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A new dawn for (oil) incumbents within the bioeconomy? Trade-offs and lessons for policy

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ABSTRACT

This paper develops a more detailed understanding of when incumbent actors may become the main locomotive driving energy transitions. It also illustrates the trade-offs between policy approaches that actively seek to involve the incumbents in transitions, and policy approaches that pursue transitions without their active involvement. The paper examines state support for the bioeconomy in Sweden and concludes that public investments have been geared towards large-scale, complex and integrated biorefineries that are dependent on the active participation of the forest industry. Incumbents in the forest industry have, however, both lacked motivation and the abilities required to take the necessary steps for commercialisation of the demonstrated concepts. Instead, a rather small investment in a joint venture between actors from the forestry and oil refinery industry in Sweden has spurred learning and revenues; and it has placed an oil refinery at the centre of the future development of what we here term distributed biorefining. The main trade-off is that while this shift has opened up for cross-industrial collaborations and the production of advanced biofuels and materials, it has also paved the way for further investments in existing fossil-fuel infrastructure.

1. Introduction

Almost 20 years ago, in a seminal paper in Energy Policy, Unruh (2000) elaborated on the underlying causes of what was termed the “carbon lock-in” and explained why the shift to renewable and sustainable energy systems is so inherently difficult. Essentially, energy transitions are hampered by multiple lock-in mechanisms that prevent destabilisation of the carbon-intensive energy system (Klitkou et al., 2015). Although progress has been made, the carbon lock-in still holds most major economies in as tight a grip as ever, and in spite of significant investments in renewable energy the overall fossil dependency has not been significantly reduced. A central lock-in mechanism holding back the energy transition is the prior investments of firms, industries and countries in production equipment, distribution facilities and knowledge, which leads to increasing returns from learning and additional build-up in relation to existing systems of production and consumption (Arthur, 1990; Hughes, 1987; Klitkou et al., 2015).

The strategic approach taken by many countries to breaking the existing lock-in has been to stimulate the growth of new and renewable alternatives outside the control of existing and dominating actors, termed incumbents, in important and often mature industrial sectors. Less attention has been given to an alternative approach, namely to depart from the existing and mature industry to develop more sustainable alternatives that can be integrated into existing operations and thereby accomplish a transition from within (Geels and Schot, 2007; Smith et al., 2005).

However, also in the case of energy, it can be hypothesized that incumbent actors may drive the transition processes, and research interests in the role of incumbents for energy transitions has been growing (e.g., Kungl and Geels (2018); Stirling (2019); van Mossel et al. (2018)). In a viewpoint article, Turnheim and Sovacool (2019; p.4) suggest that “[t]he role of incumbencies in transitions is a vibrant and promising avenue for research” which requires further attention to the question of when incumbents may be a progressive force in transition processes. Consequently, the aim of the current paper is two-fold. Firstly, we aim to arrive at a more detailed understanding of when incumbents may drive energy transitions, thereby extending existing research that has a “tendency to portray incumbents as ‘villains’ wedded to resisting, slowing down or preventing transition efforts” (Turnheim and Sovacool, 2019, p.1). We argue that this requires specific attention to the motivation and

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ability of incumbents to engage in transition processes. Secondly, we aim to illustrate the policy-related trade-offs between policy approaches that actively seek to involve incumbents in energy transitions and policy approaches that try to pursue such transitions without their active involvement. Previous research on incumbents has failed to consider how such policy-related trade-offs arise, depending on the actors that take the lead and set the agenda in transition processes.

Empirically, we study the transition towards biorefineries in Sweden with an emphasis on the role of incumbents from three key and mature industries: oil refining, forestry and energy. This makes an interesting case, since the loosely defined concepts of biorefineries constitute a set of technologies that can be integrated into various industries for the production of biofuels, in combination with other products such as heat, electricity, chemicals and materials. Sweden is also a country that has invested heavily in technology development of biorefinery technologies for a long time and where incumbent actors from these industries have played a dominant role in this development.

2. Conceptual background

Our theoretical point of departure is previous research on firms in mature industries and how they influence a potential transition to a more sustainable society. Traditionally, research on incumbents, understood as firms possessing power, resources and a large market share due to their presence in industries over a long duration has departed from the notion that firms in mature industries are unwilling to make major changes (Dosi, 1984; Nelson and Winter 1982). Accordingly, the rate of product innovation is low in these industries and the focus is rather on incremental process innovations intended to increase productivity and profitability rather than exploration and the development of new innovations (March, 1999). As argued by Dosi (1984), such incumbent actors tend to be locked into current technologies, products and markets because of their shared cognitive beliefs or paradigms.

The sustainability transitions literature has expanded and elaborated on this traditional view on incumbents. In particular, a number of contributions highlight how incumbent actors in mature industries react to the emergence of greener, potentially disruptive innovations that are based on different knowledge bases and require a different institutional set-up (van Mossel et al., 2018). Essentially, most attention has been given to the strategies employed by incumbents to prevent or slow transitions, both through individual actions and through networks spanning across sectors and the state (Newell and Johnstone, 2018). Incumbent actors often establish coalitions with policymakers and exercise a range of different forms of power in order to maintain market shares. For example, Geels (2014) as well as Kungl and Geels (2018) highlight how incumbents from the electricity sector use instrumental, discursive, material and institutional forms of power to resist climate change legislation, which may be a particularly successful approach when incumbents are facing single (rather than multiple) external pressures. Smink et al. (2015) similarly show how incumbents in the Dutch petroleum and lighting industries protect their financial interests through influencing policymakers and engaging in strategic standard-setting. Trencher et al. (2019) describe the multiple narratives used by Japanese incumbents to protect and promote investments in coal power plants, and Lee and Hess (2019) demonstrate how the intensity of resistance by incumbents is related to the strength of the threat posed by emerging technologies.

In addition to contributions highlighting how incumbents strategically seek to slow transitions to protect financial interests, research also underlines that many incumbents have insufficient capabilities to drive transitions. To exemplify, Wesseling et al. (2017) highlight that the decarbonisation potential of incumbents in energy-intensive processing industries is limited due to specialisation in incremental process innovations. Similarly, Dewald and Achternbosch's (2016) analysis of incumbents in the cement industry uncovers that they have limited internal capacity to carry out radical innovation projects and find it difficult to attract the required human capital. Bauer et al. (2018) also show that incumbents prefer intra-rather than inter-sectoral collaborations in innovation projects, which limits the scope for radical innovation.

Synthesizing these insights, we follow Hansen and Coenen (2017), who suggest that incumbents may both have limited motivation and ability to drive disruptive innovation. The lack of *motivation* relates to the low propensity of incumbents to prioritise resources for disruptive innovation. This follows from the reliance on established technologies to generate profit, which disincentivizes incumbents from developing and diffusing new competing technologies. Investments are instead steered towards deepening specialisation in current profit-generating activities. The lack of *ability* refers to the limited ability of incumbents to develop and compete in disruptive technologies. This results from the existence of organisational routines in incumbents, which are formed by the existing production system. While this allows incumbents to innovate efficiently when it comes to incremental improvements of existing products and processes, it may also result in myopia and limit the ability to develop radical innovations. Specifically regarding transition processes towards a bioeconomy, incumbents have also been found to react with great caution and resistance towards future opportunities (Bauer et al., 2017; Hansen and Coenen, 2017; Karltorp and Sandén, 2012; Näyhä and Pesonen, 2014).

At the same time, other recent contributions illustrate how incumbents may overcome this lack of motivation and ability, and a more balanced view on incumbency has received some traction (Turnheim and Sovacool, 2019). More recently, several articles have highlighted how the strategic actions of incumbents have played a key role in creating opportunities for the development of radical and more sustainable innovations. For example, Hanson (2018) illustrates how the established electrometallurgical industry has provided a foundation for building a photovoltaic technological innovation system (TIS) in Norway, and Haley (2015, 2014) reports how structural overlaps between the established hydropower regime and electric vehicle TIS in Quebec have supported the growth of the latter, for example through legitimacy benefits and knowledge development. Under some circumstances, incumbents may support the development of innovations with a potential to cannibalize on their existing markets, even if their engagement is then likely to be more volatile and vulnerable to external changes (see for example the case of off-shore wind in Norway, Mäkitie et al., 2018; Normann, 2015; Steen and Weaver, 2017).

Finally, other studies describe how incumbents may pursue contrasting technology strategies and are able to manage multi-technology paths (Berggren et al., 2015; Onufrey and Bergek, 2019, 2015). Reflecting this, incumbents have also been found to exercise dual strategies, where they marginalize and hinder the development of emerging niches, while at the same time actively investing in these same niche technologies (Hess, 2013; Smink et al., 2015). Importantly, incumbent involvement in emerging niches is likely to considerably change the niche, as exemplified by organic food, which initially challenged the industrial food production system, but eventually became a variant within it, as the incumbent food production industry became increasingly involved (Hess, 2007).

While research highlights that incumbents may promote transition processes, the sustainability transitions literature has in particular highlighted the possibilities and strategies employed by incumbents with the aim of hindering transitions (Turnheim and Sovacool, 2019). This is mirrored in research on transformative innovation policy, which emphasizes the importance of destabilizing incumbent systems, including limiting the ability of incumbents to exercise power, or completely replacing incumbent actors with new entrants (Kivimaa and Kern, 2016; Turnheim and Geels, 2012). While it is acknowledged that this may also incentivize some incumbents to take a progressive approach to transition processes (Kivimaa and Kern, 2016), and that transformative policy mixes may also include policy instruments focused on re-orientating incumbents (Grillitsch et al., 2019; Grillitsch and Hansen, 2019), the dominant focus in studies of "phase-out" (Rogge and Johnstone, 2017) or "exnovation" (David, 2017) policy is on overcoming the resistance of incumbents.

However, the role of incumbents in transitions is influenced by their motivation and ability to drive radical innovation (Hansen and Coenen, 2017), which in turn is dependent on the characteristics of incumbents and potential transition processes. More specifically, incumbents' *motivation* may be higher if a transition opens opportunities for entering new markets (contrary to cannibalizing existing markets) or for invigorating existing markets, for example under pressure from consumers or regulators (contrary to non-contested markets). The *ability* of the incumbents will likely be higher if existing market knowledge and technical competences can be utilized in the transition process (contrary to transitions requiring new competences). Importantly, we would also expect that only incumbents possessing both a high motivation and a high ability will indeed drive transitions – having just one of the two will likely be insufficient. As an example, we analyse the motivation and ability of incumbents to drive the transition towards biorefineries in Sweden in Section 4, and discuss policymaking in light of the findings in Section 5.

3. Methodology

3.1. Case description

The development of future biorefineries constitutes a subset of various different technological options that draw on both combustion technology, gasification, biochemical conversion etc. Technologies that enable future biorefineries can also be integrated into various infrastructural settings, such as in district heating, pulp and paper (P&P) production, sawmills, crop-based fuel production, production of basic chemicals, oil refineries etc. The potential products that could be produced include renewable heat, electricity, transportation fuels, chemicals, new materials, feed and food stuff, depending on the raw materials and industry integration. The technology development is therefore positioned at the intersection between several mature industries, such as the forest industry, the chemical industry, agriculture, energy and oil refining, with associated dominating incumbent actors. Thus, actors attempting to develop the technology have to access key competences from different industrial sectors, which in some cases have had little previous contact, and integrate the technology into the existing operations of incumbent actors (Bauer et al., 2018; Hellsmark et al., 2016b).

Incumbent actors, their motivation and abilities, will therefore have a significant influence on how the technology develops and which products will be produced, since not all options will be equally interesting for all industries. We therefore argue that the biorefinery case is a suitable case for comparing the motivation and abilities of incumbents moving into the field from different industries, as well as for illustrating policy related trade-offs that depend on which actors take the lead in the development.

Sweden is also a suitable setting, since the development of various technology options have been ongoing since the early 1970s, engaging all of the above industries in experiments with different biorefinery technologies (Hellsmark et al., 2016b). We limit the analysis to the main actors moving in from the forest industry, oil refinery and energy areas (utilities and district heating) since their involvement has been most pronounced, although actors from transport, the chemical and agricultural industries have also been involved in activities during some periods.

We also limit our study to the development of forest-based biorefineries, as this has been the most prominent development in Sweden. By focusing on forest-based biorefineries, we are able to include cases that cover all four main development trajectories present in the Swedish development (see Table 1). However, different from the other industries, energy utilities have only had an important role in three out of the five cases. They are still included in the analysis since they have been an important part of the development and represent an industry where biorefinery technologies could be integrated also in the future.

3.2. Five cases: two types of value chains

In this paper we focus on the main biorefinery experiments that have concerned incumbent actors since 2004. These experiments constitute our five cases, and also represent the main investments in Sweden for developing forest-based biorefineries and the development of forest-based biofuels, see Table 1 for an overview.[1]

We divided these five cases into two different "types" of biorefinery experiments. These types are based on how the production of forest-based transportation fuels is organised. The first type we call "large-scale biorefineries" that integrate all production steps into one integrated production facility, and constitute three main cases (Chemrec, SEKAB, Gobigas). These large-scale biorefinery experiments have only been loosely connected to each other and the lessons learned between these has therefore been very limited. The second type of biorefinery experiments are called "distributed biorefineries" in which an intermediary product is produced at one site and upgraded to a final product at another. This type is represented by two main cases (Sunpine, Preem). These two cases are quite closely related, and the first case (Sunpine) generated significant lessons for the second case (Preem) to learn from. These differences in learning between the two types of cases are also reflected in how the cases are presented in Section 4, where the learning between Sunpine and Preem is emphasised.

3.3. Data collection and analysis

For this study, we relied on process research (Langley et al., 2013) and qualitative data analysis (Gehman et al., 2018) to develop in-depth and historically rich case studies of the motivation and ability towards the development of biorefineries. In total, 44 formal interviews have been conducted over a period of 10 years (see the Appendix for a full list). The authors have followed biorefinery development in Sweden for more than a decade and have acquired deep insights through formal and informal contacts with the companies, research institutes and funding agents of past and current developments in the field. Formal interviews have, thus, also been supplemented with notes and insights from informal discussions with relevant actors at industry conferences, policy workshops etc. This has also contributed to allow the authors to understand the motivation and abilities of the incumbent actors to participate in the development of biorefineries.

To develop the case studies, the complete story of the development was mapped and a timeline for each experiment was re-constructed, enabling the incumbents' motivation and ability to be analysed based on secondary information and interviews. We ordered the data from the various sources chronologically for each of the analysed cases. The data analysis occurred iteratively as we went back and forth between the theoretical concepts and the data multiple times to identify the core conclusions emerging from the data. As our interpretations emerged, we verified the consistency of the account by iterating again and collecting additional secondary data (Gehman et al., 2018; Semper, 2019).

[1] Small-scale university experiments are excluded from the study, as well as experiments that do not focus on forest resources.

Table 1
Overview of the five cases included in the study.

Types of biorefineries	Case	Time period	Trajectory	Technology description
Type 1: Large scale	Case 1: Chemrec	2004–2018	Black liquor gasification	Pressurized black liquor gasification for the production of DME/Methanol.
	Case 2: SEKAB	2004–2018	Biochemical conversion	Biochemical conversion of cellulosic biomass to ethanol.
	Case 3: Gobigas	2014–2018	Gasification of solid biomass	Large scale indirect atmospheric gasification of forest residues for the production of methane.
Type 2: Distributed	Case 4: Sunpine	2006–2018	Hydroprocessing of biooils	Distillation of tall oil in combination with hydro processing into hydrogenated vegetable oil (HVO).
	Case 5: Preem	2015–2018	Hydroprocessing of biooils	Pyrolysis and lignin filtration in combination with hydro processing into HVO.

4. Findings

4.1. Sweden's position on a forest-based bioeconomy

To a large extent, Sweden can be described as a forest nation. About two-thirds of the area of Sweden is covered with forest, out of which 80 percent is cultivated. Approximately one percent of the cultivated forest is felled annually and over the past 90 years Sweden's forest resources have doubled. Approximately 80 percent of the forest products are exported, at a total value of approximately EUR 10–15 billion per year, and the industry has 70,000 people in direct employment (Swedish Forest Industries Federation, 2018). Residues such as tops, branches and bark have also formed the basis for a rapid expansion of heat and power production, benefitting a wide range of industrial purposes and this continues to be the basis for an expansion of a bioeconomy where forest-based products and services are developed and commercialized.

Given the past success of the Swedish forest industry in abating climate change and stimulating economic growth, it has been cited as one of the core pillars for delivering ambitious climate targets (Formas, 2012). The forest industry is therefore envisioned to continue to play a central role in achieving national climate ambitions and also in delivering on the targets formulated in a new climate law (Miljö- och energidepartementet, 2017a; Skogsindustrierna, 2018). The law, which has been in effect since June 2018, stipulates that:

A. Sweden will not have any net greenhouse gas emissions by 2045, and thereafter will contribute negative net greenhouse gas emissions.
B. Emissions from the transport sector will decrease by 70% by 2030.

It has been argued that reaching these targets provides new and significant opportunities in the form of jobs, better health and increased competitiveness (Department of Environment, 2017; Fossil Free Sweden, 2020; Löfven, 2015).[2] Swedish forest resources have also long been identified as key for delivering climate friendly transportation fuels needed for reducing emissions from the transport sector, Goal B, (Johansson, 2013). As such, the cases included in this study constitute the main public and private investments for developing domestic forest resources for biofuel production (Hellsmark et al., 2016b).

However, reaching ambitious targets based on Swedish forest resources is not without its challenges. For example, in the transport sector the use of biofuels has increased rapidly. As of 2017, approximately 20% of all fuels in the transportation sector are biofuels (Swedish Energy Agency, 2018). In spite of ambitious plans and significant support for building local value chains, only 15% of the total biofuels used are produced in Sweden and as little as 3% originate from the forest (see Fig. 1 for an overview of the main production facilities for biofuels in Sweden).

In the following sections we analyse the motivation and abilities of the forest, oil refinery and energy industries when attempts have been made to commercialise forest-based biorefineries with the purpose of producing transportation fuels in combination with other products in a biorefinery setting.

4.2. The motivation and ability of incumbents concerning large-scale biorefineries

Since the mid-2000s, three main industrial scale demonstration facilities have received substantial government funding for demonstrating new value chains from the forest (Energimyndigheten, 2014), (see Fig. 2 for an overview).

These three pilot and demonstration projects have been at the core of developments in new biorefinery concepts and forest-based value chains for the transport sector, receiving direct governmental funding for construction and associated research in the range of EUR 20–100 million each. The three cases are similar in that they have:

A. focused on taking forest-based biomass into a ready-made fuel that can be used for the transport sector;
B. successfully managed to technically demonstrate their respective value chain;
C. required significant up-front capital investments (in the range of EUR 200–400 million), for taking the next step in development by industrial actors that could integrate the technology into their operations or build standalone plants;
D. not been competitive with regards to their production costs compared to fossil fuels or 1st-generation biofuels under existing policy frameworks;
E. been associated with significant political risks, thereby considerably reducing the attractiveness of this type of investment by industry.

4.2.1. Case 1: Chemrec (2004–2018)

The motivation of the forest industry has varied significantly over time concerning black liquor gasification (BLG). When the small technology company Chemrec started out developing the technology for BLG during the mid-1980s, the motivation of the forest industry was high, with a focus on replacing existing recovery boilers with the new and potentially more effective technology. This had all changed by the time this story starts in 2004. By then, conventional recovery boilers had increased in performance and to replace them with a technology that had not been commercially proven and was supplied by a small firm with no backing from existing large-scale technology suppliers in the industry was thus considered a big risk. As a response to an increasing focus on climate change, the focus of Chemrec shifted to renewable fuel production based on their BLG-technology. The development was supported by the Swedish Energy Agency, who established a major research program, the BLG-Program I&II that spanned more than a decade. The program included several of the major universities and research institutes in Sweden and was combined with direct investment support for constructing a new pilot and demonstration facility (Hellsmark et al., 2016a).

[2] The forest industry and district heating sector play a key role in delivering towards Goal A, with significant biogenic CO2 emissions and the possibility of Biomass CCS (BECCS) (Karlsson, 2020).

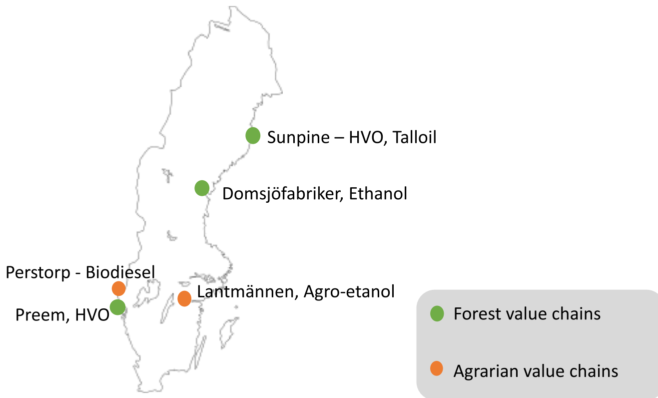

Fig. 1. Main production facilities for biofuels in Sweden (biogas not shown).

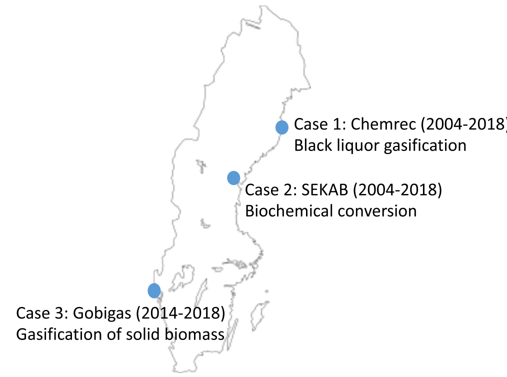

Fig. 2. Main development efforts to create large scale biorefineries from forest resources over the period 1990–2018.

The forest industry viewed the change in direction as potentially interesting, and one of the dominating firms in the industry allowed Chemrec to set up their testing facility in connection to their mill in Piteå (Table 2), but outside their core business. The forest industry adopted a "wait and see" strategy. However, with additional backing from the Swedish Energy Agency and the EU's 7th framework program, Chemrec managed to set up a consortium of companies that could demonstrate the entire value chain from black liquor to DME production, as well as a small test fleet of DME-trucks supplied from Volvo that could run on the new fuel. In combination with the industrial consortium, public policy, mainly through R&D and investment funding, was thus instrumental in taking the technology as far as fleet trials.

The oil industry was part of the consortium and supported the development (Preem and Total), as they were interested in developing the distribution system for the new fuel (DME) being developed. However, since the fuel could not be blended or integrated into their current business, they did not take a lead role in the development. After successful demonstration, a privately-owned pulp mill in Örnsköldsvik decided that they wanted to invest in a full-scale plant. The mill already produced some ethanol for the fuel market, in combination with a larger variety of other and non-conventional forestry products, which made it quite different from most actors in the forest industry.

Initial calculations indicated that profitability could be achieved under the existing support schemes (RENEW, 2008), which at the time consisted of an investment grant from the government covering approximately 10–20% of the total investment costs. Besides this grant and a general exemption from CO_2-taxes, there were no specific market-based instruments which supported the scale-up. However, the plans were abandoned as the mill was sold to the Indian multi-national Aditya Birla. Aditya Birla had no previous experience in the fuel market and had little confidence that the temporary exemption from the Swedish CO_2-tax (on which the entire profitability was based) constituted a stable framework for an investment with a payback time of 10–15 years. The stability of the framework had not been a major issue for the previous investors, who had more trust in the Swedish government and had not pushed for a different type of framework. As a result, after Aditya withdrew from the project, the interest from the forest industry reached an all-time low and, without any financial backing from private investor, Chemrec was forced to file for bankruptcy.

In the absence of Chemrec, but to keep the demonstration activities running, the Luleå University of Technology (LTU) took over the demonstration facilities and tried to re-brand the facility under the name LTU-Green Fuels, to serve a wider customer base. However, the re-branding of the facility into LTU-Green Fuels has been problematic and the interest of the forest industry for the technology has continued to be low. As a result, LTU mothballed the plant due to lack of funding and industrial interest in 2018.

During this entire period, the ability of the forest industry was high in terms of integration of the technology in the P&P infrastructure, including exchange of heat and electricity, as well as assessment of risks associated with replacing the existing recovery boiler with a novel technology. However, most actors within the forest industry lacked the necessary knowledge of the advanced chemistry and knowledge about markets for new fuels. The only exception may have been the privately owned Domsjö mill, which had experience with producing ethanol for the chemical industry. None of the incumbent forestry actors had experience with the advanced chemistry of fuel production from syngas, which was at the core of the development. The oil industry, on the other hand, had complementary abilities concerning fuel standards and distribution that would have been useful in constructing a new infrastructure for DME.

None of the incumbent actors had significant motivation and abilities to really question the Swedish exemption from the CO_2-tax or to make efforts to suggest a more stable alternative. Chemrec potentially could have seen the problem, but may have recognized it too late and did not have the resources and ability to lobby for a change.

4.2.2. Case 2: SEKAB (2004–2018)

The company SEKAB was formed as a joint venture between the companies MoDo (forest industry) and Berol Kemi (chemical industry) in 1985. MoDo owned and operated the Domsjö sulphite paper mill at the time, which produced ethanol as a by-product. SEKAB could be formed as it was supported by policy through a long-term procurement contract from the Swedish Civil Contingencies Agency[3] for increasing the security of supply of chemicals in Sweden.

The SEKAB joint venture was thus created to deal with a by-product and was not considered to be a core-business for MoDo or Berol Kemi. However, the ambitions of SEKAB grew to produce forest-based ethanol for the transportation sector. When this story starts, in 2004, a large-scale pilot facility was constructed with financing from the Swedish Energy Agency. The policy support consisted of investment support for the plant but also in long term and significant R&D program focusing on cellulosic ethanol, which involved the major universities in Sweden (Ulmanen, 2013).

In 2005, a regional consortium consisting of a mix of actors acquired SEKAB from the forest industry (Ulmanen, 2013). This consortium included municipally owned energy utility companies and other regional actors. These actors entered from a regional development

[3] "Myndigheten för samhällsskydd och beredskap" was called "Överstyrelsen för civil beredskap" in 1985.

Table 2
Motivation and abilities of the oil, forest and energy industries in developing the "Chemrec"-technology for DME.

	Oil refinery industry	Forest industry	Energy industry
Motivation	• Low: Interested in distributing the new fuel being developed but the fuel could not be blended or integrated into their current business and was therefore not at the core.	• Low: Lack of confidence in the long-term profitability and political stability concerning taxation schemes.	• Not applicable
Ability	• High: Competencies in fuel distribution and markets.	• Low: Lack of knowledge on advanced chemistry and themarkets for new fuels.	• Not applicable

perspective, considering the possibility of building 10–20 bioethanol plants in the sparsely populated northern Sweden, and were thus motivated by the possibility of creating new job opportunities in a potential growth industry (Table 3). The plans were followed up by policies aiming for a large expansion of ethanol, supporting fleet trials and support to introduce flex-fuel vehicles etc. (see for example Holmgren (2012) and Hansson et al. (2018) for an overview).

However, no investments were made by either the forest industry or the energy utilities after the technology had been developed. The lack of motivation resulted from the fact that neither of the industries who entered SEKAB considered it their core business strategy to build this type of plant. The oil industry also remained passive in relation to the projects, but had an interest in acquiring the fuel for blending in gasoline. In addition, with record high oil prices leading up to the financial crisis in 2008/2009, SEKAB and the main actors behind the company were not actively mobilizing support for changing the existing policy framework with the temporary exemption from the CO_2-tax.

SEKAB was heavily affected by the financial crisis and reached near bankruptcy in the period 2009–2012. In order to increase the focus on commercialisation of the technology and reduce the financial stress, SEKAB handed over the management of the research facility to the research institute RISE.[4]

Not only the motivation, but also the ability of the oil, forest and energy industry in developing the "SEKAB"-technology must be considered as quite low. The oil refineries were unable to integrate the technology with existing operations and could at best hope to participate as a potential fuel supplier or investor. The P&P and energy industry lacked knowledge of fuel markets and the technology needed for integrating with existing operations. They were also only observing the development in the light of a potential investment. Hence, similarly to Chemrec, SEKAB had no real backing from the incumbent actors to lobby for an alternative or updated market scheme when it became obvious that the exemption from the CO_2-tax was not enough when the oil price dropped.

4.2.3. Case 3: Gobigas (2014–2018)

The motivation for building the Gobigas plant came from the local utility Göteborg Energy. They had received permission from the government to invest in a 600MW natural gas combined cycle plant under the condition that they also made efforts towards developing the biogas market and not only relied on natural gas. Göteborg Energy had a strong interest in developing the gas market and one can argue that developing

Table 3
Motivation and abilities of the oil, forest and energy industries in developing the "SEKAB"-technology.

	Oil refinery industry	Forest industry	Energy industry
Motivation	• Low: Interested in the product mainly for blending with conventional fuels.	• Low: SEKAB was created to deal with a by-product and not develop a new business opportunity.	• Medium: Entered SEKAB from a regional development perspective.
Ability	• Low: Not possible to integrate technology with existing operations.	• Low: Lack of knowledge of markets for new fuels.	• Low: No previous experience from chemical and fuel production, or markets.

the biogas market brought political legitimacy to their natural gas business, thus investing in biogas could be used as an argument for expanding the use and distribution of natural gas in Sweden (Table 4). However, producing ordinary biogas from fermentation was considered a small-scale business that could not supply sufficient volumes and profitability. Göteborg Energy therefore decided to turn towards the opportunity to produce synthetic natural gas from large-scale gasification of solid biomass (Bio-SNG). The technology had been under development in Sweden during the 1990s and had been demonstrated for electricity production in Austria (Hellsmark, 2010).

Producing bio-SNG involved major technical challenges and a commercial scale plant could not be built without first demonstrating the technology. A procurement process was initiated for finding possible suppliers for a constructing a 100MW commercial-scale plant. Due to low technical maturity, Göteborg Energy had significant problems in finding a supplier and they were more or less forced to reformulate the project as a demonstration project. The new goal was to first construct a 20MW demonstration plant and then connect the demonstration unit with a 80MW commercial unit, which in combination could operate under commercial conditions. An alliance was formed to develop the technology, consisting of the small engineering firm Repotec, with experience from the Austrian plants, the technology supplier Valmet, Haldor Topsoe for methane catalyses and Jacobs as the EPC-contractor. Chalmers University of Technology was instrumental in setting up the alliance as well as a smaller, 8MW pilot facility for initial testing of the technology. Göteborg Energy and the Swedish Energy Agency financed the construction of the pilot and demonstration facilities as well as the associated research needed for demonstrating large-scale production of bio-SNG. When the project was initiated, no additional market support beyond the temporary exemption from the CO_2-tax was sought by the alliance, as the price of natural gas just before the 2007–2008 financial crisis was at a record high and was expected to continue increase. Initial calculations had illustrated profitability of a 100MW unit given continued high natural gas prices, the exemption from CO_2-tax, investment support and the assumption that the market for gas fuelled vehicles could be further developed.

Before the construction commenced, the financial crises became a reality. However, the initial project had already been financed and the construction of the 20MW demonstration unit continued and was taken into operation during 2014. The plant was also operated by Göteborg Energy until April 2018 (Youcefi, 2018). Given the radically changed market conditions and the fact that the plant had become a political liability within the local municipality, the demonstration plant was mothballed in 2018 and the future plans for a scale-up were abandoned.

The oil and forest industries had not been involved in the project, apart from observing it from the far distance. The oil industry could see virtues with it, since they could have used the bio-SNG in the production of green hydrogen, thereby increasing the renewable content of their HVO. However, due to the high operating cost of the plant, it was not considered a commercially viable option. The forest industry was not

[4] The facility as such is now used by a wide range of actors to demonstrate various biorefinery concepts and produce small volumes of specialised chemicals (Hellsmark et al., 2016a).

Table 4
Motivation and abilities of the oil, forest and energy industries in developing the "Gobigas"-technology.

	Oil refinery industry	Forest industry	Energy industry
Motivation	• Medium: Interested in access to bio-SNG for substituting natural gas in their hydrogen production.	• Low: No interest in the gas market.	• High: Political pressure to invest in biomass and not only natural gas. Bio-SNG gave legitimacy for expanding use and distribution of natural gas.
Ability	• Medium: Relevant technology suppliers could support the project.	• Low: Little knowledge of gas markets.	• High: Significant experience with FB-gasification and gas markets • Low: No experience with advanced chemistry for bio-SNG production.

involved at all in the project. The technology could most likely have been adapted to their purpose, but the industry had a low interest in the production of bio-SNG, having very little natural gas consumption and no connection to any gas infrastructure.

The energy utility in charge of the project had strong abilities in terms of access to biomass resources, knowledge of the FB-gasification process on which the Gobigas process was based, as well as knowledge of markets for the final product and its distribution. It also had access to district heating systems in which the technology could be integrated. However, the energy utility had very limited knowledge on the advanced chemistry involved in turning the gas from FB-gasification into bio-SNG.

None of the incumbent actors had significant motivation or the abilities to really question the Swedish exemption from the CO_2-tax and propose alternatives that were more suitable for the gas market. When the project was initiated, questioning the temporary exemption from the CO_2-tax was not really considered necessary by the main actor, Göteborg Energi. After the financial crisis a new framework would have been necessary, but by then Göteborg Energy was significantly weakened by a growing political opposition against the project, key staff leaving the company, and the company withdrawing from key positions in influential interest organisations that eventually could have argued for other types of conditions.

4.3. The motivation and ability of incumbents concerning distributed biorefineries

Partly in parallel with the late development of the three cases above, efforts were also made to develop the new concept of distributed biorefining. The concept has its background in Case 4, Sunpine, where a private entrepreneur sought to develop biodiesel production using crude tall oil as a new resource. During the development of the project, the actors behind Sunpine realized that they could reduce the complexity and associated cost of the investment if they produced an intermediate product and used the refinery infrastructure at the oil refinery Preem for creating the final product. This first experiment could then be followed by additional experiments where Preem took a central position in the development (Case 5).

These two cases have the following in common:

A. They focus on less costly technologies (distillation, lignin filtration and pyrolysis) for creating an intermediate product than in the Cases 1–3. This product can be upgraded to a ready-made fuel in an existing refinery infrastructure with capacity for hydro processing of oxygen rich fuels.
B. They focus on drawing on many small sources of intermediate products
C. They have successfully demonstrated new value chains that take advantage of existing infrastructure controlled by incumbent actors in mature industries.
D. They have received relatively limited governmental funding, less than EUR 10 million each.

4.3.1. Case 4: Sunpine (2006–2018)

Crude tall oil is a dark brown, viscous and sulphur-containing liquid obtained in the production of pulp using the sulphate process. It contains significant amounts of fatty acids that can be distilled into various products. In the Smurfit Kappa laboratories in Piteå, an inventor-entrepreneur illustrated that crude tall oil could be used for the production of biodiesel in 2006. After successful laboratory experiments, this know-how was transferred to the company Sunpine. Sunpine was further developed as a joint venture between the oil refinery Preem and the forestry firms Södra and Sveaskog, after the supply of crude tall oil was secured from P&P companies in the Piteå area during 2008. The purpose of the joint venture was to build a commercial-scale facility in the north of Sweden, using crude tall oil for producing biodiesel. The alliance between the inventor-entrepreneur, Preem, Södra and Sveaskog was formed in spite of the financial crisis and political uncertainty surrounding the temporary tax exemption at the time.

Preem's motivation to enter the joint venture was the growing market for renewable fuels in Sweden and Europe based on national and EU-legislation, providing tax incentives and mandating a high share of renewable fuels in the fuel mix (Table 5). Preem also identified the tall oil route as being significantly more attractive and legitimate than the use of crop-based routes, such as palm oil, as a base for their HVO-production. The motivation of the forest industry was mainly to get rid of the tall oil (which is a difficult and undesirable by-product in the pulp-making process, with low-value alternative uses), while capturing the value of the crude oil throughout the entire value chain.

When Preem joined the project, the concept changed from the production of regular biodiesel from tall oil to a less complex intermediate that could be used in Preem's hydro processing plant, making HVO that can be blended 100 percent with conventional diesel. This idea of distributed production, creating an intermediate product at one site and transporting that product to a different site, simplified the production at Sunpine significantly. Moreover, it lowered the overall cost of the project, since the existing infrastructure at Preem could be used in combination with their know-how in making fuels that comply with existing standards and blending requirements. The concept of distributed production went against the basic idea behind the main investments being undertaken in Sweden for developing forest-based biorefineries at the time, which focused on producing a ready-made fuel at the same site as the biomass was refined.

The first plant was taken into operation in 2010 (Fig. 3). Most of 2011 was spent solving the teething problems associated with starting up the new process. The production was stabilized in 2012, and since 2013 the plant has operated at higher than expected capacity, with high reliability. Due to the low complexity of the production, in combination with the possibility of using existing infrastructure, the cost of production was reduced significantly. Although low from the start, the

Table 5
Motivation and abilities of the oil, forest and energy industries in developing the "Sunpine"-technology.

	Oil refinery industry	Forest industry	Energy industry
Motivation	High: • Growing market for biofuels within EU and Sweden. • Tall oil presented a more environmentally friendly alternative than palm oil. • Good fit with their existing infrastructure. • Relatively low investment cost compared to previous experiments.	High • Alternative use of by-product, crude tall oil. • No need to go to final product and enter a market they did not know, but at the same time had the opportunity to capture the value of the crude oil throughout the entire value chain.	Not applicable
Ability	High: • Good fit with existing infrastructure. • Investments allowed Preem to further develop abilities related to their existing infrastructure.	High: • No need to venture outside existing abilities.	Not applicable

profitability of the plant could be secured without any additional investment or market support from policy.

The yield of intermediate biodiesel product at the start of the production was about 60 percent, which may seem low. The low yield also implies that the crude tall oil contains other substances that have alternative usages. In order to increase the yield of valuable products, Sunpine started to develop processes for extraction of rosin chemicals from the crude tall oil in collaboration with a Japanese pine chemicals company, Harima Chemicals, and its daughter company Lawter (Fig. 3). Lawter and Sunpine agreed to realize the rosin investment project and Lawter was included as a new partner in the Sunpine consortium in 2015. The effort resulted in an increase in yield to over 70%, with significant impact on overall profitability without any policy support. As a next step, Sunpine then started to extract turpentine from tall oil (Fig. 3). Turpentine is used for manufacturing many different products including paint, lacquers and perfume. The turpentine production at Sunpine is around 3000 tons per annum, compared to 25,000 tons of rosin and over 90,000 tons of tall oil diesel. These measures have had a strong and positive impact on Sunpine's financial results, but also on the motivation of the actors involved to further develop the process.[5]

With the development of Sunpine, the motivation and abilities of both Preem and the forest industry to develop the concept of distributed biorefining increased significantly. With a relatively small investment, they had managed to establish a profitable business that in the case of Preem could be used to develop their existing infrastructure.

However, crude tall oil is a very limited raw material compared to fossil oil. It will not be possible to increase the Swedish production much more and there may not be much more than 2.5 Mtonnes of crude tall oil available on a global basis. As a result, stakeholders like Preem, Sveaskog, Södra and a wide range of other firms have started to look for and develop other similar resources. Following in the footsteps of Sunpine, the goal of these stakeholders is to scale up the current concept of "distributed biorefining" in which the infrastructure at oil refineries is taken advantage of in combination with local facilities for production of intermediate products (such as lignin, pyrolysis or other oils from hydrothermal liquefaction, as well as Fischer-Tropsch waxes).

4.3.2. *Case 5: Preem (2015–2018)*

Leading up to 2018, the main barrier to the scaling up of domestic forest-based biofuel production was still the temporary exemption from CO_2-taxes that had to be approved by the EU every year or every second year. Although the Sunpine investment had been successful, the tax exemption did not create the necessary incentives to speed up the implementation of forest-based alternatives for transport fuels, since investment security was not created for more than 2 years at a time,

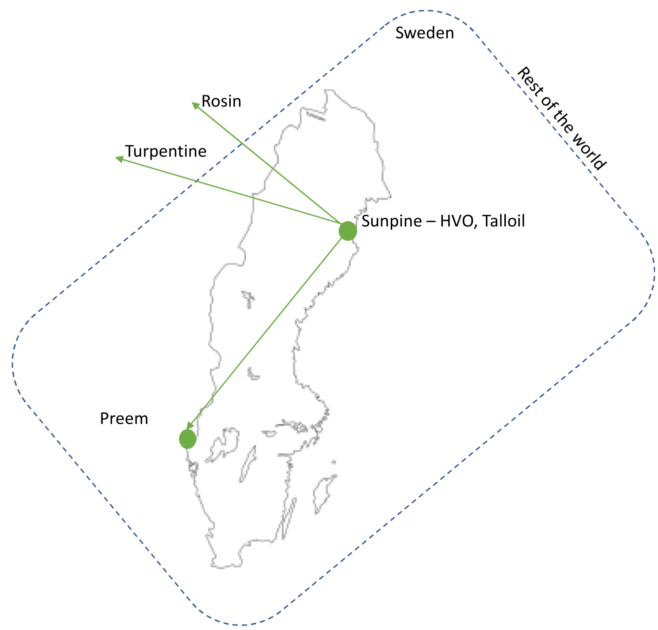

Fig. 3. Initial version of a distributed biorefinery where crude tall oil is processed at Sunpine, and then shipped to the refinery Preem for final upgrading. The biodiesel production has also enabled the production of Rosin and Turpentine, increasing the overall yield and profitability of the plant.

while the payback time for the necessary investments were typically in the range of 10–15 years.

As a relatively small oil refinery in Northern Europe, with no control over crude oil resources, and operating on what from a climate perspective would become a declining market, Preem identified developing forest-based biomass resources to be strategically important for staying competitive in the long run. Given that favourable market conditions for biofuels could be created, Preem thought that they could potentially turn a global competitive disadvantage into an advantage, being a relatively small scale and flexible refinery with good connections to the forest industry and national political decision-makers. However, for making the business case, it was considered important that: firstly, the biofuels they would develop were not directly exposed to a fluctuating oil price; secondly, that they would be promoted in relation to their CO_2-reduction potential; and thirdly, that the fuels would be considered legitimate in the eyes of the public.

Preem took the lead in suggesting an alternative to the temporary tax exemption. They were soon joined by other leading industry representatives and the Swedish Biomass Association, who also identified that a change was necessary. With slight variations, the industry soon settled

[5] However, the primary investment would not have taken place without being able to prove that the production could reach profitability based on the main product, biodiesel, regardless of the potential profitability of future by-products.

for promoting a "reduction quota" to replace the tax break. In parallel, the Swedish Energy Agency was tasked by the government in 2016 to investigate and propose an alternative to the existing tax exemption (Energimyndigheten, 2016). The investigation also suggested a reduction quota, which would give extra incentives to develop biofuels that could provide the highest reduction of greenhouse gas emissions at the lowest possible cost. In 2017, the Swedish Government announced that the reduction quota would come into effect by July 1st, 2018. Emission reduction levels were specified for the years 2018–2020 and an indicative reduction was set to 40% by 2030 (Miljö- och energidepartementet, 2017b).

With the new incentive structure in place, Preem has increased their ambitions to produce biofuels from 200,000 m^3 to 3 million m^3 by 2030. It has also spurred significant entrepreneurial activities in the field that potentially could deliver towards the new goal of Preem and Sweden's ambitions to significantly reduce the domestic emissions from the transport sector (see Fig. 4).

Two of the initiatives, Suncarbon and Renfuel, focused on various types of techniques for separating out lignin from black liquor and then converting the lignin through enzymatic and/or catalytic treatment to a biooil that can be shipped and upgraded at refinery through hydrogen treatment. The technology is still in early development, but in May 2018, Renfuel entered a joint venture with Preem with the purpose of building the first commercial-scale plant in collaboration with the P&P firm Rottneros (Renfuel, 2018).

The technology allows for separating the lignin from the black liquor and thus offloading the recovery boiler at the mill. This allows for increasing the capacity at the mill without making new and expensive investments in the recovery boiler. Hence, through a smaller investment in lignin separation for creating a lignin oil, Rottneros could postpone or avoid major investment in a new recovery boiler, while at the same time making a profit from the lignin oil. The situation was described as a "win-win situation" by Preem, while Rottneros was less certain of the benefits of the collaboration. In mid-2019 Rottneros decided to withdraw from the collaboration, citing lack of clarity on future profit sharing as one of the main reasons (Table 6).[6]

Besides the collaborations mentioned above with the large P&P industries, there are three interesting ventures going in different but complementary directions. The first two are larger sawmills in Sweden and Norway that have divested into the biofuel business, using sawdust as the feedstock for producing biofuels (Setra and Biozin). Setra, for example, has entered a technology cooperation with a European technology supplier who has been performing tests with sawdust from Setras sawmill in Gävle. In total 6 tons of biooil have been produced and the end product has been evaluated with good results by Preem. In June 2017, Setra were granted approximately EUR 11.5 million, covering 45 percent of the budgeted investment costs, to construct a commercial-scale facility. An investment decision has been taken and start of production is projected for 2021. The final example is the Finnish consortium that consists of the Finnish utility Fortum and technology supplier Valmet that has signed an agreement with Preem to explore the possibility of processing the biooil being produced in their commercial-scale pyrolysis unit in Joensuu, currently producing approximately 50 ktons of biooil annually (Preem, 2018).

The prospect of supplying various types of forest-based biooils that can be upgraded in a refinery infrastructure is therefore well under way. However, processing organic biooils requires that the refinery makes investment in renewable hydrogen production. Preem is also pursuing such a project, where they collaborate with the state-owned electrical utility Vattenfall in order to produce renewable hydrogen from electricity.

In this final case, Preem's motivation and ability to pursue the distributed biorefinery concept has increased even further. To begin with, successful interaction with policy has resulted in the development and implementation of the reduction quota, which gives a clear benefit to fuels with the highest possible CO_2-performance. It also paves the wave for smaller investments in the forest industry in which smaller volumes of biooil can be produced.

In terms of the forest industry, the motivation and abilities have also increased as the distributed concept has reduced the complexity and risk of investing. With small investments to off-load the recovery boiler, the forest industry avoids the large investments in new boilers, while also making an additional income on the lignin without having to go all the way to fuel production. The smaller investment also enables the forest industry to stepwise develop new capabilities and abilities in relation to converting lignin to new products without venturing into the fuel market. There are still challenges with regard to sharing profits between the forest and oil industry, however, where the forest industry is not interested in "just" supplying a resource to the oil industry but rather in sharing revenues created throughout the value chain. In distributed biorefinering a key challenge is to find collaborative model between the oil and forest industry where the value of the products is shared throughout the value chain. The energy industry faces a similar situation to the forest industry, as the distributed concept allows them to integrate new technology into existing operations in a stepwise manner. To date, practical experience has been very limited, and it appears as if the industry is significantly less motivated compared to the forest industry, which has their recovery boilers to off-load and does not experience any additional pressure from stakeholders or owners.

5. Discussion

As set out in the introduction, the aim of the current paper has been two-fold. Firstly, we have aimed to arrive at a more detailed understanding of when and how incumbent actors may drive energy transitions. Secondly, we have aimed to illustrate the policy related trade-offs between policy approaches that actively seek to involve incumbents in sustainable transitions, and policy approaches that try to pursue such transitions without their active involvement.

In this paper we have illustrated how this detailed understanding of when and how incumbents may drive energy transitions requires specific attention to the motivation and ability of incumbents to engage in transition processes. By analysing the motivation and abilities of incumbents from three mature industries (oil refinery, forest and energy) we are able to conclude that significant policy efforts in Sweden have been directed towards creating a forest-based bioeconomy. The main target of these government investments has been start-ups and university-based concepts, which in turn have been geared towards large-scale biorefineries with a rather complex integration with the infrastructure of mature industries, mainly in the forest and energy sectors.

The underlying logic behind these government interventions has a science-push perspective, where the state is an important sponsor of basic and applied research, while upscaling and commercialisation of the developed technologies is to a large extent left to the market. The developed concepts have thus been dependent on the active participation of primarily incumbent actors from the forest and energy industries, but overall these have shown both low motivation and abilities to actively participate in creating the necessary pre-conditions for scaling up of the demonstrated concepts (Table 7).

Although previous research has shown that incumbent actors in the pulp and paper industry are capable of engaging in both exploration and exploitation (Onufrey and Bergek, 2019), that is not an explanation for

[6] Another similar initiative is by SCA, a P&P company, venturing into biorefining and biofuel production. This example is slightly different, as SCA has not decided on a distributed production of biofuels and if they will cooperate with Preem or some other refinery. A key issue for formulating such a collaboration has been to find an agreement where they do not "just" supply a resource to an oil refinery but rather share revenues created throughout the value chain.

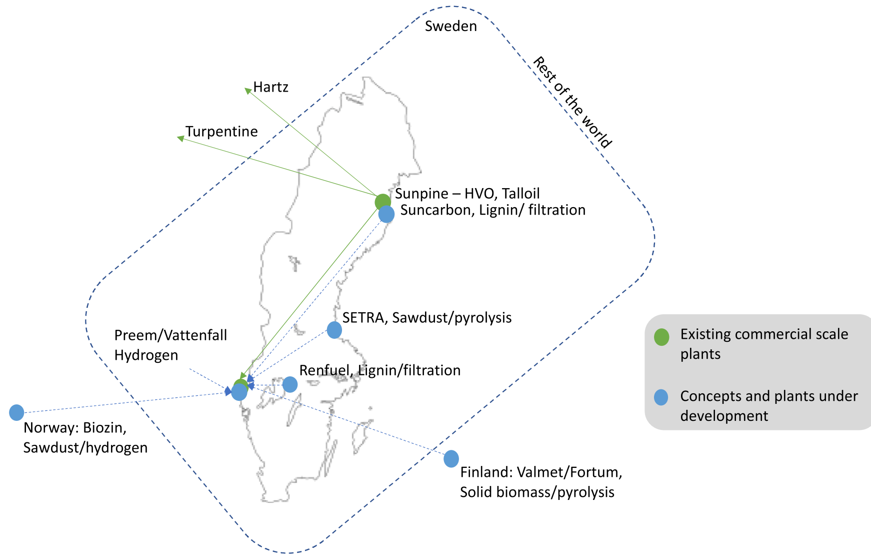

Fig. 4. Examples of significant initiatives that could deliver towards Preem's and national targets through a "distributed" biorefinery concept.

Table 6
Motivation and abilities of the oil, forest and energy industries in developing distributed biorefining.

	Oil refinery industry	Forest industry	Energy industry[a]
Motivation	• High: The profitability of Sunpine exceeded expectations as efficiency could be increased and new products added. • High: Operating on a declining fossil fuel market. • High: Lowered the risk by reducing cost and process complexity.	• High: With small investments to off-load the recovery boiler the forest industry avoided large investments in new boilers while also making an additional income on the lignin without having to go all the way to fuel production. • High: Did not disrupt or interfere with existing production.	• Low: No pressure to be part of the technology development from stakeholder or owners
Ability	• High: Mades use of and expanded abilities associated with existing infrastructure.	• High: Good fit with existing infrastructure. • High: Enabled the forest industry to stepwise develop new capabilities and abilities in relation to converting lignin to new products without venturing into the fuel market.	• High: Good fit with existing infrastructure and competencies

[a] In principle, this distributed concept could be relevant for energy utilities and district heating companies as well, but apart from the Fortum investment the existing actors have shown very little interest in the technology.

their absence from the development of future biorefineries. Instead, we argue in this paper that this absence should rather be attributed to the starting point of policymaking being focused on pilots and demonstration of the new technologies. A complementing focus would have included the existing infrastructures, competencies and the underlying motives of incumbent actors, as well as the policy and market conditions for the products coming out of the demonstrations. We argue that this is of particular importance in the biorefinery case, since reducing costs and complexity for existing concepts hinges on successful integration into existing infrastructures and the development of complementary products.

Although a collaborative model of innovation was attempted in Case 1–3 (but failed), there has not been any direct efforts by policy to increase the motivation and abilities of the incumbent actors to participate in the experiments. Consequently, when incumbent actors have encountered challenges, they have chosen to withdraw from the projects and left it to start-ups and universities to continue the development. The remaining actors have mainly focused on technology development, without deeper considerations for – or possibilities for influencing – the broader policy context, including demand-side policies (Hellsmark et al., 2016b).

It was not until a rather small joint investment by one of the incumbent oil refineries and representatives from the forest industry in Sweden happened that a better alignment between motivation and ability could be achieved (Case 4). The investment in Sunpine strengthened primarily Preem's motivation and ability to take the next step, creating significant motivation for aligning the institutional setting to their new and strategic objectives of significantly increasing their biofuel production from forest-based biomass. With these efforts the market appears to have been "tilted" towards distributed biorefining, rather than creating opportunities for standalone production that would have been pursued outside the control of the refinery industry.

This points to the fact that incumbent participation depends on the formation of markets, stable political conditions and their ability to utilize existing infrastructure for realising these markets (Bergek et al., 2013). The engagement of the oil refinery industry also meant that the complexity of realising future biorefineries was significantly reduced compared to previous concepts. The need for new infrastructure and big investments could be reduced by introducing a "distributed biorefinery principle", in which small-scale investments in existing sawmills, P&P

Table 7
Incumbent actors from mature industries and their motivation and abilities to drive the development of bio-refining.

Incumbentactors from the …	Motivation/Ability	Case 1: Chemrec	Case 2: SEKAB	Case 3: Gobigas	Case 4: Sunpine	Case 5: Preem
… oil refinery industry	Motivation	Low	Low	Medium	High	High
	Ability	High	Low	Medium	High	High
… forest industry	Motivation	Low	Low	Low	High	High
	Ability	Low	Low	Low	High	High
… energy industry	Motivation	NA	Medium	High	NA	Low
	Ability	NA	Low	High/Low	NA	High

mills, district heating etc., could be combined with the infrastructure of existing oil refineries for producing bio-based fuels, chemicals and materials. In a joint effort the incumbent actors from the two mature sectors were able to influence the institutional setting, creating more favourable conditions for a future scale up of distributed concepts. A key factor for joining forces and for successful collaboration was the profit-sharing scheme that enabled both incumbent actors from the forestry and oil refinery industries to profit from joint development throughout the value chain. Hence, when the collaboration could depart from the assets and resources of the existing industry this allowed pushing technology development, developing a favourable policy and a market context.

We noted in the introduction that previous research on incumbency has failed to consider how policy-related trade-offs arise, depending on the actors who take the lead and set the agenda in the transition processes. To begin with we would like to argue that while the shift towards "distributed biorefining" has opened up for the production of advanced biofuels and materials, it has also opened up for further investments and continued used of the fossil infrastructure.

If the earlier and more complex investments would have been realized (Case 1–3, Fig. 1), this would have opened up for an "on-site" production of fuels and chemicals in connection with the forest industry and energy sector. The unintentional consequence would have been that the oil industry would have played a smaller or insignificant role in the development of future biorefineries. Hence, with the introduction of distributed biorefining, the oil refinery industry is also included in the future development. Revenues from biofuels can also be used to revitalize the industry, which otherwise would be operating in a declining market, facing smaller margins and increased competition, making it more and more difficult to make investments in existing infrastructure. With this shift towards distributed biorefining, we can discern a new dawn for the oil industry within the bioeconomy, which also includes possibilities to invest in the fossil part of the refinery infrastructure. For example, in parallel with the investments in biorefining, Preem has applied for a permit to make necessary investments for upgrading low-grade bunker oil to gasoline and diesel on an annual basis. This is an investment that would increase the emissions from their current facility in Lysekil from 1.7 to 2.7 million ton CO_2 per year (Gustafsson and Johansson, 2019).

Furthermore, a starting point in the infrastructures, competencies and motivations of incumbents may also narrow the area of search for new technologies and impose limits on the radical nature of the solutions developed. At the same time, our analysis indicates the potential advantages, in terms of significantly lower investment needs, and greater chances of actually achieving commercialisation of new technologies, starting by considering the challenges of the industries and the possibilities for utilising available resources.

Consequently, we suggest that policymakers acknowledge the policy trade-offs between the different policy approaches when prioritising resources for stimulating sustainability transitions. It might be that neither a policy portfolio fully targeted towards the development of new technologies free from the interests of incumbent actors, nor a policy portfolio that consistently takes a starting point in the motivations and abilities of incumbents is suitable for achieving sustainability transitions. This suggests that transformative innovation policy should give more attention to considering how policy mixes may support the reorientation of incumbents rather than predominantly focusing on marginalising and replacing incumbents.

6. Conclusion and policy implications

The paper aims, firstly, to arrive at a more detailed understanding of when incumbents may drive energy transitions and, secondly, to illustrate the policy-related trade-offs between policy approaches that actively seek to involve incumbents in energy transitions and policy approaches that try to pursue such transitions without their active involvement.

In relation to the first aim, our analysis supports the conclusion that incumbents will only drive transitions when both their motivation and ability for doing so are high. Contrary to earlier experiments with large-scale biorefineries that failed to engage incumbent actors from mature industries, recent cases of distributed refineries bring together incumbents from the oil refinery and forest industries, which are highly motivated and able to utilize their abilities. Thus, without the active participation of incumbent actors and the resources they possess, including key infrastructure, future biorefineries and the production of forest-based renewable transportation fuels has not been realized. Public funding in forest biorefineries was only successful when an actor from the oil industry entered the scene and enabled distributed biorefining. The introduction of distributed biorefining has enabled the use of the infrastructure in both the oil refinery and forestry infrastructure and has aligned the motivation and ability of incumbents from these industries. However, a profit-sharing model between incumbents in the forest and oil industries continues to be a key challenge for future development. Distributed biorefining has also turned the future development of biorefineries into a core activity for the oil industry, which has allocated resources to market and policy development. In Sweden, this has resulted in a policy framework that is well aligned with the concept of distributed biorefining.

Regarding the second aim, our analysis and discussion clearly highlights the existence of trade-offs when policy actively seeks to involve incumbents in energy transitions. On the one hand, the active participation of the oil industry creates new opportunities within the bioeconomy and may contribute to meeting ambitious national climate targets. However, on the other hand, the active participation of the oil industry also opens up for future investments in the fossil-based infrastructure. To which extent these investments prolong the carbon lock-in and become an active obstacle in the transition to a bioeconomy is too early to say. The alternative, in which the biorefinery development would have been centred on the forest and energy industry, would have required a much more proactive policy approach. The focus of such an approach would have been on policy and market development and activation of key incumbent actors in the forestry and energy industry to take responsibility for the entire value chain. That would have required the development of a whole new set of competencies in advanced chemistry, fuels synthesis etc.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. List of interviewees

#	Date	Interview	Affiliation	Case
1	2007-03-01	Project leader	Göteborg Energi	Gobigas
2	2008-01-16	Project leader	Göteborg Energi	Gobigas
3	2008-12-01	Technical Director	Kappa	Chemrec
4	2008-12-02	Senior researcher	LTU	Chemrec
5	2008-12-03	CEO	Chemrec	Chemrec
6	2008-12-04	Senior researcher	Umeå University	SEKAB/Chemrec
7	2008-12-12	Project manager	Volvo	Chemrec
8	2009-01-07	Technical Director	Volvo	Chemrec
9	2009-01-08	Deputy Director General	Energimyndigheten	Chemrec
10	2009-01-15	Technical expert	Preem	Chemrec
11	2009-03-20	Senior researcher	Chalmers	Gobigas
12	2009-04-08	CEO	Göteborg Energi	Gobigas
13	2012-02-22	Project leader	Gobigas	Gobigas
14	2012-09-28	Senior researcher	Chalmers	Gobigas
15	2012-10-12	Technical Director	EON	Gobigas
16	2013-05-08	Senior researcher	LTU	Chemrec
17	2013-05-13	Technical Director	Domsjö Fabriker/Aditya Birla	SEKAB/Chemrec
18	2013-05-13	Director	Processum	SEKAB
19	2013-05-13	VP	SEKAB	SEKAB
20	2013-05-13	Senior research advisor	RISE	SEKAB
21	2013-08-16	Area manager	RISE	SEKAB
22	2013-08-23	Technical Director	SEKAB	SEKAB
23	2013-08-23	VP	SEKAB E-technology	SEKAB
24	2013-08-26	Project manager	Domsjö Fabriker/Aditya Birla	SEKAB/Chemrec
25	2013-08-26	CEO	MORE Research	SEKAB
26	2013-08-26	Director	Processum	SEKAB
27	2013-08-26	Senior research advisor	RISE	SEKAB
28	2013-08-27	Senior researcher	Umeå University	SEKAB/Chemrec
29	2013-08-28	Senior researcher	Umeå University	SEKAB
30	2013-09-27	Principal	LTU	Chemrec
31	2015-06-11	Director	ETC	Chemrec
32	2015-07-08	Project manager	Göteborg Energi	Gobigas
33	2015-09-09	Project manager	Gobigas	Gobigas
34	2015-09-10	Senior researcher	Chalmers	Gobigas
35	2015-09-22	Senior research advisor	RISE	SEKAB
36	2015-10-02	Project leader	LTU Green Fuels	Chemrec
37	2015-10-08	Project leader	Gobigas	Gobigas
38	2015-10-13	Technical Director	SEKAB	SEKAB
39	2016-02-09	Senior Officer	Energimyndigheten	All plants
40	2018-02-19	Senior researcher	Renfuel	Preem
41	2018-02-19	Technical expert	Preem	Preem/Sunpine
42	2018-02-27	CEO	Kiram	Preem/Sunpine
43	2018-03-07	Project leader	Preem	Preem
44	2018-04-14	Technical Director	Setra	Preem

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