect attributes C_2, C_3, C_4, C_6, C_7, C_9, C_{10}, C_{11}, C_{12}, and C_{13}, the scores for VL, L, M, H, and VH are 1, 3, 5, 6, and 9 respectively. On the other hand, in the negative-aspect attributes C_1, C_5, and C_8 the scores for VL, L, M, H, and VH are 9, 7, 5, 3 and 1 respectively. Consequently, all the scores x_{ij} would be positive-aspects, meaning that a higher value is more important. For each attribute, a weigh of w_j $(j = 1, .., n_i)$ indicting the importance should be specified in a way that:

$$w_1 + w_2 + .. + w_n = 1 \quad (1)$$

Many techniques are provided in the state-of-the art of MADM. A survey of the methods has been presented in a paper by Hwang and Yoon (1981). This paper proposes technique for order performance by similarity to ideal solution (TOPSIS) (Lai et al., 1994), which is one of the known classical MADM methods first developed by Hwang and Yoon (1981) for solving an MADM problem. TOPSIS is a multiple attribute method to identify solutions from a finite set of alternatives. It is based upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. In the process of TOPSIS, the weights of the attributes w_j $(j = 1,..,n_i)$ are given as exact values. The procedure of TOPSIS can be expressed in six steps as follows:

(1) Calculate the normalized decision matrix; the normalized value n_{ij} is calculated by Equation 2:

$$n_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} {x_{ij}}^2} \tag{2}$$

(2) Calculate the weighted normalized decision matrix; the weighted normalized value v_{ij} is calculated by Equation 3:

$$v_{ij} = w_i \times n_{ij} \tag{3}$$

(3) Determine the positive ideal and negative ideal solution respectively as Equations 4 and 5.

$$A^{+} = \{v_1^{+},..,v_n^{+}\} = \left\{\max_{\mathrm{i}} \mathrm{v_{ij}}\right\} \tag{4}$$

$$A^{-} = \{v_1^{-},..,v_n^{-}\} = \left\{\min_{\mathrm{i}} \mathrm{v_{ij}}\right\} \tag{5}$$

(4) Calculate the separation measures, using the *n*-dimensional Euclidean distance; the separation measures of each alternative from the ideal solution are respectively given by Equations 6 and 7:

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+}\right)^2} \tag{6}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2} \tag{7}$$

(5) Calculate the relative closeness to the ideal solution; the relative closeness of the alternative A_i with respect to A^{+} is defined by:

$$R_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{8}$$

(6) Rank the preference order; for ranking DMU's using this index, DMU's can be ranked in a decreasing order.

4.2. Scoring the selected attributes

In order to develop a scoring scale for each of the attributes, a comprehensive study of similar jobs has been done and accordingly a scoring system has been defined. Next, the scoring of all of the 13 selected attributes is respectively described.

Based on Figure 3 (Segunieau, 2008), the scoring system for "distance to market" is as follows. Consequently, the decision-makers (DM) should determine their situation and then use Table 2 to score "distance to market".

- Situation 1: Distance: 0-5000 KM / flow rate 0-500 MMSCFD;
- Situation 2: Distance: 0-5000 KM / flow rate 500-1000 MMSCFD;
- Situation 3: Distance: 5000-10000 KM / flow rate 0-500 MMSCFD;
- Situation 4: Distance: 5000-10000 KM / flow rate 500-1000 MMSCFD.

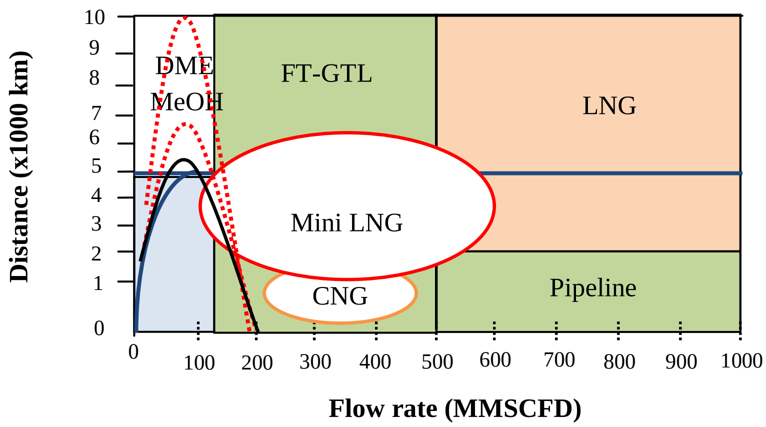

Figure 3
Distance to market.

Table 2
"Distance to market" scoring.

Fuel (NG)	Situation			
	Situation 1	Situation 2	Situation 3	Situation 4
CNG	7	3	1	1
LNG	9	5	3	9
DME	1	1	7	1
GTL	3	1	9	3

Considering the attribute "internal demand increment", the experts' opinions show the scores of the Table 3. DM's should determine their continent and then use Table 3 to score this attribute.

Table 3
"Internal demand increment" scoring.

Fuel (NG)	Continent			
	America	Europe	Asia	Africa
CNG	5	5	7	7
LNG	1	5	9	9
DME	3	5	7	7
GTL	7	7	5	3

Scoring for "consumption trends" is based on Table 4, which is also extracted from experts' opinions.

Table 4
"Consumption trends" scoring.

Fuel (NG)	Consumption trends
CNG	9
LNG	5
DME	3
GTL	3

Table 5 answers the question of "which alternative fuels are the oil companies talking about (or not) on their websites?" (Seisler, 2012). Studies indicate that more big companies such as BP, ENI, EXXON MOBIL, SHELL, STATOIL, and TOTAL have initially focused on CNG-related researches and development activities. Thus the attribute "big companies concentration" directs us to establish Table 6.

Table 5
Which alternative fuels are the oil companies talking about (or not) on their websites?

Company (#) Euro retailer	Ethanol	Other bio-liquids	Hydrogen	NG for vehicles	Other
BP (3)	Yes	Biodiesel, 2nd Gen	Yes	NO	LPG, Wind, solar, CCS
ENI (5)	Yes	Biofuels, Green Diesel, ETBE	Yes	CNG	LPG,CCS, Methanol
EXXON MOBIL (4)	Yes	Algae biofuels	Yes	NO	LPG, CCS
OMV(9)	Yes	FAME, ETBE, Vegetable oil	Yes	CNG, bio-CNG, SNG	LPG
SHELL (1)	Yes	Biofuels	Yes	CNG, LNG	LPG, CCS
STATOIL (11)	Yes	Biodiesel, Bioethanol	Yes	CNG, GTL, LNG	CCS, Methanol, Wind, Geothermal
TOTAL (2)	Yes	DME	Yes	NO	Methanol, ETBE, FAME, Solar

To measure the attribute of "impact on environment", four elements of air, water, soil, and noise are considered. Table 7 shows the impacts of mega-projects on the selection of environmental resources (ICF International, 2012). Table 8 translates the qualitative values in Table 7 to quantitative ones. In

Table 8, DM may consider one or more environmental resources to obtain an average as the scores for "impacts on environment".

Table 6
"Big-company concentration" scoring.

Fuel (NG)	Big companies concentration
CNG	5
LNG	3
DME	1
GTL	1

Table 7
Impact of mega-projects on the selection of environmental resources.

Fuel (NG)	Impact on the selection of environmental resources			
	Air	Water	Soil	Noise
CNG	Small	Small	Medium	Very small
LNG	Medium	Medium	Very small	Very small
DME	Medium	Small	Small	Small
GTL	Medium	Very small	Very small	Very small

Table 8
"Impacts on environment" scoring.

Fuel (NG)	Impacts on environment				Average
	Air	Water	Soil	Noise	
CNG	7	7	5	9	7
LNG	5	5	9	9	7
DME	5	7	7	7	7
GTL	5	9	9	9	8

Two attributes of "cleanness for gasoline type engines" and "cleanness for diesel engines" are derived from Taupy (2011) as shown in Figure 4. This directs us to establish Table 9.

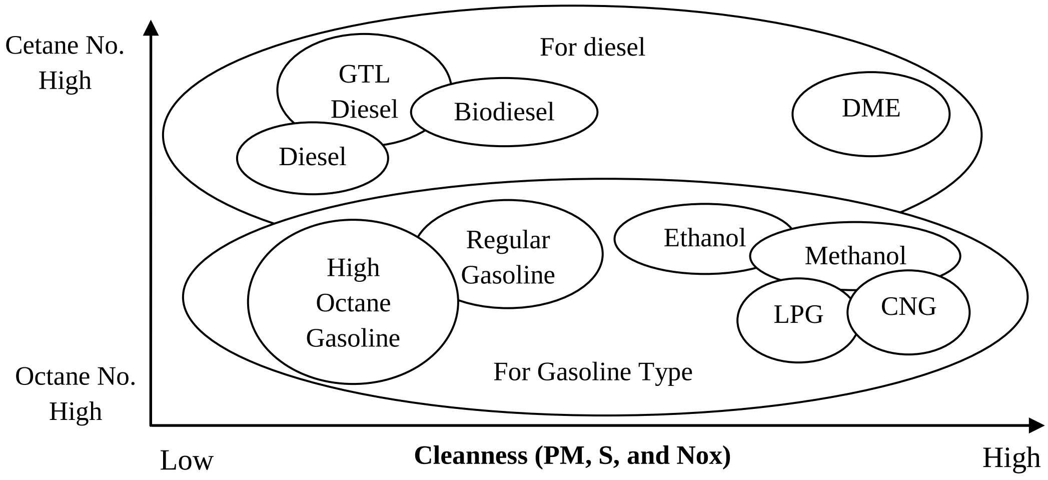

Figure 4
DME as the cleanest diesel alternative.

Table 9
"Cleanness for gasoline type engines" and "cleanness for diesel engines" scoring.

Fuel (NG)	Cleanness for gasoline type engines	Cleanness for diesel engines
CNG	9	7
LNG	3	3
DME	7	9
GTL	3	1

The "capital cost" required to establish the facilities of an identical refinery for the NG's is shown in Table 10, which is based on the experts' opinions.

Table 10
"Capital cost" scoring.

Fuel (NG)	Capital cost
CNG	1
LNG	5
DME	3
GTL	5

The "energy density" for CNG, LNG, DME, and GTL are 266, 635, 500, and 550 1000 BTU/ft^3 respectively (Boehman, 2012). Table 11 presents the scores considered for energy density.

Table 11
"Energy density" scoring.

Fuel (NG)	Energy density
CNG	3
LNG	9
DME	7
GTL	7

Analyzing the "market price" is related to oil and NG price. Figure 5 (Wood et al., 2012) presents NG and oil prices for GTL and LNG. Furthermore, Table 12 shows the fuel cost for all NG products (Oberon Fuels, 2012). Hence four situations may be assumed as follows. DM's should determine their situation and score "market price" as summarized in Tablet 13.

- Situation 1: High oil price / high NG price
- Situation 2: High oil price / low NG price
- Situation 3: Low oil price / high NG price
- Situation 4: Low oil price / low NG price

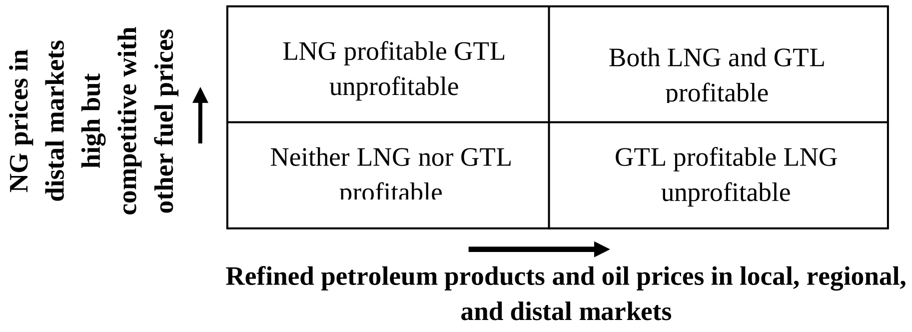

Figure 5
Large-scale GTL versus LNG; NG and oil prices.

Table 12
Fuel costs (energy equivalent).

Variables relative to diesel	DME	LNG CI/SI*	CNG CI/SI*	Diesel
Fuel cost (energy equivalent)	$$	$	$	$$$

Table 13
"Fuel costs" scoring.

Fuel (NG)	Situation 1	Situation 2	Situation 3	Situation 4
CNG	7	5	3	3
LNG	9	7	1	1
DME	7	3	3	2
GTL	9	1	7	1

The "NG reserve" shows a high volume of LNG in the world. According to Figure 6 (Seguineau, 2008), Table 14 may be constructed to score "NG reserve".

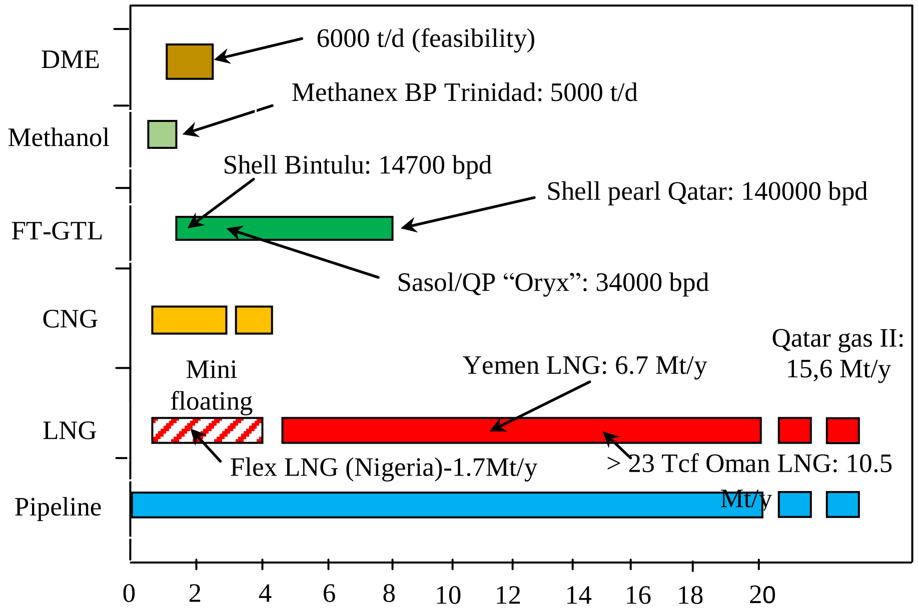

Figure 6
NG reserves versus products.

Table 14
"NG reserve" scoring.

Fuel (NG)	0-5	5-10	10-15	15-20
CNG	9	1	1	1
LNG	3	7	9	9
DME	9	1	1	1
GTL	7	9	1	1

By employing Figure 7 (Seguineau, 2008), the "technology maturity" is scored as given in Table 15.

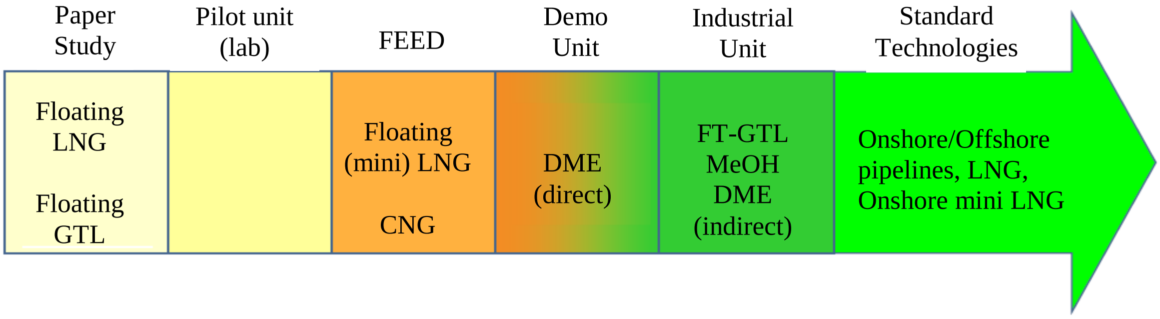

Figure 7
Technology maturity.

Table 15
"Technology maturity" scoring.

Fuel (NG)	Technology maturity
CNG	3
LNG	9
DME	5
GTL	3

Finally, regarding Table 16 (Seguineau, 2008), the "efficiency" is scored as displayed in Table 17.

Table 16
Efficiency of LNG, CNG, FT-GTL, and DME.

	LNG	CNG	FT-GTL	DME
Efficiency	~80-85% (ex:10,000 km+regas)	~90% (ex:1700 km) f (distance)	~55-60%	~62%

Table 17
"Efficiency" scoring.

Fuel (NG)	Efficiency
CNG	9
LNG	7
DME	5
GTL	5

5. The numerical case

Now a sample country is considered to analyze the proposed model. Regarding the attribute of "distance to market", the situation 1 is considered. Considering the "internal demand increment", the continent of Asia is considered. Moreover, analyzing the attribute of "market price" directs DM's toward the situation 2. Finally, the "NG reserve" for that country is considered between 15 and 20. Therefore, the MADM matrix can be constructed as shown in Table 18.

Table 18
The MADM matrix for the case selected.

Scores	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
CNG	7	7	7	5	7	9	7	1	3	5	1	3	9
LNG	9	9	9	3	7	3	3	5	9	7	9	9	7
DME	1	7	3	1	7	7	9	3	7	3	1	5	5
GTL	3	5	3	1	8	3	1	5	7	1	1	3	5

The calculations of the TOPSIS technique are provided in Tables 19 to 24. It should be noted that all the attributes are supposed to be equal in weight.

Table 19
The TOPSIS technique: normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
CNG	0.050	0.047	0.050	0.050	0.035	0.050	0.034	0.028	0.016	0.039	0.030	0.042	0.050
LNG	0.064	0.061	0.064	0.070	0.035	0.028	0.034	0.065	0.037	0.050	0.090	0.042	0.039
DME	0.007	0.020	0.007	0.010	0.026	0.039	0.044	0.046	0.037	0.028	0.010	0.024	0.028
GTL	0.021	0.020	0.021	0.050	0.035	0.028	0.025	0.046	0.048	0.028	0.030	0.024	0.028

Table 20
The TOPSIS technique: attributes weights.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Weight	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077

Table 21
The TOPSIS technique: weighted normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
CNG	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.002	0.001	0.003	0.002	0.003	0.004
LNG	0.005	0.005	0.005	0.005	0.003	0.002	0.003	0.005	0.003	0.004	0.007	0.003	0.003
DME	0.001	0.002	0.001	0.001	0.002	0.003	0.003	0.004	0.003	0.002	0.001	0.002	0.002
GTL	0.002	0.002	0.002	0.004	0.003	0.002	0.002	0.004	0.004	0.002	0.002	0.002	0.002

Table 22
The TOPSIS technique: positive ideal solution (A+).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Max	0.005	0.005	0.005	0.005	0.003	0.004	0.003	0.005	0.004	0.004	0.007	0.003	0.004

Table 23
The TOPSIS technique: negative ideal solution (A-).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Min	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.002	0.002

Table 24
The TOPSIS technique: separation measures and relative closeness to the ideal solution.

	d+	***d-***	***R***
CNG	0.00653	0.0690	0.51384
LNG	0.00221	0.01119	0.83492
DME	0.01093	0.00278	0.20268
GTL	0.00838	0.00477	0.36264

Table 24 shows the rank of NG's as LNG, CNG, DME, and GTL. Now, DM's may consider some marginal indexes such as available budget and political risks to specify the NG portfolio.

6. Conclusions

The goal of this research is to develop a model for decision making to select one or more of the CNG, LNG, DME, and GTL to be used in vehicle fleets. According to the proposed model, each country is able to consider its preference by weighting the selected attributes. Finally, the proposed model was validated using real world facts extracted from industrial and scientific sectors.

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