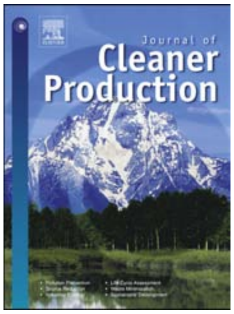
Paper:
Upham, P and Smith, B (2014) *Using the Rapid Impact Assessment Matrix to synthesize biofuel and bioenergy impact assessment results: The example of medium scale bioenergy heat options.* Journal of Cleaner Production, 65. 261 - 269. ISSN 0959-6526

10.1016/j.jclepro.2013.09.041



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PII: S0959-6526(13)00654-9
DOI: 10.1016/j.jclepro.2013.09.041
Reference: JCLP 3691

To appear in: *Journal of Cleaner Production*

Received Date: 9 January 2013
Revised Date: 26 September 2013
Accepted Date: 27 September 2013

Please cite this article as: Upham P, Smith B, Using the rapid impact assessment matrix to synthesize biofuel and bioenergy impact assessment results: the example of medium scale bioenergy heat options, *Journal of Cleaner Production* (2013), doi: 10.1016/j.jclepro.2013.09.041.

7,553 words including the regular tables and references

Using the rapid impact assessment matrix to synthesize biofuel and bioenergy impact assessment results: the example of medium scale bioenergy heat options

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Revised format version submitted 26th September 2013

Abstract

Despite the potential opportunities, there remain widespread concerns about bioenergy and biofuel feedstock sustainability, assessment and policy. This paper illustrates the value of the Rapid Impact Assessment Matrix (RIAM) for transparently presenting evidence and judgements relating to four biomass options that are potentially suitable for supplying heat to a university-sized facility. The RIAM approach provides comparable scores for: soybean biodiesel, waste cooking oil biodiesel, anaerobically co-digested food waste and manure; and timber pellets made from sawmill by-product. The high-level nature of the RIAM allows the user to structure a broader range of considerations and contingencies than the life cycle approach embodied in EU biofuel legislation. We advocate the RIAM not as a substitute for LCA or any other form of assessment in a bioenergy context, but as a means of synthesising the results of different types of impact assessment and for making broader debates and uncertainties explicit, such that non-specialist knowledge users are both guided and made aware of differing scientific and stakeholder opinion.

Keywords
Bioenergy, heat, sustainability assessment, rapid impact assessment matrix, appraisal

1. Introduction

Although still routinely treated as a technical exercise, the assessment of bioenergy and biofuel systems is often contentious (IPCC, 2009). In Europe, legal targets on biofuel use are subject to on-going change as the adverse consequences of incentivising the use of feed crops for fuel become increasingly difficult to ignore (EC, 2012a). In the scientific literature there is also fundamental debate over appropriate assessment methods and assumptions (Giampietro et al.), including heuristic assumptions, such as the lower impact of second generation feedstocks (Melamu and Von Blottnitz, 2011). As ever, there is also the inherent issue of the relative weighting of different impacts (Myllyviita et al., 2012). For policymakers of any description, the complexity of the situation is compounded by the breadth of potential feedstock and conversion technology combinations, by the range of variously used indicators (Arvidsson et al., 2012) and by the sheer quantity of information.

Arguably, scientific policy advisors should guide while making key judgements transparent. It is perhaps surprising that in the scientific biofuels and bioenergy literature, there is relatively little work on tools to aid policy communication and deliberation in this area, particularly deliberation by non-specialists. There is also relatively little work comparing alternative assessment methods in this context. An exception is Buytaert et al. (2012), who conclude that none of the tools that they examine (criteria and indicators, life cycle assessment (LCA), environmental impact assessment, cost benefit analysis, exergy analysis and system perturbation analysis) are able to perform a comprehensive sustainability assessment of bioenergy systems. While one option is to view information on biofuel impacts obtained from a variety of studies and methods through one perspective, such as ecosystem services (Gasparatos et al., 2013), this poses as my problems as it solves [ibid]. Here, we take the view that there is utility in tools that aim at relatively transparent synthesis of relevant information, that simplify (Thornley and Gilbert, 2013) that guide via expert judgement and that make the reasons for those judgements clear (Pastakia, 1998; Pastakia and Jensen, 1998).

The purpose of the paper is thus three-fold. First, we show how the RIAM (Rapid Impact Assessment Matrix) can perform the above role, being used to structure a range of evidence on the performance of selected feedstocks and associated conversion technologies. This does not involve exhaustive data collection, but rather the use of evidence considered representative by the analysts. Second, we show that the RIAM helps to structure evidence from a variety of sources and derived from a variety of methodologies. Thirdly, we use the RIAM results to discuss wider issues relating to bioenergy impact assessment. While the case study that we use relates to the UK, specifically options for supplying heat to a university, most of the issues are internationally applicable.

2. Material and methods

We use the RIAM (Pastakia, 1998) to collate, systematically evaluate and compare candidate bioenergy technology-feedstock combinations in terms of their potential value for space heating at a university-sized facility. The options considered are: soybean biodiesel; waste cooking oil biodiesel; gas from anaerobically digested food waste and manure; and virgin timber pellets.

As an impact assessment method, the RIAM reflects the recognition that simple, semi-quantitative assessment tools can be both appropriate and beneficial (Pastakia and Jensen, 1998; Canter, 1996), particularly in cases where the number of candidate policy, siting or technology options is such that full Environmental Impact Assessment (EIA) or site-specific life cycle analysis would not be plausible. The RIAM is also useful for organising, analysing and presenting the results of pre-existing impact assessments (Kuitunen et al., 2008; Lee et al., 1999), allowing the results of disparate studies to be brought together in a logical and comprehensible manner (Ljäs et al., 2010).

2.1 Heat supply: candidate bioenergy/biofuel feedstocks and technologies

The heating sector, largely fuelled by fossil energy, accounts for nearly half of the UK's final energy demand, generating around a third of the UK's total greenhouse gas (GHG) emissions (DECC, 2012a). As a result, UK policy has recognised heat supply as an aspect of renewable energy usage that needs to increase, with bioenergy viewed as particularly promising (DECC, 2012b) – though more recently UK policy has signalled that it will end subsidies for the use of wood in dedicated electricity generation plants in the medium term, judging these ineffective in carbon abatement terms (DECC, 2013). In general, a variety of concerns remain in relation to bioenergy, here defined as including biofuels. Key issues include the environmental and social performance of different forms of bioenergy in terms of their GHG emissions reduction potential, competition with food supply, air quality impacts, land and water resources and biodiversity impacts as well as issues relating to logistics and economics (CCC, 2011).

The biomass feedstocks most widely used to generate heat are derived from food and fodder crops, energy crops, agricultural residues, virgin wood, wood residues, wet waste and biodegradable solid waste (CCC, 2011). While these are largely solid fuels, more recently biodiesel has been recognised as an option for emission reductions in the heating sector (CCC, 2011). In the UK, biodiesel for heating is available in a 30% blend with kerosene (standard heating oil) (Macor and Pavanello, 2009); our first two candidate feedstocks are biodiesel and waste cooking oil (WCO). In the first months of 2012, 53% of biofuel supplied in the UK was biodiesel, of which 45% was from used cooking oil, the major suppliers of which are registered as the Netherlands, the UK, and the United States (DfT, 2012). We consider both biodiesel feedstocks, though it should be noted that in the UK bioliquids are currently not included under the Renewable Heating Incentive (RHI) due to government concerns about sustainability and competition with transport, with plans being to only support their use in non-domestic combined heat and power (CHP) (DECC, 2012c).

Regarding the third candidate technology of anaerobic co-digestion, with some higher education institutions now being the size of small municipalities (Zhang et al., 2011), a university campus generates considerable quantities of food waste (the case study, the University of Leeds, UK, generated 36 tonnes in 2011). Additionally universities often have agricultural units: the University of Leeds maintains three research farms that produce manure (Schmieder, 2012). Co-digestion of wastes has been recognised as attractive relative to digestion alone, improving digestion performance by stabilising the AD process, thereby increasing digestion rates and biogas yields (Khalid et al., 2011).

Turning to pellets, the fourth option considered here, these are produced by compressing fine sawdust in a die, with the heat generated melting the lignin and binding the particles together (Thornley et al., 2008). The main advantages of pellets over woodchips or other forms of woodfuel are that they are more convenient for the end-user in terms of handling properties and fuel consistency. This decreases the likelihood of reliability problems, such as blockages in feed handling systems (Thornley et al., 2008). Regarding Forest Stewardship Council (FSC) timber pellets from sawmill by-product, while importation to the UK market is more than possible, it is also likely that the FSC brand is sufficiently well recognised in the UK to justify the assumption that these pellets will come from FSC forests. The life cycle performance of wood pellets is strongly influenced by the source of the energy used for pelletisation (Reijnders, 2011).

2.2 The Rapid Impact Assessment Matrix (RIAM) method

The RIAM is an impact assessment method proposed by Pastakia (1998) as a response to concerns that EIA involves subjective judgments of the possible impact, spatial scale and potential magnitude of future events. Pastakia (1998) identifies this issue as relating not simply to the role of subjectivity itself, which is to some extent unavoidable, but specifically to the way in which the reasons for judgements and/or scoring in EIA can be obscured by numerical values. The RIAM is intended to improve the transparency of judgements in EIA by decomposing the process, standardising and codifying it, such that decision processes are explicitly recorded. Overall performance of alternatives is evaluated on the basis of explicit assessment criteria and for each of these, an individual score is determined for a given technology-feedstock option. This gives a total score for each option, allowing both for ready comparison between options as well as inspection of the reasons for the score. The scoring method is available in Pastakia (1998). Here for brevity we limit the number of reference sources per judgement.

3. Results and analysis

This section presents the RIAM results, providing overall sustainability performance scores for each assessment criteria in Tables 1-4. In a modification of the RIAM method, the symbol (•) is used to demonstrate where we have less confidence in the stated value than on average. The reasons for each score are provided; details of the sustainability score method and calculations are appended <Appendix 1> and <Appendix 2> respectively. In the RIAM method, the A1 term for the importance of the impact is given a higher (additional one third) weighting than the other terms. Clearly this will affect the final score set, as intended, but it is arguably not so high as to dominate. In the RIAM, each score is relatively explicitly justified, but is also contestable: the point is to not to achieve definitive scoring, but to make the associated judgements explicit so that decision-makers or deliberators can better understand the issues, their importance and the performance of each option in those terms.

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Using the RIAM, it is relatively straightforward to visually distinguish the final performance scores and profiles (Figures 1-4) of each technology-feedstock combination. Comparing Figures 1-4, it can be seen that soy based biodiesel scores relatively poorly on all assessment criteria. Considering the life-cycle of impacts of this option, and assuming that it is currently not possible to ensure avoidance of direct and indirect land use change with bioenergy based on food crops, we can conclude that environmentally and also in other regards, the various risks associated with this option are relatively high.

Virgin-timber pellets from sawmill by-product offer more reliable GHG reductions by comparison. Nonetheless, uncertainties relating to the value of FSC certification as regards the impacts of industrial forestry on biodiversity, soil and land resources, as well as the long regrowth time for mature forests and issues regarding the baseline for GHG accounting, keep this option at third best. WCO-based biodiesel, being a problematic waste product with limited emissions during the production life-cycle, offers positive environmental benefits and emissions savings in proportion to the concentration of its fossil fuel blend. WCO-based biodiesel combustion also benefits from being judged as having lower impacts on air quality and fewer technical and logistical concerns than biomass boilers, particularly in terms of maintenance and storage. Nonetheless, in the UK RHI payments will not be available for heating from bioliquids, reducing the attractiveness of WCO-based biodiesel for heat supply[1].

Anaerobic digestion (AD) of the University's food-waste and manure from research farms is judged as the best option in principle. Fugitive methane emissions aside, this option has the ability to avoid CO_2 emissions through replacing fossil natural gas with renewable biogas, to reduce the impacts of existing waste management strategies whilst also attracting a subsidy under the RHI. The feedstocks are free of charge and the cost of waste collection is neutral relative to existing disposal measures. However there are significant logistical considerations attached to this option, particularly relating to the location of the AD facility. Issues of heating back-up or supplementation also apply, as they do to all of the technologies considered.

4 Discussion

The RIAM method facilitates a relatively transparent comparison of options (Pastakia, 1998) in common with other methods such as multi-criteria assessment (Janssen, 2001). Rather than avoiding value judgements, particularly the need to make judgements that arise from applying differing weights to the criteria and/or to the available knowledge, the method encourages a statement of what information the analyst considers relevant. The approach does not oblige a formal mathematical weighting of criteria: multi-criteria decision analysis (MCDA) is arguably more useful for investigating the values of individuals, whereas the strength of the RIAM is in presenting

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[1] There is also an issue here in relation to second order impacts. In the pellets case we take into account the impacts of forestry, despite the pellets being a by-product, as we are using the RIAM to take a broad systems-level perspective. For consistency it could be argued that we should therefore also consider the impacts of the agricultural production of feed oil crops. We choose not to do this because we want to include issues related not only to use of the forestry by-product but also to forestry, particularly industrial forestry.

evidence alongside a judgement of that evidence, so inviting discussion, agreement and disagreement. In common with other assessment approaches it is also possible to misuse the RIAM: to define boundaries and to select and present evidence to suit one's purpose. In this regard the integrity and objectivity of the user remain fundamental.

This open potential for critique makes the RIAM potentially useful for deliberative contexts: users individually or in a group can readily re-score an option, introduce new and other evidence and change the implicit or explicit weightings. For example, in the present case, the method awards anaerobic co-digestion the best overall impact and performance profile, but logistical or practical constraints may in practice or for some users render one of the other options preferable. A waste cooking oil (WCO)-based biodiesel blend may be an easier option for facilities with in situ oil-based heating, particularly if this is not in near-term need of replacement. Moreover, the results are contingent on present conditions: future changes in subsidy regulation could also make waste-based biodiesel more attractive. In general, industrial bioenergy is very much dependent on, and co-evolving with, existing policy and regulation.

There are also methods-related issues that high-level, organising, framework approaches such as the RIAM can take into account and relay to decision-makers. The issues themselves are not new – they relate to all impact assessment methods – but they are normally not referred to in the recommendations inferred from impact analysis. In contrast the RIAM can include analytic debate and uncertainty in the main body of evidence that the analysts consider.

The main such issue relates to the choice of analytic boundary and hence the appropriate impact assessment methods (we could also include indicators). Under the Renewable Energy Directive, biofuels and bioenergy feedstocks are subject to performance criteria, intended to act as protective constraints, against which feedstocks are to be assessed using life cycle analysis and project level environmental assessment. Hence the European Parliament secured conditions under which biofuels must deliver life-cycle CO_2eq savings of initially 35%, then 50% from 2017, rising to 60% relative to fossil transport fuel when produced from new refineries that come on-stream from 2017 onwards (European Parliament, 2008). Additional environmental criteria also prohibit the use of biomass from biodiverse, high-carbon stock and wooded land, where conversion to biomass production for biofuels has taken place in or after January 2008 (European Parliament, 2008)[2].

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[2] The European Biofuels Technology Platform is a useful source of updated web-links to biofuel and bioenergy policy, legislation and EC-commissioned studies: http://www.biofuelstp.eu/legislation.html

After four years of on-going contestation, the European Commission in October 2012 published a proposal for additional safeguards, namely: (a) a reduction of the permissible contribution of feed crops to its 10% renewable transport fuels target to 5%; (b) increasing the minimum GHG saving threshold for new refinery installations to 60%; (c) additional incentives for 2nd and 3rd generation biofuels; and (d) the inclusion of include indirect land use change (ILUC) factors in reporting (EC, 2012a). The methods to be used for verifying compliance with the other sustainability criteria are a form of project- or farm-level environmental audit and an increasing number of certification schemes are available for this purpose (EC, 2012b).

The method adopted in law for determining GHG performance in Annex V(C) of the Renewable Energy Directive could be described as a partial attributional LCA (ALCA) approach that focuses on GHG emissions only. These emissions are calculated for specific categories: the extraction or cultivation of raw materials; carbon stock changes caused by land-use change; processing; transport and distribution; fuel in use; any emission saving from soil carbon accumulation via improved agricultural management; any saving from carbon capture and geological storage or replacement; and any saving from excess electricity from cogeneration (Janssen, 2001). In July 2013, in relation to the Fuel Quality Directive, the European Parliament's Environment Committee voted for mandatory reporting of iLUC factors for first generation crops and a 5.5% limit on an energy content basis on the use of first generation crops (cereal and other starch rich crops, sugars and oil crops) from 2020 (Euractive, 2013).

European regulatory decisions in this context are subject to on-going change and both political and scientific debate, amplified by the investments that policy has now induced. Although European regulation of biofuel production is at the time of writing heading in a strengthened direction, it remains to be seen whether this combination of sustainability assessment methods and associated incentives will be sufficient to shape the behaviour of the biofuel producers in the intended directions. Land use modelling (IFEU, 2009) suggests the need for methods using broad analytic boundaries that capture changes in relevant systems, such as consequential LCA (CLCA). In addition, analysts point to the need to be careful about baseline assumptions relating to carbon sequestration by biomass, particularly when harvesting live trees for bioenergy (EEA, 2011). While CLCA to inform crop and region-specific iLUC factors would seem a methodological option it is likely that significant uncertainties and debate will remain, particularly as iLUC factors are likely to involve averaging across locations. In general, bioenergy and biofuel impact assessment continues to push the limits of impact assessment methods.

It is particularly in this type of context that we suggest the RIAM has potential for its ability to explicitly collate information on scientific uncertainty, disagreement and knowledge deficits. Biofuels and bioenergy are arguably the most scientifically contested of low carbon mitigation options and this contestation is explicitly recognised in the IPCC Special Report on Renewable Energy (IPCC, 2009). A variety of concerns about bioenergy risks have been evident in the scientific literature in addition to the above for a number of years (Upham et al., 2009), as well as disputes regarding the life cycle performance of feed crops for biofuels (Pimental et al., 2008). In addition the vexed phenomenon of iLUC is now formally acknowledged at EC level (Euractive, 2013). The RIAM cannot substitute for ALCA, CLCA, or detailed EIA, but it can be used to bring together information from these in such a way that analysts' weightings and selection of evidence are transparent.

5. Conclusions

Illustrative use of the RIAM in the context of bioenergy and biofuel options shows that soy based biodiesel scores relatively poorly on all assessment criteria; that virgin-timber pellets from sawmill by-product perform better, but that this performance is reduced by the various environmental impacts of industrial forestry; that WCO-based biodiesel offers positive environmental and logistical benefits but lacks a financial subsidy for heating purposes in the UK due to its prioritisation in policy for transport; and that anaerobic digestion of catering food-waste and manure from research farms offers the best environmental and financial option but involves logistical complications.

Impact assessment inevitably involves some degree of subjectivity and uncertainty (Morris and Therival, 2009). These vary by method, but typically include the choice of analytic boundary, treatment of trade-offs and choices; and presentation of numerical values that are themselves dependent on further assumptions and conventions of measurement and accounting. Structured impact assessment techniques reinforce these judgements by encoding them methodologically. Users, particularly policy users, may be more or less aware of their consequent limitations.

The RIAM can help to make value judgements explicit, though the role and integrity of the analyst are important in achieving this. In principle, it should be possible to further codify the RIAM scoring process and also to test for inter-scorer reliability. This has not been done in the present case, as the purpose is to illustrate the value of the method in a new context, rather than to develop it further. As a simple, score-based, organising framework, the RIAM has the capacity to present assessment material derived using social, economic criteria as well as environmental criteria. The method has the ability to make use of the results of different types of environmental assessment and to make uncertainty and lack of knowledge explicit. Here we have illustrated its use in the context of heat supply for a university-scale facility. It is likely that the RIAM has further potential for organising assessment results for discussion in other contentious environmental contexts. The RIAM cannot substitute for detailed ALCA, CLCA or EIA, but it can set these and other modelling results in a context that encourages an awareness of their conditionality. In this way we would suggest that, despite being a simple tool that largely synthesises and weights detailed assessment results, the RIAM has the potential to facilitate informed debate and decision in bioenergy and biofuel contexts.

Acknowledgements

Thanks to anonymous reviewers for helpful comments and to James Dixon-Gough, Sustainability Officer at the University of Leeds, for comments during the initial research process. The views expressed here are those of the authors.

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Figure captions

Figure 1. Soybean biodiesel: boiler combustion

Figure 2. Waste cooking (vegetable) oil: boiler combustion

Figure 3. Anaerobic digestion of food waste and manure

Figure 4. Virgin-timber pellets for biomass boiler combustion

Key to Figures 1-4

Figure A1a: Scoring Criteria for each assessment criteria (Pastakia and Jensen, 1998, p.465)

Figure A1b: Conversion of ES score to Sustainability performance range bands (Pastakia and Jensen, p.466)

Table captions

Table 1. Rapid impact assessment matrix for soy-based biodiesel

Table 2. Rapid impact assessment matrix for waste cooking oil (WCO)-based biodiesel

Table 3. Rapid impact assessment matrix for anaerobic co-digestion (AD) of food waste and manure slurry

Table 4. Rapid impact assessment matrix for boiler combustion of FSC virgin wood sawmill by-product

Table 1. Rapid impact assessment matrix for soy-based biodiesel

Assessment Criteria	**Sustainability Rating**		**Justification**
GHG Emission Reductions	Sourcing Feedstock	-5	Cultivation is the major negative influence on life-cycle emissions from biodiesel feed-crops, particularly fertiliser production and application and crop processing (JNCC, 2009). With more stringent EC standards on GHG performance, soybean may become ineligible for EC biofuel targets (Tomei and Upham, 2009).
	Processing Biodiesel	-1	While the production stage of soy biodiesel generates GHG emissions, these are low relative to the cultivation stage (Zah et al., 2007).
	Transport	-4	Emissions associated with intercontinental transport constitute less than 10% of life-cycle emissions if by tanker ship (Zah et al., 2007).
	Overall Emission Reductions	-4	Energy intensive inputs are the norm when growing soybeans (Gibbs et al., 2008).
Land Use Impacting Emissions	Direct LUC	-5	Soybean cultivation continues to occur at the expense of vegetated land, generating a carbon debt. Land converted to agricultural land also leads to increased N_2O emissions (Gibbs et al., 2008).
	Indirect LUC	-4	As soybean expansion increases, smallholder farmers are pushed further into forestland, increasing deforestation (Nepstad et al., 2008).
Biodiversity	-3 •		Large monocultures, deforestation and adoption of GM soybeans has detrimental impacts on biodiversity (Raghu et al., 2006).

Land Resources	-3	Deforestation can increase soil erosion, reducing land fertility and productivity, further encouraging agricultural expansion and deforestation (Raghu et al., 2006).
Water Resources	-4	Excess nutrient application causes eutrophication and heightened nutrient levels in drinking water via leaching and surface runoff. Soybean cultivation is also water intensive, generating concerns over water availability (Mattsson et al., 2000). Mismanagement of agrochemicals has been a problem for human health in Argentina, a major producer of soybean (Tomei and Upham, 2009).
Food Availability	-4 •	Use of food-crops for biodiesel is likely to reduce the well-being of the world's poor through direct competition. Food cultivation may also be pushed to less productive land, reducing yields and potentially raising food prices (Lin et al., 2011).
Air Quality	-1 •	Relative to fossil fuel, biodiesel combustion reduces particulate matter (PM), hydrocarbons (HC), dry soot (DS) carbon monoxide (CO) and volatile organic compounds (VOCs) (Macor and Pavanello, 2009). Whether biodiesel combustion generates increased NOx emissions may relate to burner settings (ibid).
Economic Performance	-3	Soy based biodiesel is currently not cost competitive with fossil fuels and is less economically viable than woody biomass and waste cooking oil biodiesel. Additionally biodiesel is not currently covered under the RHI. As of 2010, the UK Department for Energy and Climate Change (DECC, 2010) take the view that that use of bioliquids made from arable crops for heating is not cost effective relative to options such as woody biomass.
Logistical Issues	-1 •	While blends of at least 30% appear to be capable of replacing fuel oil without noticeable changes in boiler performance,

		higher blends may impact on non-metallic parts (seals etc) (Krishna, 2001). While this may be a relatively minor issue to remedy, it is a potential constraint on use.

Table 2. Rapid impact assessment matrix for waste cooking oil (WCO)-based biodiesel

Assessment Criteria	Sustainability Rating		Justification
GHG Emission Reductions	Sourcing Feedstock	0	WCO is a waste material and hence requires no additional energy input at the feedstock production stage.
	Processing Biodiesel	-1	The production phase of WCO processing is relatively low in GHG emissions (JNCC, 2009).
	Transport	0	If WCO is collected as part of waste management, the only additional transport emissions will be from delivery of the final fuel.
	Overall Emission Reductions	5	Being a waste product WCO avoids emission intensive energy inputs directly, though there are associated transport and processing emissions.
Land Use Impacting Emissions	3		Collecting and processing WCO does not cause land use change directly, as it is a waste material.
Biodiversity	1		Collecting and processing WCO may improve biodiversity through pollution reduction associated with illegal waste practices and dumping (Krishna, 2001; Cchetri et al., 2008).
Land Resources	2		WCO avoids impacts upon land associated with crop cultivation and its collection reduces polluting discharges that can affect soil resources (Cchetri et al., 2008).
Water Resources	2		As for land above, however additionally WCO collection reduces illegal dumping and drain blocking, reducing pollution discharge into watercourses (Cchetri et al., 2008).

Food Availability	0	Being a waste product, WCO reduces ethical concerns about conflicts with food production.
Air Quality	1 •	In general studies show that, relative to fossil fuel combustion, biodiesel blends reduce smoke, other pollutants and in some cases NOx (Cchetri et al., 2008).
Economic Performance	-2	WCO biodiesel is around 2-3.5 times cheaper to produce and purchase than soy-based biodiesel (Demirbas, 2009). This is significant, as feedstock costs equate to approximately 70-95% of total biodiesel production costs (ibid). However WCO biodiesel is still not economically competitive with fossil fuels. WCO biodiesel is unlikely to be rewarded under the RHI except in conjunction with CHP (DECC, 2012d).
Logistical Issues	-1 •	While blends of at least 30% appear to be capable of replacing fuel oil without noticeable changes in boiler performance, higher blends may impact on non-metallic parts (seals etc) (Krishna, 2001). While this may be a relatively minor issue to remedy, it is a potential constraint on use.

Table 3. Rapid impact assessment matrix for anaerobic co-digestion (AD) of food waste and manure slurry

Assessment Criteria	**Sustainability Rating**		**Justification**
GHG Emission Reductions	Sourcing feedstocks	0	As both feedstocks are waste products there are no direct energy inputs associated with their sourcing.
	Reduced emissions from slurry and composting	3	AD reduces emissions of NH_3, N_2O and CH_4 associated with composting (DEFRA, 2011) and reduces methane emissions associated with untreated manure (Meyer-Aurich et al., 2012).

	Transport	0	Emissions savings from eliminating waste collection are matched by emissions from manure delivery. Utilising digestate would however reduce emissions from fertiliser delivery (Berglund and Börjesson, 2006).
	Overall Emission Reductions	4	AD generates no net increase in atmospheric carbon as CO_2 released from biogas combustion is part of the recent carbon cycle cycle (Ward et al, 2008). Biogas combustion also releases lower NO_x emissions compared to fossil fuels (Jingura and Matengaifa, 2009).
Land Use Impacting Emissions	3		Utilising digestate instead of fertilisers can reduce nitrogen leakage, but also indirectly reduce emissions from fertiliser production. AD of manure converts organic-bound nitrogen into ammonium which is more available to plants, allowing for higher fertilisation precision and less nitrogen leakage (Lukehurst et al, 2010).
Biodiversity	1 •		There is limited research on the impacts of utilising digestate or managing manure slurries on biodiversity, however reducing the possibility of eutrophication and improving soil structure are both likely. Nutrients from the digested material tend to be retained in the soil (Lukehurst et al, 2010).
Land Resources	1 •		Digestate can perform at least equally to artificial fertiliser (Holm-Nielsen et al., 2009). Digestate usage may also improve soil quality by improving structure, increasing water holding capacity, improving draining and increasing biological activity, all of which combine to reduce soil erosion (Boldrin et al., 2009).
Water Resources	2		AD produces digestate that contains nutrients that are readily available to crops (Jingura et al., 2009), thereby reducing leaching into surrounding watercourses, potentially by as much as 20% compared to raw manure or synthetic fertilisers (Börjesson and Berglund, 2007). Utilising digestate reduces nutrient leaching to watercourses and pollution from manure run-off (Chen et al, 2008). Even if

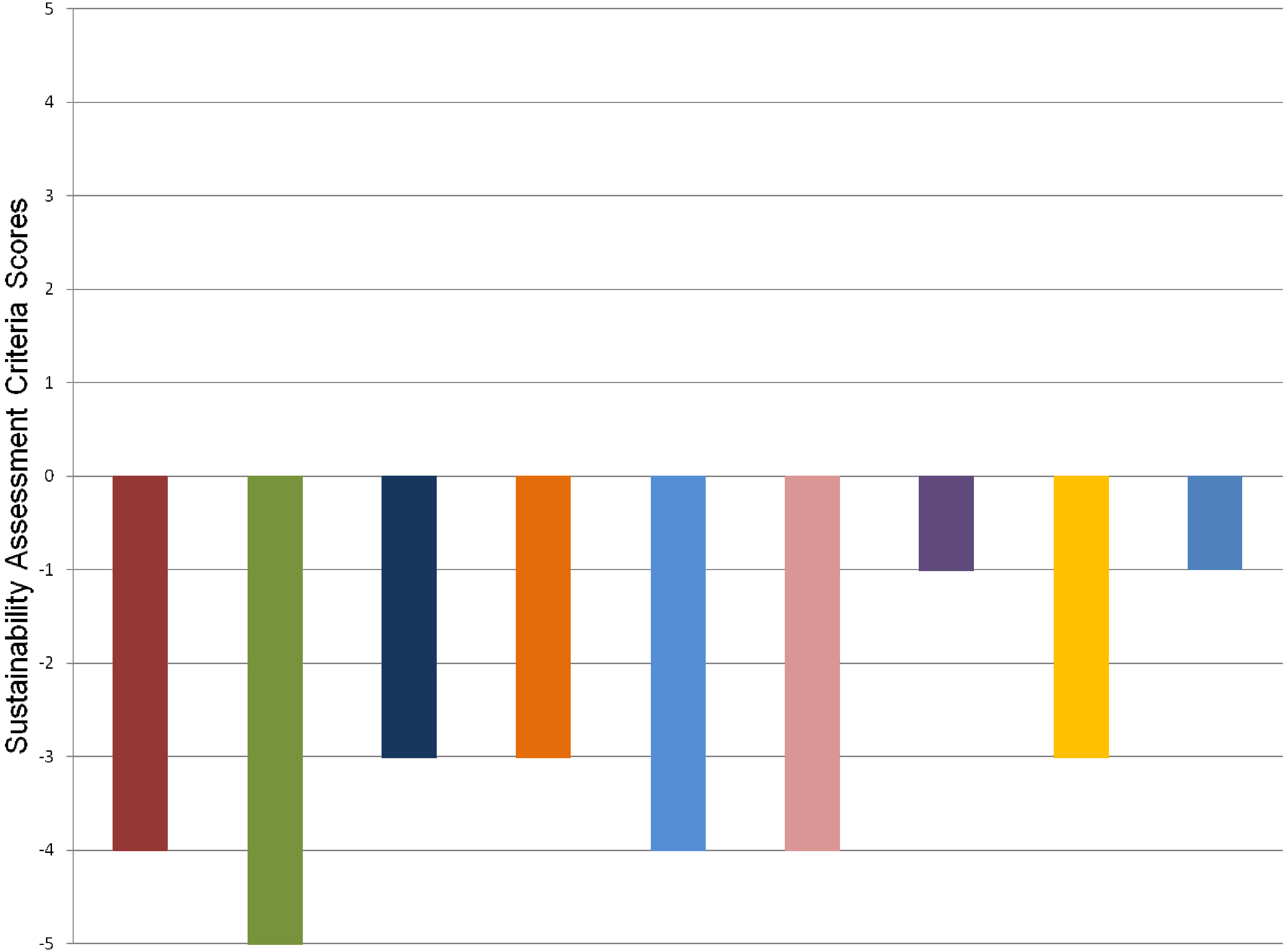
		digestate does pollute watercourses, AD removes around 70-90% of the BOD (Bywater, 2011).
Food Availability	0	Utilising food-waste and manure slurries for AD does not conflict with food production.
Air Quality	-1 •	AD reduces odour nuisances associated with manure spreading (Massé et al., 2011). During AD odorous compounds of manure are consumed by anaerobic bacteria, reducing odours by up to 80% (Monnet, 2003). Odour at the AD facility should be minimal due to the air-tight nature of equipment (Williams, 2012), but may still be a concern locally.
Economic Performance	3	Despite high setup costs, a return on investment could be rapid due to RHI payments, replacing costly fertiliser on research farms, eliminating feedstock purchases and reducing waste disposal costs. Schmieder (2012) estimate the cost of a small AD facility at the case study University of Leeds as £300,000 to £400,000, with a return on this investment in perhaps 8 years, accounting for all financial costs and benefits.
Logistical Concerns	-2 •	AD requires a suitable location and poses a fire risk that is similar to gas storage (Balsam, 2006). Although co-digestion of food-waste and manure significantly improve AD efficiency, stability and overall performance (Chen et al., 2008), AD requires regular and frequent monitoring (Balsam, 2006) to avoid costly downtime. Moreover, food-waste can have high concentrations of inhibitors of methane production (Banks et al., 2011).

Table 4. Rapid impact assessment matrix for boiler combustion of FSC virgin wood sawmill by-product

Assessment Criteria	**Sustainability Rating**	**Justification**

GHG Emission Reductions	Sourcing Feedstock	0 •	FSC requires that for every tree logged another is planted, such that, in principle, CO_2 emissions resulting from combustion will be absorbed during new tree growth (Lippke et al., 2011). If the land has been previously vegetated, however, carbon neutrality would not apply (Sikkema et al., 2010). Moreover carbon reabsorption is a decadal process in softwood forests (Zanchi et al, 2010).
	Pelletisation and Drying	-1	For pellets derived from by-products, the main sources of direct CO_2 emissions are feedstock drying, pellet production and transportation. Nonetheless suppliers estimate the energy input required for processing and producing the final pellet as only some 2.7% of the overall energy produced (Pelletshome, 2009).
	Transport	-1	While vehicle transport is required, transport efficiency can be high and a WCO-based biodiesel blend can be used in transport fleets.
	Overall Emission Reductions	4 •	Wood pellets avoid the large majority of direct CO_2 emissions relative to fossil fuels (Thornley et al., 2008). However there remains indirectly the issue of decadal sequestration timescales (Zanchi et al., 2010).
Land Use Impacting Emissions	0 •		Use of woodchip by-products avoids competition with food crops (Thornley et al., 2008). Pellet production using a by-product is not directly associated with land use emissions. Nonetheless there remains indirectly the issue of decadal sequestration timescales (Zanchi et al., 2010).
Biodiversity	0 •		Impacts on biodiversity are only indirectly associated with pellet production. FSC certification prohibits genetic improvement as well as excessive fertiliser and herbicide addition (Friedman, 1999) but nonetheless plantations change landscapes substantially. There is also no conclusive evidence on the influence of forest certification on biodiversity (Van Kuijk et al., 2009).
Land Resources	0		In principle there should be no significant direct impact on soil resources as FSC certified forests should ensure soil damage and compaction are minimised.

Water Resources	0	As above with respect to water resources.
Food Availability	0	Utilising wood pellets from sustainably managed forests avoids ethical debates regarding food availability and price rises (Monti et al., 2009).
Air Quality	-2	Filter control of air pollutants is necessary, as relative to fossil fuel, woody biomass combustion can lead to heightened NO_x, PM, ozone and NO_2 in ambient air. Additionally incomplete combustion can lead to further harmful emissions if not controlled (Nussbaumer, 2003).
Economic Performance	-3	Despite relatively low fuel costs, overall the cost of delivered heat is relatively high when efficiency issues and maintenance, service and delivery costs are included. Investment costs are higher than for oil or gas equipment (Schuller, 2004). In the UK at the time of writing, the Renewable Heat Incentive provides 4.9p per kWth under the highest tier for units between 200kWth and 1,000kWth (Ofgem, 2012).
Logistical Issues	-3	Fouling, slagging, corrosion and agglomeration are common in biomass boiler technologies, reducing efficiency and increasing emission releases and maintenance costs (Demirbas, 2005).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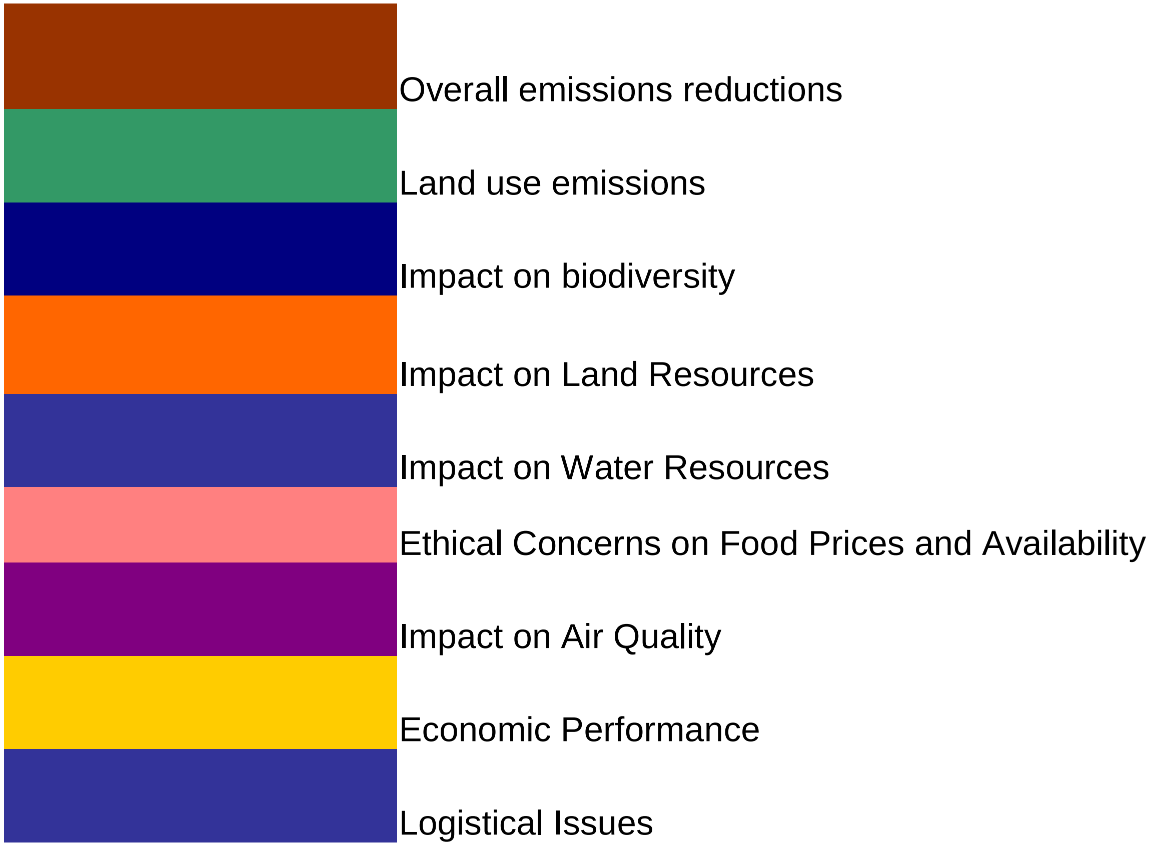
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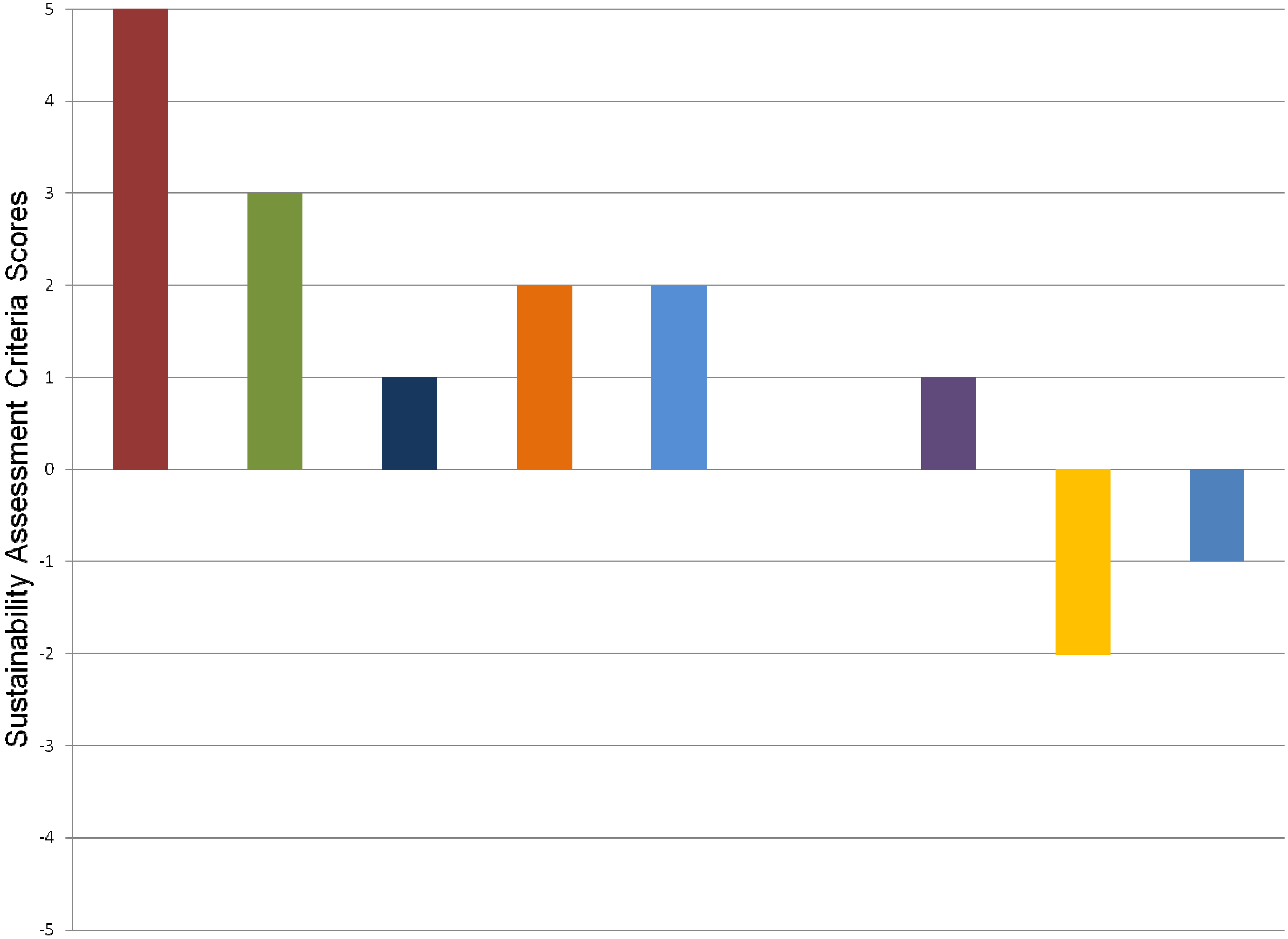
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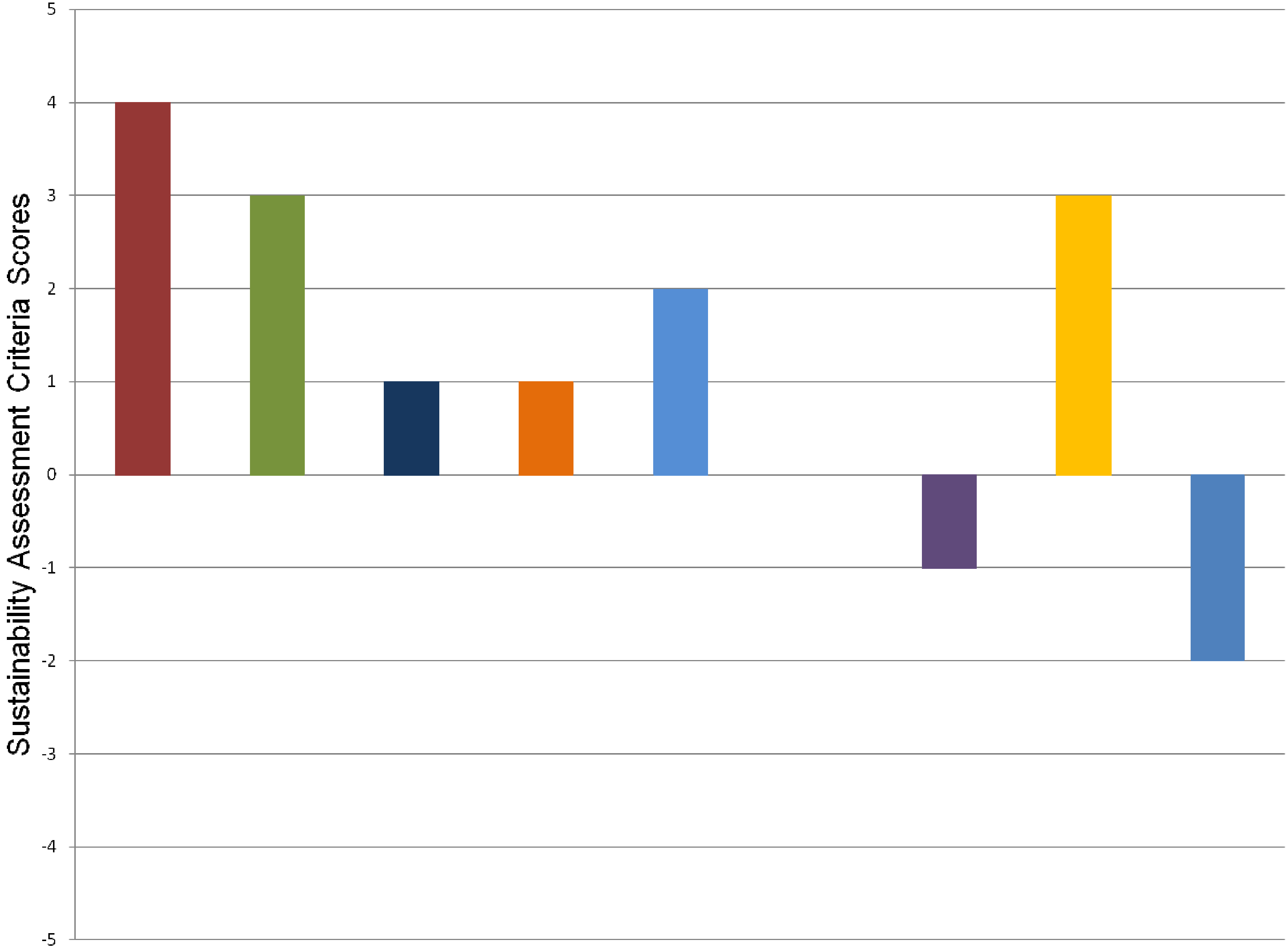
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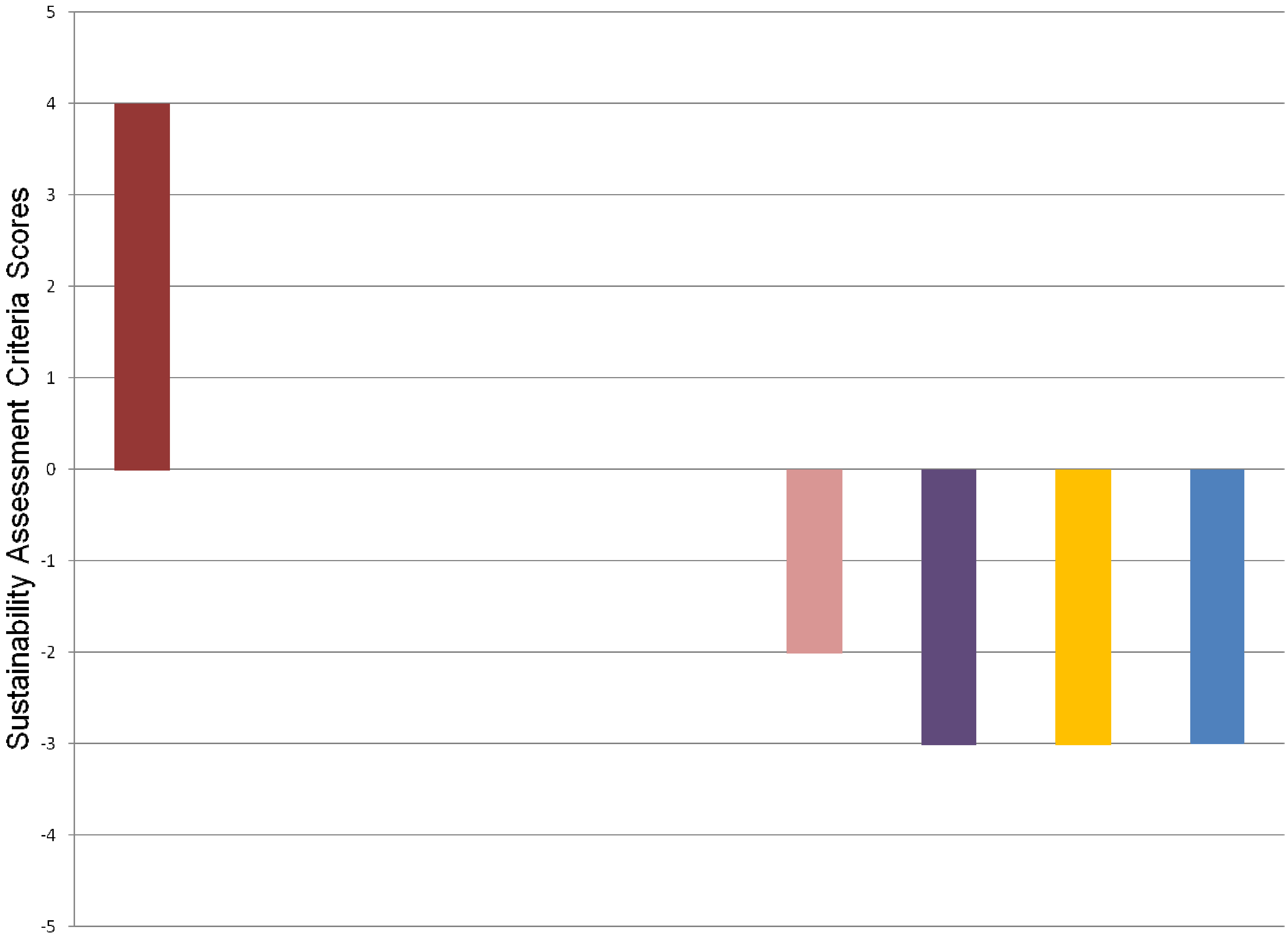
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Sustainability Assessment Criteria Scores

- The Rapid Impact Assessment Matrix (RIAM) has potential in policy deliberation
- This follows from its ability to transparently synthesise disparate analytic outputs
- Analytic criteria and trade-offs are made clear for a non-specialist audience
- We illustrate this with a case study of bioenergy and biofuel options

Appendix 1: the RIAM scoring method

The scoring criteria are placed into two groups; 'A' and 'B' (Pastakia, 1998). The 'A' criteria relate to the importance of the condition (A1) and the degree or the magnitude of the impact (A2) and the B criteria relate to whether a condition is temporary or permanent (B1), can be altered or changed (B2), or whether the impact would have cumulative effects (B3). Each assessment component is scored accordingly, as shown in Figure A1a below.

Figure A1a: Scoring Criteria for each assessment criteria (Pastakia and Jensen, 1998, p.465).

Criteria	Scale	Description
A1: Importance of condition	4	Major importance
	3	
	2	↓
	1	
	0	No Importance
A2: Magnitude of change/impact	+3	Major positive change
	+2	Significant positive change
	+1	Positive change
	0	No change
	-1	Negative change
	-2	Significant negative change
	-3	Major negative change
B1: Permanence	1	No change
	2	Temporary
	3	Permanent
B2: Reversibility	1	No change
	2	Reversible
	3	Irreversible
B3: Cumulative	1	No change
	2	Non-cumulative
	3	Cumulative

After scoring each assessment criteria component, an overall sustainability score (ES) is generated through simple multiplication and addition, thereby providing comparable scores for each feedstock:

(A1) * (A2) = AT (1)
(B1) + (B2) + (B3) = BT (2)
(AT) * (BT) = ES (3)

ES is the final overall sustainability score for each individual criterion (Pastakia, 1998) and once calculated, the overall sustainability performance score is identified in terms of the corresponding range band, as shown in Figure A1b.

Figure A1b: Conversion of ES score to Sustainability performance range bands (Pastakia and Jensen, p.466).

Environmental Score	Numeric Range Bands	Description of Range Bands
+72 to 108	+5	Major positive change/impact
+36 to +71	+4	Significant positive change/impact
+19 to +35	+3	Moderate positive change/impact
+10 to +18	+2	Positive change/impacts
+1 to +9	+1	Slight positive change/impacts
0	0	No significant change/impact
-1 to -9	-1	Slightly negative change/impact
-10 to -18	-2	Negative change/impact
-19 to -35	-3	Moderate negative change/impact
-36 to -71	-4	Significant negative change/impact
-72 to -108	-5	Major negative change/impact

Appendix 2

Table A2a: Assessment criteria scoring for each of the assessment criteria for soybean based biodiesel

Please see appendix 1 for the definition of terms.

Assessment Criteria		**A1**	**A2**	**AT (A1 x A2)**	**B1**	**B2**	**B3**	**BT (B1 + B2 + B3)**	**ES (AT x BT)**	**Range Value**	**Description of Range Bands**
GHG Emissions	Emissions from Sourcing Feedstock (Cultivation)	4	-3	-12	3	2	3	8	-96	**-5**	Major negative change/impact
	Emissions from Processing crops to Biodiesel	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact
	Transport	4	-2	-8	3	2	3	8	-64	**-4**	Significant negative change/impact
	Overall Emission Reductions	4	-2	-8	3	2	3	8	-64	**-4**	Significant negative change/impact
Land Use Emissions	Direct LUC	4	-3	-12	3	2	3	8	-96	**-5**	Major negative change/impact
	Indirect LUC	4	-2	-8	3	2	3	8	-64	**-4**	Significant negative change/impact
Impacts upon Biodiversity		1	-3	-3	3	3	3	9	-27	**-3**	Moderate negative change/impact
Impact on Land Resources		1	-3	-3	3	3	3	9	-27	**-3**	Moderate negative change/impact
Impact on Water Resources		3	-2	-6	3	3	3	9	-64	**-4**	Significant negative

										change/impact
Ethical Concerns over Food Prices and Availability	4	-2	-8	3	2	3	8	-64	**-4**	Significant negative change/impact
Impact on Air Quality	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact
Economic Performance	2	-2	-4	3	2	3	8	-32	**-3**	Moderate negative change/impact
Logistical Concerns	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact

Appended Table A2b: Assessment criteria scoring for each of the assessment criteria for WCO based biodiesel

Please see appendix 1 for the definition of terms.

Assessment Criteria		A1	A2	AT (A1 x A2)	B1	B2	B3	BT (B1 + B2 + B3)	ES (AT x BT)	Range Value	Description of Range Bands
GHG Emissions	Emissions from Sourcing Feedstock	4	0	0	1	1	1	3	0	**0**	No change/impact
	Emissions from Processing crops to Biodiesel	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact
	Transport	3	0	0	1	1	1	3	0	**0**	No change/impact
	Overall Emission Reductions	4	2	8	3	2	3	8	64	**4**	Major positive change/impact
Land Use Emissions		3	2	6	3	2	0	5	30	**3**	Moderate positive change/impact
Impacts upon Biodiversity		1	1	1	3	3	3	9	9	**1**	Slight positive change/impact
Impact on Land Resources		1	2	2	3	3	3	9	18	**2**	Positive change/impact
Impact on Water Resources		1	2	2	3	3	3	9	18	**2**	Positive change/impact
Ethical Concerns over Food Prices and Availability		4	0	0	1	1	1	3	0	**0**	No change/impact

Impact on Air Quality	1	1	1	3	2	3	8	8	**1**	Slight positive change/impact
Economic Performance	2	-1	-2	3	2	3	8	-16	**-2**	Negative change/impact
Logistical Concerns	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact

Appended Table A2c: Assessment criteria scoring for each of the assessment criteria for anaerobic co-digestion of food waste and manure slurry

Please see appendix 1 for the definition of terms.

Assessment Criteria		**A1**	**A2**	**AT (A1 x A2)**	**B1**	**B2**	**B3**	**BT (B1 + B2 + B3)**	**ES (AT x BT)**	**Range Value**	**Description of Range Bands**
GHG Emissions	Emissions from Sourcing Feedstock	2	0	0	1	1	1	3	0	**0**	No change/impact
	Reduced GHG emissions from slurry and composting	2	2	4	3	2	3	8	32	**3**	Moderate positive change/impact
	Transport	2	0	0	1	1	1	3	0	**0**	No change/impact
	Overall Emission Reductions	4	2	8	3	2	3	8	64	**4**	Significant positive change/impact
Land Use Emissions		3	1	3	3	2	3	8	24	**3**	Moderate positive change/impact

Impacts upon Biodiversity	1	1	1	3	3	3	9	9	**1**	Slight positive change/impact
Impact on Land Resources	1	1	1	3	3	3	9	9	**1**	Slight positive change/impact
Impact on Water Resources	1	2	2	3	3	3	9	18	**2**	Positive change/impact
Ethical Concerns over Food Prices and Availability	4	0	0	1	1	1	3	0	**0**	No change/impact
Impact on Air Quality	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact
Economic Performance	2	2	4	3	2	3	8	32	**3**	Moderate positive change/impact
Logistical Concerns	1	-2	-2	3	2	3	8	-16	**-2**	Negative change/impact

Appended Table A2d: Assessment criteria scoring for each of the assessment criteria for virgin wood pellets

Please see appendix 1 for the definition of terms.

Assessment Criteria		**A1**	**A2**	**AT (A1 x A2)**	**B1**	**B2**	**B3**	**BT (B1 + B2 + B3)**	**ES (AT x BT)**	**Range Value**	**Description of Range Bands**
	Emission from sourcing feedstock	2	0	0	1	1	1	3	0	**0**	No change/impact
	Pelletisation and Drying	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact
	Transport	1	-1	-1	3	2	3	8	-8	**-1**	Slight negative change/impact

	Overall Emission Reductions	4	2	8	3	2	3	8	64	**4**	Significant positive change/impact
Land Use Emissions		1	0	0	3	2	3	8	0	**0**	No change/impact
Impacts upon Biodiversity		1	0	0	3	3	3	9	0	**0**	No change/impact
Impact on Land Resources		1	0	0	3	3	3	9	0	**0**	No change/impact
Impact on Water Resources		1	0	0	3	3	3	9	0	**0**	No change/impact
Ethical Concerns over Food Prices and Availability		4	0	0	1	1	1	3	0	**0**	No change/impact
Impact on Air Quality		1	-2	-2	3	2	3	8	-16	**-2**	Negative change/impact
Economic Performance		2	-2	-4	3	2	3	8	-32	**-3**	Moderate Negative change/impact
Logistical Concerns		2	-2	-4	3	2	3	8	-32	**-3**	Moderate Negative change/impact