The Danish Biofuel Debate: Coupling Scientific and Politico-Economic Claims

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Abstract

What role does scientific claims-making play in the worldwide promotion of biofuels for transport, which continues despite serious concerns about its potentially adverse social and environmental effects? And how do actors with very different and conflicting viewpoints on the benefits and drawbacks of biofuels enrol scientific authority to support their positions? The sociological theory of functional differentiation combined with the concept of advocacy coalition can help in exploring this relationship between scientific claims-making and the policy stance of different actors in public debates about biofuels. In Denmark two distinct scientific perspectives about biofuels map onto the policy debates through articulation by two competing advocacy coalitions. One is a reductionist biorefinery perspective originating in biochemistry and neighbouring disciplines. This perspective works upwards from the molecular level and envisions positive synergies in the use of biomass. The other is a holistic bioscarcity perspective originating in life-cycle analysis and ecology. This perspective works downwards from global resource scope conditions, and envisions negative consequences from an increased reliance on biomass. Understanding how these scientific perspectives and policy stances are coupled sheds light on three contentious policy questions: how Denmark should include biomass in its energy provision, what role Denmark might play in the global development of biofuels, and what kind of subsidy schemes should be implemented.

Keywords: Biofuels, functional differentiation, advocacy coalition, public debate, bioeconomy

Biomass feedstocks are in abundant supply, and the reduction in CO2 emissions – up to 90% compared to gasoline – is impossible to ignore, as is the potential of cellulosic ethanol to boost energy independence and create jobs (from www.novozymes.com)
The production of biofuels can indirectly cause additional deforestation and land conversion, including of fragile ecosystems. When existing agricultural land is turned over to biofuel production, agriculture has to expand elsewhere to meet the previous and ever-growing demand for crops for food and feed – often at the expense of forests, grasslands, peat lands, wetlands, and other carbon rich ecosystems. This results in substantial increases in GHG emissions from the soil and removed vegetation (Friends of the Earth, Europe)

Introduction

The use of fossil fuels for transport is increasingly considered problematic. The reasons are manifold, including climate change, dependency on oil supplies from politically unstable regimes, and the depletion of fossil resources (Gallagher 2008, Nuffield Council 2010). Biofuels – liquid fuels produced from biomass – have been promoted and developed by the biotech industry and policy actors as an allegedly sustainable alternative to fossil fuels (Carolan 2009, Mol 2010, White and Dasgupta 2010). However, during the past decade other actors have voiced concerns about potentially detrimental social and environmental effects from large-scale biofuel production (McMichael 2009, Moll 2007, 2010, White and Dasgupta 2010). In 2007 the ‘fuel vs food debate’ highlighted a link between the increased use of bioethanol in the US and rising food prices in the world market (Pimentel et al. 2008).

As shown by the two quotes above, opinions on the merits and potentials of biofuels have become strongly polarised. Public debates around the world contain both optimistic praise for and pessimistic warnings against biofuels as a substitute for fossil fuels. Participants in these debates make reference to and claim support from scientific knowledge. However, it is difficult for both the general public and decision-makers to discern what should count as well-founded knowledge or not in these different claims and scenarios. It is therefore pertinent for STS scholars to explore what role science – the conventional arbiter in disputes about factual matters – plays in the controversies around biofuel policies. While the
developments of biofuels have begun to register in the STS literature and neighbouring fields, most of the existing critical social science research on biofuels focuses on the economic interests driving the development of the evolving ‘biofuels complex’ (Borras et al 2010, Moll 2007) and the discursive formation of an emerging ‘bio-based knowledge-economy’ (e.g. Birch et al 2010, Richardson 2012). So far, less attention has been devoted to the specific role played by scientific knowledge production and claims-making in this development.

In this paper I wish to complement the existing literature with more detailed attention to the scientific dimension of the controversies about biofuels. I ask the following questions: What role does science play in the controversies around biofuels? How is it that very different scientific assessments of the potential merits of biofuels are used in public debates? And how are techno-scientific developments and policy-making in the biofuel domain interrelated?

The answers to these questions will be based on a case study of the public debates about liquid biofuels in Denmark. This debate is embedded in more encompassing questions about the availability and prioritisation of biomass, which is increasingly seen as a valuable resource that must be both utilised and protected (Birch et al 2010, Richardson 2012). In a yet wider frame, the topic is also embedded in debates about the future livelihood of the Danish nation as Europe allegedly moves towards such a bioeconomy. However, the debate about liquid biofuels for transport will be my empirical focus as they most vividly epitomise the conflicts around the use of biomass.

The paper is structured in the following way: first, I outline the analytical framework of the analysis, the sociological theory of functional differentiation and the concept of advocacy coalition. Second, I trace the biofuel policy debates in the Danish context diachronically. Third, I identify synchronically two different scientific perspectives on biofuels, biorefinery and bioscarcity, which inform the public debate. Fourth, I analyse how these two perspectives are coupled to diverging policy stances on biofuels promoted by two competing advocacy coalitions. The conclusion summarises the argument and answers the questions posed above.
Analytical framework

The conventional understanding of the relationship between science and politics assumes that good policies are supported by robust knowledge through neutral, objective expert advice. However, since the 1960s this relationship has come under pressure with growing public attention to scientific uncertainty and incomplete knowledge bases, in particular in domains such as nuclear power, climate change and biotechnology. Some observers suggest that scientific uncertainties are often the cause of political controversies over novel technologies (e.g. Beck 1992). In other cases it has been suggested that political competition is likely to fuel scientific controversy (e.g. Jasanoff 2004). Combining those two perspectives, an influential contribution suggests that the boundaries between science and politics are eroding (Nowotny et al. 2001).

In this paper, I take a different approach rooted in the sociological theory of functional differentiation (Luhmann 1994), which assumes that “a fundamental difference between scientific knowledge and political decision-making remains” (Maasen and Weingart 2004: 3). As a consequence, “[i]t appears most fruitful to conceive of the relationship between science and politics as one between two differentiated subsystems with fundamentally different codes of operation as an analytical frame. While science, as a subsystem, primarily adheres to the code of ‘truth’, politics is primarily guided by the code of ‘power’.” (ibid: 4). In my view, this distinction is an indispensable analytical precondition for understanding the more enduring structural features of the interaction between science and politics (Hansen 2009).

However, while analytically distinct, science and politics are undoubtedly mutually dependent. In contemporary societies, many interactions thus occur between science and politics, but rather than a blurring of boundaries, the theory of functional differentiation assumes that “the nature of the relationship between science and politics is one of ‘coupling’” (Maasen and Weingart 2004: 4), a mutual conditioning of distinct modes of communication. This leads to the dual processes of ‘scientification of politics’ (political
decision-making is increasingly directly dependent upon scientific knowledge) and ‘politicisation of science’ (political competition has ever more direct reverberations in knowledge production) (ibid, Weingart 2005). The theory of functional differentiation thus assumes an increased mutual conditioning of science and politics, but maintains that a fundamental distinction between the two remains.

While science and politics are analytically distinct modes of communication based on a stable set of binary codes (‘truth’ and ‘power’, respectively), individuals and organisations can and must switch between different modes of communication. In conversation, individuals can smoothly alternate between addressing scientific, political and economic aspects of biofuel production, exactly because such codings exist as established and stabilised repertoires beyond the specific conversation. Similarly, organisations can consider political, scientific, economic, legal etc distinctions in their operations. The analytical point, however, is that this must be done sequentially, by alternating between different perspectives, not by blurring the distinctions between them. There are, however, some significant asymmetries between the roles affiliated with the different modes of communication. Only individuals and organisations with scientific credentials are allowed to speak authoritatively on matters of fact, whereas politicians must defer to scientific expertise in such questions. Scientists and scientific organisations, on the other hand, often enter into policy arenas and participate in political communication benefiting from the cultural authority of science. In short, scientists can double as policy actors, whereas other policy actors cannot double as scientists. As a consequence, policy actors are motivated to ally themselves with sources of scientific authority that align with their interests. I suggest that the nature of such alliances can be analysed as advocacy coalition to be discussed below.

According to the theory of functional differentiation both science and politics are internally differentiated in the application of their respective communicative codes. As a consequence, couplings between the two modes of communication takes place at multiple places simultaneously, often in ways that may be in conflict or competition with each other. It is therefore necessary to examine the specific ways in which science and politics are coupled in particular settings, such as public debates and policy
arenas. The internal differentiation of scientific communication suggests that (at least some of) the political struggles about biofuels are better understood as propelled by scientific *diversity* rather than scientific *uncertainty*. By scientific diversity I refer to situations where different but in principle equally scientific perspectives relevant to a given policy problem are propagated simultaneously, leading to different policy recommendations. Such differences of perspective are possible because of the disciplinary differentiation of scientific knowledge production. This can neither be adequately understood as ‘proper’ versus ‘junk’ science, nor as competing scientific theories or paradigms confronting each other *in* scientific communication where empirical evidence is (temporarily) inconclusive. Rather, the challenges to policy-makers and the general public are rooted in the fact that different branches of scientific knowledge bear upon complex policy problems in different ways, creating what Sarewitz (2004) has called an ‘excess of objectivity’; i.e. multiple, possibly conflicting, scientific claims are at the disposal of decision makers simultaneously with no meta-criterion to adjudicate.

To examine how the coupling of science and politics play out in situations with an excess of objectivity, I apply the concept of ‘advocacy coalition’. This concept is conceived in political science to pay greater analytical attention to the role of scientific knowledge in policy making and change. The framework implicitly makes assumption about functional differentiation between science and politics, but tends to overlook the internal differentiation of science as it sees science as a (potential) neutral source of objective knowledge. Nevertheless, the concept is useful for my present purpose.

Advocacy coalitions consist of ‘a variety of public and private organisations who are actively concerned with a policy problem or issue, such as agriculture, and who regularly seek to influence public policy in that domain’ (Sabatier 1998: 99). A key idea in the advocacy coalition framework is that actors have belief systems with three layers: 1) *Deep core beliefs* of an ontological and normative nature, such as the relative valuation of individual freedom versus social equality (ibid); these impinge on 2) the *policy core beliefs* ‘which represent a coalition’s basic normative commitment and causal perception across an entire policy domain or subsystem, ... deciding for instance the relative importance attached to economic
development versus environmental protection’ (ibid); finally, actors hold 3) secondary policy beliefs, which are more specific and empirical in nature, pertaining to particular problems, situations and institutions. Deep core beliefs are unlikely to change and policy core beliefs only change slowly, whereas secondary beliefs are more prone to learning and compromise. The advocacy coalition framework contends that ‘policies and programmes are best thought of as translations of beliefs’ (Weible et al 2009: 122). Shared policy core beliefs serve as the ‘glue’ of advocacy coalitions: they unite coalitions and facilitate collaboration of actors from different sectors etc.

Advocacy coalitions socially intertwine scientific knowledge (causal beliefs) with policy positions (normative beliefs) and compete for societal support for their beliefs and interests in different arenas. Advocacy coalitions are relatively loosely coupled networks of actors who share policy beliefs and coordinate in various ways to manifest them, although members of a coalition may in other respects be competitors. I thus use the concept of advocacy coalitions as an analytical lens to observe how scientific claims-making emerging from different parts of the scientific system are coupled with the struggles about biofuel policy in political arenas. In relation to the theory of functional differentiation, advocacy coalitions do two things. First, provide a social locus for the coupling of scientific and political modes of communication. Secondly, and in extension thereof, they serve to align normative and causal beliefs into more or less coherent policy stances, compensating for the fundamentally orthogonal nature of scientific and political modes of communication.

In the case of biofuels, evaluations among key actors in Denmark today span a spectrum from those who are very optimistic (Rasmussen 2008) and those who reject biofuels as leading to a technological lock-in, which will only prolong fossil fuel dependence (Henningsen 2009). This has generated a struggle to define desirable future technological trajectories. In this struggle, actors holding and publicly representing different policy beliefs position themselves in relation to each other and seek to strengthen their own positions by de-legitimising their opponents in the public sphere. As a consequence ‘coalition members will resist information suggesting their [...] core beliefs may be invalid and/or unattainable, and usually will use
formal policy analysis [or other sources of scientific claims, *jh*] to buttress and elaborate those beliefs (or attack their opponents’ beliefs)’ (Sabatier 1998: 105).

The following description and analysis is based on qualitative analysis of policy documents and reports from government departments, industry organisations and companies, environmental NGOs and research organisations, mostly retrieved through Internet searches. This was combined with a series of 10 semi-structured interviews with central actors in the debates including scientists, industry representatives, policy makers, NGO representatives, a trade organisation and a public-private innovation-promotion venture, as well as participant observation in various public and semi-public meetings addressing biofuel policy. The interviews were carried out in the period between October 2009 and September 2011. Many features of the Danish debate are of course intricately linked to international developments, in particular in EU policy. However, developments at that level are here considered as set parameters for the analysis. Most interviews were carried out relatively shortly after the EU released its Renewable Energy Directive (2009/28/EC) in 2009. This meant that the topic had high salience to my interviewees, but also that several of them considered biofuel policy as an issue that was temporarily settled, which allowed them to be straight-forward in their responses.

**The Danish case in a European context**

Denmark has been at the forefront of developing sustainable alternatives to fossil fuel energy for a long time. The Danish windmill industry has been very successful and currently controls about 40% of the world market, accounting for 8.5% of the country’s exports (www.windpower.org). Likewise, biomass currently accounts for about 10% of energy production in Denmark, primarily in heat and power generation. However, like most countries, the transport sector is Denmark’s Achilles’ heel in terms of GHG emission reductions. Hence, when biofuels appeared on the techno-scientific horizon, most actors were initially enthusiastic. However, sceptical voices quickly emerged and the prospective biofuel trajectory
became contested, inducing similar social polarising dynamics as other contested technologies such as GMOs, for example, though so far with less public visibility and resonance (Interview, technology assessment organisation, November 2009).

Initially, the Danish debate was characterised by their novelty as most actors were uncertain about their technical feasibility. Consequently, much of the initial policy discussion focused on what might be technically and economically feasible, not whether biofuels would be a desirable technological path to pursue. This was evident in a hearing organised at the Danish Parliament in 2001 (Teknologirådet 2001). Here it was taken for granted by most actors that biofuels were sustainable, while the technical and economic feasibility was debated intensely. This was an exploratory phase, where only incipient alliances can be detected. Later, this situation was reversed as advances in scientific knowledge had made the technical feasibility less uncertain and economic feasibility became framed as a question of political will to prioritise and subsidise. Sustainability was increasingly contested by more actors and either made conditional on a range of factors involved in the production or simply rejected by opponents. This designates a phase of stronger polarisation of the discussions.

The initial political stance in Denmark in the first half of the decade from 2000 was one of ‘wait and see’, leaving the initiative to international developments. In this respect Denmark is distinct from Sweden and Germany, which both made strong commitments to promote biofuels from early on (Eklöf 2012, Franco et al 2010). In order to understand the subsequent developments, it is necessary to briefly explain the difference between 1st and 2nd generation biofuels and place the Danish case in the context of EU policy developments.

A distinction between 1st and 2nd generation technology has become central to the debates about biofuels. 1st generation biofuels are produced from crops which are also used for food production or animal feedstuff. 2nd generation biofuels are produced from biomass which cannot serve as food or feedstuff (Charles et al 2007). Proponents claim that 2nd generation fuels will remove competition with food production. Some observers also talk about 3rd generation fuels derived from algae, which is claimed to
alter energy production completely in the future. Whereas the 1\textsuperscript{st} generation fuels are already in wide commercial circulation, 2\textsuperscript{nd} generation ones are still not commercially viable and 3\textsuperscript{rd} generation fuels are still in early R&D stages. However, significant investments are being made in developing these technologies, and the prospect of 2\textsuperscript{nd} (and eventually 3\textsuperscript{rd}) generation biofuels serves an important legitimising function in the debates. The proponents of biofuels claim that only by getting the technological infrastructure up and running through 1\textsuperscript{st} generation technology will be possible to introduce 2\textsuperscript{nd} generation on a commercially viable basis later on (Richardson 2012).

The EU has been instrumental in shaping the international developments in bioenergy. In 2003 the EU issued a Directive (2003/30/EC) to promote biofuels and other renewable sources of energy in transport and introduced blending targets as a means to pave the way for market penetration. The idea was that once a market is established, competition and innovation would follow, leading to commercial viability of 2\textsuperscript{nd} generation fuels. Biofuels were seen as an important vehicle to drive the Union towards a more advanced bioeconomy where industrial biotechnology was designated as an essential driver of economic growth (Birch et al 2010, Richardson 2012). The directive set targets for a 2\% market share for renewable energy in the transport sector in 2005 and 5.75\% by 2010. This target was an average one for the whole Community and thus not initially made mandatory for individual member states. However, member states were obliged to formulate strategies for the introduction of renewable fuels in the transport sector and report regularly on their advances.

At this point, the Danish government assessed that bioethanol blending was not a cost-effective means of CO2 reduction as the country already used a significant volume of biomass for stationary energy production where CO2 substitution was cheaper. Consequently, the government initially set its target at 0\%. However, as the EU was resolute in its ambition to push the biofuel technology forward, Denmark needed to do something to appease the Commission. Simultaneously, representatives from research and industry began to flag a concern that Denmark should take care not to fall behind the movement towards the bioeconomy, which they claimed is well suited for Danish innovation capacities. This was argued with
particular force by two Danish biotech companies, Novozymes and Danisco (now a subsidiary of DuPont), which are considered important flagships of Danish industry. In 2005 the Danish Energy Agency therefore initiated work on a vision for the development of liquid biofuels in Denmark, as well as a strategy to coordinate the activities of different actors in this field through public-private partnerships (Energistyrelsen 2008).

In 2006 the EU Commission made the 2010 target of a 5.75% blending mandatory in all member states, projected to rise to 10% renewable fuels in 2020. Further policy action was thus required to meet the EU requirements. In April 2006 another hearing was organised at the Danish Parliament on ‘Green transport’ (Teknologirådet 2006). Here the tone among the invited experts was predominantly optimistic. Biofuels were now framed and debated not only as a technology that could provide environmental benefits and resource independence, but also a potential export market where Denmark has great potential.

However, due to existing infrastructural investments in heat and power production, the Danish Energy Agency continued to contest the claim that bioethanol blending was a cost effective means to reduce CO2 emissions. The political system thus remained reluctant to change the subsidy schemes for different biomass uses (Interview, civil servant, September 2011). This induced complaints from scientific and industrial actors that policies were biased in favour of existing technologies and biomass applications to the detriment of Danish competitiveness.

Around this time (2006/2007) however, critical voices began to manifest themselves internationally, and critical framings of biofuel began to gain attention in Denmark. This induced a more vivid, symbolic struggle in the public sphere about the rationality and consequences of a large-scale reliance on biofuels. In 2007 an international coalition of environmental organisations made a joint statement urging the EU to backtrack from its announced policy on biofuels (Biofuelwatch 2007). The Danish chapter of Friends of the Earth co-signed the statement and promoted the message to the Danish public. They claimed that increased reliance on biofuels will be detrimental to the environment, especially in developing countries, and aggravate global inequalities. In November 2007, the OECD published a policy
brief that problematised biofuels policies (OECD 2007). This generated some resonance in Denmark. For instance, the then minister for the environment, Connie Hedegaard, declared that “We should not pour food into the petrol tank”, but confirmed her support for 2nd generation technologies as the clever alternative (quoted from politiken.dk 15th April, 2008).

The Danish case is thus one where the biofuel trajectory was not embraced wholeheartedly by the government when compared with neighbouring countries like Sweden and Germany. However, as the EU continued to push biofuels via mandatory blending targets, and Danish scientists and industry warned that Denmark should not let this opportunity for innovation be passed up, significant public funds were made available for university-industry collaborations on R&D.

**Competing scientific perspectives in the biofuel controversy**

I now move on to examine how different scientific knowledge claims are coupled to policy objectives. I interpret the governance of biofuel innovation in Denmark as a struggle between two competing advocacy coalitions, which each produce their own distinct couplings between scientific claims (causal beliefs) and policy stances (normative beliefs), and use scientific claims to gain leverage in different policy arenas.

Different aspects of biomass and biofuel production have been made the object of research within different scientific specialisations. I suggest that the central issues of the public debate on biofuels in Denmark can be aligned along two encompassing but distinct scientific perspectives emerging from academic science. Each of these perspectives has affinities to one of the advocacy coalitions. In the first step I examine how each of these scientific perspectives frames the biofuel trajectory and what their representatives consider to be the key issues at stake.

Subsequently, I examine how these claims form part of the justificatory basis of policy claims in the public debates.
The biorefinery optimists

The scientific arguments used to support biofuels are delivered predominantly by researchers with a disciplinary base in biochemistry and molecular biology. A guiding vision is the biorefinery as a generic process technology, whereby any biomass can be transformed into a plant-based equivalent of crude oil. For convenience, I shall refer to these scientists as ‘biorefiners’. Their participation in the public debate entails a two-pronged argument in favour of biofuels. Firstly, they suggest that plants are a most powerful capturer of energy from the sun through photosynthesis. Significant scientific progress has been made recently in extracting this energy through various biochemical process technologies, in particular enzymatic degradation of cellulosics. These process technologies will allegedly allow a 2\textsuperscript{nd} generation extraction of energy from crop residues and non-food crops, which were impossible to process with a positive energy balance in the past:

\begin{quote}
\textit{We can now do a lot of things at the molecular level, and we have shown the potential is huge. If it becomes technically possible to realise these potentials on a large scale, we would in principle only need bioenergy in the future. But the limiting factor is how to use the available arable area in an optimal fashion, so we don’t need to compromise food production and biodiversity.} (Interview, biochemist, September 2009)
\end{quote}

Thus, while recognising some of the problems raised by biofuel sceptics, the biorefiners \textit{secondly} suggest that novel process technologies will allow for significant synergies in production chains and they envision a symbiotic mode of production where residues from one process serve as input in the next process, described with phrases such as “‘up-cycle’ rather than ‘re-cycle’” (Interview, sector organisation, October 2011). In short, the main argument goes as follows:
What limits us is not really how much biomass we have available, but how we use the available areas. If you combine technologies and use the same biomass to produce food, fuels, chemicals and climate-friendly fertilisers etc. you can do more with the same biomass. Whereas if you simply burn the biomass, or use it for food only, that is a completely one-dimensional way of looking at things... you don’t see the interactions, the synergies that are possible (Interview, biochemist, September 2009).

When presented in public, the science is framed as an optimistic narrative suggesting scientific ingenuity as key to solving most of the pressing challenges facing the world (e.g. Felby 2010):

We’re in it up to the neck. We are facing some very significant restructurings, but the biggest barriers are in our heads; it is not that we lack the necessary technologies. The risk-willingness in the political systems is very small – but we don’t have 200 years to solve our problems, and we need to launch many different initiatives (Interview biochemist, September 2009).

When questioned more specifically about whether it makes sense to use biomass to fuel cars, my interviewee, who is a leading university scientist and one of the most articulate representatives of this research in Denmark, suggested that no realistic alternatives to biofuels are on the horizon and transition is urgent. Cars running on biofuels may not be the ideal solution in the long run, but:

...any technology can be criticised. However, time is short and we risk that the ideal of the perfect solution becomes the enemy of good solutions. (Interview, biochemist, September 2009)
In this assessment, the major obstacles to such a technological trajectory gaining momentum in Denmark are rooted in political and regulatory hesitations, rather than technical limitations per se. In this view, the hesitation is primarily caused by pressure from environmental NGOs, which fail to differentiate between good and bad ways of producing biofuels, referring to the distinction between 1st and 2nd generation fuels. Resistance to change is thus primarily ascribed to deficient rationality and vested interests among NGOs.

Not all environmental NGOs reject biofuels, though. Similar scientific claims regarding the potential benefits of biochemical research can be found in a report from the World Wildlife Foundation (WWF), which undertook a joint project with the biotech company Novozymes to explore paths towards a ‘low carbon economy’. They suggest that:

... industrial biotechnology can enable a shift toward a biobased economy... based on production paradigms that rely on biological processes and, as with natural ecosystems, use natural inputs, expend minimum amounts of energy and do not produce waste as all materials discarded by one process are inputs for another process and are reused in the eco system (WWF Denmark, n.d.: 6)

While not particularly keen to promote biofuels for cars, WWF align themselves with the optimistic scenarios entailed in the image of a low carbon economy promoted by biorefiners, accepting that bridging technologies are a necessary step on the way (cf. Richardson 2012).

It is characteristic that the scientific claims of the biorefiners rely on a reductionistic ‘building-blocks’ metaphor, where scientific advances at the molecular levels allow for novel combinations based on organic matter to be scaled up in biorefineries. Such biorefineries are projected to solve more macro-level societal problems via step-by-step expansion. When observed upwards from the molecular level, biomass is framed as an abundant and extremely flexible resource, and any potential scarcities are associated with suboptimal uses and regulatory rigidities.
We can thus observe how authorised scientific knowledge generated at the molecular level is coupled to societal visions in two ways. On the one hand science-based projections are made about what can be done in future technological applications. These projections are not established scientific facts, but derive credibility from their scientist sources. On the other hand, the projections locate the responsibility for the realisation – or not – of future applications outside the scientific system and direct demands at policy makers. There is a noteworthy temporal dimension to this coupling: current research results are used to envision future technological applications, the realisation of which requires particular policy choices in the present. This also illustrates the asymmetries between scientists and other policy actors, where scientific authority is translated into political credibility, which cannot easily be dismissed by non-scientists policy actors. For this, counter-expertise in form of alternative scientific perspectives and interpretations are required.

‘Biofuel optimists suggest positive synergies between different usages of biomass in closed loops of constant ‘up-cycling’’. Source: U.S. Department of Energy Joint Genome Institute.

The bioscarcity pessimists

The scientific arguments articulated against biofuels in Danish public debates derive primarily from researchers with a disciplinary base in environmental science, ecology and life-cycle analysis. These scholars argue that although seemingly abundant at present, biomass will be a limited resource in the future. Depleting fossil resources have sparked emerging technologies in many sectors reliant on biomass (fuel, heat and power, chemical engineering etc. in addition to food production). Because these technologies develop in parallel, the central problem from a life-cycle analysis perspective is how to prioritise between different uses of biomass and avoid the detrimental knock-on effects of land-use change in the developing
world when demands grow in the rich countries. In such analyses liquid biofuels, whether 1st or 2nd generation, do not perform well:

Even the theoretically maximum available biomass is going to run out long before we have fulfilled more pressing needs than road transport... The energy sector in the rich parts of the world is potentially a much larger ‘customer’ for biomass than the global food market. This means that fulfilling even a fraction of the needs of the transport sector world-wide will demand a relatively large share of the areas needed for food production. (Interview, life-cycle analyst, October 2009)

Liquid biofuels are a primary object of technological innovation today, but from a life-cycle analysis perspective, road transport represents a suboptimal use of biomass. Furthermore, life-cycle analysts suggest that intensified biomass production is expected to produce a number of undesirable knock-on effects in terms of technological lock-ins, delaying the transition from combustion engines to electric or hydrogen-powered vehicles or even more substantial changes in infrastructures to lower the demands for individualised mobility. Also, biomass shortages in the richer parts of the world are likely to call for imports from economically and ecologically more vulnerable parts of the world:

The current US target is to use 30% biofuels in road transport in 2030. That will require something like 125% of their arable area. In the meantime, consumption is projected to go up, meaning that the fossil consumption stays at the same level in absolute terms. What should then be the next step? How will they solve other problems such as dependency on fossil fuels, CO2 emissions etc. Through imports of biomass? As I see it, it is a dead end, which will diverge from the search for genuinely sustainable alternatives for a number of years. (Interview, life-cycle analyst, October 2009)
There is some contention about how to delimit the systemic aspects of biofuel production and consumption. Nevertheless, the general consensus suggests that liquid biofuels constitute a suboptimal use of biomass. When biorefiners compare (future 2nd generation) biofuels favourably to currently used fossil fuels, they ignore the fact that the same biomass could be used more cost effectively to reduce CO2 emissions if applied differently (Wenzel 2009). Publicly, this perspective is framed in more pessimistic tones, suggesting that incumbent interests are the primary obstacles for a more sustainable development (e.g. Hedegaard et al. 2008).

The scientific perspective of life-cycle analysis thus moves holistically from a macro-scale to consider biomass as a scarce and fragile resource, depending critically on many interlocking factors in the production chain. This perspective compares estimates of the energy available to extract from biomass, either at regional or global level and the estimated energy required to refine it for different purposes. Though researchers may disagree about the most suitable metrics for different problems (e.g. energy balances, CO2 removal, land use change, etc.), my interviewees suggested that there is fundamental agreement among academic life-cycle analysts that liquid biofuel for the transport sector is suboptimal when taking alternative uses into consideration. However:

...from early on the agenda for this area was captured by commercial interests to serve as a ‘green agenda’ for the petrol industry, car manufactures and agriculture (Interview, life-cycle analyst, October 2009).

[PICTURE II GOES ABOUT HERE]

‘Biofuels sceptics suggest that the need to fuel cars in the richer parts of the world will crowd out food production in the poorer parts’. Source: ActionAid
Similar to the biorefinery perspective, we can observe a coupling between authorised scientific knowledge – here regarding circulation of energy and resources – and projections about future developments linked to extra-scientific concerns. Also here, scientists speak authoritatively about what ought to be done. Temporally, this perspective place less significance on the distinction between 1st and 2nd generation biomass. It suggests that future growth in biomass consumption will likely shift production patterns in ways that will cancel any sustainability gains and shift the burden onto fragile ecologies and communities. In the following I examine in more details how these scientific claims are coupled to policy debates.

Advocacy coalitions as interfaces between science and politics in the biofuel debate

Two distinct scientific perspectives on biofuels can thus be discerned in the Danish debate a reductionistic biorefinery perspective pointing towards a search for biochemical synergies in the application of biomass on a trial-and-error basis, and a holistic bioscarcity perspective focussing on the need for overall prioritisations in the use of available biomass According to my interviews, the most prominent scientists representing each of these perspectives are well-known to all actors in this domain and provide scientific inputs and credibility for other actors engaged in the policy arena. This coupling between science and policy-making takes place via two opposing advocacy coalitions.

I label these advocacy coalitions biofuel optimists and biofuel sceptics, respectively, to designate their overall policy stance on biofuels. Both coalitions include actors with various degrees of enthusiasm for and commitment to the respective policy stance. Among the biofuels optimists in Denmark we find the biotechnology industry, which is dominated by two very large enzyme producers (Novozymes and Danisco), who share among them approximately 80% of the world market in enzymes, the biggest energy company (DONG), which is running the currently largest pilot production facility for 2nd generation biofuels in the world (Inbicon), and the dominant agricultural sector interest organisation (Landbrug og Fødevarer),
representing both primary producers and the food industry. Landbrug & Fødevarer gives priority to food production, but is keen to promote energy crops and the use of crop residues as sources of additional income for farmers.iii

The biofuel-sceptical coalition comprises environmental and developmental NGOs, most of which by now vehemently reject the biofuel trajectory, even if they admit in interviews that it is sometimes difficult to explain in public why something labelled ‘biofuels’ is a bad thing (Interview Greenpeace DK (October 2009), Danmarks Naturfredningsforening (November 2009)).iv However, less publicly visible, it emerged that parts of the energy sector as well as the Danish Energy Agency are less enthusiastic about the prospect of competition for biomass, which currently goes into what they consider a relatively well-functioning power production

As introduced above, by advocacy coalition I understand loosely coupled networks of actors which are organisationally distinct but share policy beliefs. However, while an advocacy coalition is not a formal entity, nor is it an observer construct. The actors affiliated with an advocacy coalition are well aware of each other as alliance partners in their particular cause. Organisations affiliated with a particular advocacy coalition observe each other in the public sphere and they regularly meet each other in policy settings such as public hearings, government advisory committees etc.

That the Danish public debate is indeed characterised by two opposing coalitions is evidenced by several factors in this inquiry.

All interviewees referred in a matter of fact manner to ‘opponents’ and ‘allies’ in their respective endeavours, and they have clear perceptions of which actors belong in which coalition. My interviews also revealed a general tendency to mutually ascribe questionable motives and deficient rationalities to the other camp, a tendency described by the advocacy coalition framework as ‘devils shift’ (Sabatier 1998: 110).v Advocacy coalitions are thus relational entities, which derive their unity through positioning vis-à-vis opponents.
In their contributions to the public debate policy actors often make references to scientific research. However, they do so in a selective manner, aligning their arguments with one or the other of the scientific perspectives described above, and seldom engage seriously (in public) with scientific claims proposed by their opponents. Here policy core beliefs work as filters, selecting information that is aligned with those policy beliefs and ignoring or questioning information that is not.

Finally, when queried in interviews about the scientific ambivalence surrounding the the biofuel trajectory, the actors readily concede that the issues are complex and knowledge uncertain. Yet they reaffirm that ‘their’ knowledge is the least flawed alternative, least biased by ideological or economic interests, and a secure enough knowledge base to act on.

In the following I contrast the positions of the two coalitions on three issues: 1) whether Denmark should actively aim to include biofuels in the country’s own energy provision, 2) what role Denmark should play in the global developments in biofuels and 3) what kind of subsidies should be provided – and how – in this area. A summary of the analysis is provided in Table I.

**TABLE 1: CONFLICTING POLICY STANCES ON BIOFUELS**

<table>
<thead>
<tr>
<th></th>
<th>Biofuels optimists</th>
<th>Biofuels sceptics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key problem framing</strong></td>
<td>Pressing need to develop and implement alternatives to fossil fuels in transport sector</td>
<td>Pressing need to foster long-term, sustainable CO2 reductions in global perspective</td>
</tr>
<tr>
<td><strong>Central scientific claims</strong></td>
<td>Breakthroughs in biochemistry and process engineering allow synergistic uses of biomass in multi-purpose production, where all residues and waste can be ‘up-’</td>
<td>Biomass will inevitably be a scarce resource in the future and must be prioritised for most sensitive sectors. Heavy reliance on biomass in many sectors will have</td>
</tr>
<tr>
<td>Cycled' (Reductionistic biorefinery perspective)</td>
<td>Detrimental social and ecological knock-on effects (Holistic bioscarcity perspective)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>Biomass availability</strong></td>
<td>Biomass an abundant resource. Limiting factors are regulatory and technical barriers to be overcome by innovation and targeted economic incentives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biomass a scarce resource. Uncurbed needs in Western world will shift adverse effects to developing countries and fragile ecologies</td>
<td></td>
</tr>
<tr>
<td><strong>1st/2nd generation</strong></td>
<td>1st generation may be problematic, but necessary to get technology development. 2nd generation will solve conflicts with food production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1st/2nd generation distinction untenable in practice. Increased consumption will necessitate imports to developed world, inevitably putting pressure on food production and increasing CO2 emissions.</td>
<td></td>
</tr>
<tr>
<td><strong>Favoured solutions</strong></td>
<td>Synergies in clever uses of biomass facilitated by science-based innovations to underpin continued economic growth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optimise biomass use in terms of CO2 substitution, change technological basis of transport sector through innovation along novel technological paths, curb consumption</td>
<td></td>
</tr>
<tr>
<td><strong>Role of industry</strong></td>
<td>Key driver of innovation that utilises existing Danish strengths to create jobs and growth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Private economic interests tend to overrule the socially, environmentally and technically</td>
<td></td>
</tr>
</tbody>
</table>
optimal solutions

| Key obstacle to realising solution | Lack of political commitment manifested in insufficient support for research, outdated subsidy structure and absence of incentives for investment by private sector | Path-dependencies in existing automotive infrastructure and incumbent interests promoting their narrow interests at expense of genuine sustainable development |

**Biofuels as bridge or diversion?**

A key difference in the policy stance of the two coalitions is how potential benefits and potential costs of biofuel production and consumption should be framed, and consequently also how they should be weighed against each other. The optimists argue that biofuels are the only feasible means to reduce GHG emissions from the transport sector in the short to medium-term:

*There is no one solution for solving the CO2 problem, but one thing is certain: there will be more cars on the roads. And the only means to reduce emissions in the next 10 years is bioethanol – so we better just get started* (Interview, Novozymes, October 2009)

The sceptics, on the other hand, argue that biofuels are a suboptimal way of using biomass. This is the standpoint taken by the Danish Energy Agency, for example:

*...there will not be any alternative fuels with a large production potential, which will ensure CO2 reductions and increased use of renewable energy within a short-time horizon without significant additional costs, which are estimated to be higher than potential measures in other sectors.*
Generally, for the time being, biomass is used most energy-efficiently in power and heat production in Denmark (Energistyrelsen 2008: 4).

The sceptics therefore suggest that all investments in biofuel technology and infrastructure will create technological lock-ins and are thus likely to postpone what they consider genuinely sustainable solutions, including a curbing of consumption:

... With the law on biofuels, incentives are created to use food and biomass to make inefficient biofuels to tank up inefficient engines (Greenpeace 2009).

In this debate, the scientific differences conceptualised as ‘reductionistic’ versus ‘holistic’ are here manifested in two different temporalities in the views on how to solve the problems affiliated with GHG emissions etc. The biofuel optimists generally operate with a shorter time horizon, which makes the search for stepwise improvements of existing structures and technologies in different sectors the most suitable policy. The sceptics generally accept a longer time horizon for their end goals and call for a more encompassing planning effort, which includes a more active search for reduction in energy consumption. These differences in time horizon are linked to the two coalitions’ preferences for either market-based (incremental) or state-based (planning) types of solutions, which belong at the level of policy core beliefs, where they differ markedly. However, they may still be able to reach compromises regarding more specific policies. The dominant actors in the biofuel optimistic coalition are clearly adherents of market-based approaches as part of their policy core beliefs. However, at the practical policy level they are willing to accept subsidies and other market-correcting measures such as the EU blending targets.

Likewise, though generally in favour of active state intervention and long-term planning, parts of the biofuel-sceptic coalition support the efforts of local entrepreneurs developing tailor-made solutions to local problems, such as small-scale biobased energy production in local power stations that can counter the
dominance of big commercial players. Similarly, while the EU blending targets occur problematic to the sceptics, at least some of the coalition members are willing to compromise on this specific policy level when blending targets are accompanied by sustainability certification schemes.

Local growth or global responsibility?

The differences in temporal perspectives are further linked to a geographical dimension. The biofuel optimist coalition sees another important motive for biofuels in the potential for economic growth. Biofuels are not considered only a means to save the planet from overheating in the long run, but also a way of creating jobs and export opportunities in the present. This is most vividly illustrated in the suggestion that biofuel production has the potential to become a new windmill adventure:

*As it was the case with the windmills, biofuels can now move from being a research-based and experimental platform to become an actual production. In addition to the obvious environmental benefits it can create many new jobs for engineers and researchers in agriculture, production and high-tech companies* (Rasmussen 2008)

The debates about biofuels thus reach significantly beyond issues of environmental and energy policy and into something which is a key question in Danish politics: the future livelihood of the nation in the emerging bioeconomy. The biofuel sceptics are no strangers to this agenda, but draw different conclusions. They claim that Denmark has already achieved remarkable results in producing bioenergy in power and heat production, a niche area in which the country should continue to innovate and step up its export efforts to remain self-supportive. From the sceptic’s perspective the key driver of the biofuel trajectory at the global level is the protection of incumbent interests in existing value chains. Hence, they
seek to couple the debates about biofuels to questions of global justice and land use change in the developing world:

*The outcome is that the EU’s policies are grabbing food from the mouth of the world’s starving and pouring it into European fuel tanks* (Mellemfolkeligt Samvirke 2010).

*It is very problematic that Denmark has decided a target for the use of biofuels, which can only be fulfilled if a large part of it is imported from third world countries* (NOAH 2009)

In this respect, biofuel optimists and sceptics forge links between core policy beliefs and preferences of economic prosperity and global justice as desirable futures and the causal beliefs entailed by the reductionistic and holistic scientific perspectives. The first are mostly occupied with the challenges to national prosperity from global competition and frame biofuels as a win-win technology, whereby Denmark can simultaneously contribute to solving some of the problems affiliated with fossil energy and generate sources of future export incomes. Sceptics, on the other hand, see biofuels as a neo-colonial project, which will inevitably work to the disadvantage of vulnerable people and ecosystems. Therefore, it is unacceptable to opt for technologies which will require, even temporarily, imports of biomass from more vulnerable parts of the world. As a consequence of these differences, the two coalitions are also divided when it comes to the kind of policies they want the Danish state to initiate.

*What to subsidise?*

When questioned about the main obstacles for a successful development of biofuels in Denmark, the optimists all refer to an alleged lack of political support. Several of my interviewees claimed that rhetorically politicians are all in favour of novel forms of renewable energy, but they are very reluctant to
provide the level of subsidies and favourable taxation schemes that would facilitate serious commercial involvement. In order to protect previous investments in facilities based on biomass combustion, existing policies discriminate against novel uses of biomass and hence, in effect, inhibit the potential of Danish innovation in this field.

If you burn straw you get huge subsidies. If you turn it into bioethanol, you don’t get anything

(Interview, public-private venture, October 2011).

If the same subsidies were given to bioethanol production [as to straw burned in incinerators], you couldn’t find one straw in Denmark. It would all be turned into bioethanol (Interview, biochemist, September 2009).

The Danish government is thus continuously criticised for being much more reluctant in this area than the neighbouring countries Sweden and Germany, whereas the EU is generally applauded for its visionary policies of the mandatory mixing directive. EU policies may not be perfect, as biomass needs to be imported from other parts of the world to fulfil the requirements, but they create incentives to innovate and build up capacity for the coming 2nd generation fuels. This illustrates the legitimating function of an emerging future 2nd generation of biofuels for the present commercial activities, which are all based on 1st generation technologies. As mentioned above, for the biofuel optimist coalition, this is justified as public investment in incubating an emerging technology, which must be temporarily protected from competition from incumbent fossil technologies.

The biofuel sceptics, on the other hand, consider subsidies for biofuels both a waste of public money and a disservice to the climate. They argue that CO2 substitution can be done in greater volumes at lower prices by focussing public investments and subsidies on other applications of the available biomass.
“Why should we do it? Denmark is unique in regard to stationary power production, which utilises all the energy available in biomass compared to the 45-50% achievable through biofuels. The only reason this is being promoted is to maintain the interests of industry actors (Interview, Greenpeace, October 2009)

There are thus notable differences in the core policy beliefs between the two advocacy coalitions in regard to whether technological R&D is best managed by incremental market mechanisms or state-based planning efforts. However, when it comes to more pragmatic considerations, there is general acceptance that subsidies are necessary policy tools to implement more sustainable technologies. Here, the disagreements pertain to the technological paths which will provide the best environmental outcomes and returns on investment, and whether environmental protection or economic growth should weigh more heavily in subsidy policies. As the analysis has shown, such assessments are closely coupled to the scientific framings of biofuels based on, respectively, a reductionistic perspective stressing biorefineries and a holistic life-cycle perspective stressing bioscarcity.

Conclusion

The critical social science literature on biofuels primarily focuses on economic drivers and consequences of biofuel technology, whereas the scientific dimension of biofuel controversies appears to be neglected even though scientific authority plays a key role. I therefore set out to explore the following questions: What role does science play in the controversies over biofuels? Why is it that very different scientific assessments of the potential merits of biofuels continue to compete in public debates? And how are techno-scientific developments and policy-making in the biofuel domain interrelated? These questions were explored through a case study of public debates bout biofuels in Denmark.
My analysis is guided by the sociological theory of functional differentiation, claiming 1) that science and politics are two fundamentally different modes of communication which, however, are increasingly tightly coupled to each other and 2) that science as well as politics is internally differentiated.

Based on this, I suggest that the societal controversies about biofuels cannot be attributed to either scientific uncertainty or conventional scientific controversy. The internal differentiation of science produces different ways of framing biofuel production and consumption, leading to different and conflicting policy implications. This creates an ‘excess of objectivity’ (Sarewitz 2004) in public debates, where scientific claims-making and policy stances can be linked in different ways.

My analysis has examined how the coupling of scientific and political modes of communication manifests itself in the public debates about biofuels in Denmark. As scientific communication is internally differentiated, policy actors can make reference to very diverse sets of science-based arguments. In this case I identified two distinct scientific perspectives, ‘biorefinery’ and ‘bioscarcity’, rooted in different disciplines. The reductionistic biorefinery perspective works upwards from the molecular level and envisions positive synergies in the use of biomass for many different purposes. The holistic bioscarcity perspective, in contrast, works downwards from global scope conditions and envisions negative externalities from a growing reliance on biomass in the rich parts of the world. The existence of these two diverging scientific perspectives explains why different scientific claims continue to compete in public debates. Scientific researchers provide authority and legitimacy for other actors that have more immediate political and economic stakes in how biofuel technology will eventually be developed and governed. These actors need scientific backing to operate convincingly in public debates and policy arenas and thus invite scientist to communicate their knowledge in public, leading to a growing scientification of politics.

While the theory of functional differentiation is useful to interpret the differentiation in knowledge production as well as the analytical relationship between science and politics, it is less specific about how science and politics are coupled in practice. I have thus used the concept of advocacy coalition to explore how different scientific perspectives on biofuels are coupled to policy stances by relating causal and
normative beliefs to each other socially. Advocacy coalitions align causal and normative beliefs and translate them into concrete policy stances. Coalitions form when actors share beliefs and interests, which are opposed by other actors. The case study showed how the scientific perspectives affiliated with biorefinery and bioscarcity perspectives, respectively, are taken up selectively by two different coalitions. These scientific perspectives map onto different political concerns regarding the temporal, spatial and economic transitions towards a bio-based knowledge-economy. Here a number of differences between the optimistic and the sceptical coalition were identified. They pertained to whether Denmark should aim to include biofuels in its energy provision, what role the country might play in the global development of biofuels, and how subsidies should be applied in this area. In these three dimensions, clear affinities between the scientific perspectives and policy positions could be identified with the two coalition camps. The scientific perspectives thus go hand in hand with core policy beliefs of the respective coalitions, which are antagonistic in several aspects regarding preferences for markets versus state planning and local growth versus global responsibility. However, the case also showed how compromises can be struck when specific policies can be aligned with secondary policy beliefs.

This analysis should not be taken to suggest that policy stances are shaped exclusively by scientific perspectives, or that research priorities are formed wholly independently of policy objectives and political interests. There are both subtle and not-so-subtle mechanisms of mutual feed-back in operation in such cases. The key concluding point is that the case study has demonstrated that scientific knowledge production play an independent and differentiated role, which deserves attention in its own right in addition to the economic interests in play in the biofuels field.

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**Biographical note**

Janus Hansen holds a doctorate in social and political science from the European University Institute in Florence. He is currently associate professor in sociology at Copenhagen Business School. His research interests concern the interplay between science, politics and public debates, in particular in relation to novel biotechnologies. He is the author of *Biotechnology and public engagement in Europe* (Palgrave, 2010) as well as a number of peer-reviewed journal articles.
As an anecdotal example, a representative of Greenpeace explained in my interview that in 2001, Greenpeace rigged one of their vans to run on rapeseed oil, and were very proud of it. He immediately added that a few years later they calculated what the implications would be if all cars were to run on rapeseed oil – and scrapped the.

This may be ascribed to the election of a liberal-conservative government in 2001, which in its first years in office put little emphasis on climate and environmental issues – until Denmark was designated as host for the now infamous UN COP 15 meeting in Copenhagen in 2009, after which the government quickly adopted a ‘green growth’ agenda.

The agricultural sector is already intensely involved in energy production in the form of biogas as a means with which to solve environmental challenges posed by the manure from the very large production of pigs in Denmark. This has encouraged a positive attitude to bioenergy in general and Landbrug & Fødevarer are not concerned with competition between food and energy in the Danish context (Interview trade organisation).

They prefer other labels such as agrofuels or – as one interviewee suggested – ‘food-petrol’

This picture is not entirely black and white, as my interviewees also differentiated between actors in the opposite camp and described some as reasonable and trustworthy discussion partners, whereas others where characterised as too blinded by ideological filters and self-serving interests to engage in meaningful interaction. There are thus degrees of opposition, indicating that advocacy coalitions span a broad spectrum of viewpoints.