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A VALUE TREE FOR MULTI-CRITERIA EVALUATION OF SUSTAINABLE AVIATION FUELS

Salman Ahmad[1], Jamal Ouenniche[2], Phil Greening[1], Ben Kolosz[3], John Andresen[3], Mercedes Maroto-Valer[3], Bing Xu[1*]
[1]Edinburgh Business School, Heriot-Watt University, Edinburgh, United Kingdom
[2]Business School, University of Edinburgh, Edinburgh, United Kingdom
[3]Research Centre for Carbon Solutions (RCCS), Heriot-Watt University, Edinburgh, United Kingdom

ABSTRACT

Sustainable aviation fuels (SAFs) can play a crucial role in reducing the aviation industry's carbon footprint. Unlike conventional jet fuel production, SAFs could be produced via a combination of chemical processes and feedstocks. However, current studies have primarily focused on the techno-economic analysis of a single conversion pathway (chemical process plus feedstock), there is a lack of study on multi-criteria evaluations of multiple conversion pathways simultaneously. In this paper, a survey instrument is developed in which 106 experts participated in evaluating thirty-eight performance criteria across six production technologies or conversion pathways along the SAF supply chain. A generic value tree is thus obtained. The recommendations of this work are to be utilized as a foundation for stakeholder assessment of SAF planning.

Keywords: sustainable jet fuels, value tree, environment and climate change, multi-criteria decision analysis (MCDA)

NONMENCLATURE

Abbreviations	
GHG	Greenhouse gas
SAF	Sustainable aviation fuel
IATA	International Air Transport Association
MCDA	Multi-criteria decision analysis

1. INTRODUCTION

The transport sector relies on petroleum-based fuels and these fuels contribute 19% of global manmade carbon dioxide (CO_2) emissions [1]. Within transportation, the commercial aviation sector shares 2%-2.6% of annual global CO_2 emissions. In 2012, this amounted to 698 million tons of CO_2 [2]. The International Air Transport Association (IATA) estimates global air passenger numbers to reach 7.2 billion by 2035 [3]. Likewise the overall aviation industry activity is estimated to grow by 4.5-4.8% annually [4]. As a result aviation's contribution to fossil emission may reach 3% by 2050 [5]. A long-term aspirational goal set by IATA is to reduce industry's net carbon emissions by 50% in 2050, compared to 2005 levels while achieving net zero emission by 2020. In this regard, SAF is conceived to play a major role [6] and it is believed that 20% inclusion SAF may make a substantial impact by 2030 [7]. Other strategies to mitigate emissions are: new aircrafts; engine and fuselage modification, and optimized take-off and landing routines, to name a few [8].

Unlike conventional jet fuel, there are several ways in which various feedstock and chemical processes can be combined to make sustainable aviation fuel [9–12]. Therefore, selecting a particular conversion pathway (chemical process plus feedstock) becomes an important production decision amid high level of uncertainty. So far, SAF pathway evaluation has been dominated by techno-economic analysis [13,14]. Traditional cost-benefit analysis and net present value may be useful, but the complexity of the problem warrants multi-criteria decision analysis (MCDA) to be considered to support decision-making [15].

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[*] Corresponding author. Tel: +44(0)131-451-3294. Email: b.xu@hw.ac.uk.

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MCDA has been used in different applications such as evaluating energy strategies [16]; prediction models [17,18], biofuel policies and biofuel options [19,20]. Less attention has been paid on the low carbon aviation fuels. Only [21] has proposed an MCDA framework to evaluate the competing low carbon jet fuels production options without integrating stakeholders' preferences into their empirical example. Therefore, the aim of this paper is to fill this gap by developing a multi-criteria model that integrates stakeholders' perspectives into sustainable aviation fuel production options.

2. VALUE TREE FRAMEWORK

2.1 *Value Tree Development*

Value trees are part of multi-criteria decision analysis tool kit. They support stakeholders to evaluate various options with a hierarchical framework to organize criteria [22].

This study commenced with criteria identification for evaluating various pathways for SAF production from the literature. A large body of literature have looked into the assessment of low carbon fuels for road transportation [23,24]. Another line of literature is the techno-economic analysis of a specific SAF pathway [2,3,7,25–27]. Owing to the similarities, both lines of enquiry were considered for criteria identification.

2.2 *Preference elicitation model*

Expert elicitation plays a crucial role when data is sparse. In this research, data providers from the aviation fuel field were surveyed through an online questionnaire. To be able to reach mutually agreed assessment criteria, Delphi method is leveraged in this study. An extensive literature review was conducted, and a preliminary value tree was developed.

Experts are then asked to give their ratings on a five-point Likert scale varying from Very Important (5) to Negligible (1). A sixth category, Not Applicable, is also included. The category is added on the pretext of any identified criteria not suitable at all. Furthermore, participants are asked to provide their feedback on the wording of criteria, or any additional criteria deemed necessary for the value tree.

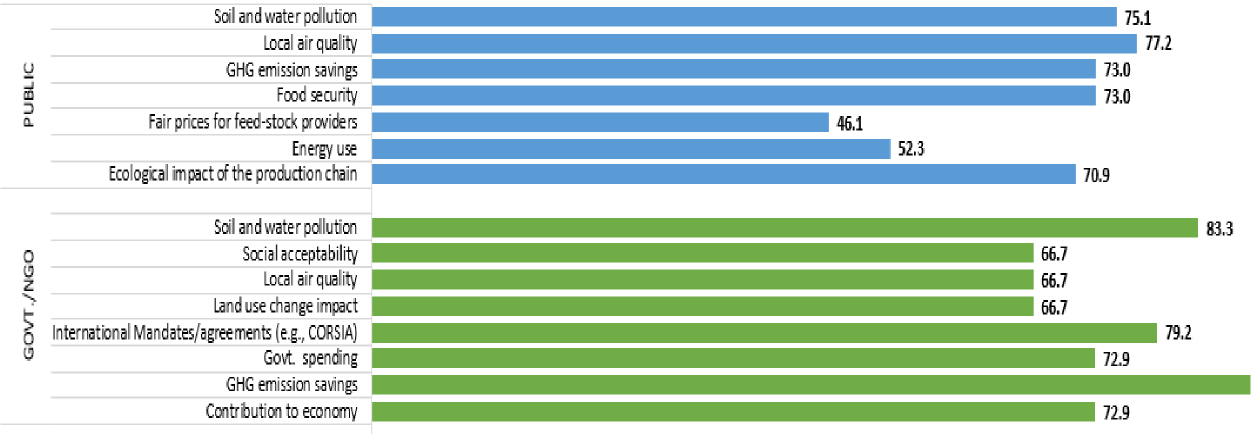

Fig 1 Degree of Importance of Criteria for Govt/NGO and Public Sector Stakeholder Groups

2.3 *Key metrics*

To determine which criterion to be accepted or to be removed from the aggregate value tree, or needs re-evaluation, two metrics are calculated. They are (1) Degree of importance index and (2) Degree of consensus index - borrowed from [22].

2.3.1 *Degree of importance index*

For each criterion i, the degree of importance index (II_i) is calculated using the following equation:

$$II_i = [\{(100 \times No.of\ \text{'very important' responses}) + (75 \times No.of\ \text{'important' responses}) + (50 \times No.of\ \text{'moderate' responses}) + (25 \times No.of\ \text{'not important' responses}) + (1 \times No.of\ \text{'negligible' responses})] - (100 \times No.of\ \text{'not applicable' responses})\}]/Total\ No.of\ respondents$$

Thus, the numerator of the degree of importance index is a weighted sum of the Likert-scale evaluations adjusted for the number of 'not applicable' responses. This ratio indicates the importance level of each criterion by respondent.

2.3.2 Degree of consensus index

This index reflects the level of agreement of participants regarding the importance of criteria. Three categories of importance are devised: Category A comprises 'very important' and 'important' responses; Category B comprises 'moderate' responses, and Category C comprises 'not important' and 'not applicable' responses.

There is no final value available for setting the threshold for two metrics. We followed the literature [19] and adopted a 50% threshold for degree of importance and consensus metrics is used for developing an aggregate value tree.

3. RESULTS

This paper presents the preliminary results. The survey is ongoing. In this round, a total of 102 data providers from low carbon fuels/aviation sector were identified and contacted via email. 6 email contacts bounced back. So far, the response rate is 26% (i.e., 25 out of 96 recorded their responses).

3.1 Importance index

We computed the importance index of each criterion across the seven stakeholder categories. Fig 1 provides details on the relative importance of each criterion for Public and Govt. /NGO stakeholder groups. Soil and water pollution is the most important criterion for public sector group, while GHG emission savings is the most important for government/NGO stakeholder group.

Fig 2 shows the criteria weights for airliners and aircraft manufacturers. For airliners, fuel safety is the most important criterion (93%) closely followed by fuel cost (88%). Aircraft manufactures focus more on the technical criterion of SAF flash point (80%) followed by conventional fuel compatibility criterion (73%). It should be noted that survey respondents suggested that the technical characteristics of SAF be summed in one criterion of conventional fuel compatibility. A similar suggestion was made by producers for "process efficiency" and "process yield". Capital and operational costs were rated at 85% and 77% respectively by producers. For feedstock providers, economic factors of profitability (85%) and land productivity (79%) were the most important criteria. For other criteria importance refer to Fig 3.

The two least important criteria were recorded for the public sector stakeholder. They being, fair prices for feedstock providers (46%) and energy use (52%).

3.2 Consensus index

Most criteria fell under category A of consensus. Crop diversification, fuel density, energy use, and fair prices for feedstock providers got into category B and C.

Based on a 50% threshold for each criterion, 32 out of 38 are retained in the value tree; 6 needs further investigation while one Local air quality is eliminated from the tree.

Criterion	Further action
Fuel density	Next round
Crop diversification	Next round
Energy use	Next round
Fair prices for feed-stock providers	Next round
Green branding	Next round

Table 1 Criteria requiring further investigation

Fig 2 Degree of Importance of Criteria for Airline and Aircraft Manufacturer

Fig 3 Degree of Importance of Criteria for Feedstock Providers, Producers and Distributors

4. CONCLUSIONS

SAFs have yet to become a major factor in aviation sector. Environmental, economic and sustainability issues along with technical factors makes decision-making in SAF a complex task, which requires the utilization of multi-criteria decision-making methods to assess SAF production alternatives.

In assessing alternatives, it is essential to adequately identify the relevant performance criteria under which SAF production alternatives will be assessed.

This study proposes a methodology to define a criteria framework for SAF assessment. A comprehensive literature review provided a preliminary value tree. A structured expert elicitation was conducted by means of an online survey. The output of the process is an aggregated value tree of criteria distributed among seven stakeholder groups across the supply chain.

Future work will involve a higher number of respondents for enhanced results impact. The findings of this study have substantial implications for SAF project stakeholders, as it provides the means by which the various SAF pathways will be assessed.

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