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Original research article

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

Table 1
Failures and System Functions.

	Failure I:lack of risk capital	Failure II:lack of expertise	Failure III:lack of government support
1. Entrepreneurial activities	X		
2. Knowledge development and learning processes		X	
3. Knowledge diffusion through networks		X	
4. Guidance of the search			X
5. Market formation			X
6. Resource mobilisation	X	X	X
7. The creation of legitimacy and counteracting resistance to change			X

biofuels industry is due to a lack of risk capital, a lack of expertise or insufficient government support. To test the validity of these explanations, we develop three types of failures that correspond to each of these three explanations – a capital shortage failure, an absence of expertise failure and a policy insufficiency failure. We assume, as in Suurs's concept of motors of innovation [26], that some functions and interactions between functions play a more prominent role in these failures, and we assign a set of dominant interacting system functions to each of these three failures, based on the type of processes that they indicate as having hampered the development of the Norwegian advanced biofuel industry (see Table 1).

We investigate the *first* explanation – that there was not enough available risk capital to fund promising advanced biofuel projects in Norway – by examining whether there existed a 'capital shortage' failure that was dominated by the functions 'resource mobilisation' and 'entrepreneurial activities'. Resource mobilisation is a function that refers to the availability of financial, human and natural resources within a TIS. Entrepreneurial activities, on the other hand, is a function that refers to the presence of projects aimed at turning these resources into an "emerging technology in a practical and/or commercial environment" [26]. Concerning this failure, it is the availability of financial capital and the ability of entrepreneurs to produce viable business cases for advanced biofuels that are the most important factors. We assume that this failure is present if the advanced biofuels industry develops successfully until an acute lack of financial capital and entrepreneurial activity brings the system to a halt.

We investigate the *second* explanation – that Norway lacked relevant technological expertise to successfully exploit advanced biofuel opportunities – by examining whether an 'absence of expertise' failure existed that was dominated by the functions 'knowledge development,' 'knowledge diffusion' and 'resource mobilisation'. Knowledge development is a function that refers to learning processes related to a technology, occurring through activities such as basic research and development, laboratory experiments and adoption trials. Knowledge diffusion, on the other hand, is a function that refers to network activities where heterogeneous agents exchange knowledge, such as conferences and workshops. Finally, 'resource mobilisation' is the same function as in the capital shortage failure, but the focus in this failure is on human capital rather than financial capital. Concerning this failure, it is the availability of comprehensive and accessible expertise and the human resources necessary to exploit this knowledge that are essential, and we assume that this failure is present if the advanced biofuels industry develops successfully until an acute lack of expertise on advanced biofuels brings the system to a standstill.

We investigate the *third* explanation – that the Norwegian government has failed to provide adequate incentives and support measures to stimulate the development and production of advanced biofuel – by examining whether a 'policy insufficiency' failure existed that was dominated by the functions 'guidance of the search,' 'market formation,' 'the creation of legitimacy and counteracting resistance to change' and 'resource mobilisation.' Guidance of the search is a function that refers to processes of formulating expectations and visions related to a technology and includes activities such as formulating R&D priorities, conducting foresight studies and setting policy targets that are often carried out in conjunction by 'governments, technology producers, technology users and NGOs' [26]. Market formation, on the other hand, is a function that refers to support measures that enable emerging technologies to compete with incumbent technologies in an open market, such as financial support measures, minimal consumption quotas or taxes on the use of incumbent technologies. The creation of legitimacy and counteracting resistance to change is a function that refers to activities that create acceptance and support for an emerging technology, such as lobbying activities and advisory activities that help to counteract resistance to change [28,29]. And, finally, 'resource mobilisation' is the same function as in the previous two failures, but the focus in this failure is on public funding for RD&D (research, development and demonstration) rather than financial or human capital. Concerning this failure, it is the existence of clear public priorities accompanied by targeted public incentive schemes that are the most important factors, and we assume that this failure is present if the advanced biofuels industry develops successfully until misguided policies or inadequate incentive schemes brings the system to a halt.

Although we assign a specific set of dominant system functions to each of the three failures, this does not imply that this study is based on an assumption that these functions operate isolated and alone. Rather, we assume that system functions not assigned to a particular failure can both mitigate and exasperate those failures through positive or negative feedback loops. In essence, we assign a set of dominant system functions to each of the three failures to guide the empirical analysis towards crucial processes that – in conjunction with other processes (functions) – could have led to the lacklustre performance of the Norwegian advanced biofuels industry.

What we have devised could to some extent be described as a 'failure framework' much like that described by Weber and Rohracher [30] and Woolthuis et al. [31]. Our 'absence of expertise' failure, for instance, bears a great deal of resemblance to what these authors call 'capabilities failure.' Nevertheless, while Weber and Rohracher [30] and Woolthuis et al. [31] aimed to introduce a failure framework that could help guide policy more generally, our failure framework has been developed to deal specifically with explaining the lacklustre performance of the Norwegian advanced biofuel industry.

3. Methodology

The article carries out a study of four companies – Cambi, Norske Skog/Xynergo, Weyland and Borregaard – developing three types of advanced biofuels – advanced bioethanol, biodiesel and biogas. These companies were chosen because they are the main Norwegian business players in advanced biofuels and account for practically all of Norway's commercial activity within this field. Their success or failure can therefore be seen as a key indicator of the condition of the emerging TIS for advanced biofuels in Norway.

Table 2
Operationalization of system functions, adapted from Hekkert & Negro [24].

	Event category
Entrepreneurial activities	Project started Contractors provide turn-key technology Project stopped Lack of contractors
Knowledge development	Desktop studies Assessment studies Feasibility studies Reports R&D projects Patents
Knowledge diffusion through networks	Conferences Workshops Platforms
Guidance of the search	Positive expectations of renewable energies Positive regulations on renewable energies Negative expectations on renewable energies Negative regulations on renewable energies
Market formation	CO_2 taxes Feed-in rates Environmental standards Green labels Expressed lack of feed-in rates Expressed lack of environmental standards Expressed lack of green labels
Resource mobilisation	Subsidies Investments Expressed lack of subsidies Expressed lack of investments
Creation of legitimacy/counteract resistance to change	Lobby by agents to improve technical, institutional and financial conditions for particular technology Expressed lack of lobby by agents Lobby for other technology that competes with particular technology Resistance to change by neighbours (NIMBY attitude)

This article studies these companies by making use of 'event-history analysis.' Event-history analysis is a method that conceptualizes development and change processes as sequences of events, and in the words of Hekkert et al. [7], 'encompasses continuous and discontinuous causation, critical incidents, contextual effects and effects of formative patterns.' Event-history analysis was developed by Van de Ven and Poole [8] as a method for identifying development patterns in qualitative data and has been applied successfully in TIS studies by a number of researchers (i.e., [24,7,26]. This method has proven useful both for identifying patterns of technological development and diffusion in innovation systems and for assessing policy initiatives aimed at influencing the rate and direction of technological change.

To carry out the event history analysis, a database was created that listed all relevant events for the four advanced biofuel companies specifically and other relevant events within the Norwegian advanced biofuels field more generally. This data was generated through a review of Norwegian reports, technical news, newspaper articles, research projects and publications, patent data, and national policy and legal documents that were published in the period from when the Norwegian advanced biofuel industry emerged in 1998 up until 2015. The result was a database that included information about: the year or time period when the event took place, the company involved (if relevant), the data source, the related function in the TIS, the event category (for every system function a set of event categories was defined, see Table 2) and a description of the positive or negative impact that the event had on the development of the Norwegian TIS for advanced biofuels.

The events themselves were identified and categorized by following standard procedures for event-history analysis. In event-history analysis, it is usual to distinguish between simple incidents and events: while an incident is more or less an empirical observation, an event is a "conceptual construct in a model that explains the patterns of incidents" [8] (p. 319). This implies that some incidents were categorised as the same event, while other incidents were categorised as multiple events. After the incidents were categorized into events, the events were further categorized according to the functions of the technological innovation system and associated event categories. The result of this exercise was a rich and structured data set that laid the foundation for the detailed narrative of the Norwegian advanced biofuel industry that is presented and analysed in Sections 5 and 6.

4. Technological background

Production techniques for conventional biofuels have been developed and deployed over the last thirty years, with different countries focusing on different types of fuel and utilising different kinds of feedstock. Bioethanol has mainly been produced in the U.S. (based on corn) and in Brazil (based on sugarcane), while biodiesel has mainly been produced in Europe and in the U.S. (typically based on rapeseed, soya bean and palm oil). However, researchers, governments and NGOs have raised concerns about the sustainability of conventional biofuels. They have pointed out that production of conventional biofuels offers limited greenhouse gas (GHG) reduction benefits, can contribute to higher food prices by competing with food crops and has been linked to accelerated deforestation, declining biodiversity and water shortages in regions with scarce water resources (see, for instance, [32], p. 6). In the light of these concerns, a new generation of biofuels (advanced biofuels) has emerged that draws upon more recent scientific breakthroughs, utilizes non-food feedstock and is less demanding with regard to the use of land and water resources. There are presently many types of so-called 'advanced biofuels' being produced and new types are under development, but this article will focus on three types – bioethanol, biodiesel and biogas.

Although advanced bioethanol, biodiesel and biogas can be produced from a variety of feedstock, Norwegian companies have mainly produced (or have attempted to produce) bioethanol and biodiesel from lignocellulosic biomass (such as leaves, tree bark, straw, bagasse or woodchips) and biogas from biosolids[1] (treated sewage) and biowaste (food waste and slaughterhouse residues). Norwegian companies use a variety of processes to produce these biofuels, which can be classified into three main categories: a thermo-chemical (biomass-to-liquid) approach, a bio-chemical approach and anaerobic digestion (Fig. 1).

The thermo-chemical and bio-chemical approaches are used to produce bioethanol and biodiesel. The *thermo-chemical approach* involves heating the biomass with or without oxygen. When the biomass is heated in the absence of oxygen, the process is called *pyrolysis* and results in pyrolysic oils (bio-oils) that can be upgraded by catalysis to high-value phenols and/or biofuels. When the biomass is heated with oxygen the process is called *gasification* and results in a synthetic gas (syngas) that can be converted into synthetic biodiesel or bio-ethanol by a catalytic process (e.g. the Fischer-Tropsch process) [33].

[1] Biosolids is a term used by the wastewater industry to designate the solid "leftovers" after municipal and industrial sewage has undergone treatment to remove disease causing pathogens and volatile organic matter. This treatment process is usually carried out in an oxygen-enriched environment at a wastewater treatment plant tank, where bacteria and other microorganisms digest the organic matter (aerobic digestion). The biosolids consist primarily of the remains of the microorganisms that have cleaned the sewage and can be processed further to create biogas and fertilizer.

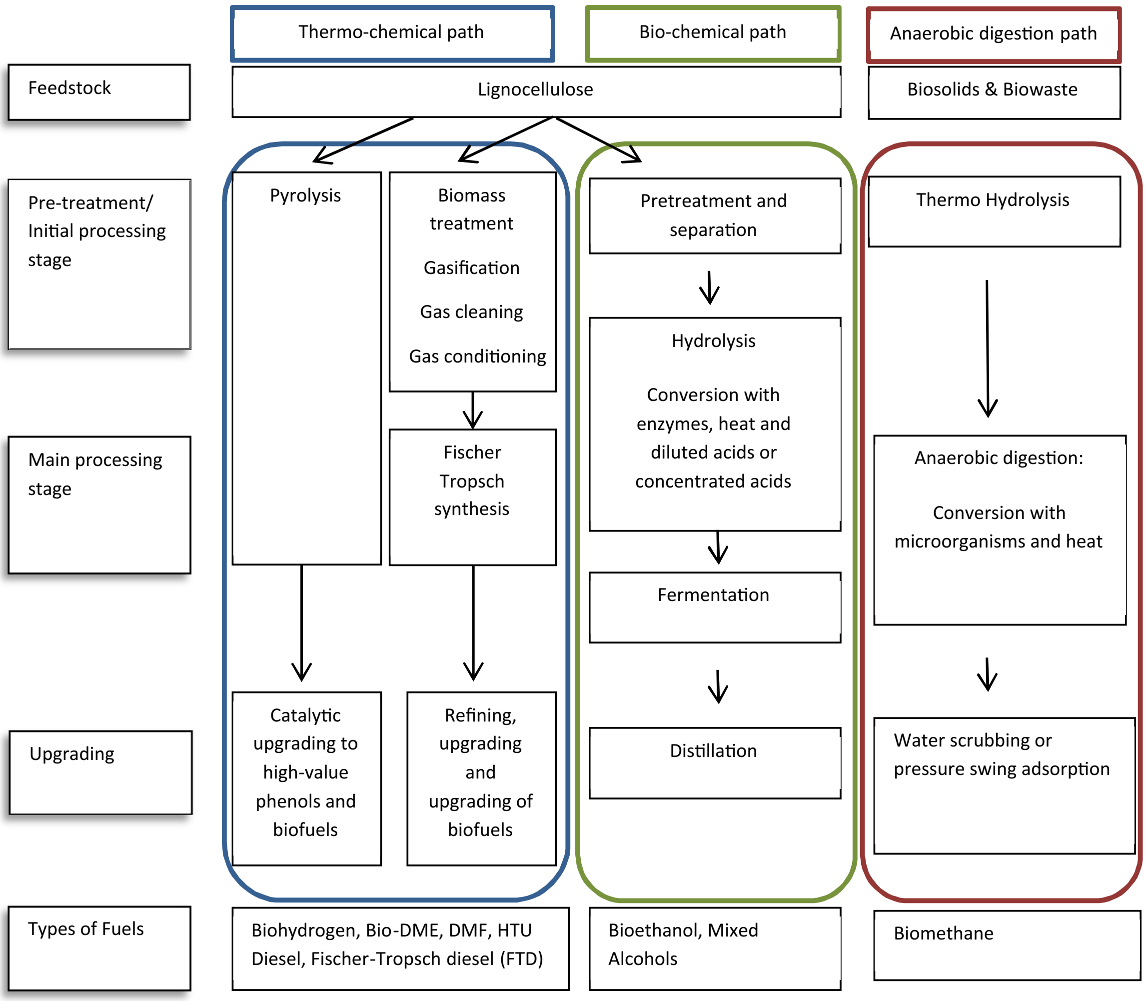

Fig. 1. Technological approaches for the production of second generation biofuels.

Table 3
Development of TIS functions over time, 2001–2014 (N = 203).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
Creation of legitimacy/counteract resistance to change	0	0	0	0	0	1	1	8	1	3	6	3	0	0	*23*
Entrepreneurial activities	1	0	0	0	0	5	2	6	5	8	4	0	1	0	*32*
Guidance of the search	2	0	1	0	1	1	0	4	2	0	2	0	2	3	*18*
Knowledge development	2	0	0	1	3	1	1	10	13	21	1	3	5	3	*64*
Knowledge diffusion through networks	1	0	0	0	0	2	0	2	4	7	2	1	0	2	*21*
Market formation	0	0	0	0	0	1	2	3	4	1	1	0	0	0	*12*
Resource mobilisation	2	0	1	0	0	1	1	1	10	8	1	4	3	1	*33*
Total	*8*	*1*	*2*	*0*	*4*	*12*	*7*	*34*	*39*	*48*	*17*	*11*	*11*	*9*	*203*

The *bio-chemical approach*, on the other hand, is technique that turns lignocellulosic biomass into ethanol in a four-stage process [34]. In the first stage of the process, the pre-treatment, cellulose, hemicellulose and lignin are separated, usually by means of steam heating, steam explosion or enzymatic pre-treatment (see [34]; Table 3). In the second stage, the hydrolysis, the cellulose and hemicellulose are hydrolysed into sugar molecules by the use of enzymes, concentrated acids or diluted acids and heat. In the third stage, the fermentation, the sugar molecules again are fermented to produce bioethanol. Finally, in the fourth stage, the upgrading, the bioethanol is distilled. The bio-chemical approach is often applied by integrated biorefinery that separates biomass resources into their chemical building blocks and converts them into biofuels and other valuable chemical compounds [35,36], p. 2233).

Anaerobic digestion is used to produce biogas from biosolids and biowaste. The anaerobic digestion process normally comprises several stages. An optional first stage (pre-treatment) is often included where the biosolids or biowaste undergo a pre-treatment to destroy and dissolve cell structures and naturally occurring cell polymers (a form of protein) into an easily digestible feed. In the second stage (main processing stage), the biosolids and biowaste undergo an anaerobic digestion process in an oxygen free/depleted environment where biogas is extracted from the biomass by microorganisms [37]. Since the resulting biogas usually consists of only 45–85% methane, a third upgrading stage is often required before the biogas can be used as vehicle fuel. Through processes such as water scrubbing or pressure swing adsorption [38], the methane content can be increased to improve the power density of the fuel and hydrogen sulphide and volatile siloxanes can

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be removed to prevent damages to vehicles' engines. The result is bio-methane – which usually consists of at least 97% pure methane and is chemically "identical" to natural gas.

5. Event-history analysis

In our event-history analysis, we divide the evolution of the Norwegian advanced biofuels industry into four unevenly spaced periods: 1998–2005, 2006–2007, 2008–2011 and 2012–2014. This categorization follows previous work, such as [26], in dividing the event history thematically rather than symmetrically and grouping together events based on whether they share common characteristics rather than some arbitrary time interval. We identify four themes that characterize the four different periods. The first period can be characterized as a period of 'sporadic activities,' since the activity that took place in the biofuel industry was mostly limited to irregular experimentation. The second period, on the other hand, can be described as a period of 'commitment and confusion,' since both the companies and the government began to explore, in a somewhat disorderly manner, how biofuels could be produced sustainably and economically. The third period, however, can be characterized as a period of 'industry formation,' since companies began to invest heavily in biofuels and the government started to introduce policies to support these developments. Finally, the fourth period can be described as a period of 'retraction and reorientation,' since most companies terminated their large-scale advanced biofuel activities and produced biofuel mostly as a by- or niche product.

In our event history analysis, we make use of a total of 203 events that can be divided across the seven TIS functions (see Table 3 below). We use these events and associated functions to create a narrative that account for how different aspects of the technological innovation system shaped the development of the Norwegian advanced biofuel industry. Due to the sheer number of articles (incidents) that the analysis draws upon, we will only occasionally refer to individual articles in the narrative, but we provide a complete list of all the sources as Supplementary material to this article.

Although the focus of this article is on advanced biofuels, the event history analysis occasionally discusses related activities, such as the production of first generation biofuels and wood pellets. These related activities were part of the four case-study companies' product portfolio, and events that affected these related activities also affected how these companies operated in the advanced biofuels market. In this sense, the event history analysis covers some events that – strictly speaking – belong to other technological innovation systems, when these events affect the technological innovation system for advanced biofuels.

5.1. *First period: sporadic activity (1998–2005)*

In the *first period* – which lasted from the late 1990s to 2005 – there were only sporadic activities involving advanced biofuels. Commercial involvement with bioenergy was mostly limited to the production of firewood or pellets for stationary use in households, and the Norwegian government lacked, for most of the period, a clearly formulated biofuel policy. Nevertheless, there were some important activities and events that took place in this period that laid the foundation for the later evolution of an advanced biofuel industry in Norway.

Among the most important events was the entrance of two new companies in the Norwegian advanced biofuels industry. The first company was Weyland, which was founded, in 2001, by two researchers from the Bergen University College. The two researchers had developed a new technology for the production of bioethanol using strong acid hydrolysis, and they established Weyland to commercialise the technology. Their technology made use of a process of recovery and recycling of the acid used in the hydrolysis process that enabled them to produce bioethanol from forest residuals much more economically. The other company that entered the industry was Cambi. Cambi switched, during the 1990s, from producing wood pellets to extracting biogas through anaerobic digestion. It developed a pre-treatment process – the 'thermal hydrolysis process' – that enabled it to increase the yield of biogas, in close collaboration with researchers from the Norwegian University of Science and Technology (NTNU) and other European research organisations. Important milestones in Cambi's development included an agreement in 1998 with the largest UK wastewater treatment company, Thames Water PLC, for the use of its technology in the treatment of sewage and food waste and a contract in 2001 to design and build a facility for the treatment of food waste in Lillehammer, Norway.

Another important event was that Norske Skog – a Norwegian-based, global producer of newsprint and magazine paper – prepared to enter the advanced biofuel industry. In the early 2000s, Norske Skog was in a critical economic situation, and a consultancy suggested that it could improve its financial situation by making use of its forest residuals to produce synthetic biodiesel (consultancy report, KanEnergi). However, Norske Skog found that it was difficult to raise capital and develop a reliable technology for producing biodiesel. It therefore began to search for partners who could help develop the technology and find investors who would be willing to invest in a new advanced biofuel venture.

The only company (of the four considered in this study) which had continuous production of advanced biofuels throughout this period, was the chemical company, Borregaard [39]. Borregaard produced, throughout this period, about 20 million litres of bioethanol annually. The production of bioethanol was nevertheless not Borregaard's primary activity, nor was the bioethanol necessarily used as vehicle fuel. Its primary activity was the extraction of valuable chemicals from woody resources, and bioethanol was more of a by-product that it produced, largely, from residues from its commercial refinery operations.

In terms of government policy, advanced biofuels was, in this period, a neglected area. Public funding for advanced biofuels was not prioritized in Norwegian energy RD&D programmes, such as Renergi. Although, the public industrial development organisation, Innovation Norway, established a bioenergy programme in 2003 and the Government Declaration by the new Centre-Left Government [40], in the autumn of 2005, spelt out a clear commitment to foster the development of bioenergy – none of these initiatives focused directly on advanced biofuels. Instead, these initiatives were directed at fostering the production and use of bioenergy and biofuels in general. Nevertheless, the representatives from the industrial associations were keen to point out these shortcomings, as they did in one instance, by criticising a study of sustainable transportation that Econ Analyse carried out for the Ministry of Transport for neglecting to discuss advanced biofuels.

5.2. *Second period: commitment and confusion (2006–2007)*

The *second period* was characterised by a growing commitment by companies and the government to the production of biofuels, but also an increasing confusion as to how this production could be carried out both sustainably and economically.

During this period, both Cambi and Weyland became more ambitious and expanded their operations. In 2006, Cambi began the development and construction of a biowaste and biosolids treatment facility in the municipality of Verdal. The facility treated food waste and sewage for 41 municipalities in the geographical region of Trøndelag and Helgeland and was at the time the largest facility of its kind in Norway. Nevertheless, neither this facility nor Cambi's existing facility at Lillehammer made use in this period of the biogas to produce biofuels (bio methane); instead, they used the biogas to produce electricity. In addition, the Verdal facility experienced efficiency losses due to difficulties with sorting out non-biological waste from the feedstock, and the Lillehammer facility received complaints from local residents arising from problems of limiting unwanted odours – both events that led to much negative publicity. Weyland also embarked on a new commercial venture, commencing, in 2007–2008, with the development and construction of an ambitious pilot plant to test its technology, with financial backing from the Research Council of Norway.

Another important event in this period was that Norske Skog began to realize its ambitions of producing biodiesel by forming a partnership with Norwegian investors and companies and foreign technology providers. Norske Skog agreed in 2006 with Hydro (now Statoil) to collaborate on a feasibility study that would investigate the possibilities for biodiesel production in Norway. Norske Skog also explored possibilities for cooperation with the German technology provider, Choren. Choren had been involved in the development of an advanced BtL (biomass-to-liquid) process based on gasification of woody biomass and an FT synthesis into synthetic diesel and could serve as a capable technology provider for Norske Skog [41], p. 6850). Nevertheless, at the end of 2007, Hydro (now Norsk Hydro) decided to establish its own advanced biofuel facility in Denmark based on straw as feedstock, and withdrew from the cooperation with Norske Skog, partly because it considered the costs of the project being too high. On the other hand, Norske Skog received some encouragement, when it learned that some of the buses in the Norwegian capital, Oslo would start running on biodiesel.

A related, but important event was that Borregaard became involved in the production of conventional biofuels (or first generation biofuels). In 2006, Borregaard took part in a joint venture together with Habiol, Unikorn AS and Østfoldkorn AS to establish the biofuel company, Uniol. Uniol, according to these companies' plans, was supposed to build a large production facility for biodiesel, with an annual production capacity of 100 million litres, based on soya oil, rapeseed oil and domestic slaughterhouse waste as feedstock. This new venture came as an addition to Borregaard's existing production of bioethanol, and not as a replacement.

In terms of government policy, the Norwegian government showed an increased commitment in this period to foster the development and use of biofuels, but it was unclear whether the government favoured the development and use of conventional or advanced biofuels. The Norwegian government stated in the White Paper on Norwegian Climate Policy [42] a general ambition for targeted and coordinated policy measures for increased use of bioenergy (up to 14 TWh by 2020), while also expressing a specific need for increased use of advanced biofuels. The government introduced a tax exemption for bioethanol-based fuel for vehicles, as long as the new fuel was largely based on bioethanol. In response to this, the oil company, Statoil, launched a new gasoline type in May 2006 that included 85% bioethanol, known as E85. However, this fuel did not necessarily consist of advanced bioethanol, and Statoil admitted that the fuel was based on corn from Europe and sugar cane from Brazil. In 2007, the Norwegian government extended these incentives by reducing the Vehicle Import Duty, on vehicles running on ethanol or mixed fuel (E85 cars) with of 10,000 NOK (ca. 1200 Euro). Nevertheless, this policy prompted several Norwegian environmental NGOs to request stronger sustainability criteria to be applied to imported biofuels.

5.3. Third period: industry formation (2008–2011)

The *third* period was characterized by a new industrial dynamic in the advanced biofuels industry. Norwegian policy-makers introduced a wide range of policies to further develop advanced biofuel processing technologies and create a market for advanced biofuels. The advanced biofuel companies responded to these policy changes by undertaking considerable investment in pilot and demonstration plants in preparation for launching full-scale production. Nevertheless, by the end of this period, few biofuel companies had actually begun full-scale commercial production of advanced biofuels.

In the third period, the Norwegian government took on a leading role and attempted to build a comprehensive policy framework to support the advanced biofuel industry. It made an important step towards building this policy framework, when it in 2008 managed to convince the Norwegian Parliament (Stortinget) to sign a bipartisan 'Agreement on Climate Policy' ("Klimaforliket"). This agreement set a broad but ambitious agenda for emission cuts and development of renewable technologies and prepared the ground for more targeted strategies and policies that dealt specifically with biofuels. These strategies and polices can loosely be grouped into two categories – 'push-based' policies that encouraged the development of advanced biofuel production processes and 'pull-based' policies that encouraged the use of advanced biofuels.

In terms of push-based policies, the government instructed its subordinate agencies to put in place a broad range of mechanisms for supporting research, development and demonstration activities. The Research Council of Norway responded to these instructions, in 2009, by significantly increasing its funding for advanced biofuels projects in its existing programmes (such as Renergi) and by establishing a new centre dedicated to the development of bioenergy (CenBio), which would carry out several R&D projects on advanced biofuels. In the same year, the government also established a new agency under the Ministry of Transport, TRANSNOVA, which was given the task of reducing CO_2 emissions by the transport sector through sponsoring demonstration projects on new sustainable modes of transportation, where advanced biofuels was one of several target areas. In 2010, Innovation Norway, launched a new funding scheme for environmental technologies, where a substantial amount of money was set aside for pilot and demonstration facilities designed to produce advanced biofuels.

In terms of 'pull-based' policies, the government made use of two types of policy to bolster demand for biofuels – tax exemptions on biofuels and minimum proportion targets on biofuels. Minimum proportion targets on biofuel was a policy that the government used to compel fuel retailers to blend bioethanol and biodiesel with the conventional fuel that they sold. Although the policy required that only a certain percentage of the gasoline and diesel that the retailers sold was bio-based, most retailers found that it was easier to sell the biofuel when they blended the biofuel with conventional fuel in low concentrations, rather than to sell the biofuel separately or in higher concentrations. The government introduced its first minimum proportion target of 2.5% in 2009 and increased this target to 3.5% in 2010. Although the minimum proportion policy ensured a reliable market for biofuels, the target was set lower and introduced later than that which the political discourse had led many NGOs and industrial actors to expect. In addition, the minimum proportion was not accompanied by any sustainability criteria that could have favoured advanced biofuels over conventional biofuels.

The other type of policy that the government used to bolster demand was tax exemptions on biofuels. In Norway, vehicle fuel has been subject to two forms of taxation – a 'CO_2 tax' that places a duty on climate gas emissions and a 'road-use tax' that pays for highway maintenance and associated infrastructure. The two taxes have historically been relatively high and in the period under investigation accounted for 45–55% of the pump price of conventional fuels. Nevertheless, of these two taxes, the road-use tax was by far the largest – comprising about 46% of the pump price for gasoline and about 40% for diesel, while the CO_2 tax accounted for only about

9% of the pump price for gasoline and 6% for diesel.[2] With regards to the CO_2 and road-use tax, the government continued to exempt both biodiesel and bioethanol from the CO_2 taxes (a tax exemption from which they had benefitted since 1991), but it made some important changes in the road-use tax on biodiesel that would have important ramifications for the biofuel industry.

Biodiesel had since 1999 been exempt from road-use tax in all concentrations. It was therefore in a very favourable situation compared to bioethanol, which was only exempt in concentrations above 50% (see previous period). Since most retailers sold biofuels blended with conventional fuel in low concentration and biodiesel in lower concentrations had a much better tax profile than bioethanol. Biodiesel was practically the only biofuel that was sold in Norway up until 2010.

Nevertheless, this situation changed at the end of this period. In the fall of 2009, the government decided to remove the exemption from road-use tax that biodiesel had enjoyed hitherto and subject it to a 50% road-use tax from 2010 and a 100% road-use tax from 2011. The government justified this decision publicly by pointing out that vehicles running on biofuels also contributed to the erosion of roads and should therefore be subject to the same road-use taxes as conventional vehicles. The government also pointed out that as biofuels had become more popular, the costs of maintaining the tax exemption had increased and argued that there were other climate-change policies which offered more value for money [43]. Nevertheless, this decision was controversial even within the government, and the two smaller partners of the 'Centre-Left coalition' government – the Centre Party and the Socialist Left Party – fought to maintain the tax exemption. Nevertheless, the coalition's largest partner, the Labour Party, was in a particularly strong position having achieved a notable election result that fall and forced through the removal of the tax exemption. Besides that, biogas was neither subject to CO_2 nor road-use taxes in any of the periods investigated in this article.[3]

Borregaard experienced, in this period, both successes and failures. Borregaard had invested considerable funds in Uniol, a Fredrikstad-based company that was to produce first-generation biodiesel. Uniol spent 360 million NOK (45 million euro) in this period on the construction of a biofuel plant and commenced production of biodiesel in the summer of 2009. Nevertheless, three months later, Uniol closed down production, due to the withdrawal of the tax exemption from road-use taxes on biodiesel. The explanation given by representatives of Uniol was that fuel retailers no longer had any incentive to buy biodiesel. Biodiesel was more expensive than imported bioethanol and when neither received any exemption from road-use taxes, the fuel retailers would only import cheap bioethanol based on corn and sugar canes to cover the government's 3.5% minimum proportion target. This event was widely covered in the media, and environmental NGOs and industry associations strongly criticised the government for the inconsistency and unpredictability of their environmental policies.

Nevertheless, Borregaard did much better with its bioethanol production. In this period, Borregaard engaged in a wide range of government sponsored research, development and demonstration projects, receiving grants from ENOVA, the EU Framework Programme 7 and the Research Council of Norway's BIA-programme to improve various aspects of its processes. Perhaps the most prominent of these projects was the development of the BALI pretreatment process, a process that reduced lignin inhibition and that resulted in important patents and a publication in the prestigious journal, Science [44], p. 17; [45]. Borregaard also became, in this period, increasingly committed to supplying bioethanol for fuel purposes, when it received a contract for supplying 1 million litres of bioethanol annually to the public transport company, Ruter, to help run its bus fleet in Oslo.

Norske Skog's ventures into advanced biofuels did not prove very successful. In 2008, Norske Skog established, in collaboration with the technology provider Choren in Germany, a new subsidiary that aimed to produce diesel from wood-based resources (BtL-diesel) – Xynergo. Since the technology was still not fully developed, Xynergo started to collaborate with experts on the gasification of wood at the Norwegian research institute, Sintef, and received in the following two years substantial financial support for these development projects, from both public institutions, such as TRANSNOVA and the Research Council of Norway, but also from private investors, such as its own parent company, Norske Skog, and the oil company, Statoil.

Xynergo planned to establish one or two full-scale plants for the production of BtL in Norway. However, in 2010, the company was in dire need of new investors, after Statoil withdrew from the joint venture and Norske Skog announced that the financial crisis had put such a strain on the company that it did not want to remain the majority shareholder in Xynergo. It was estimated that a full-scale facility could be operational by 2015, provided it received investments of 6–7 billion NOK (ca. 800 million Euro) [46]. However, in November 2010, Norske Skog decided to shut down Xynergo because it was unable to attract sufficient investment. Norske Skog's decision came along with new reports from a Norwegian research institute (Vestlandsforsking) suggesting potential health threats associated with the use of biodiesel and announcements from Xynergo's technology provider, Choren, that it was struggling to make its technology work and that it faced serious financial problems. Some months later, in July 2011, Choren went bankrupt.

Weyland managed, in this period, to convince private companies that they should invest in the company and public funding agencies that they should support the development of its strong acid hydrolysis technologies. Weyland managed to attract investment from a wide range of companies, including the oil company StatoilHydro, and received funding for several RD&D projects from among

[2] The pump prices of gasoline and diesel varied from day to day in this period, and there were small adjustments in the taxes once or twice pr. year. Nevertheless, the relative contribution of the CO_2 tax and road-use tax to the pump price remained fairly stable. The following example illustrates how the percentage contribution of the CO_2 tax and road-use tax was calculated using data from Norsk Petroleumsinstitutt: In 2009, the CO_2 tax on gasoline was 0.84 NOK and the road-use tax was 4.46 NOK, in addition a 25% value added tax was added to the pump price. If we add the value added tax to the CO_2 and road-use tax, we get a CO_2 tax on 1.05 NOK and a road-use tax on 5.58 NOK. With an average pump price of 12.02 NOK in 2009, the CO_2 tax on gasoline accounted for 9% of the pump price and the road-use tax accounted for 46% – and in combination the two taxes accounted for 55% of the pump price for gasoline. In the same way, the CO_2 tax on diesel was 0.57 NOK and the road-use tax was 3.50 NOK, in addition a 25% value added tax was added to the pump price. If we add the value added tax to the CO_2 and road-use tax, we get a CO_2 tax on 0.71 NOK and a road-use tax on 4.38 NOK. With an average pump price of 10.98 NOK in 2009, the CO_2 tax on diesel accounted for 6% of the pump price and the road-use tax accounted for 40% – and in combination the two taxes accounted for 46% of the pump price of diesel.

[3] Another demand-side factor that it would have been reasonable to assume affected investments in biofuels in Norway is the oil and gas prices. When oil and gas prices increased considerably during the 2000s, biofuels should have become more competitive vis-à-vis conventional gasoline and diesel and the demand for biofuels should have increased significantly. Nevertheless, during this time period, the Norwegian gasoline and diesel prices remained fairly stable – for two less than obvious reasons. First, the oil and gas sector in Norway comprised a considerable part of the Norwegian economy. When the oil and gas prices increased, the Norwegian currency – kroner – appreciated against foreign currencies, such as the US dollar. Since fossil fuels are bought and sold globally, this appreciation made it less expensive for Norwegian gas stations to purchase gasoline and diesel, and they could offer these fuel types to their consumers for a more reasonable price. In this way, the Norwegian currency functioned as a buffer that reduced the volatility in the gasoline and diesel prices in Norway. Second, Norway introduced a number of fuel taxes, which comprised a large share of the pump price of gasoline and diesel (see previous endnote). These taxes ensured that even a considerable increase in the purchasing price of gasoline and diesel for the gas stations, result in a modest percentagewise price increase for the consumers (See Statistics Norway).

others, Innovation Norway, the Research Council of Norway's Renergi programme and the Nordic Top-level-initiative. Through the RD&D projects, Weyland collaborated with reputable companies and institutions, such as Sintef and Statoil in Norway, Inventia in Sweden, VTT in Finland, DTU in Denmark, and Matis-Food in Iceland. Nevertheless, despite involvement in several successful RD&D projects and ensuring patent protection for key features of its technology, Weyland was not able raise the 300–400 million NOK required to build a full-scale advanced bioethanol facility [46].

Cambi was possibly the advanced biofuel company that experienced the greatest commercial success. In this period, Cambi embarked on an international expansion and won contracts to build biogas facilities throughout the world (including the U.S.A., Chile, the Middle East, and the Baltic countries). At the same time, it also entered the biofuel industry in earnest. In 2011, among others, it commenced construction of a new facility on the outskirts of the Norwegian capital, Oslo, which was to supply 135 busses with biomethane produced from the capital's biological waste. Although much of Cambi's success could be attributed to its prize-winning technologies and its well-executed strategies, it was also helped by EU legislation, such EU's landfill directive (Council Directive 1999/31/EC) which forced European municipalities to find to alternative ways of dealing with their biological waste than to deposit it in landfills.

5.4. *Fourth period: retraction and reorientation (2012–2014)*

The fourth period was a period of retraction and reorientation. Most of the companies that had the ambition of producing advanced biofuels either ceased production or refocused their attention towards producing niche products, such as bio chemicals and bio pharmaceuticals.

The Norwegian government maintained, for most of this period, its existing biofuel policies, but mentioned that it considered withdrawing the tax exemption on bioethanol sold in higher concentrations. Nevertheless, at the end of 2013, there was a change of government, from a government based on a 'Centre-Left coalition' to a Conservative minority government. The new Conservative minority government was more positive towards biofuels and gradually introduced policies that were more favourable to the advanced biofuel industry. Among others, they introduced a sustainability criterion that provided incentives for fuel retailers to sell advanced (second generation) rather than conventional (first generation) biofuels and signalled that it would increase the minimum proportion targets and reduce the road-use tax on biodiesel.

Industrial activity in the Norwegian advanced biofuel industry declined in this period. Borregaard maintained a low level of production of advanced bioethanol based on residues from its production of bio-based chemicals. Nevertheless, it made no effort to expand its biofuel production and it expressed no interest in increasing its Norwegian biofuel production in the future. At the same time, Weyland found itself unable to raise sufficient investments to build a production plant based on its technologies, and began to consider moving to the US and focus on bio chemicals rather than biofuels. And with Xynergo gone, there were no other companies that had developed or produced advanced biodiesel. The only exception was Cambi, which benefitted from tighter regulation on organic waste treatment and continued to expand its biogas business both in Norway and globally.

By the end of 2014, the advanced biofuel industry consisted of some distributed biogas facilities and small-scale plants for bioethanol production that produced fuel mostly for public transport. Nevertheless, some new industrial initiatives began to emerge as a response to a more favourable policy environment. One of these initiatives, among others, involved using wood-base resources to produce aviation fuel.

6. Discussion and conclusions

Based on this analysis, we can now discuss which of the three competing claims best account for Norway's lacklustre performance in advanced biofuels – a lack of risk capital, a lack of expertise or insufficient or inadequate government incentives and support measures.

Based on the event history analysis, the article finds some support for the *first* explanation. The *first* explanation suggested that the petroleum sector acquired the available risk capital that could have funded promising advanced biofuel projects, and we defined this explanation (in the theory section) as a 'capital shortage' failure, dominated by the functions 'resource mobilisation' and 'entrepreneurial activities.' Particularly in the first two periods and the initial part of Period 3 (1998–2009), the event history analysis found few events related to a lack of risk capital and many events related to entrepreneurial activity. Not only did the advanced biofuel companies manage to raise sufficient capital to develop and demonstrate their technologies, they also received a considerable amount of their funds from petroleum companies, such as Statoil and Hydro (which later merged to form StatoilHydro (2007–2009) and then Statoil). In this sense, there was little evidence of 'capital shortage' failure in this period, since both the functions resource mobilisation and entrepreneurial activities were strong and interacted positively with the rest of the TIS.

Nevertheless, this situation changed in the latter part of Period 3, when both Xynergo and Weyland were unable to obtain sufficient capital to commence full-scale production of advanced biofuels. However, Xynergo and Weyland tried at that time to raise capital after the government had withdrawn the tax exemption on biodiesel. This event was probably one of the main reasons why investors were unwilling to fund their production plants (in addition to the problems Xynergo faced, among others, with its technology provider, Choren). In this sense, the lack of risk capital was as much a symptom of a changing policy regime as any real shortage of risk capital and illustrates how functions such as guidance of search interacts with resource mobilization and entrepreneurial activity.

The article finds only limited support for the *second* explanation. The *second* explanation suggested that Norway lacked the relevant technological expertise to exploit advanced biofuel opportunities, and we defined this explanation as an 'absence of expertise' failure, dominated by the functions 'knowledge development,' 'knowledge diffusion' and 'resource mobilisation'. The event history analysis found that the Norwegian companies carried out a great deal of R&D and exchanged knowledge and expertise with other companies and research institutions, both nationally and internationally. Most of the Norwegian companies – such as Borregaard, Weyland and Cambi – also developed their own processing technologies and these technologies were considered to be at the forefront of international developments. However, Xynergo proved to be the exception. It did not develop its own advanced biodiesel technology and had to licence its BtL technology from the German company, Choren. In this sense, there was little evidence of absence of expertise failure, since both the functions knowledge diffusion and resource mobilisation were strong and interacted positively with the rest of the TIS.

The article does, however, find support for the *third* explanation. The *third* explanation suggested that the Norwegian government had failed to provide adequate incentives and support measures to stimulate development and production of advanced biofuels, and we defined this explanation as a 'policy insufficiency' failure, dominated by the functions 'guidance of the search,' 'market formation,' 'the creation of legitimacy and counteracting resistance to change' and 'resource mobilisation.' In the event history analysis, we saw that the government supported the advanced biofuel industry through push-based and pull-based policies. The push-based policies involved a number of RD&D programmes that the government introduced to support the advanced biofuel industry. Although these RD&D programmes started later and were funded less generously than comparable programmes in other European countries, the event-history analysis found that the programmes were popular among the advanced biofuel companies and contributed positively to these companies' capability building. In this sense, the government strengthened the resource mobilisation in the system and this function interacted positively with entrepreneurship and helped spawn some of the first Norwegian advanced biofuel ventures.

The event history analysis also points to some critical government decisions that seemed to have had a particularly negative impact on the advanced biofuel industry. The pull-based policies, in contrast, involved tax exemptions and minimum proportion targets that the government introduced to stimulate the demand for biofuels. The event history analysis found that the pull-based policies initially provided strong incentives for fuel retailers to sell biodiesel blends and that the advanced biofuel companies responded to this by investing heavily in the production and development of first-generation (Uniol) and second-generation (Xynergo) biodiesel. Nevertheless, when the government unexpectedly removed the exemption on road-use tax on biodiesel in 2009, it set in motion a series of events. First, the fuel retailers switched from biodiesel to bioethanol, and biodiesel companies, such as Uniol and Xynergo, went out of business. Then, the uncertainty surrounding future biofuel policies prevented Weyland from acquiring the necessary capital to start full-scale production and convinced Borregaard to abandon any future plans of expanding its bioethanol production in Norway. In this sense, the event history analysis illustrates how a negative event related to 'market formation' (introduction of road-use tax) first spreads to 'guidance of search' (uncertainty about future policies), then to 'resource mobilization' (lack of risk capital) and 'entrepreneurial activity' (diminished interest in biofuel production) – and finally bringing the whole advanced biofuel based innovation system to a halt.

In conclusion, the analysis in this article has highlighted how important an adequate and consistent policy regime is for the development of an advanced biofuel industry. Contrary to popular belief, the article has shown that the oil sector was not so resource demanding that there was no available risk capital to fund promising advanced biofuel projects in Norway or that the Norwegian knowledge base was so entrenched in hydro carbon extraction that the country simply lacked the relevant technological expertise to successfully exploit advanced biofuel opportunities. Both a lack of risk capital and a lack of relevant knowledge might have contributed to Norway's lacklustre performance in advanced biofuels, but these factors were not the primary reasons. The article finds that the primary reason for Norway's lacklustre performance was that the Norwegian government failed to provide a reliable and predictable policy regime which would stimulate the development and production of advanced biofuels. In this sense, the article finds that the Norwegian petroleum industry cannot be blamed directly for Norway's lacklustre performance in advanced biofuels. Nevertheless, it remains an open question whether the petroleum industry affected the advanced biofuel industry indirectly, by shaping the policy framework through, among other methods, lobbying.

The analysis carried out in the article has implications for both theory and policy. In terms of theory, the analysis clearly shows that old, incumbent industries can have both a positive and a negative influence on new, green industries. Although the oil and gas companies produced the main competing products and they might have lobbied against advanced biofuels, they also provided funding for technological development and construction of the first demonstration plants. In this sense, the analysis shows that future research needs to take into account the dual role that old, incumbent industries can play with regards to new, green industries, and it illustrates the need for contextual approaches within the TIS approach, such as Bergek et al. [16], that can account for the interaction between old and new industries.

In terms of policy, the analysis highlights two main implications. The first implication is that push-based approaches alone are insufficient to develop an advanced biofuel industry. The analysis found that the emergence and growth of the Norwegian advanced biofuel industry required the combination of both pull-based tax incentives and regulations and push-based RD&D. The second implication is that an inconsistent policy support can have a detrimental effect on the development of new green industries. The analysis found that the main reason for the Norwegian advanced biofuel industry's lacklustre performance was the uncertainty that was created when the government reinstated taxes on bio-diesel.

In closing, we want to point to some limitations of this study and provide some suggestions for future research. This article is based primarily on an analysis of written material (such as Norwegian reports, technical news, newspaper articles, research projects and publications, patent data, and national policy and legal documents) and such sources tend to highlight dramatic and well-publicized events. Other sources, such as in-depth interviews with businesses, industry associations, NGOs and policy makers, could provide greater detail about the motivations of the various actors and more insights about subtle processes or events that did not reached the public eye. Such sources could have shed more light on whether the petroleum industry exerted any political influence over the advanced biofuel industry. This question, however, must be consigned to future research.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.erss.2016.10.010.

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