Hybrid Algorithm of Mathematical Programming for Evaluation of Gasoline Substitutes

Lutfu S. Sua*, Figen Balo

Department of Industrial Engineering, Firat University, Turkey

Keywords


Abstract

The aim of this paper is to select the most feasible oxygenates and alcohols for fuel manufacturing through the use of a quantitative approach enabling multi-factor decision making procedure and mathematical modeling. Among oxygenates and alcohols, the problem of selecting the most proper one is evaluated, using numerous properties of gasoline substitutes and their related sub-properties. Two separate quantitative techniques are used within the framework of a proposed hybrid algorithm. The first technique applied is the multi-factor evaluation method where each property is appointed a relative weight based on expert evaluations. The second applied method is mathematical modeling where the problem is modeled using integer programming. The objective of the problem is designed as a function to calculate the total absolute difference between the values of gasoline and those of alternatives for each property. Thus, the model tries to find the alternative that minimizes the objective function. The proposed algorithm is a comprehensive decision analysis technique because it considers the significance of each property and incoherence in the rankings are confirmed. The results indicate that the proposed mathematical model enables more advanced choices as it considers the relative weights of the properties. The application of the proposed method and the conclusions of this paper supply an idea on how this method can be performed as a decision-making tool in alcohol and cellulose-derived oxygenates selection as substitutes for gasoline.

1. Introduction

The diesel, kerosene and gasoline that are purified from petroleum-based oil are utilized as fuel for automobile industry [1]. Among these fuels, gasoline has been the choice of world to power vehicles since 1990 [2]. By energy sources, the energy consumption [3] and major fuel manufacturing regions [4] in the world are shown in Figure 1. World fuel demand growth by manufacture and crude demand by region (b) are displayed in Figure 2 [5].

Biomass-derived bio-fuel is a sustainable, renewable and clean energy that is thought to be a potential replacement for traditional automotive fuels (diesel and gasoline) [6, 7]. Rising request from the automotive sector along with environmental laws has encouraged the gasoline fuel’s development from vegetable-based resources to substitute traditional automotive fuels. The matters arising from heat-trapping gas emissions and a confined petroleum-based fuel source support research efforts to investigate alternative fuels from sustainable-renewable resources [8, 9]. The bio-based fuels, which are produced from vegetal sources, are obtained in several types of forms, involving alcohols. By many researchers, alcohols, primarily methanol and ethanol, have been considered as optional fuels for internal combustion engines [10–14]. The methanol can also be made from bio-based materials as well as from petroleum-based fuels or coal. By agricultural residues’ alcoholic fermentation, the ethanol, which is a bio-based renewable-sustainable fuel (bio-ethanol), is made [15–18]. Due to their high octane numbers, methanol and ethanol are efficient spark-ignition engine fuels. Researches on the utilization of methanol and ethanol in internal combustion gasoline engines, with the principle goal of improving engine effectiveness and emission reduction have been indicated in various articles [19-24]. Generally, the publications displayed an important boost on engine effectiveness and a

* Corresponding Author:
E-mail address: lutsua@gmail.com– Tel, (+90) 2370000

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decrease in alcohol blended fuels’ pollutant emissions compared to gasoline. The butanol is considered as a clean energy source in spark-ignition engines that can be commonly implemented by blending with gasoline and utilized as a clean fuel [25–29]. The butanol’s chemical structure supplies several benefits, compared to methanol and ethanol by its lower vapor pressure that decreases the vapor lock’s chance. It has high fuel economy because of its higher energy intensity, it has a skill to utilize current gasoline delivery system, and it can be mixed with gasoline at higher densities without retrofitting vehicles. [30–32]. The butanol chemical structure is formed in four diverse isomers, namely n-butanol (normal butanol or 1-butanol), s-

butanol (secondary butanol or 2-butanol), i-butanol (isobutanol) and t-butanol (tertiary butanol). Even so, it was noted that the utilization of t-butanol and s-butanol as near future bio-fuels is unclear since an encouraging undertake for their generation has not yet been constituted [33]. Compared with t-butanol and s-butanol, diverse methodologies for increasing the generations of n-butanol and iso-butanol are presented lately [34–39]. Researches on the utilization of iso-butanol and n-butanol in internal combustion engines, with the fundamental considerations of pollutant emissions and increasing performance of engines, have been obtained in a number of articles.

Martin reported decreases in HC, NOx, CO2, and CO emissions and increase in engine energy at utilizing 10% normal butanol in gasoline fuel [40]. Deng et al. examined normal butanol–gasoline mixtures with 35% normal butanol and displayed that with the normal butanol extra hydrocarbons and carbon monoxide, gas emissions diminished and internal combustion engine effectiveness was fixed [41]. By adding normal butanol to gasoline, Williams et al. argued that thermal performance, fuel combustion performance and pollutant emissions were not affected [42]. By volume, Yang et al. examined performance and emissions of normal butanol–gasoline mixtures, utilizing 35–10% normal butanol [43].

In this paper, the comparative assessment of oxygenates and alcohols is provided. The aim of this paper is to select the most feasible oxygenates and alcohols for fuel manufacturing through the use of a quantitative approach enabling multi-factor decision making procedure and mathematical modeling. Among oxygenates and alcohols, the problem of selecting the most proper one is evaluated, using numerous main factor related sub-properties. Use of hybrid algorithms for multi-factor problems has wide range of applications in the literature [44–45].

This study involves physicochemical properties of the selected alcohol and cellulose-derived oxygenates. The properties are lower heating value, latent heat of vaporization, lower and upper flammability limits, auto ignition temperature, flash point closed cup, boiling and melting points, RON, MON, viscosity, specific gravity, solubility of water in compound, and solubility of compound in water. 9 different alcohols and 7 cellulose-derived oxygenates are compared using multi-factor analysis and mathematical modeling.

Based on the nature of variables and the limitation, the problem is designed as an integer problem. Thus, integer programming approach was used for the solution of
optimization problem. When a model includes integer, binary or all different constraints, it is called an integer programming problem. Integer constraints make a model non-convex, and finding the optimal solution to an integer programming problem is equivalent to solving a global optimization problem. Such problems may require far more computing time than the same problem without the integer constraints. Since nonlinear solution method is used, a Branch and Bound method is applied for the integer constraints.

2-Hybrid Algorithm

The method uses a tree diagram of nodes and branches to organize the solution partitioning. This is an intelligent search procedure for either an optimal or a good-enough approximation to the optimal solution to all-integer of mixed-integer problems. Figure 3 presents the tree representation of the algorithm.

In this model for biodiesel production, all decision variables are integer, thus resulting in an all-integer problem. The steps of the algorithm can be summarized as follows:

1- Apply multi-factor analysis to obtain factor weights.
   1a. Calculate factor weights through pairwise comparison of the factors using expert opinions.
   1b. Calculate scores of the alternatives through pairwise comparison of the alternatives using factor weights obtained in previous step.

2- Apply branch and bound algorithm to solve the integer programming problem.
   2a. Solve the LP relaxation of the mathematical model which means treating the problem as a Linear Problem. If the optimal LP solution is integer, it is optimal for the Integer Problem (IP).
   2b. Divide the problem into two or more sub-problems (branching) that divides the feasible area into regions that removes the current LP optimal solution from the new feasible region. An upper bound (UB) and a lower bound (LB) on the value of the objective function is set.
   2c. Start branching from the variable with the greatest fractional part. The variable is branched out to

Figure 3. Hybrid Algorithm
include only values greater than the integer above and less than the integer value below the optimal LP solution. The branches represent additional constraints to the original problem.

2d. The optimal solution for each branch is determined. Sub-problems whose objective function is worse than the established feasible bounds are eliminated from further consideration.

2e. The remaining sub-problems are used to modify the bounds, then subdivided and investigated.

2f. This process is repeated until no further subdivision is possible, at which point the optimal solution has been reached.

3- Compare the results obtained from multi-factor analysis and mathematical modeling.

2.1. Multi-Criteria Evaluation Method

In a method for choosing the best alternative among others, the goal would be to choose the most appropriate alternative that satisfies various types of factors. A large set of 16 factors are considered within this research. 9 different alcohols and 8 cellulose-derived oxygenates are compared with the same properties of gasoline using the proposed technique.

While measurements for some factors are readily available, some others can only be estimated with respect to other variables. As it is the case in all multi-factor decision making methods, the relative weights of such factors need to be determined. This is accomplished by pairwise comparison of the factors. Below are the resulting priorities of related factors shown in Figure 4.

All these elements are compared as to how significant impact they have on the overall goal.

2.1. Pairwise Comparison of the Alternatives with Respect to the Factors

After determining the priorities of each factor in regard to the objective, pairwise comparison of the alternatives with respect to each factor will also determine the best alternative based on the multi-factor analysis alone. Chemical and physical properties of gasoline and 9 different alternatives determined for the purpose of this investigation are presented in Table 1.

While gasoline and diesel are mixtures of a variety of compounds and thus can exhibit a range of properties, many of those properties are limited by federal regulation and ASTM specifications. In contrast, alcohols are singular compounds with specific chemical properties. Note that the properties of various isomers with the same chemical formula may differ significantly.

The next step in applying the technique is two by two comparisons of the alternatives with respect to each factor.

In order to design an objective scheme for this purpose, the maximum and minimum values of the alternatives for each factor is determined. This range is divided into nine even ranges since the method requires pairwise comparisons on a scale from 1 to 9. Finally, each alternative is placed in one of these ranges based on their values to compare them with each other.

Based on the calculations above, the relative priorities corresponding to the attractiveness of each alcohol alternative about all factors are presented in Figure 5 below.

The obtained results from the multi-factor analysis indicate that the ethanol with a global priority of 0.1971 is the option that obtains the closest score to the one of Gasoline based on all the criteria selected while t-butanol is ranked second.

The properties of the biofuels are listed in Table 2. These data were compiled from a wide range of reference sources. The source of each value is listed below the table and should be considered prior to applying these values.
### Table 1. Chemical and Physical Properties of Gasoline and Alcohols

<table>
<thead>
<tr>
<th>Compound</th>
<th>Gasoline</th>
<th>Ethanol</th>
<th>n-propanol</th>
<th>iso-propanol</th>
<th>n-butanol</th>
<th>iso-butanol</th>
<th>s-butanol</th>
<th>t-butanol</th>
<th>n-pentanol</th>
<th>iso-pentanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS Number</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formula</td>
<td>C₆H₁₂O₆</td>
<td>C₄H₈O</td>
<td>C₄H₈O</td>
<td>C₄H₈O</td>
<td>C₄H₁₀O</td>
<td>C₄H₁₀O</td>
<td>C₄H₁₀O</td>
<td>C₄H₁₀O</td>
<td>C₅H₁₂O</td>
<td>C₅H₁₂O</td>
</tr>
<tr>
<td>Lower heating</td>
<td>41–44</td>
<td>26.8</td>
<td>30.7</td>
<td>30.4</td>
<td>33.2</td>
<td>33.1</td>
<td>32.9</td>
<td>32.7</td>
<td>34.0</td>
<td>35.4</td>
</tr>
<tr>
<td>value (MJ/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latent heat of</td>
<td>352</td>
<td>919.6</td>
<td>792.1</td>
<td>756.6</td>
<td>707.9</td>
<td>686.4</td>
<td>671.1</td>
<td>527.2</td>
<td>647.1</td>
<td>617.1</td>
</tr>
<tr>
<td>vaporization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower flammability limit (%)</td>
<td>1.4</td>
<td>3.28</td>
<td>2.13</td>
<td>2.02</td>
<td>1.45</td>
<td>1.68</td>
<td>1.7</td>
<td>2.4</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Upper</td>
<td>7.6</td>
<td>18.95</td>
<td>13.50</td>
<td>11.80</td>
<td>11.25</td>
<td>10.9</td>
<td>10.9</td>
<td>9.0</td>
<td>8.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Flammability limit (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor pressure at 20°C (kPa)</td>
<td>50–100</td>
<td>5.8</td>
<td>2</td>
<td>4.4</td>
<td>0.58</td>
<td>1.2</td>
<td>1.7</td>
<td>4</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Reid Vapor Pressure, (kPa)</td>
<td>54–103</td>
<td>16.0</td>
<td>6.2</td>
<td>12.4</td>
<td>2.2</td>
<td>3.3</td>
<td>5.3</td>
<td>12.2</td>
<td>0.83</td>
<td>1.0</td>
</tr>
<tr>
<td>Autoignition temp (°C)</td>
<td>257</td>
<td>363</td>
<td>371</td>
<td>456</td>
<td>343</td>
<td>415</td>
<td>405</td>
<td>478</td>
<td>320</td>
<td>350</td>
</tr>
<tr>
<td>Flash point</td>
<td>-43</td>
<td>13</td>
<td>15</td>
<td>12</td>
<td>29</td>
<td>28</td>
<td>24</td>
<td>11</td>
<td>43</td>
<td>45</td>
</tr>
<tr>
<td>closed cup (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiling point (°C)</td>
<td>27–225</td>
<td>78</td>
<td>97.2</td>
<td>82.3</td>
<td>117.7</td>
<td>107.9</td>
<td>99.6</td>
<td>82.4</td>
<td>137.8</td>
<td>132</td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>-40</td>
<td>-114</td>
<td>-126.2</td>
<td>-88.5</td>
<td>-89.3</td>
<td>-108</td>
<td>-114.7</td>
<td>26</td>
<td>-78.2</td>
<td>-117</td>
</tr>
<tr>
<td>RON</td>
<td>88–98</td>
<td>109</td>
<td>104*</td>
<td>96*</td>
<td>105*</td>
<td>105*</td>
<td>105*</td>
<td>105*</td>
<td>105*</td>
<td>105*</td>
</tr>
<tr>
<td>MON</td>
<td>80–88</td>
<td>90</td>
<td>89*</td>
<td>99</td>
<td>85*</td>
<td>90*</td>
<td>93*</td>
<td>89*</td>
<td>74(94)</td>
<td>(84)</td>
</tr>
<tr>
<td>Viscosity 20°C (cSt)</td>
<td>0.37–0.44</td>
<td>1.5</td>
<td>2.7</td>
<td>3.1</td>
<td>3.6</td>
<td>8.3</td>
<td>4.7</td>
<td>4.2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Specific gravity, 20°C</td>
<td>0.69–0.79</td>
<td>0.794</td>
<td>0.804</td>
<td>0.789</td>
<td>0.810</td>
<td>0.802</td>
<td>0.808</td>
<td>0.791</td>
<td>0.816</td>
<td>0.8</td>
</tr>
</tbody>
</table>

### Figure 5. Scores of Alcohol Alternatives
The obtained results in Figure 6 indicate that the valero-lactone with a global priority of 0.1782 is the option that obtains the closest score to the one of gasoline based on all the factors selected.

![Figure 6. Scores of cellulose-derived oxygenates Alternatives](image-url)
2.2. Mathematical Modeling Algorithm

\[
\begin{align*}
\min Z &= \frac{\sum_i \sum_j (G_j - C_{ij} \ast w_j x_i)}{|G_j|} \\
\text{subject to:} & \quad \sum_i x_i = 1 \\
\forall x_i &= \{0, 1\}
\end{align*}
\]

where:

- \(G_j\): \(j^{th}\) factor value of gasoline
- \(C_{ij}\): \(j^{th}\) factor value of \(i^{th}\) alternative
- \(x_i\): solution value \(i^{th}\) lubricant

The objective function (Eq. (1)) of the model aims to minimize the total absolute difference between the reference value of gasoline for a given factor and the value of an alternative for the same factor. The function calculates the total absolute differences throughout the factors as defined by the cost parameter \(G_j - C_{ij}\). Absolute differences of each alternative for each factor are divided by the absolute value of gasoline for each factor. Finally, the resulting value is multiplied by the factor weight obtained from the multi-factor analysis. The variable for each alternative is represented by \(X_i\), where \(i\) is the alternative number.

The first constraint (Eq. (2)) ensures that only one of the best alternative is chosen by the model. The last constraint (Eq. (3)) forces the model to assign only binary values to the variables.

First, nine different alcohols are evaluated through the application of branch and bound algorithm. As opposed to the multi-factor analysis which determined ethanol as the best alternative to gasoline, the obtained results from the hybrid model indicate that the 1-butanol is the option that contributes the most to the goal of selection the best alternative that satisfies all the factors selected (Table 3).

### Table 3. Solution of the Mathematical Model

<table>
<thead>
<tr>
<th></th>
<th>Ethanol</th>
<th>n-propanol</th>
<th>i-propanol</th>
<th>n-butanol</th>
<th>i-butanol</th>
<th>s-butanol</th>
<th>t-butanol</th>
<th>n-pentanol</th>
<th>i-pentanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>1,2141</td>
<td>1,0116</td>
<td>0,9497</td>
<td>402,9823</td>
<td>416,2854</td>
<td>1049,7086</td>
<td>836,35</td>
<td>186,0250</td>
<td>178,7987</td>
</tr>
<tr>
<td>LHV</td>
<td>0,0928</td>
<td>0,0704</td>
<td>0,0722</td>
<td>0,0361</td>
<td>0,0567</td>
<td>0,0578</td>
<td>0,0590</td>
<td>0,0470</td>
<td>0,0435</td>
</tr>
<tr>
<td>LHVap</td>
<td>0,2933</td>
<td>0,2274</td>
<td>0,2090</td>
<td>0,1839</td>
<td>0,1728</td>
<td>0,1649</td>
<td>0,0905</td>
<td>0,1525</td>
<td>0,1370</td>
</tr>
<tr>
<td>Low Fl</td>
<td>0,1750</td>
<td>0,0679</td>
<td>0,0577</td>
<td>0,0047</td>
<td>0,0261</td>
<td>0,0279</td>
<td>0,0931</td>
<td>0,0186</td>
<td>0,0186</td>
</tr>
<tr>
<td>Up Fl</td>
<td>0,1946</td>
<td>0,1011</td>
<td>0,0720</td>
<td>0,0626</td>
<td>0,0566</td>
<td>0,0240</td>
<td>0,0869</td>
<td>0,0497</td>
<td>0,0420</td>
</tr>
<tr>
<td>Vapor Pr</td>
<td>0,0846</td>
<td>0,0892</td>
<td>0,0863</td>
<td>0,0999</td>
<td>0,0902</td>
<td>0,0896</td>
<td>0,0968</td>
<td>0,0999</td>
<td>0,0912</td>
</tr>
<tr>
<td>Reid Vap</td>
<td>0,0731</td>
<td>0,0845</td>
<td>0,0773</td>
<td>0,0891</td>
<td>0,0878</td>
<td>0,0855</td>
<td>0,0775</td>
<td>0,0907</td>
<td>0,0905</td>
</tr>
<tr>
<td>Autoignit</td>
<td>0,0264</td>
<td>0,0284</td>
<td>0,0495</td>
<td>0,0214</td>
<td>0,0393</td>
<td>0,0368</td>
<td>0,0550</td>
<td>0,0157</td>
<td>0,0232</td>
</tr>
<tr>
<td>Flash P.</td>
<td>0,0833</td>
<td>0,0863</td>
<td>0,0818</td>
<td>0,1071</td>
<td>0,1056</td>
<td>0,0997</td>
<td>0,0004</td>
<td>0,1280</td>
<td>0,1309</td>
</tr>
<tr>
<td>Boiling P.</td>
<td>0,0168</td>
<td>0,0101</td>
<td>0,0153</td>
<td>0,0029</td>
<td>0,0064</td>
<td>0,0093</td>
<td>0,0153</td>
<td>0,0041</td>
<td>0,0021</td>
</tr>
<tr>
<td>Melting P.</td>
<td>0,0818</td>
<td>0,0953</td>
<td>0,0536</td>
<td>0,0045</td>
<td>0,0752</td>
<td>0,0826</td>
<td>0,0729</td>
<td>0,0422</td>
<td>0,0851</td>
</tr>
<tr>
<td>RN</td>
<td>0,0052</td>
<td>0,0036</td>
<td>0,0042</td>
<td>0,0036</td>
<td>0,0039</td>
<td>0,0039</td>
<td>0,0039</td>
<td>0,0049</td>
<td>0,0003</td>
</tr>
<tr>
<td>MON</td>
<td>0,0022</td>
<td>0,0018</td>
<td>0,0054</td>
<td>0,0004</td>
<td>0,0022</td>
<td>0,0032</td>
<td>0,0018</td>
<td>0,0036</td>
<td>0,0000</td>
</tr>
<tr>
<td>Viscosity</td>
<td>0,0547</td>
<td>0,1149</td>
<td>0,1350</td>
<td>0,1601</td>
<td>0,3959</td>
<td>0,2153</td>
<td>0,1902</td>
<td>0,2303</td>
<td>0,2303</td>
</tr>
<tr>
<td>Sp. Grav.</td>
<td>0,0015</td>
<td>0,0018</td>
<td>0,0014</td>
<td>0,0019</td>
<td>0,0017</td>
<td>0,0014</td>
<td>0,0014</td>
<td>0,0021</td>
<td>0,0017</td>
</tr>
<tr>
<td>Sol.of water</td>
<td>0,0145</td>
<td>0,0145</td>
<td>0,0145</td>
<td>290,7660</td>
<td>289,3194</td>
<td>867,9871</td>
<td>0,0145</td>
<td>153,3325</td>
<td>141,7591</td>
</tr>
<tr>
<td>Sol.of Com.</td>
<td>0,0145</td>
<td>0,0145</td>
<td>0,0145</td>
<td>111,3791</td>
<td>125,8458</td>
<td>180,8192</td>
<td>0,0145</td>
<td>31,8123</td>
<td>36,1523</td>
</tr>
<tr>
<td>Z = 0,8635</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

The selected seven cellulose-derived oxygenate alternatives are evaluated through the algorithm. The obtained results as shown in Table 4 indicate that the Valero-lactone is the option that contributes the most to the goal of selection the best alternative that satisfies all the factors selected. This result is aligned with the one obtained from running the multi-factor analysis alone.
3-Conclusions

The continuously diminishing fossil sources and the growing demand for energy have led to the research for alternative fuel types which are sustainable and renewable. This study aims to find the most appropriate alternatives based on various factors based on available standards and regulations. Two separate quantitative techniques are used within a proposed hybrid algorithm as a way of confirming the results. The first technique applied is the multi-factor evaluation method where each factor is appointed a relative weight as a result of expert evaluations. Then, the multi-factor evaluation method is applied to the resulting scheme to determine the best alcohol and biofuel alternative to the gasoline as a source of confirmation to the results to be obtained from the hybrid algorithm. The second applied method is mathematical modeling where the problem is modeled using integer programming. The objective function of the problem is designed to calculate the total absolute difference between the values of gasoline and those of alternatives. Thus, the model tries to find the alternative that minimizes that objective function. The factor weights obtained from the multi-factor analysis are used within the objective function. The results indicate that the proposed mathematical model makes more advanced choices as it considers the relative weights of the factors and minimizes the total difference between the factor values of gasoline and those of the alternatives.

The proposed algorithm is a comprehensive decision analysis technique because it considers the significance of each of the factors and incoherence in the rankings are confirmed.

The application of the mathematical modeling and multi-factor decision analysis techniques and the conclusions from this paper supplies an idea of how both methods can be performed together as a decision-making tool in alcohol and cellulose-derived oxygenates selection.

This analysis presented here could be beneficial for both policymakers and researchers. The results of this paper aids researchers working on a broad array of fields on related subjects compare relative effects of the fields in which they can potentially contribute. In a global context, policymakers can also utilize from the conclusions of this analysis by assessing the multidirectional performance of their R & D investments on related fields.

References