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A fuel too far? Technology, innovation, and transition in failed biofuel development in Norway

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ABSTRACT

This article explores whether old, incumbent industries can prevent new, green industries from emerging by studying the rise and fall of the Norwegian advanced biofuel sector. It investigates three competing explanations that have been proposed to account for why Norway failed to develop a vibrant industry within this field: (i) the petroleum industry acquired all available risk capital, (ii) the petroleum industry captured all relevant technological expertise and (iii) the government failed to provide adequate incentives and support measures. The article applies a qualitative event-history analysis to chart the development of the most important Norwegian advanced biofuel companies – Borregaard (bioethanol), Cambi (biogas), Weyland (bioethanol) and Xynergo (biodiesel) – and uses their success and eventual failure as a key indicator of the condition of the emerging technological innovation system within this field. The article finds that the advanced biofuel companies were hampered mostly by inconsistent and unpredictable government incentives, and concludes that the third explanation best accounts for Norway's limited success in advanced biofuels.

1. Introduction

Norway needs, in the coming years, to transform its economy. The Norwegian economy is currently rigged towards exploiting the large petroleum reserves that the country has beneath the North Sea, and its private sector is dominated by firms that are involved in exploration, extraction and refinement of oil and gas resources. Nevertheless, the petroleum sector will not be able to sustain the same level of economic activity in the future since the Norwegian oil and gas supplies are declining and the use of fossil fuels must be reduced to meet international emission reduction targets. Many commentators have suggested that Norway could solve this problem if it managed to convince its companies to switch focus from fossil resources to renewable energy. However, Norway has so far struggled to develop viable green industries [1], even in areas where natural resources should have provided the country with a comparative advantage – such as advanced biofuels and offshore wind power. This has led some commentators to suggest that the success which Norway enjoys in the petroleum industry has somehow prevented it from developing new green industries. This article aims to contribute to this debate about whether old, incumbent industries can prevent new, green industries from emerging, by *explaining why Norway failed to develop a vibrant advanced biofuel industry*.

Three competing explanations have been proposed – by researchers, investors and policy makers – to account for Norway's lacklustre performance in advanced biofuels [2–4]. The *first* explanation claims that the oil sector is so resource demanding that there simply is no available risk capital to fund promising advanced biofuel projects in Norway. The *second* explanation maintains that Norway has a knowledge base that is so entrenched in hydrocarbon extraction that the country simply lacks the relevant technological expertise to successfully exploit advanced biofuel opportunities. And the *third* explanation states that the Norwegian government has failed to provide adequate incentives and support measures to stimulate the development and production of advanced biofuel. This article explores which, if any, of these explanations are true.

This article investigates the validity of the three explanations by exploring the formation of technological innovation systems (TIS) for the production of three types of advanced biofuels: advanced bioethanol, biodiesel and biogas. It applies the technological innovation system approach [5,6] in combination with a qualitative event-history analysis [7,8] to track the development of the main Norwegian companies working in these fields – Borregaard (bioethanol), Cambi (biogas), Weyland (bioethanol), and Xynergo (biodiesel). These companies' endeavours comprise prac-

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tically all of Norway's commercial activity in advanced biofuels, and they therefore serve as a good starting point for unravelling the wider technological innovation system within these fields, which include a broad range of actors, institutions, and technologies.

The article applies the TIS perspective to test the validity of specific explanations rather than to explain general patterns of technological development, diffusion and deployment. The article adopts this approach because it aims to contribute to an ongoing debate about the lacklustre performance of the Norwegian advanced biofuels industry, rather than to provide a complete description of all Norwegian activity in advanced biofuels. The article follows the TIS perspective and assumes that (seven) processes exist – referred to as 'functions' in the TIS perspective [7] – that could have contributed to a successful development of the Norwegian advanced biofuels industry. However, the article also assumes that some weaknesses were present in the Norwegian advanced biofuels industry – a lack of risk capital, a lack of expertise or insufficient government support – that prevent this from happening and that these weaknesses can be identified as failures in one or more of the interacting system functions.

The analysis carried out in this article finds considerable support for the third explanation (policy failure) but only some support for the first (lack of risk capital) and the second explanation (lack of relevant knowledge). Although there were examples of Norwegian companies struggling to raise capital and develop new technologies, the analysis reveals that the Norwegian companies were generally able to develop their own processing technologies and raise sufficient funds to demonstrate them. The analysis finds, on the other hand, that the Norwegian government failed to establish a reliable and predictable policy regime and that this failure put several biofuel companies out of business and scared off investors.

Although the focus of this article is on the Norwegian advanced biofuel industry, the aim of the article is to contribute to a wider debate about whether old, incumbent industries can prevent new, green industries from emerging [9,10]. This debate is not solely relevant to Norway, but also for other countries which are trying to establish green industries upon an industrial base that is heavily invested in a fossil energy regime, which is the case for many European countries [11]. The existing literature points out that old, incumbent industries can have both a positive and a negative influence on new, green industries. They can prevent new, green industries from emerging through competition and political lobbying [12,13] or they can facilitate the growth of new, green industries by providing access to technology, markets and capital [14] (see also discussion in [15]. Within the TIS literature this dilemma has recently been described as one of 'external links' and 'structural coupling,' where an emerging industry is affected by or is part of development processes in another technological innovation system [16]. Nevertheless, only limited empirical work has so far been conducted on this topic, and this article aims at helping to fill this research gap.

The article is also related to and further builds upon several recent contributions in *Energy Research & Social Science* that have discussed the development and deployment of biofuels [17,18], and it addresses several of the questions that *Energy Research & Social Science* aims to answer, such as "what are the most effective strategies for catalysing private sector investment in innovative low- or no-GHG emissions technologies" and "what are some of the endogenous and exogenous causes of failed energy innovation" [19].

The article is organised as follows: Section 2 presents the analytical framework adopted in this study, while Section 3 presents the methods; Section 4 provides some technological background information; Section 5 presents the event history analysis, while Section 6 discusses the main results of this analysis.

2. Analytical framework

The theoretical starting point for this article is the technological innovation system (TIS) approach, which was introduced in the 1990s by Carlsson and Stànkiewicz [5,6]. Since its inception, the TIS approach has undergone a series of developments and has been applied in a number of empirical studies [20–23]. And in recent years, it has been adapted specifically to study the dynamics of emerging technologies and has been used extensively to analyse renewable energy systems [20,24,7,25–27]. It is its suitability for analysing emerging technologies and renewable energy systems – which is the reason that the TIS approach is applied in this article.

The current TIS approach is summarized by Hekkert et al. [7] as an approach that 'focuses on the most important processes that need to take place in the innovation systems to lead successfully to technology development and diffusion.' These processes or 'functions' are defined by Hekkert and Negro [24] as: (i) Entrepreneurial activities, (ii) Knowledge development (learning), (iii) Knowledge diffusion through networks, (iv) Guidance of the search, (v) Market formation, (vi) Resource mobilisation, and (vii) Creation of legitimacy/counteract resistance to change. These functions interact with each other, and generate positive and negative feedback loops, through a combination of strong or weak system functions and strong or weak interactions of functions [26]. These interactions again determine whether a TIS contributes to the successful development and diffusion of a technology.

Although all functions have a part to play in the successful development and diffusion of a technology, some functions and interactions between functions can play a more prominent role. This idea is expressed through Suurs's concept of 'motors of innovation' [26]. Suurs describes the 'motors of innovation' as frequently occurring forms of cumulative causation or feedback loops generated by a specific set of interacting system functions. Suurs distinguishes between four different types of motors: the 'Science and technology push motor', the 'Entrepreneurial motor', the 'System building motor' and the 'Market motor'. Each of these motors highlights a specific form of feedback loop that leads to the successful development and diffusion of a technology by drawing extensively on a subset of interacting system functions. For instance, the science and technology push motor draws extensively on knowledge development (ii), knowledge diffusion through networks (iii), guidance of the search (iv) and resource mobilisation (vi). This motor might start with expectations of a positive research outcome (iv), which leads to public R&D (vi), which leads to technological development and diffusion (ii & iii), which again lead to greater expectations of positive research outcomes (iv) and more public and private funding for R&D (and so on).

Our theoretical conjectures are derived from the idea of motors, but we approach the concept from a different angle. Rather than thinking that there are some interacting system functions which serve as the main drivers of the development and diffusion of a technology, we envision that there are some interacting system functions which serve as the main impediments to the development and diffusion of a technology. We envision that some parts of the TIS might contain weaknesses that are so substantial and far-reaching that the system as a whole grinds to a halt – creating, if you will, a 'motor failure.' In the example above with the science and technology push motor, we could envision a positive feedback loop between positive research outcomes (iv) public R&D (vi) and technological development and diffusion (ii and iii). Nevertheless, we might also envision that this positive feedback loop collapses – after a few iterations – because of an acute lack of private capital (vi) to fund demonstration plants and commercialize the technology.

In this article, we use the TIS approach to test the validity of the claims that the lacklustre performance of the Norwegian advanced