Application of Multi-Stakeholder Multi-Criterion Decision Analysis for Biodiesel Feedstock Selection in Vietnam

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Abstract

Biodiesel has been proposed as a renewable energy source to replace fossil diesel in Vietnam. Vietnam government has a policy to produce and use biodiesel to blend with diesel, from B1 to B5 (1-5% biodiesel and 99-95% diesel). There is however no sustainability assessment of biodiesel production that has been done under Vietnam conditions. Decision-makers in Vietnam need to assess the sustainability that consists of the balance of social, technical, economic and environmental aspects. In order to assess the sustainability, multi-criterion decision analysis (MCDA) may be an appropriate methodology to find the most preferred alternative. Analytic hierarchy process (AHP) is one of the most commonly used MCDA methods, and AHP was applied in this study to rank three possible feedstock options for biodiesel production: namely jatropha oil, fish fat and waste cooking oil. The study could provide the feasible guidance of biodiesel development under current conditions in Vietnam. More specifically, the judgments of different Vietnamese stakeholders, such as university professors, heads of biodiesel projects, managers of Petrovietnam corporation, and engineers were incorporated to evaluate the economic, environmental, social and technical aspects. The results showed that waste cooking oil is the most preferable feedstock to produce biodiesel in Vietnam followed by jatropha oil (second) and fish fat (third).

Keywords: Renewable and Environmental Solutions, Multi-criteria decision analysis, Analytical hierarchy process (AHP), Multi-stakeholders, Biodiesel

1. Introduction

Currently, the main source of energy worldwide is fossil fuel. However, the amount of fossil fuel is limited. Moreover, the rapidly increasing demand for fossil fuel may result in some big global problems, global warming and environmental pollution (Atadashi *et al.,* 2011). In order to reduce the dependence on non-renewable energy sources, it is necessary to find renewable energy alternatives. Currently, biodiesel, produced from biological sources such as animal fats or vegetable oils, is a promising candidate (Knothe, 2010). Biodiesel production has been investigated for a long time and produced to replace conventional fossil fuel in many countries. However, biodiesel is not a perfect alternative fuel so far because of some shortcomings, such as high cost, energy effectiveness, source of raw materials, land use etc. So the decision makers of each country need to weigh these conflicting options to decide the direction of biodiesel production and development.

Vietnam has had rapid economic growth and energy consumption has rapidly increased in parallel with economic development. The Vietnam energy sector is also facing several challenges , such as ensuring energy supply, protecting environment from energy activities as well as the social and political issues (Minh Do *et al.,* 2011). Vietnam has an area of about 33 million hectares of which 50 percent is in productive use and 21 percent of the total area is used in agriculture. Biodiesel produced from agricultural products or waste would be a promising alternative energy resource (Khanh Toan *et al.,* 2011). In order to diversify the sources of energy, Vietnam government has a policy to develop biodiesel as an alternative to conventional fossil fuel. Decision No. 177/2007/QD-TTg of Government of Vietnam approved the scheme on development of biofuel up to 2015 and the vision to 2015. Decision No. 1842/QD-BNN-LN indicated that Vietnam would focus on using jatropha as a main feedstock and strongly encouraged the use of other feedstocks, such as waste cooking oil, fish fat, for biodiesel production.

Vietnam government has carried out some projects to research and develop biodiesel production. Project No. DTDL.2007G/19 performed by Ha (2007) evaluated the situation of technique of biodiesel production and application testing of biodiesel based on fish fat in Vietnam. Project No. 257.10.RD/HD-KHCN performed by Thinh (2011) investigated jatropha plantation as material for biodiesel production in Vietnam. Biodiesel has been recommended as an effective renewable resource of energy to replace fossil fuel. However, some studies showed that replacing diesel by biodiesel in Vietnam still faces some disadvantages. Particularly, Le et al. (2013) indicated that the biodiesel substitution for fossil diesel in Vietnam may remain not cost-effective but may improve environmental impacts. So we could find that using biodiesel as an alternative energy may have some positive impacts and some negative impacts. In order to build a comprehensive view of biodiesel based on the current conditions in Vietnam, the sustainability development of biodiesel should be evaluated on the overall process from production to use. A completed assessment of biodiesel needs to be addressed on the technical, social, environmental and economic aspects. For the decision makers, the selection of best feedstock among several feasible ones for biodiesel production is the most challenging (Manzardo *et al.,* 2012). The aim of sustainability assessment is to provide decision-makers policy guidance based on science, technology and comprehensive perspectives (Halog and Manik, 2011).

The goal of sustainable development must be a balance between social, technical, economic and environmental aspects (Wang *et al.,* 2009). They might take many conflicting criteria into assessment formulation to optimize the various impacts of biodiesel on human life. In order to make a sustainability assessment, multi-criteria decision analysis (MCDA) would be an appropriate method to support decision-making (Myllyviita et al., 2013). The most applied application of this method is to find the optimum alternative from all of feasible alternative by ranking the criteria (Torfi *et al.,* 2010). There are many tools of MCDA that were used in sustainable energy planning, such as TOPSIS (Kaya *et al.,* 2011), ELECTRE (Beccali *et al.,* 2003), PROMETHEE (Haralambopoulos *et al.,* 2003), VIKOR (San Cristóbal, 2011), SWOT (Terrados *et al.,* 2009) and AHP (Erol *et al.,* 2012). Among these methods, Analytic Hierachy Process (AHP) is the most widely applied method that has been applied successfully in many problem domains (Wang *et al.,* 2009). AHP is relative measurement theory introduced and developed by Thomas Saaty (1977; 1980) to derive priorities among multiple alternatives under multiple criteria. AHP has been used for forecasting the results of a policy and determining the performance of various impacts issued from products or services. It is a structured technique for dealing with complex decisions to give the best suitable answer for the problem (Erol et al., 2012).

2. Methodology

2.1. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is known as a measurement method from pair-wise comparisons of homogeneous elements to derive dominance priorities for alternatives (Saaty, 1977). These comparisons may be obtained from a fundamental scale of the relative preferences between the selected factors (Saaty, 1987). The fundamental scale based on the definition of Saaty (1990) is shown in Table 2.

Table 1. Saty's nine-point fundamental scale for pair-wise comparison

Numerical scale	Definition	
	Criteria	*Alternatives*
1	Equally important	Equally preferred
3	Moderately more important	Moderately more preferred
5	Strongly more important	Strongly more preferred
7	Very strongly more important	Very strongly more preferred
9	Absolutely more important	Absolutely more preferred

The procedure to apply AHP in sustainability assessment of biodiesel development is illustrated via the following steps:

Step 1: forming the hierarchy structure of related elements. The hierarchy system must show the relationships between the goal, criteria and alternatives.

Step 2: determining the weights for each criteria and alternatives. The attributes are denoted by a_1, a_2, …, a_n and the weights are denoted by w_1, w_2, …, w_n, the pairwise comparisons is represented by the following matrix:

$$A = \begin{bmatrix} a_{11} & \dots & a_{1j} & \dots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \dots & a_{nj} & \dots & a_{nn} \end{bmatrix}$$

One of the objectives of AHP is to find the pair-wise comparison $a_{ij} = w_i/w_j$. a_{ij} should be obtained from the preferences of multi-stakeholders. The priority (weight) vector is represented by the vector (w):

$$w = \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix}$$

Step 3: finding the eigenvector (w) with respective λ_{max} for $(A - \lambda_{max}I)w = 0$.

Step 4: checking the consistency ratio that is an indicator to measure how a given matrix compare to a random matrix in terms of their consistency indices (Chang et al., 2007). If the consistency ratio is equal or less than 0.1, the degree of consistency is satisfactory and the AHP may yield meaningful results (Mateo, 2012).

Step 5: ranking the sequence of the alternatives. The alternative that has higher final weight would have higher ranking.

2.2. Hierarchy structure

Before establishing the pair-wise comparison in the AHP method, it is necessary to make the hierarchy system of various levels according to criteria and sub-criteria. The criteria consist of major issues in producing and using biodiesel. And each criterion was decomposed to sub-criteria: economic aspect would consist of investment cost (Jovanovic et al., 2009; Doukas et al., 2007), operation cost (Pilavachi et al., 2009; Mamlook et al., 2001) and profit (Ding, 2009); environmental aspect would consist of CO_2 emission, NO_x emission into the air and land use (Wang et al., 2008); technological aspect would consist of safety (Mohsen et al., 1997), applicability (Zabaniotou et al., 2008) and efficiency (Dinca et al., 2007); social aspect would consist of social acceptability (Liposcak et al., 2006), job criterion (Doukas et al., 2007) and political acceptability (Ding, 2009). The hierarchy structure used to rank the alternatives in this study is shown in Table 2.

Table 2. Hierarchy structure for selection of the feedstock of biodiesel production

Goal	Level 1st (Criteria)	Level 2nd (Sub-criteria)	Level 3rd (Alternatives)
The most appropriate feedstock for biodiesel production	Economic (**Ec.**)	Investment cost (**I.**) Operation cost (**O.**) Profit (**P.**)	1. Waste cooking oil (**W.**) 2. Fish fat (**F.**) 3. Jatropha oil (**J.**)
	Environmental (**En.**)	CO_2 emission (**CO_2**) NO_x emission (**NO_x**) Land use (**Land**)	
	Technological (**Te.**)	Safety (**S.**) Applicability (**A.**) Efficiency (**E.**)	
	Social (**So.**)	Social acceptability (**Soc.**) Job creation (**Jo.**) Political acceptability (**Po.**)	

As mentioned above, there are three main feasible feedstocks for biodiesel production in Vietnam: waste cooking oil, fish fat, jatropha oil. In order to choose the best one according to the current condition in Vietnam, the perspectives of multi-stakeholder were used in this study to evaluate the impacts of biodiesel production and use on all aspects: social, technical, economic and environmental aspect. Four groups of decision-makers and experts were invited to participate in making sustainability assessment in this study. The first group consists of 5 engineers, the second group consists of 4 heads of biodiesel projects in Vietnam, the third group consists of 3 university professors who have experience on biodiesel production, and the last group consists of 6 managers of Petrovietnam corporation. All of them are experts in the biodiesel field and play an important role in decision making of biodiesel development in Vietnam.

In this study, a survey questionnaire was designed to compare the priorities of two criteria or two alternatives, and distributed to stakeholders to evaluate the feasibility of each alternative. The weights of criteria and alternatives were obtained from the judgments of multi-stakeholders and quantified by AHP. In order to combine the different options from different respondents, geometric mean method of all the entries was applied to aggregate individual priorities (Aczel & Saaty, 1983). The calculation was followed the above steps to determine the priority of criteria and alternatives. Each evaluation result is checked the consistency ratio to make sure that the preferences of stakeholders are consistent enough to be satisfactory. The final result incorporated the judgments of multi-stakeholders may show the sustainability assessment index of biodiesel feedstock from WOC, Fish fat, Jatropha oil. Sensitivity analysis was applied to test the stability of the priority ranking of alternative (Chang et al., 2007). It is performed by selecting and varying a criterion weight and observing the changing score and ranking order of alternative (Chatzimouratidis et al., 2009). In this study, sensitivity analysis was carried out in the Super Decision Software version 2.2.3 (Adams et al., 2012).

3. Results and discussion

3.1. The perspective of professors

Under university professors' judgment, the calculation of preference is shown in Table 3. The weights of criteria indicated that ranking priorities are decreasing according to following order: Environment impact (0.394), Economic impact (0.364), Social impact (0.124) and Technical impact (0.118). It is found that environmental and economic impact is much more important than technology and social impact in professors' opinion. It is clearly shown in level 2nd that profit is most preferred with respect to economic aspect, CO_2 emission and land use is given higher priority than NO_x emission. In the social aspect, political acceptance is the most important factor affecting the decision making of biodiesel development. In other words, the government policy would pay important role in decision making according to the judgments of professors group.

Table 3. The priority of criteria under the perspective of professors (Meanings of abbreviations may be found in Table 2).

Level 1st	Ec.			En.			Te.			So.		
	0.364			0.394			0.118			0.124		
Level 2nd	I.	P.	O.	CO_2	NO_x	Land	S.	E.	A.	Soc.	Po.	Jo.
	0.241	0.613	0.144	0.371	0.223	0.406	0.336	0.252	0.412	0.169	0.498	0.332

The ranking order of alternatives is shown in Table 4 of sustainability index. It indicates that WCO (0.446) > Fish fat (0.315) > Jatropha (0.239).

Table 4. The rank of alternatives under perspective of professors

Alternative	**Jatropha**	**Fish fat**	**WCO**
Final weight	0.239	0.315	0.446
Ranking	3rd	2nd	1st

3.2. The perspective of engineers

The engineers' perspective is shown in Table 5, environmental impact is most salient factor among the criteria. The weight of one (0.413) is much more than the weight of economic impact (0.299), social impact (0.157) and technical impact (0.131). So engineers may provide that environment should pay the most important role in decision-making of biodiesel production and use. In economic aspect, the perspective of engineers is quite like the one of professors, profit is most preferred factor followed by investment cost and operation cost. But in environmental aspect, the engineers think that CO_2 emission is higher environmental impact than NO_x emission and land use. In technical aspect, the order of the preference of sub-criteria is applicability > safety > efficiency. The weights of impacts in social aspect are very close so that these are almost equivalent.

Table 5. The priority of criteria under the perspective of engineers (Meanings of abbreviations may be found in Table 2).

Level 1st	Ec.			En.			Te.			So.		
	0.299			0.413			0.131			0.157		
Level 2nd	I.	P.	O.	CO_2	NO_x	Land	S.	E.	A.	Soc.	Po.	Jo.
	0.290	0.572	0.138	0.514	0.253	0.233	0.476	0.364	0.160	0.355	0.369	0.276

The ranking order of alternatives in Table 6 shows that Jatropha (0.410) > WCO (0.298) > Fish fat (0.292).

Table 6. The rank of alternatives under perspective of engineers

Alternative	**Jatropha**	**Fish fat**	**WCO**
Final weight	0.410	0.292	0.298
Ranking	1st	3rd	2nd

3.3. The perspective of heads of biodiesel project

Similarly, the priorities of criteria and alternatives were evaluated and ranked by the heads of biodiesel projects in Vietnam. The results of assessment of technology, environment, economic and society are shown in Table 7. For the first level, the weight of environmental aspect is provided as the highest score (0.584) that is much higher than other aspect, economic (0.235), technology (0.095) and society (0.087), respectively. This indicates that, in their judgment, environment should be considered as the most important factor when making decision for biodiesel development. For the third level, the heads of biodiesel give prominence to the role of profit in economic aspect, CO_2 emission in environmental impact, safety in technical impact and political acceptance in social impact.

Table 7. The priority of criteria under the perspective of heads of biodiesel project (Meanings of abbreviations may be found in Table 2).

Level 1st	Ec.			En.			Te.			So.		
	0.235			0.584			0.095			0.087		
Level 2nd	I.	P.	O.	CO_2	NO_x	Land	S.	E.	A.	Soc.	Po.	Jo.
	0.237	0.558	0.205	0.407	0.251	0.342	0.660	0.101	0.239	0.254	0.553	0.193

The sustainability index Table 8 that was evaluated by heads of biodiesel projects shows that jatropha (0.392) is the most appropriate candidate for biodiesel production in Vietnam and followed by fish fat (0.306) and WCO (0.302).

Table 8. The rank of alternatives under perspective of heads of biodiesel project

Alternative	**Jatropha**	**Fish fat**	**WCO**
Final weight	0.392	0.306	0.302
Ranking	1^{st}	2^{nd}	3^{rd}

3.4. The perspective of managers of Petrovietnam corporation

Table 9 summarizes the sustainability measurement based on the preferences of managers of the Petrovietnam corporation. The results show the priority of each criterion as following order, economic (0.410), technology (0.212), environment (0.203) and society (0.175). It is given that economic is the most important aspect in the opinion of managers of Petrovietnam when they decide to use biodiesel as alternative of fossil fuel. It is quite different from other groups that provide the priority of environment higher than economic. The evaluation also indicate that in economic aspect, the order of impacts is profit (0.520) > investment cost (0.315) > operation cost (0.165); in environmental aspect, one is CO_2 emission (0.416) > NO_x emission (0.362) > land use (0.221); in technical aspect, one is safety (0.474) > efficiency (0.280) > applicability (0.246) and in social aspect, one is job creation (0.419) > political acceptance (0.301) > social acceptance (0.279).

Table 9. The priority of criteria under the perspective of managers of Petrovietnam (Meanings of abbreviations may be found in Table 2).

Level 1st	Ec.			En.			Te.			So.		
	0.410			0.203			0.212			0.175		
Level 2nd	I.	P.	O.	CO_2	NO_x	Land	S.	E.	A.	Soc.	Po.	Jo.
	0.315	0.520	0.165	0.416	0.362	0.221	0.474	0.280	0.246	0.279	0.301	0.419

Table 10 is the result of sustainability index according to the preferences of managers of Petrovietnam. WCO (0.371) is most preferred feedstock followed by jatropha (0.351) and fish fat (0.278).

Table 10. The rank of alternatives under perspective of managers of Petrovietnam

Alternative	**Jatropha**	**Fish fat**	**WCO**
Final weight	0.351	0.278	0.371
Ranking	2nd	3rd	1st

3.5. Summary

From the evaluation results of different stakeholders, we could find that there are some differences in their preference. The weights of each criteria and sub-criteria from each group are quite different from other. This could result in the different ranking orders of alternatives when choosing feedstock for biodiesel production. However, almost all groups provide high evaluation for economic and environmental aspect than technical and social aspect in decision making. In the evaluation from professors group, the weights of the economic and environmental aspects are quite close. For the groups of engineers and heads of biodiesel project, the environment is evaluated much higher than the economic aspect whereas the weight of economic aspect is much higher than one of environment according to the judgment of managers of Petrovietnam. If we give equal priority to the perspectives of multi-stakeholder we could get the average value of sustainability assessment. The final ranking order that incorporates multi-stakeholders inputs is shown in Table 11. It indicates that the most appropriate feedstock for biodiesel based current condition in Vietnam is WCO and followed by jatropha and fish fat.

Table 11. The overall rank of the alternatives incorporated multi-stakeholders

Alternative	**Jatropha**	**Fish fat**	**WCO**
Final weight	0.3484	0.2976	0.3540
Ranking	2nd	3rd	1st

The weights of alternatives with respect to each criterion are shown in Table 12. In the economic aspect, fish fat is considered as the most preferred with regard to investment cost and operation cost but it is the least preferred with respect to profit, while jatropha along with waste cooking oil is given higher priorities with respect to profit. In other words, in the opinion of multi-stakeholders, if fish fat was chosen to produce biodiesel, it would reduce the investment cost and operation cost but get lower profit. For the environmental aspect, the result shows that jatropha has the best impact on CO_2 and NO_x emission but the others could have more positive impact on land use. For the technical aspect, the weights of three alternatives are almost equivalent under safety criterion, jatropha could be the most efficient and waste cooking oil has the highest weight with respect to applicability aspect. For the social aspect, the weights of these feedstock options are quite close but it is found that waste cooking oil is most preferred with respect to social acceptability and followed by fish fat and jatropha. The weights of alternatives in political aspect show that jatropha and waste cooking oil could be supported by the policy of biodiesel much better than fish fat. Lastly, multi-stakeholders judge jatropha as the best selection for the ability of job creation in biodiesel production in comparison with the others.

Table 12. The priority weights of alternatives with respect to each criterion (Meanings of abbreviations may be found in Table 2).

Economic aspect			**Environmental aspect**			**Technical aspect**			**Social aspect**		
I.	J.	0.229	***CO_2***	J.	0.446	***S.***	J.	0.300	***Soc.***	J.	0.324
	F.	0.458		F.	0.225		F.	0.316		F.	0.298
	W.	0.313		W.	0.329		W.	0.385		W.	0.378
P.	J.	0.414	***NO_x***	J.	0.519	***E.***	J.	0.161	***Po.***	J.	0.414
	F.	0.181		F.	0.233		F.	0.464		F.	0.181
	W.	0.404		W.	0.248		W.	0.375		W.	0.404
O.	J.	0.270	***Land***	J.	0.149	***A.***	J.	0.214	***Jo.***	J.	0.438
	F.	0.412		F.	0.455		F.	0.345		F.	0.268
	W.	0.318		W.	0.396		W.	0.441		W.	0.294

3.6. Sensitivity analysis

The sensitivity analysis of the economic aspect is shown in Table 13. It indicates that there was no change in the ranking of alternatives when the priority value was varied. But the sensitivity analysis of technology indicates that one rank reversal was occurred when the priority of technology increases beyond 0.48. The rank of jatropha would decreases from 2^{nd} to 3^{rd} whereas fish fat has rank reversal. This means that the technical aspect prefers fish fat than jatropha in biodiesel production. For social and environmental aspects, the result also shows that there is a reversal of ranking order when the priority of society come over 0.358 or one of environment come over 0.805. So it is very clear that the social and environmental aspects affect the rank of jatropha positively and one of WCO negatively. The result of sensitivity analysis also indicates that the change of ranking is not highly sensitive to small changes in criteria weight.

Table 13. The sensitivity analysis of each criteria

	Aspects						
	Economic	**Technology**		**Society**		**Environment**	
	Priority						
	0.000÷1.000	*< 0.480*	*>0.480*	*<0.358*	*>0.358*	*<0.805*	*>0.805*
WCO	1st	1st	1st	**1st** ↔	**2nd**	**1st** ↔	**2nd**
Jatropha	2nd	**2nd** ↔	**3rd**	**2nd** ↔	**1st**	**2nd** ↔	**1st**
Fish fat	3rd	**3rd** ↔	**2nd**	3rd	3rd	3rd	3rd

4. Conclusion

The study provides a new approach to investigating sustainability of biodiesel in Vietnam that makes an overall review for the feasibility of biodiesel application under multi-stakeholders' perspective. To our knowledge, most of the previous studies of biodiesel in Vietnam mainly focused on the technology of biodiesel production (Ha, 2009; Thinh, 2011) and a few calculated the environmental impacts and economic impacts, such as the study of Le (2013). These previous studies did not consider all sustainability issues connected with biodiesel production and use. This study serves as another part to complete the comprehensive evaluation to determine the direction of biodiesel in Vietnam in the future.

The sustainability assessment of biodiesel was evaluated by multi-stakeholder to provide a guidance for choosing the appropriate feedstock among some feasible materials, such as WCO, jatropha oil and fish fat according the current conditions in Vietnam. The evaluation incorporates four most important criteria that are technical, social, environmental and economic aspect and 12 sub-criteria. AHP is applied to make the priority ranking of these aspects and alternatives. The sustainability assessments were checked if consistence ratio is less than 0.1 to ensure that the judgments of multi-stakeholder are consistent with AHP model. In the judgment of experts, the priority of economic and environmental aspect was evaluated much higher than social and technical aspect. It is also given that the best feedstock for biodiesel production in Vietnam is WCO and the least favorable option one is fish fat. The sensitivity analysis was obtained by using Super Decision Software. Changing the weight of economic aspect would not change the rank of alternatives that are WCO > jatropha > fish fat. Changing the weight of technical aspect over 0.480 would result in rank reversal between jatropha and fish fat. The sensitivity analysis also indicate that social and environmental aspect affects jatropha positively and WCO negatively. The rank of WCO would be changed from 1st into 2nd and one of jatropha is reverse when the weight of social and environmental aspect increases more than 0.358 and 0.805, respectively.

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