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Biofuels under the spotlight: The state of assessment and potential for integration

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Alongside substantial biofuel development over the past decade, a vast number of assessments have also been produced. These have had an important influence upon biofuel discourse, policy and development, but they also vary in their methods, scope and quality. This makes it difficult to identify and evaluate assessments and to coordinate knowledge in a useful way. We applied a systematic evaluative framework to a set of 'key' assessments and conducted a workshop with expert producers and users to consider the quality and value of biofuel assessments. It was suggested that a more integrated approach to assessment is needed, perhaps with the establishment of a committee to integrate findings. Such a 'findings-level' approach to integration differs from the 'data-level' approach often found in the literature, and may present a more appropriate means of integrating knowledge gained in biofuel assessments to inform policy.

Keywords: biofuels; technology assessment; integrated assessment; technology policy.

1. Introduction

The dominant definition of biofuels is as liquid transport fuel derived from non-fossilised biological materials such as sugar cane (for bioethanol) and palm oil (for biodiesel). Conventional biofuels refers to those produced from sugary or oily substances that are already intensively cultivated for other purposes, usually as food or feed. The term advanced biofuels (also commonly described as second-generation biofuels) refers to those produced from lignocellulosic materials, including residues from other production processes and other biomass that is not, or cannot be, used directly for food or feed. As policy-makers consider how to bring advanced biofuels to market from their current pre-commercial stage, there has been a significant increase in assessments: studies which attempt to identify and measure specific aspects of development, usually their environmental, economic or social impacts.

While most assessments are based upon qualitative analysis and are intended to shape development in some way—for example by informing government policy or industrial methods—there is a diverse range of approaches and purposes exhibited in the growing body of biofuel assessments. As discussed in this paper, the assessment of different approaches to biofuel production has become increasingly important in shaping discourse, policy and ultimately, the development of biofuels. This can be seen as part of a long-term trend in evidence-based policy in the 'age of assessment' (Rayner 2003). As biofuel assessments grow in abundance and their coupling with policy-making deepens, one can discern both the scientification of the politics of biofuels and the politicisation of the science of biofuels (Weingart 1999). In many cases, the assessments can be described as analycentric: using data from secondary sources, scientific or practical, to feed algorithms which are then applied as directly as possible to decision-making (Hoppe 1999). The diversity in the methods deployed and results obtained can make it difficult to combine their insights in a coherent way. This has led to calls for a more integrated approach to assessment that would facilitate the combination of insights and make them more useful for policy-makers.

The remainder of this paper will highlight the important role of assessment in the UK and Europe, consider various characteristics of several important assessments, and explore the prospects for such an integrated approach. The research was part of the EST-Frame project, and is one of four case studies looking at the assessment literature in this way (along with nano-food, cloud computing and synthetic biology). The broad aim of the project is to improve decision-making processes for technologies in situations where high levels of uncertainty, complexity, and divergent underpinning values prevail (Wesselink and Hoppe 2011). Insights from the four case studies will be brought together to support the development of a framework for more integrated technology governance. The first step in this process is to study how assessments are designed, performed and evaluated to consider how they can be made more collectively useful for policy-makers.

2. Biofuel technology, policy and assessment in the UK and Europe

The European Commission's Biofuels Directive (2003/30/EC) formed the cornerstone of the current European strategy for biofuel development. Framed by ambitions to reduce greenhouse gas (GHG) emissions, improve energy security and promote rural development, it set overall targets for biofuels to constitute 5.75% of the fuel mix by 2010, with individual member states free to implement measures themselves. The UK already supported biofuels to some extent with tax exemptions but, in announcing the Renewable Transport Fuel Obligation (RTFO) (Secretary of State 2007) to implement the Biofuels Directive, mandatory blending targets were set for transport fuel suppliers, maintaining a market incentive in the form of a trading scheme for compliance certificates.

The introduction of the RTFO in 2007 saw significant increases in the quantity and variety of biofuel assessments and the emergence of a controversy. This focused particularly upon the potential impact biofuels would have on food prices, and the indirect impacts of biofuel production (Boucher 2012). Alongside policies to advance biofuel use, there has been significant public investment in bioenergy research. In the UK, for example, approximately €10 m has been invested through the Biotechnology and Biological Sciences Research Council. Some of this funding supported the development of systematic biofuel assessment approaches through the coupling of life cycle assessment (LCA),[1] economic modelling and social sustainability studies with streams focused on the technological development of biofuel production. More specifically, work focused on the development and application of systematic approaches to the generation of knowledge about biofuels and their impacts to support decision-making. This programme, amongst others, played an important role in the increased quantity of biofuel assessments observed in recent years. It may also have allowed assessment to take a prominent role in policy.

While the biofuel controversy that emerged in 2007 may have been fuelled by the conflicting evidence presented in assessments, it also seems to have contributed to biofuels' rising position in the energy agenda and acted as a catalyst for further assessment, and the further development of assessment methods (Gasparatos et al. 2013). In response to the concerns raised in the controversy, the UK government commissioned the Gallagher Review (Renewable Fuel Agency 2008) into the indirect impacts of biofuel production and subsequently amended the RTFO to soften its targets (Secretary of State 2009). Two studies published around this time (Searchinger et al. 2008; Fargione et al. 2008) raised significant concerns about the role of indirect land-use change (ILUC) in particular. They showed that restricting biofuels to those produced on land previously used for agriculture was not enough to stop land-use change, because the activity that took place before biofuel production, which is not subject to land restrictions, would be displaced and result in net land-use change. Where biofuel production leads to an increase in the total demand for land, land-use change will prevail. The authors argued that it did not matter whether land-use change makes way for biofuel production directly or for some other agricultural activities displaced by biofuels production. If these changes were accounted for in LCA then biofuel production would be seen to increase rather than reduce GHG emissions, contradicting a central motive for biofuel development.

The following year, the Renewable Energy Directive (RED) (2009/28/EC) made the Biofuels Directive obsolete, allowing member states greater flexibility in meeting broader renewable energy targets. Under the RED, certificates are issued to suppliers when they introduce qualifying biofuels to the fuel mix. Those that do not generate sufficient certificates are obliged to buy them from other suppliers with excess certificates or pay fines. Biofuels produced on 'sensitive land' or offering GHG emissions reductions of less than 35% against fossil fuels did not qualify for meeting targets and, therefore, were not incentivised by the issuance of certificates. This definition of certified biofuels is based upon the assessment of specific production and supply chains. In doing this, the role of assessment in biofuel policy was extended from one which helped to shape its broad direction (e.g. by bringing land-use change onto the policy agenda) to one which permeates the ongoing implementation and enforcement process (by underpinning the issuing of sustainability certificates).

In the RED, the EU recognised the problem of ILUC and pledged an investigation into its mechanisms and management. This culminated in the late 2012 proposal to amend biofuel policy again (2012/0288(COD)). Individual ILUC factors would be calculated and applied to the

assessments of emissions from biofuels. These factors are adjustment figures which are multiplied by the calculations of the GHG emissions to take account of further emissions associated with ILUC. For example, a barrel of biofuel may directly cause 40% less GHG emissions than its fossil fuel counterpart, but a factor of 0.75 could be applied to account for GHG emissions associated with ILUC impacts, leading to a total GHG emissions reduction of 30%. In other examples, ILUC impacts may lead to negative balances, for instance, greater GHG emissions than fossil fuel equivalents. In an earlier draft of the proposal (leaked before the official publication), these factors would be applied to the final calculation of the GHG emissions associated with biofuels, used to determine their eligibility for meeting targets. This would have pushed the biofuels in the example beyond the 35% compliance rate, and consequently removed the incentive to produce them. Following industry lobbying, however, the factors were reduced to a reportage status, and are not applied to the figures used to establish legal compliance. This means that the barrel described in the example would still qualify for certificates and contribute to meeting targets despite the total GHG emissions reduction being below the standard that the policy was designed to achieve (Kretschmer and Baldock 2013).

At the highest level, academic assessments such as those by Searchinger et al. (2008) and Fargione et al. (2008) have clearly shaped the broad direction of biofuel policies (e.g. towards recognition of ILUC). Furthermore, the implementation of biofuel policy is permeated by ongoing assessments. For example, deciding which biofuels accrue certificates is a process of assessing and quantifying the complex characteristics of products and their production, resulting in a number that represents the GHG emission profile of a given batch of biofuels against the fossil fuels they are assumed to displace. In doing so, a number of impacts are assessed throughout the product's lifecycle, reduced to a common scale and aggregated. A binary decision is then applied at the 35% threshold to determine whether the biofuel will accrue compliance certificates. However, these impacts may not always be measurable on a common scale, and some important impacts may not even be quantifiable. Some impacts may have complex interrelations that mitigate or exacerbate other impacts affecting the validity of the aggregated figures. Finally, all assessments have embedded assumptions that can profoundly affect the results, such as the scope of the study, the methods of collecting data and the baseline figures used. If these assumptions are ignored, they are reduced to procedurally neutral technicalities, rather than normative decisions with political implications.

In this study, we consider the character of biofuel assessments, with particular reference to their potential for integration and value for policy-making. In Section 3 we describe how we identified a set of key assessments, before describing our analysis in Section 4. In order to maintain continuity throughout the four EST-Frame case studies, we adopted a standard procedure for the qualitative evaluation of various features and characteristics of assessments, including their purpose, process and substantial characteristics, such as: the level of transparency and participation, the focus on uncertainties and consideration of value bases. We also held a one-day workshop where we discussed biofuel assessment in the context of these evaluations with a range of policy-makers, consultants, academics and representatives of non-governmental organisations who had been involved in some key developments in biofuel assessment and policy over the past decade. The process and findings from this workshop are described in detail elsewhere (Boucher et al. 2013). In Section 5 we consider two potential approaches to integration. First, the integration of data as part of the assessment process; and second, the integration of findings as part of a political process. We conclude that the latter is more appropriate, as it reflects the political character of evaluating and balancing a range of findings, as well as the inevitable gaps and uncertainties, with reference to the wider problems (such as land-use change) that motivate policy action.

3. Identifying biofuel assessments

We gathered a set of 'key' assessments that was sufficiently small to allow a detailed analysis of their character. This process began with a snowballing approach to identify a very wide range of publications about biofuel. This included systematic searches of academic databases and other web sources using search terms relating to biofuel and bioenergy. Of the 1,348 published sources identified, 618 were categorised as public domain reports produced by academics, consultancies, political institutions, international bodies and non-governmental orgaisations. There were 550 peer-reviewed journal articles, largely produced by academics. The remaining 180 sources comprised: web pages, position statements, newspaper reports, pamphlets and letters. We established a formal definition of assessments as:

> Strategies and/or standardised procedures for gathering, prioritising and communicating information about biofuels, involving analysis and judgement, and meant to support decision-making or policy forming.

Of these, 'key' assessments were defined by their influence on policy, gauged by their being commissioned, produced or used directly by policy-makers, or by achieving a salient impact upon the broader debate. We selected 20 assessments that meet these criteria while balancing UK, EU and international sources. All take the form of standalone reports, rather than journal articles or book chapters, and are publically available. While many were written by academics and have been peer reviewed, and

all refer to the academic literature, they were published by a range of non-academic organisations (see Table 1).

The process of identifying assessments to use in a study is one of many examples of decisions that can deeply affect the research process and become embedded in its results. Selection reflects the interests of the project. Another method or selection process would have led to different choices. This point applies not only to the present research, but to all assessments which draw upon existing bodies of work, and also to the policies that respond to the findings of assessments. In each case, a range of assessments is considered, a smaller group of assessments is identified as relevant and valuable, and the contents of these assessments affect the research or policies under production. This process is seldom made explicit within assessments and policy documents. We discussed this issue at the expert workshop and discovered that many assessment practitioners and policy-makers do not deploy systematic methods to identify and evaluate assessments. It was also claimed that many do not use academic journals because of the investment of time and money required to keep abreast of developments in a field. Instead, more informal methods are deployed such as querying peers and using free online 'scholar search' tools.

4. Analysis of assessments

Across all four case studies of the EST-Frame project, the desk-based qualitative analysis of key assessments was structured by two separate analytical frameworks. The purpose of this was to give an overall picture of the character of assessments. The first was a 'purpose analysis' framework, adapted from the Technology Assessment Methods and Analysis (TAMI) project (Decker and Ladikas 2004) and used here to capture the intended output and outcome of a given assessment. The second was an 'assessment characterisation' framework, which structures the identification and analysis of a broad set of features of a given assessment. A calibration document was produced, defining how the analyses should be undertaken, with particular reference to the codes that are ascribed to reflect the characteristics of assessments. This involved refining the definition of specific features and clarifying under what circumstances each code should be applied to an assessment characteristic. It was important to have a general calibration document that could be applied by the EST-Frame case study teams to consider different emerging technologies. The teams frequently discussed the analytical process. To promote

Table 1. List of key assessments

#	Authors	Title	Year
1	Hart et al. (E4Tech)	Liquid biofuels and hydrogen from renewable resources in the UK to 2050: A technical analysis	2003
2	Biofuelwatch, Carbon Trade Watch/TNI, Corporate Europe Observatory, Econexus et al.	Agrofuels: Towards a reality check in nine key areas	2007
3	Evans (National Non-Food Crops Centre)	Liquid transport fuels: Technology status report	2007
4	Round Table on Sustainable Development	Biofuels: Is the cure worse than the disease?	2007
5	United Nations-Energy	Sustainable bioenergy: A framework for decision makers	2007
6	Wuppertal Institute for Climate, Environment and Energy	What we know and what we should know: Towards a sustainable biomass strategy	2007
7	AEA Technology	Review of work on the environmental sustainability of international biofuels production and use	2008
8	Renewable Fuel Agency	The Gallagher Review of the indirect effects of biofuels production	2008
9	Royal Society	Sustainable biofuels: Prospects and challenges	2008
10	SAC Consulting	An assessment of the potential impact on UK agriculture and the environment of meeting renewable feedstock demands	2009
11	SNV and World Wildlife Fund	Developing sustainable pro-poor biofuels in the Mekong Region and Nepal	2009
12	United Nations Environmental Programme	Towards Sustainable production and use of resources: Assessing biofuels	2009
13	United Nations	The biofuels market: Current situation and alternative scenarios	2009
14	Action Aid	Meals per gallon: The impact of industrial biofuels on people and global hunger	2010
15	International Energy Agency	Sustainable production of second-generation biofuels: Potential and perspectives in major economies and developing countries	2010
16	BirdLife Europe	Meeting Europe's renewable energy targets in harmony with nature	2011
17	German and Schoneveld (Center for International Forestry Research)	Social sustainability of EU-approved voluntary schemes for biofuels	2011
18	Committee on Climate Change	Bioenergy review	2011
19	Nuffield Council on Bioethics	Biofuels: Ethical issues. Summary and Recommendations	2011
20	Slade et al.	Energy from biomass: The size of the global resource	2011

consistency, assessments were coded separately by two researchers within the team and discussed in the context of the calibration document. This process was repeated with assessments from the other case studies, to ensure that the coding process was broadly consistent across the wider project. The purpose of the codes is to help capture and illustrate some key characteristics and broad trends of the assessment landscape and, along with discussions at the expert workshop, support a deeper qualitative reflection on the assessments analysed.

4.1 Purpose analysis

The purpose analysis table (see Table 2) draws upon a set of 21 predefined roles (drawn from Decker and Ladikas 2004), which were labelled A–U and organised into a two-dimensional matrix with nine cells. This analysis examines the aims of assessments. The horizontal axis of the matrix, or 'impact dimension', captures the intended purpose of the assessment from three possible roles:

- raising knowledge (a cognitive role)
- forming attitudes (a normative role)
- initialising actions (a pragmatic role)

The primary goal of an assessment that aims to take a cognitive role would typically be to make its audience aware of a particular issue or set of issues. These could be technical uncertainties and risks, scientific developments, or the perspectives of a given set of stakeholders. In contrast, a normative role captures an author's intention to contribute to, shape, or structure actors' discussions around a technology. The final 'pragmatic' role captures explicit desires to shape the place of the technology within society, for example by proposing changes to policy, or attempting to mobilise sets of actors in support or opposition, or calling for research programmes which the authors might conclude are understudied (Hennen et al. 2004).

The vertical axis of the TAMI matrix, the 'issue dimension', captures the specific aspect of the technology—technological/scientific, societal or policy—that the assessment aims to address. The first, a focus on 'technical' aspects would be concerned with questions such as: 'what are current development paths?' and 'what might be the technical barriers to scaling up a technology?' The social dimension is typically concerned with knowledge around stakeholder perspectives and potential tensions between them, the values and interests that underpin these perspectives as well as other social relationships associated with a technology. Finally, assessments coded within the policy cluster would typically aim to make statements about the current quality of policies, their objectives and implications, and the political negotiation that goes on around the technology.

A set of letters, corresponding to the roles described in this matrix, was used to capture the interpretation of the

Table 2. Aggregated TAMIs

		Impact dimension–role of assessment			
		Raising knowledge	Forming attitudes/opinions	Initialising actions	∑
Issue dimension–object of assessment	**Technological/ scientific aspects**	A: Technical options assessed and made visible **12** B: Comprehensive overview on consequences given **8**	F: Setting agenda in political debate **4** G: Stimulating public debate **3** H: Introducing visions or scenarios **3**	O: New action plan or initiative to further scrutinise problem **7** P: New orientation in policies established **1**	38
	Societal aspects	C: Structure of conflicts made transparent **1**	I: Self-reflection among actors) **1** J: Blockade running **0** K: Bridge building **1**	Q: New ways of governance introduced **2** R: Initiative to intensify public debate taken **2**	7
	Policy aspects	D: Policy objectives explored **11** E: Existing policies assessed **13**	L: Comprehensiveness in policies increased **11** M: Policies evaluated through debate **0** N: Democratic legitimisation perceived **0**	S: Policy alternatives filtered **2** T: Innovations implemented **0** U: New legislation passed **0**	37
	∑	45	23	14	82

intended purpose of each assessment. The calibration document provided a guide to support the allocation of codes during the examination of assessments. The aggregated results of the purpose analysis are presented in Table 2. Some clear patterns are visible in the distribution of the tallies. These are illustrative of some points regarding the body of biofuel assessments. Most of the tallies are recorded in the column on the far left-hand side, indicating that they adopt knowledge raising roles. Many of the remaining tallies were in the middle row reflecting the attitude/opinion forming roles they adopt. Over 80% of the tallies occupy these two columns of raising knowledge and forming opinions. This distribution reflects a broad tendency of assessments to report that not enough is yet known about the impacts of biofuel development, and that more knowledge is needed before actions are implemented. This sentiment is made explicit in many of the key assessments, which claim that more knowledge is required, often justified by the degree of complexity and the extent or importance of certain 'unknowns'. Of the minority of tallies recorded in the right-hand column, titled 'initialise action', half called for more action to scrutinise the problems at stake. This is a clear illustration of the tendency of biofuel assessments to position the technology in an 'opening' stage of development, where the issues and ideas surrounding it are subject to development, change and broadening of scope. It also captures the drive within the assessment community to produce ever-increasing numbers of assessments to support policy decisions.

Considering Table 2 on a row-by-row basis, the issue dimension, illustrates the assessments' tendency to consider scientific and technological aspects (top row) and policy aspects (bottom row), with relatively little attention to societal aspects (middle row). Many assessments that do consider societal aspects also expressed concern that the 'social pillar of sustainability' is not as well developed as its economic and environmental counterparts (German and Schoneveld 2011). The most dominant roles are captured in A, B, D, E, L and O of Table 2, attracting more than three-quarters of the tallies recorded. This reflects an assessment landscape that primarily aims to consider the impacts and uncertainties associated with technical options and policies, calls for the extended scope of policies, and initialises further scrutiny of the issues.

4.2 Process and substantial characteristics

The process and substantial characteristics category of our analytical framework captures aspects of assessments that may be used to evaluate their procedural quality, including: transparency, impartiality, participation, evidence basis, focus on uncertainties, and explicit attention to ethics/values. Such characteristics represent common challenges and points of contestation in the governance and assessment of emerging science and technology (Forsberg et al. this issue). Both impartiality and transparency were graded based on the extent to which they were addressed within the document by making the methods, commissioners and funding sources explicit. Participation was evaluated in terms of expert, lay and stakeholder involvement, scoring highest where there was evidence that a two-way participation had informed the conclusions. The evidence base was considered in terms of quality and completeness of references, with an evaluation being made regarding the coverage and providence of sources, prioritising peer-reviewed sources. Finally, the attention devoted to both the uncertainties and ethics/values was evaluated on the basis of their prominence within the assessment and the role that each played in informing the conclusions. Table 3 presents the results of these eight process and substantial characteristics, which were coded on a scale 1–5 with reference to the calibration document. A code of 1 reflects the absence of discussion or engagement and 5 reflects a substantive discussion or priority engagement.

Impartiality was coded at 3.5 and transparency at 3.0, although there is some variation amongst the reports. Transparency is particularly varied, with some assessments omitting the description of their approach, scope, methodology and limitations while others provide these with studied reflexivity. Generally, assessments written in a more traditional academic style were coded highly in this regard. These measures of impartiality and transparency exhibit the greatest correlation of all variables applied to the biofuel assessments with a coefficient of 0.78 (where 1 is perfect correlation).[2] This correlation may be due to impartiality being demonstrated through the transparent description of analytical contexts and procedures (including findings, methods, assumptions and limitations). Failing to describe or justify such decisions may imply a partial or partisan assessment.

All three measures of participation were low. This is particularly the case for lay participation (1.4) and is slightly higher for stakeholder and expert participation (2.1 and 2.6, respectively). This highlights and potentially contributes to the broader tendency for assessments to adopt a technocratic, science-led approach to decision-making, whereby recommendations for policy decisions are based upon quantitative measures of economic or environmental impacts produced by assessment experts with limited opportunity for non-expert voices to inform findings.

Analysis of the assessments' substantial characteristics—the scientific evidence basis, focus on uncertainties and explicit treatment of values and ethics—reveals that they have a varied but generally strong scientific evidence basis, coded at 3.4. Most assessments cited a respected corpus of peer-reviewed literature, although they were used in the assessments to different extents. The focus upon uncertainty was coded at 2.8 but was also quite varied, with

Table 3. Core process and substantial characteristics, A–H

Characteristic	1	2	3	4	5	Average	Standard deviation
A. Impartiality	1	2	6	8	3	3.5	1.02
B. Transparency	3	3	7	5	2	3.0	1.18
C. Participation, experts	2	10	3	4	1	2.6	1.07
D. Participation, lay people	15	4	0	1	0	1.4	0.73
E. Participation, stakeholders	8	7	2	2	1	2.1	1.16
F. Scientific evidence basis	0	6	4	6	4	3.4	1.11
G. Focus on uncertainties	2	7	6	3	2	2.8	1.12
H. Explicit values/ethics	4	7	8	0	1	2.4	0.96

most recognising the presence of uncertainty in the field or in their own analyses (coded 2–3) and a minority considering uncertainty systematically in the assessment itself or the formulation of the findings (coded 4–5). As discussed in a report on methodological issues in risk assessment (Scientific Committee on Health and Environmental Risks et al. 2013), the basic assertion of uncertainty and the need for further research is often vague and unhelpful for risk managers and policy-makers. While greater attention to uncertainties may be useful, many policy-makers recognise the epistemic inevitability of the persistence of a degree of uncertainty. In the workshop which accompanied the analysis of key assessments, a civil servant who uses assessments to develop UK biofuel policy noted:

> . . . we have all the time to remind scientists that science is by its nature uncertain [. . .] to expect certainty is somehow the wrong expectation. (Boucher et al. 2013).

Few studies reflect upon their own normative position or value base. Those that do so tend to consider societal and ethical aspects explicitly, such as the report by the Nuffield Council on Bioethics (2011). Instead, most reports are technical in nature and adopt a somewhat scientistic or technocratic position accompanied by a deficit approach to other non-expert concerns. This tendency may be related to the low level of participation observed across biofuel assessments. It is also noted that some studies adopt a strong normative or even explicitly partisan position. For example, Action Aid's (2010) 'pro-poor' position permeates their discussion and clearly guides their priorities in making recommendations. This may be justifiable through alignment with a specific position on economic development, such as redistributive justice, but is adopted normatively.

Moving onto the 'impacts considered' aspect of the analysis (see Table 4), we examined the specific dimensions of a technology that the assessments focus upon. As is common, the three primary dimensions of impacts were the so-called 'triple bottom line' of environmental, social and economic impacts (Elkington 1998; Norman and MacDonald 2004). Environmental impacts covers a broad range of potential consequences of biofuel development including but not limited to: GHG emissions, biodiversity, land use, soil quality and water resources. Economic aspects include: regional and international development and trade. Many assessments that claim to assess social impacts adopt a rather narrow definition of the social, for example by using socio-economic measures such as local employment but eliding questions about social values, ethics, culture or even cursory consideration of local perspectives, framings and discourse. As such, self-reported consideration of social impacts was not always a reliable guide to the impacts assessment of issues. Each of the EST-Frame case studies also profiled security impacts (for biofuels, these included energy and food security) and health and safety impacts (which were not found amongst the biofuel assessments).

Almost all of the 20 assessments consider environmental impacts, and more than half of them consider economic impacts. This domination of environmental and economic aspects in the assessment of biofuels will not surprise those familiar with the literature. Comparing the primary impacts considered (bracketed) against all included, however, illustrates a more interesting tendency. Within these assessments, economic and security issues are not generally featured as the primary consideration, whereas social and environmental impact assessments generally are. This could mean that assessments do not consider economic and security impacts such as food price inflation to be of particular importance in themselves, but as a means of understanding environmental or social impacts such as poverty and carbon emissions, that are considered to be more important.

As part of the impact characterisation, the assessments were profiled as anticipatory or retrospective in their analysis, also recording whether they anticipated (or reflected) five, 15 or more years into the future (or past). All assessments have some anticipatory and retrospective elements, if only to describe a situation and suggest developments. To ensure meaningful data, only the analytical components of the assessments have been counted. Thus, mentioning past events would not be enough to be considered retrospective analysis. Likewise, suggesting further

Table 4. Nature of impacts considered

Impact	Considered (as primary focus)
Environmental	17 (12)
Economic	11 (3)
Social	8 (5)
Security	4 (0)

Table 5. Retrospective and anticipatory analysis

Timescale in years	Retrospective	Anticipatory	∑
1 (0–5)	17	4	21
2 (0–15)	0	3	3
3 (15+)	0	6	6
∑	17	13	

research or a particular regulatory approach is not considered anticipatory analysis, whereas analytical work such as a foresight study or economic scenario modelling would (see Table 5).

Studying Table 5, it is clear that the retrospective aspects of analysis in biofuel assessments tend to be short term (up to five years), focusing on the state-of-the-art, whereas anticipatory aspects of analysis are spread across a longer timescale, most often 15 years plus. Many of the anticipatory analyses are linked to pre-existing political scenarios and government targets, such as the European targets for 2020 or UK targets for 2050.

5. Biofuel assessments and the potential for integration

Many assessments are structured by particular groups of technologies (such as biofuels) rather than particular problems (such as sustainable land-use, transport, GHG emission reductions or economic development) that actually drive technology policies like the Biofuels Directive and RED. Just two of the 20 key assessments considered here assessed bioenergy as one of several technologies or solutions that may be part of a response to a given problem. As the assessment literature has grown, biofuel impacts have been identified and explored in greater detail than many other sectors, but this approach of putting the technology 'under the spotlight' may not always be effective. For example, in regulating against land-use change but not holding other land-using activities such as food and feed production up to the same standards, the problem of land-use change can elude policy efforts, becoming manifest in other less regulated sectors. ILUC is only indirect from the perspective of assessments that focus upon direct drivers such as biofuels, rather than systemic problems such as the allocation of limited land resources. Under a system that would focus upon the systemic problem, rather than one of many manifestations of it, the standards applied to biofuels would not differ substantially from those expected of other technologies and practices, because singling out one driver incentivises indirect manifestations of the problem instead.

Most assessments seek to inform better management of biofuel production and development in a way that responds to one or more problems with the environment, land use, energy, economy, international development or transport. Some have suggested methods for integrating a range of assessments in a way that is more useful for policy-makers to resolve such problems. Usually, they either call for a more unified approach to assessment, or for greater coordination with assessments from other fields. Despite this, no clear strategy for achieving improved integration was presented. One option is to combine data from various sources and perform a type of meta-assessment that weighs the costs and benefits of different options. In this model, integration would occur as part of the assessment process itself, and involves the combination of data that is analysed to assess impacts. We refer to this as data-level integration. A second option, findings-level integration, would coordinate the insights of different assessments. Instead of being framed as part of the scientific or technical process of analysis, this type of integration would be part of the political policy-making process of evaluating and balancing different findings as well as contradictions, gaps and uncertainties.

Considering these approaches from a scientific perspective, the former option of data-level integration may appear more intuitive. However, it requires systematic procedures and methods for integration within an analytical field, such as LCA or bio-economic modelling, and also across different assessment traditions such as impact assessment, risk assessment and social sustainability assessment (Glithero et al. 2012; Elobeid et al. 2013). The approach is backed in calls for unifying analytical frameworks for the evaluation of environmental, social and economic (as well as other) aspects of biofuel use. These usually take the form of broad sustainability assessments (Elghali et al. 2007), ecosystem services or sustainability science (Gasparatos et al. 2011), or make use of an integrated assessment framework (Giampietro and Ulgiati 2005; Giampetro et al. 2006). While the data-level integration approach may succeed in certain situations (Glithero et al. 2012), problems emerge as the number of assessments begins to increase, a phenomena observed in the proliferation of biofuel literature observed in the past decade (Gasparatos et al. 2013; Michaelopolis et al. 2011). Even relatively well-established analytic approaches such as LCA can embed very different assumptions and

boundaries that can render results increasingly incommensurable and difficult for practitioners to integrate at a data-level (Mohr et al. 2012). Adding the assessments of more complex impacts, such as biodiversity, rural development or ethical values, compounds these questions of commensurable measurement. Qualitative assessments of social impacts, which may not even be quantifiable, would be so difficult to express in the terms that are used to capture other impacts that they may be excluded entirely. As such, a unified framework operating on the principle of data-level integration can easily become a gatekeeper which favours certain types of assessment at the expense of others that deploy marginal methods and examine underrepresented impacts.

Instead of combining data and analytical processes, the findings-level approach to integration would consider the results as well as the processes involved in many assessments and use informed (value) judgement as an input to the policy-making process. Instead of encouraging assessment designs that produce results that can be combined with those of other assessments, it allows assessment practitioners to deploy the assumptions and approaches that benefit the analysis and give voice to the impacts considered. Furthermore, it may reduce the temptation to exclusively consider different types of impacts (social, economic, biodiversity and GHG emissions) as costs and benefits to be balanced or traded off against each other. Instead, diverse impacts should be considered in their own terms as part of a large, complex system with many interdependencies between technologies, practices and impacts (Mohr and Raman 2013). There have been some promising methodological steps in this direction from academic biofuel assessment studies. For example, the rapid impact assessment matrix brings together insights from diverse assessment methods in a format that is easy to understand yet does not hide the diverse assumptions and values embedded in assessments, nor the areas of contention within the literature (Upham and Smith 2013). Such approaches do not combine insights to produce a final result, but present a range of insights together in a format that is primed for policy decisions. Subsequent decisions, which represent the integration of findings to an overall assessment, have a political character that should be made explicit. If performed as part of the assessment process, the normativity and politics involved in evaluating and balancing knowledge claims are disguised as value-free science. It also places demands on policy-makers who are entrusted with the task of understanding a wide range of assessments as well as the problems that brought the assessments to the political agenda, and potential remedial action. This approach may be supported by bodies such as the Intergovernmental Panel on Climate Change, which does not deliver new assessments but delivers a high-level evaluation of existing findings, informing the direction of further studies.

6. Conclusions

To summarise, our analysis of the purpose of the key assessments revealed that they tend to aim to consider the impacts and uncertainties associated with technical options and policies, call for the extended scope of policies and initialise further scrutiny of the issues. Levels of impartiality and transparency vary, although the scientific evidence base is generally strong. The assessments tended neither to assess their own uncertainty, nor to reflect on their own value base, or to integrate non-expert perspectives. Environmental and economic impacts are considered most often. Many assessments have an anticipatory element, considering over 15 years into the future, and many assessments have called for greater integration to improve the management of biofuel development as an effective response to challenges such as ILUC and reductions in GHG emissions.

Features of assessments that would be more readily coordinated or integrated with others would include transparency and reflection upon the values and assumptions embedded in the design of assessment methods. Whether a data- or findings-level approach to integration was adopted, this would allow results to be better coordinated with those of other assessments. Indeed, many assessments could be more amenable to integration and, perhaps, useful for policy-makers through more detailed reporting of the means by which results were achieved. In some circumstances, this may allow assessments to remain useful where conditions, such as regulatory targets, change. Without the ability to adjust the input parameters to assessments, relatively small policy changes may render work with insufficient methodological transparency obsolete.

While more knowledge will always be desirable in the governance of technology, it may be valuable to focus less on the resolution of assessments and more on how existing knowledge can be coordinated. Calls for unifying frameworks are likely to grow stronger as the assessment literature grows, but if a framework cannot accommodate diverse and sometimes unquantifiable impacts such as biodiversity, rural development and social values, and cannot represent marginal voices such as vulnerable and distant communities, it may act as a damaging gatekeeper, narrowing the communication channels that run between assessment and policy-making. An explicitly political policy-making approach to integration would be more appropriate for the normative process of identifying and valuing different types of assessment. Without the need for results to fit a unifying assessment framework, assessments can be designed and deployed to capture the impacts they focus upon in their own terms, be that quantifying GHG emissions, calculating demand for land or representing public concerns. Insights presented to policy-makers in this format would broaden the options available to them.

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Notes

1. LCA is an analytic method which examines the environmental burden of a product over its entire life. The approach has become central to the assessment of biofuels, with particular focus being on the quantification of GHG and energy balances (Singh et al. 2010).
2. Aside from transparency and impartiality, the strongest correlations in the study were found between the participation of experts (c), scientific evidence basis (f), and focus on uncertainties (g) (c&f = 0.64, c&g = 0.64 and f&g = 0.66). The causal links underlying these correlations, if any, are not clear.

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