Challenges of sustainable industrial transformation: Swedish biorefinery development and incumbents in the emerging biofuels industry

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Abstract: This paper investigates the transformation challenges related to incumbent industries caused by technology development and industry convergence in the transition to a bioeconomy in the context of Swedish biorefinery development. It involves the emergence of new value chains and several incumbent industries such as the pulp and paper industry, the oil refinery sector, the chemical process industry, and the heat and power sector. In 2019, Sweden had Europe’s largest share of biofuels in the transport sector, roughly 20% on an energy basis, and this share has increased by around 300% during the last decade. At the same time, domestic production has stalled, and even though Sweden has beneficial conditions for biofuel production, the share of biofuel that is imported or based on imported feedstock has recently ranged between 85% and 90%. We discuss three transformation challenges: (i) inertia and lack of absorptive capacity creating lock-in effects at the organizational level; (ii) weak and inefficient actor networks at the industry level; and (iii) contradictory policy instrument mixes and lack of coordination at the government level. The findings underscore the need for policy integration and alignment across various policy domains, and an increased focus on policy mixes that can stimulate the emergence of more disruptive innovations and value chains. There is also a need for industrial initiatives, such as improving absorptive capacity and strengthening actor networks, to help build the value chains needed to realize a sustainable bioeconomy. © 2021 The Authors. Biofuels, Bioproducts and Biorefining published by Society of Industrial Chemistry and John Wiley & Sons Ltd

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Introduction

The concept of bioeconomy has received growing interest in recent decades. It goes beyond greenhouse gas mitigation, and embraces security-of-supply concerns, rural economic development, and industrial renewal. Against this background, many studies have highlighted the potential for increased use of biomass to produce novel products and applications in multiple industries. Examples of such products are transport biofuels, bio-based chemicals, various chemical products, and bio-based fibers and materials. Nevertheless, if biomass is to replace fossil fuels and fossil feedstock in a variety of applications, which in many ways is the essence of a bioeconomy, this would imply a transition of not only one but a range of incumbent process industries.

For the process industries as well as the transport sector, significantly increasing the use of biomass depends largely on the development of so-called advanced biorefineries, which are fueled by forestry and agricultural-based biomass residues and by-products. Deployed at commercial scale, advanced biorefineries have the potential for a renewal of mature process industries, such as the forestry and chemical industries, while creating opportunities for novel businesses through the establishment of new value chains and bio-based products. Today, most advanced biorefinery technologies linger at laboratory scale and up to pilot and demonstration scale.

In this article, a biorefinery is considered to fulfil the following criteria for its main activities: (i) the absolute majority of the raw materials used should be biogenic; (ii) at least two products are produced; and (iii) the product or the production process should be innovative or novel. Thus, firms producing, for instance, biofuels are referred to as biorefineries, whereas companies producing hygiene products are not. Advanced biorefineries are biorefineries that are fueled by forestry and / or agricultural biomass residues and byproducts.

This article investigates the key transformation challenges of the affected incumbent industries in the light of the ongoing emergence of biofuel value chains in a converging industrial landscape. The analysis uses the Swedish biorefinery development and the emerging biofuels industry as an illustration, and also discusses ways to address the transformation challenges encountered.

The analysis thus rests on the assumption that the new biorefinery industry will, to a large extent, be a product of the merging of companies, value chains or industry segments among several incumbent industries. The eventual success of such a transition is, however, far from given and will be contingent on industry and technology characteristics, as well as institutional obstacles and policy uncertainty. Thus, to realize the bioeconomy, we need to know more about the key transformation challenges that face the incumbent industries and the actor networks surrounding these industries, and what could be done to address the most significant challenges.

The aim of this paper is to investigate the transformation challenges of incumbent industries caused by biorefinery technology development and industry convergence, and how these challenges could shape and impact the emerging industries in terms of structure, actor collaboration, and value chains.

The case of Swedish biorefinery development and the emerging biofuels industry is an interesting and relevant one, not least because biorefinery technology development connects with several incumbent and capital-intensive segments of the process industries. These include the oil refinery industry, the forest industry, the chemical process industry, the agricultural industry, and the heat and power sector. For the emerging biofuels industry, there are multiple possible feedstocks, technological pathways, and final products, but not yet any clear dominant design for a future value chain. In fact, several value chains tend to develop in parallel, not only in Sweden but also in other countries. Moreover, the actors involved in the formation and development of this emerging industry are heterogeneous, and they come from a broad span of incumbent industries and sectors where the value chains have historically not been intertwined.

The article proceeds as follows. The next section provides some key theoretical points of departure, while the subsequent section describes the methods used. The empirical part of the paper is divided into two main sections. In the first of these, we introduce and discuss the emerging biofuels industry in Sweden, with a focus on the key sectors and actors involved, and elaborate the progress made so far. The second empirical section focuses on the challenges facing the different actors moving forward as industries converge and new biofuel value chains emerge. The paper ends with a discussion around the key transformation challenges, including industry and policy issues of relevance.

Theoretical points of departure

The sustainability transitions literature emphasizes the dynamics between incumbent technological regimes and emerging niches in the processes of industrial renewal. It highlights the need for initial protection of path-breaking niches, i.e., breeding places for evolving new technological solutions, which will otherwise fail to compete with incumbent socio-technical regimes. Incumbent actors are in turn specialists in their existing core process technologies...
and are, by definition, the established actors who dominate the existing regime. Moreover, incumbent actors typically possess substantial power and resources to influence the technological trajectories that will dominate in the future. Previous research argues that lock-in and path-dependence in existing systems and structures are key reasons why the transition to a bioeconomy sometimes stall. Here, incumbent actors are often incentivized to keep the existing regime stable, either by not actively participating in efforts to propel new innovations or by strategically endorsing initiatives that undermine such new innovations. It is frequently argued that incumbents lack both the motivation and the key capabilities to actively participate in radical innovation and associated transitions. In addition, the business environment of incumbent firms often does not allow them to pursue disruptive innovations when they first arise. The profit margins are often thin, and pursuing new development paths can take scarce resources away from sustaining existing ones. New innovations may also undercut sales and any prevailing business models. Incumbent firms may therefore address potential transformation challenges by trying not to make them happen.

However, recently, a contrary perspective on radical shifts in existing socio-technical regimes is put in substantial efforts to adapt the dominating regime. These efforts include strategic support of novel niche actors and activities. The two perspectives are not mutually exclusive. For example, Smink et al. have illustrated how incumbents in the energy sector sometimes strategize and implement dual approaches – both supportive and prohibitive – with respect to new innovations (in their case, LED lights and biofuels), ‘temporarily keeping sustainable innovation on a leash,’ (p. 86). Such action can be viewed as a way of hedging the risk of anticipated system / regime shifts, and the transformation challenges that arise from these shifts. In other words, incumbent actors can be both supportive and prohibitive of sustainability transitions – sometimes even both at the same time.

In radical innovation, such as the shift to a bioeconomy, industry can sometimes act on its own but the literature also shows that policy interventions can be needed. On the one hand, industrial policy that shields and nurtures a niche until it can compete on its own may be needed to break the path-dependence of the existing regime. However, there may also be cases of ‘transition from within’, i.e., to depart from the existing system and strive for a transition process that can benefit from the dominant system characteristics but that nevertheless is sustainable, e.g., less carbon-intensive. Both situations are relevant in the empirical context of the transition to a bioeconomy. For example, so-called low molecular transport fuels (e.g., methanol), which are efficient to produce but require new distribution systems and new (or adapted) vehicles (perhaps due to the different characteristics of methanol as a fuel compared with conventional diesel or gasoline – such as methanol being more corrosive; alcohols are in general more corrosive) are an example of the ‘disruptive approach’ (new system/niche development). In contrast, so-called drop-in fuels, such as synthetic biobased diesel and gasoline, such as hydrogenated vegetable oil (HVO), which can be produced in an integrated fashion in an existing refinery infrastructure, and then be put to use in existing distribution systems and vehicles, are examples of the ‘transition from within’ approach (the adaption of existing systems). Both trajectories may bring about their specific sets of transformation challenges, and could, by extension, shape and impact an emerging industry in different ways.

The convergence of previously separated industries, which is required to realize a bioeconomy, further complicates development and gives rise to additional transformation challenges. For the purposes of this paper, the concept of industry convergence is especially relevant because the emergence of a biofuels industry will require the convergence of parts of existing incumbent industries, e.g., oil refineries, forest companies, the chemical process industry, as well as the agricultural sector. Industry convergence is thus a major cause of transformation challenges for incumbent industries.

A second reason underscoring the relevance of industry convergence is that the new processes for the conversion of lignocellulosic biomass to utilities such as fuels, chemicals and products, are very capital intensive. This creates important process constraints and barriers to entry, which limit the industry’s attractiveness to new entrants. In economic terms, capital-intensive industries often benefit from the fact that, once the capacity is in place, the investments costs are sunk. Hence, when replacement of aging equipment is considered, the choice is between building a new plant and extending the life of the existing plant (sometimes in a modified form). The greater the difference between the total cost of a new replacement plant and the variable (avoidable) cost of the existing plant, the greater the incentive to keep the existing plant in operation. In other words, capital intensity provides strong incentives for a more intense utilization (including new uses) of investments already undertaken in industrial infrastructure. For this reason, the emerging bioeconomy will likely, to a non-trivial extent, draw upon the existing infrastructure of several incumbent industries.

Industry convergence also implies the emergence of new value chains, and this concept has been applied to investigate the emergence of a range of different, mainly high-tech,
Industry convergence can, in and of itself, lead to far-reaching transformation challenges such as the need to secure access to new technological knowledge that a specific incumbent firm currently does not possess. In an industrial landscape marked not only by convergence, but also by incumbents both enabling and prohibiting transitions, and where policy is sometimes needed (and sometimes not), it is increasingly important to shed light on the key transformation challenges that face incumbent industries in the transition to a bioeconomy.

Methods

This paper takes an in-depth view of the key transformation challenges of the incumbent industries caused by technology development and industry convergence in the transition to a bioeconomy in Sweden. It provides a novel analysis of the key transformation challenges at the organizational, network, and policy levels. This analysis is grounded in a previous longitudinal research program, but provides a fresh perspective and a synthesis on transformation challenges as well as a discussion of how these challenges can be addressed by the key actors involved, including through policy interventions. The contribution thus provides perspectives and synthesis, rather than extracting novel research findings. Nevertheless, the discussion also attempts to raise a couple of generic issues, which should also be relevant in other empirical contexts (e.g., biofuel development in other countries).

A transition to a bioeconomy implies an increased use of biomass, which is a key option for reducing greenhouse gas emissions across a variety of industrial sectors. The research program upon which the current article draws is summarized in prior publications by the author team. The current article overlaps empirically with these prior articles but the research question is new. For details on empirical data sources and analysis, we refer to the methods sections in those prior papers.

Swedish biorefinery development and the emerging biofuels industry

Sweden has several beneficial conditions for biorefineries, including significant agricultural and forest industry sectors utilizing domestic forest resources and agricultural land. Sweden also has an almost fossil-free heat and electricity generation system, and district heating grids in most cities (providing potential for the utilization of industrial excess heat). The country also hosts a rather diverse process industry with multiple strong – and for the Swedish economy important – industrial sectors. All these incumbent industries have communicated strategic intentions and development activities with direct relevance to the emerging bioeconomy. In line with these intentions, during the last decade, an increasing number of initiatives related to the progression of a bioeconomy and biorefineries have emerged.

In Sweden today, though, the most visible outcomes can be found in the road transport sector. This is due to the ambitious domestic policy target stipulating a fossil-independent vehicle fleet by the year 2030. It is interpreted as a reduction of carbon dioxide emissions from the road transport sector by 70% by 2030 compared to the corresponding emission level in the year 2010. Sweden also has the goal of net zero emissions of greenhouse gases by the year 2045, implying, in turn, a fossil-free transport sector by this date. For domestic road transport in Sweden, the use of biofuels has (on an energy basis) increased from about 2% of total fuel use in 2005 to close to 20% in 2019 (see Fig. 1). The 2019 share corresponds to around 30% if calculated applying EU double counting for certain feedstocks, and this equals roughly 20 TWh per year. Among the EU member states, Sweden has the by far the highest share of renewables in the transport sector. The country also scores high in terms of absolute volumes. Only France (38 TWh per year, i.e., 9%) and Germany (30 TWh per year, i.e., 7%) display higher absolute levels of renewable fuel use in the transport sector.

As shown in Fig. 1, there is significant diversification of the biofuels used in Sweden, including the different fuel segments of biodiesel, ethanol, and biogas, as well as both low-blend and high-blend (‘pure’) fuels. Three distinct phases can be identified. First, until 2012, the share of biofuel use grew at a steady but not too rapid pace from 2% to almost 7%, and with increasing shares for all biofuel types except the low-blended ethanol (which has decreased since 2005, in part reflecting the gradually lower share of gasoline cars in Sweden). The second phase, from around 2012 until 2016/17, delineates a more rapid increase in the share of biofuels. However, this increase consisted (more or less) solely of HVO, first as a drop-in fuel but from 2015 and onwards also as pure so-called HVO 100 in significant volumes. During this second phase, the share of fatty acid methyl ester (FAME) remained roughly at the same level whereas the share of ethanol decreased. The share of biogas has increased steadily but rather slowly since 2005, and from initially low volumes. The third phase, from 2017 and onwards, displays stable levels and a continued trend from 2015 for biogas (slowly but surely increasing), ethanol (stable very low levels for the high-blend and a continued slow decrease for the low-blend) and FAME (steady levels) but a more volatile development for HVO. In 2018, the Swedish government introduced a new so-called reduction quota system with a blending mandate...
for gasoline and diesel. At the same time, the previous system with carbon tax exemptions for biofuels was removed. As the initial levels in the reduction quota system were modest, the new system did not stimulate increased levels of renewables in the transport sector. It instead acted as a cap on biofuel use, and this explains the decline after 2018, not least the reduction in the use of HVO (mainly low-blend). In December 2020, the government introduced more stringent quotas.

The feedstocks vary between the different fuel segments, but roughly consist of either of agricultural crops or oil, and/or starch-based waste and residues (where the waste/residues to a large extent stem from agricultural activities – examples include slaughterhouse waste, palm oil fatty acids distillates (PFAD), manure and various food wastes). Both these types of feedstocks are however limited with respect to larger (sustainable) volume increases in the future. Thus, adding larger volumes of sustainable biofuels to the market require other feedstocks, such as residues from the agricultural and/or forest sector (i.e., lignocellulosic feedstock). Several studies have shown that Sweden holds a large potential to acquire forest and agricultural residues. Specifically, the potential for acquiring forest residues (including lignin) amounts to at least 35–45 TWh per year, while the agricultural residues potential represents an additional 13–20 TWh per year (in turn excluding around 5 TWh in biogas). Depending on the choice of conversion technology, this would be equal to a biofuel potential in Sweden of around 22–35 TWh per year (this estimate builds on a conversion efficiency of around 60%).

However, Sweden is currently (2021) dependent on imports of biofuels and to some extent on imports of the biobased feedstock needed for existing domestic biofuel production. In fact, roughly 85–90% out of the biofuels used in Sweden are imported or are based on imported feedstocks. Since 2017, the ratios between imported biofuels/feedstock on the one hand and domestic production/feedstock on the other, have remained fairly constant. No large production facilities based on domestic feedstock have been taken into production and the modest increase in, for instance, the domestic production of biogas has been evened out by a small increase in the total use of biofuels.

The share of import and the origin of feedstock (fuel) vary for the different fuel assortments. This goes for the imported biofuels as well as for the domestically produced biofuels. (Sweden uses a significant share of the HVO produced in the world, i.e., 35% of world production and about 65% of European HVO production.) In crude terms, the biogas used is predominantly supplied by domestic feedstock, the FAME (biodiesel) and the ethanol originate from other European countries whereas the HVO comes from countries worldwide. In 2018, the share of domestic feedstock for the HVO used in Sweden was 5%, for the FAME 6% and for the ethanol used the share of domestic feedstock was 16%. Finally, when considering the specific case of feedstock choice for domestic production, there exist no official statistics. Still, in general, it can be noted that the share of domestic feedstock is high in Swedish biogas production, and this is also true for the domestic production of rape-seed methyl ester (RME) and ethanol. Domestic production of HVO is instead more dependent on imported feedstock.

Sweden hosts a fair amount of domestic production capacity for biofuels (see Table 1). In addition to the
Table 1. The most significant biofuel producers in Sweden (2017).

| Company (start year) | Core business of company/group | Type of process/fuel |
|----------------------|--------------------------------|----------------------|
| Domsjö Fabriker (the ethanol marketed by Sekab) (1910) | Textile pulping | Ethanol, byproduct from the production of textile fiber pulp. Lignin is also produced as a byproduct, and in the future this could be further upgraded for, e.g., fuel production. Still, today the lignin is sold as is. |
| Ecobränsle (owned by Energifabriken) (1993) | Family-owned business originating from the farmers’ cooperative (Lantmännen), focusing on bioenergy and agriculture. | RME (biodiesel based on rapeseed). |
| Lantmännen Agroetanol (1999) | Agricultural cooperative active in agriculture, machinery, bioenergy and food. | Ethanol, the majority based on grains but also some production based on food waste. |
| Addesso bioproducts (previously Perstorp) (2007) | Originating from the chemical process industry (Perstorp) | RME (biodiesel based on rapeseed). Until 2019, it was fully owned by Perstorp (a chemical industry company). |
| Sunpine (2010) | Refining of raw tall oil from the chemical pulping industry | Raw tall diesel and other related products (based on talloil) – capacity expansion under way. |
| Preem (2010/2016) | Oil refinery with station operations (fuels retail). | Hydrogenated vegetable oil (synthetic diesel) based on mixed oils and fats including talloil (crude talloil refined by the company Sunpine to raw tall diesel, then upgraded by Preem). Increased production of HVO and synthetic gasoline in 2016, and further capacity expansions under way. |
| St1 (2017) | Oil refinery with station operations (fuels retail). | Ethanol based on food waste such as old brea and bakery waste. |
| Gasum Jordberga (2014) | Energy company with a focus on gas | Biomethane, around 110 GWh/year. |
| Scandinavian biogas Henriksdal (2011/2016) | Energy company with a focus on biogas | Biomethane, design capacity 225 GWh per year. |
| Additional 250+ smaller biogas production plants | The majority are co-digestion plants and municipal sewage treatment plants. | Biomethane, around 1230 GWh/year. |

Total domestic biofuel production capacity (2017) | About 6–7 TWh per year |

Sources: Svebio (2018) and own consultations.

Production plants in operation, there are also several advanced biofuels development initiatives in Sweden. These initiatives are listed in Table 2, and they all aim to utilize side or waste streams from the forest industry and / or the pulp and paper sector. While a few larger pilot and demonstration plants, such as LTU Green Fuels and Gobigas, are mothballed at present, new plants have been built. For instance, in 2020, the smaller-scale methanol separation and upgrading pilot plant at the Södra Mönsterås Mill came into operation.

Finally, there exist a few Swedish biofuels production initiatives in the planning phase, which are intended to commence operation in the near future. Some of these pilot and demonstration plants under construction and production facilities in planning phase are listed in Table 3. As this shows, the commercial-scale plants in the planning phase all rely on proven technologies, e.g. biogas production through digestion. The other initiatives, primarily aiming for pilot or demonstration trials, are instead focused on the processing of side or waste streams from the forest industry and / or the pulp and paper industry.

As is evident from Tables 1–3, Swedish biorefinery development and the emerging biofuels industry are heterogeneous, and are made up of several incumbent actors from a wide range of industries, including the agricultural, forestry, chemical process, and refinery industries, as well as the heat and power sector and the recycling sector (Fig. 2). These incumbents have different key resources and competences. They have also not been in much contact prior to these recent developments. For this reason, barriers to collaboration, e.g. due to diverging goals and perceptions, likely exist.9

When analyzing the Swedish biorefinery development, and the emerging biofuels industry, it should be clear that the challenges and prerequisites for further progress vary among
the different incumbent industries involved. One key reason for this is that different types of value chains are emerging, and the resources and capabilities as well as capability gaps are contingent on the part of the value chain that is undergoing change. In the context of biorefinery development, there are two types of value chains – and changes within these – that appear particularly relevant. 

First, there is the refinery value chain (see Fig. 3). This value chain applies to incumbents in the refinery industry and the chemical industry (where the former is more common in Sweden). By gradually increasing the use of bio-based feedstock, so-called ‘drop-in concepts’ are created. These can make use of the existing value chain downstream, e.g., the distribution and use in vehicles, without any significant adaptions. One example involves Preem’s efforts towards developing bio-based oils, which can be fed into and processed in a refinery together with fossil-based feedstock. An important challenge is then that the biomass, among other things, contains much more oxygen, thus resulting in

Table 2. Ongoing development initiatives in the advanced biofuel field in Sweden.

| Pilot and demonstration plants | Feedstock / product | Technology | Type of plant |
|--------------------------------|---------------------|------------|--------------|
| Biorefinery demonstration plant (2005) | Lignocellulosic feedstock/ethanol (and other products from the sugar platform) | ‘The sugar platform’ – biochemical conversion | Demonstration plant (small) |
| LTU Greenfuels (2011) | Black liquor (Kraft pulp mill side-stream)/DME, methanol | Gasification | Pilot plant (currently mothballed) |
| Gobigas (2014) | Wood pellets, forest residues/methane, synthetic natural gas (SNG) | Gasification | Demonstration plant (currently mothballed) |
| RenFuel Bäckhammar (2017) | Lignin / bio-oil aiming for upgrading to synthetic diesel and gasoline (in refinery environment) | Lignin separation and upgrading | Demonstration plant |
| SCA Obbola (2017) | Lignin / bio-oil aiming for upgrading to synthetic diesel and gasoline (in refinery environment) | Lignin separation and upgrading | Pilot plant |
| Södra Mönsterås (2020) | Lignocellulosic feedstock (stripper gases)/methanol | Methanol separation (cleaning/upgrading) | Demonstration/first commercial plant |

Table 3. Upcoming and planned development initiatives in the advanced biofuel field in Sweden.

| Plants in planning phase* (the year of intended operation) | Feedstock/product | Technology | Type of plant |
|----------------------------------------------------------|-------------------|------------|--------------|
| Colabitoil (202X) | Lignocellulosic feedstock/synthetic diesel and gasoline | Biochemical conversion | Pilot plant |
| Pyrocell (2021, under construction) | Sawdust/biooil aiming for upgrading to synthetic diesel and gasoline (in refinery environment) | Pyrolysis | Demonstration plant |
| St1 (2021, under construction) | Mixed oils and fats including talloil/HVO and synthetic gasoline | Hydrotreatment | Commercial plant |
| SCA Östrand (202X) | Lignocellulosic feedstock crude tall oil/biooil | Separation/upgrading/hydrotreatment | Demonstration plant |
| RenFuel (202X) | Lignin/biooil aiming for upgrading to synthetic diesel and gasoline (in refinery environment) | Lignin separation and upgrading | Demonstration plant |
| Six biogas plants (two under construction) | Waste and residues | Digestion | Commercial plants |

*There are several additional plants, which have been communicated for the period 2022–2025. However, in these cases, the uncertainty regarding actual implementation was judged to be high. They were therefore not included in this table.
the bio-oil being more oxygen-rich than conventional oil. For this reason, there is an increased need for hydrogen gas to remove the oxygen.

One key is therefore to develop new ways of managing feedstock, including pre-processing methods to make the feedstock fit for subsequent processing in the refinery. Preem partly lacks both the knowledge and the infrastructure for doing this, although it is currently under development. Still, the downstream infrastructure can remain largely unchanged, and existing market knowledge is still relevant for the new modified products. Likewise, the biobased fuels can be distributed and used without modification in distribution channels or vehicles.

Second, there is the forestry and / or agriculture-based value chain, which applies to the forestry and agricultural-based...
industries or sectors (see Fig. 4). In this case, the upstream part of the value chain (processing of feedstocks and pre-treatment) is largely unchanged, while the downstream part results in new products (e.g., clean and / or high-blended biofuels) that, in turn, require new solutions (e.g., in distribution channels and use). One prominent example of this is the development pursued by Södra, who produces methanol from gas stripping. In doing this, one sidestream in the pulp plant is cleaned up and sold as fuel instead. The upstream parts of the value chain remain more or less unchanged; existing resources, capabilities, and infrastructure can be utilized. However, new knowledge and new infrastructure are needed to clean the methanol produced (equivalent to a ‘mini refinery’ in the pulp plant), and there is also a need for a new distribution system compared to the two existing ones used for pulp and fossil fuels, respectively. Yet another challenge in this case involves entering a new market (transportation fuels), where an established market position and key resources and capabilities are lacking. Furthermore, if used for transport purposes, the methanol cannot be used directly in existing vehicles; it requires modifications (pilot projects are ongoing in, for instance, shipping).

There are also developments that connect and transcend the two value chains mentioned above. The initiatives of Setra (a sawmill company), and its focus on the manufacturing of pyrolysis oil from the sawdust by-product, are an example. Pyrolysis oil is not a pure transportation fuel but rather an intermediary product intended for further processing in a refinery. In Setra’s case, the latter stage is pursued through a joint venture with Preem (Pyrocell).

As the above underscores, Swedish industry currently engages in important innovative activities and experiments. Despite these and similar initiatives, there are several challenges and problems that need further elaboration. These have hampered the transition to a bioeconomy in the country, not least in terms of the expansion of domestic biofuel production based on advanced biorefinery concepts. Sweden, despite having favorable conditions and a growing market for biofuels, along with important investments in pilot and demonstration plants to spawn technological development, has not witnessed domestic production increase proportionally. Concerns about the fact that the significant potential for a domestic biorefinery and biofuels industry has been far from fully realized have also been raised by some expert authorities in Sweden. It is therefore important to elaborate and deepen the analysis of the key challenges and how these can be addressed.

Transformational challenges in the Swedish biofuel industry

The previous section elaborated on the development of the biofuels industry in Sweden, and the two key emerging value chains. We identified a few specific challenges associated with each of these value chains. In this section, we broaden the perspective by discussing three overall challenges for Swedish biofuel development. These challenges concern three distinct levels: the organizational level, the actor network level, and the policy level. While the scope and the nature of these differ, they all in different ways relate to the presence of incumbent actors in biofuel development. In this section, we introduce each of these challenges, and explain how they tend to play out in the empirical context of the Swedish biofuel industry. These findings are discussed below and the ways in which the

Figure 4. Comparison of the established biobased industry (forestry/ agriculture) value chain and the value chain for pure / high-blend biofuel concepts (green shading highlights the modified parts of the value chain).
various challenges can be addressed, by the industrial actors and not least by policy makers, are elaborated.

The organizational level: inertia and lack of absorptive capacity create lock-in effects

Incumbent actors sometimes try to adapt the current technological regime and set it off in another direction, including through the support of niche experiments. Nevertheless, in Swedish biorefinery development and the emerging biofuels industry, such experiments and the attempts to break path-dependence are far from the norm. In fact, the key incumbent industries, e.g., the pulp and paper and refinery industries, do not push for radical innovations. There are at least five circumstances, which create and / or sustain inertia and compliance with the current technological regimes.

First, the incumbent process industries involved have thin profit margins in their core businesses and depend on production plants running continuously over the year. An unplanned shut down could erase large shares of annual profits in one blow, so the industries are conservative when it comes to implementing new process technologies. For example, this is evident in the pulp and paper industry, and it has been manifested by their hesitation towards implementing black liquor gasification, which involves replacing the traditional recovery boiler. In a similar vein, strict priority is typically given to investments that increase the production capacity of existing products. Integration of new process technologies needs to be scheduled according to planned stops, but these tend to be rare (and short). For instance, in the refinery industry, significant changes and implementation ‘windows’ may appear as seldom as every 5–10 years.

Second, high investment risks in combination with lack of funding and investment support sustain inertia. The development of radical innovations is likely to be a lengthy and highly risky process, and few actors may be willing to assume the initial investment risks. The risks encountered are not only technical risks but also risks related to institutional obstacles and the nature of the future market. Research on Swedish biorefinery development confirms the importance of various types of significant investment risks. Even though pilot plants may be instrumental in producing the knowledge required and reducing technical problems and risks, many actors perceive the political and wider institutional uncertainties to be high. For instance, the Swedish carbon dioxide tax policy (with exemptions for biofuels) lacked stability and credibility before the advent of the reduction quota in 2018 as frequent exemptions from the EU were needed, were only granted for short periods, and then had to be renewed. The Sunpine investment was one of the few investments taking place despite this uncertain policy environment. Venture capitalists will typically not fill such funding voids in the early stages of technological development, not least in knowledge-based sectors in which the capital intensity and technological complexity are high. For this reason, policy support is needed but this has often proved to be insufficient. For example, to comply with EU state aid rules, only 25% of the investment costs can be provided in public support (see further below).

Third, there is a natural ‘lock-in’ effect because resources and capabilities for pursuing new technologies and products may be lacking. For example, for companies in the forestry industry to diversify their product portfolio into fuels, capabilities not only in large-scale production but also in selling fuels and buying key insert materials need to be built. This is indeed difficult, as capabilities are built-in path-dependent learning processes. Companies build on accumulated technology-specific knowledge when developing new or better performing products and processes, and the technology choices are likely to be particularly self-reinforcing if investments are characterized by high upfront costs. In a similar vein, inertia is also sustained as sales representatives in the incumbent companies are incentivized to sell current products rather than thinking about future products.

Fourth, there is also a cognitive bias in favor of the existing technologies – so-called old technology primacy – which further exacerbates any inertia. There may be a reluctance to participate in the development and progression of new technology, and incremental product and process development are preferred over advanced biorefinery development. This may be especially problematic in the advanced biorefinery case where incumbent actors, e.g. the pulp and paper industry and the district heating sector, control large flows of biomass and strategic infrastructure that could be deployed to integrate new technologies at a significantly lower cost than creating new biomass routes from scratch by erecting new production capacity.

Fifth, and finally, the lack of absorptive capacity among incumbents will also contribute to sustaining inertia and creating lock-in effects. Absorptive capacity is a company’s ability to acknowledge the value of new information, assimilate it, and apply it for commercial purposes. One indicator of the relative lack of absorptive capacity in the incumbent industries is the low level of corporate R&D investments. For instance, in the Swedish pulp and paper industry, the R&D shares of total turnover have typically been well below 1%, and the investments made have typically been oriented towards improving existing process
technologies rather than product diversification. Key strategy documents for the forest industries also underscore that the predominant focus is traditional and does not center on, for instance, biofuel development. The Swedish Forest Industries has even criticized the more stringent obligations in the domestic reduction quota for biofuels (see above), but this position has in turn been questioned by individual forest companies (e.g., Södra and SCA), which endorse future increases in biofuel use.

Likewise, the Swedish chemical industry also holds a lack of absorptive capacity. This is manifested not least by the relatively low share of incumbent companies engaging in private R&D. As noted above, however, some incumbents have revealed investments in biofuels and other bio-based products. Others, such as Perstorp, have sold off their biofuels division (Adesso Bioproducts) and now focus on core competences. It should also be noted that the lack of absorptive capacity is not only relevant to technological know-how, or regarding future markets and customers of a more diversified product portfolio. It may also relate to procedural knowledge, such as how incumbent industries can collaborate with a diverse set of actors in development projects and share experiences and learning. The next challenge makes this clear.

The actor network level: weak and inefficient actor collaboration

Successful biorefinery development rests on the emergence of actor networks that represent a wide set of roles and competences, i.e., technology providers, infrastructure managers, funders, etc. Establishing effective actor networks, which can help shape the collective structures and resources that need to be associated with an emerging biofuel industry, is often not straightforward. For our purposes it is useful to highlight two key characteristics of high-performing actor networks. These include actor diversity and level of integration of the actor network. Below, we argue that Swedish biofuel development faces challenges associated with both these characteristics.

First, actor diversity and heterogeneity enable the actors involved to secure the necessary resources, e.g., competence and funding, and this should help increase the resilience of the actor collaboration. An important challenge in Sweden has been the activation of actors that are deemed essential for the commercialization of the new technologies. In particular, the development projects have often lacked participation from the incumbent industries, and this has caused difficulties in establishing strategic partnerships with actors along the novel value chains. Still, exceptions exist, and there are projects in which incumbent industries participate. One example is the Renfuel Bäckhammar case where a strong actor network with complementing resources and competences has emerged. This network has included venture capitalists, technical expert companies, research organizations, and incumbent industries such as the forestry and refinery sectors. The plan is to construct a new lignin production plant jointly with Preem. Another important example, which involves key incumbent actors, is Sunpine. In this case, the technology company Kiram managed to act as a bridge between the forest-based industry (Sveaskog and Södra) and the refining industry (Preem). The raw tall diesel is first separated from the raw tall oil in the jointly owned Sunpine facility, and then the raw tall diesel is processed to HVO diesel fuel by Preem. Some incumbent actors engage in the development of more than one value chain. For instance, Sveaskog and Preem also have stakes in the so-called Suncarbon project, involving lignin oil production.

These cases, though, also illustrate the relatively passive roles assumed by the incumbents; they take part in larger consortia and actor collaborations but are typically not actively driving the change. Corporate R&D efforts, e.g., in the pulp and paper industry, have been modest, but development activities in the biofuel sector take place in niche organizations, machine suppliers, etc. This puts pressure on the incumbent industries to engage in actor network constellations that are initiated beyond industry borders. Nevertheless, as the incumbents have clear incentives to prioritize development projects that do not come into conflict with core skills and practices, technology developers find it difficult to activate incumbents in the networks pursuing less-developed – yet promising – technologies. The two dominating value chains in Swedish biofuel development (see Figs 4, 5) are clear illustrations of this. In these cases, the challenges encountered when taking the step from successful technical verification experiments in pilot projects to commercialization have been modest, and activities have benefitted from an opportunity to utilize existing infrastructure and logistical solutions. In other words, so far, technology developers have not been able to activate incumbent actors in networks that pursue more advanced and less technologically mature biorefinery developments.

Second, while actor diversity is an important prerequisite for high-performing actor networks, so is the level of integration (collaboration) in the network. Actor networks with many connections (i.e., alignment structures) and a clearly designated coordinating unit, are often better equipped to define collective challenges and make the priorities needed to progress the development. Actor
diversity and integration, though, involve difficult trade-offs. Previous research has delineated the key managerial and organizational challenges that have arisen in and around various pilot and demonstration plants in Swedish biorefinery development,\textsuperscript{28} including LTU Green Fuels, the Biorefinery Demonstration Plant and Gobigas. This work shows that actor network diversity can give rise to significant managerial challenges, such as coordinating the actor network, aligning interests, and granting access to the plant, as well as various organizational challenges, e.g., dealing with the temporary nature of work and organization, shortages of funding, and the often unclear ownership structure of the plants.

Another challenge that could hamper the intensity of actor collaboration concerns the protection of immaterial rights,\textsuperscript{52} not least in projects seeking to commercialize novel biorefinery technologies. (Previous research has analyzed the establishment of local biogas production in Sweden and argued that intense sharing of information among actors is also critical in the case of relatively mature technologies, e.g., as a way of stimulating behavioral change, reducing uncertainty and avoiding misinterpretations.)\textsuperscript{53} The imperative for profiting from an innovation is that, unless the inventor / innovator enjoys strong natural protection against imitation and / or has strong intellectual property protection, then potential future streams of income could be at risk. The relevant appropriability regime is thus critical to shaping the possible outcomes. One recent study on patenting strategies among a set of Swedish biorefinery actors concludes that the protection of immaterial rights through patenting could be a double-edged sword.\textsuperscript{54} A non-patenting strategy encourages collaboration in the actor network and permits learning among the involved actors. However, this could risk removing the incentives for commercial actors to contribute to these learning processes in the first place. For instance, in the case of the Lignoboost pilot and demonstration plant in Bäckhammar, the adopted commercialization strategy was beneficial in attracting the leading equipment manufacturer Valmet, but after this company had bought the patenting, further development was constrained by its intellectual property rights ambitions.

Finally, efficient collaboration among actors in networks also requires efficient role taking among the actors involved in the development. Collaboration in the established value chains implies that all the roles actors can take are known, accepted, and understood but, in emerging sustainable value chains, this is not necessarily the case. For instance, many of the biorefinery pilot and demonstration plants initially rallied strong support for construction, often with municipal resources contributing significant parts of the budget (e.g., Gobigas). Over time, however, a debate has emerged about whether it is really the role of municipal companies (such as local energy utilities) to take on risky and expensive technology development projects, thereby risking the taxpayers’ money.\textsuperscript{26}

It has also been argued that a few of the actors in networks surrounding new biorefinery concepts have had to assume roles for which they may not be well suited. One example concerns the owners of the existing biorefinery pilot and demonstration plants in Sweden. The main task of some of these plants has changed over time, i.e., from an emphasis on technology verification to the operation of more open permanent test centers focusing on a broader set of experiments.\textsuperscript{28} This, though, implies that the business logic for managing the plant changes, and the manager of the plant, e.g., a university (as in the case of LTU Greenfuels) may not have the suitable capabilities to help progress the field further.\textsuperscript{27}

The policy level: dealing with an incomplete and contradictory policy environment

As noted above, policy typically plays a vital role in reducing the risks associated with investments in sustainable technological development, not least because existing capital markets often fail to provide risk-management instruments for immature technologies. The literature suggests that policy therefore needs to build on a mix of policy instruments to support the emergence of sustainable technologies; specifically, technology-push instruments that support the provision of basic and applied knowledge (e.g., R&D grants), and demand-pull instruments that encourage the formation of new markets and value chains (e.g., blending mandates, carbon taxes).\textsuperscript{55} Previous research has emphasized that Swedish biorefinery development has benefitted from relatively generous technology-push policies, while there has been a lack of stable demand pull policies.\textsuperscript{5,56} However, there exist yet other policy gaps and inconsistencies that hamper the development of biofuels.

First, another policy gap concerns the role of supporting actor collaborations. Given the difficulties in activating incumbent industries in novel technology development, policy could play the role of broker and mediator between actors.\textsuperscript{56} This thus involves policy instruments that support various functions at the innovation system level, including so-called network management, i.e., activities deliberately implemented to influence the structure and substance of actor networks as well as the collaborative processes taking place in these.\textsuperscript{48,49} These activities could involve the activation of actors (coalition-building), stimulating strategy development and joint goals, as well as providing organizational solutions.
In Sweden, network management has been used, e.g., connected to the collaborative R&D programs run by the Swedish Knowledge Centre for Renewable Transportation Fuels (F3) and BioInnovation, jointly with public actors such as the Swedish Energy Agency and the research council Vinnova. The Swedish government has also launched so-called strategic innovation agendas, which rest on sector-bridging collaboration. Nevertheless, previous studies argue that the collaboration across knowledge and organizational boundaries have been relatively weak in Swedish biorefinery development.\(^2\)\(^9\) For instance, scholars have suggested that existing arenas for interaction between biorefinery industrial actors are often organized according to single industry platforms, and policy therefore needs to take a more active role in facilitating the establishing arenas for interactions that take the prospective novel value chains as starting points.\(^1\)\(^2\)

Neglecting the key roles of network management may have several negative consequences, some of which do characterize biofuel development in Sweden. Notably, there will be a lack of resources and interpretative knowledge, in turn leading to a bias towards incremental innovation, and to a few actors being forced to assume roles in the network for which they are not well suited (see above). Moreover, there is also a risk that the allocation of resources (e.g., public funding, human capital) will become scattered across competing networks, all with limited ability to develop new technologies further.\(^5\)\(^1\)

Second, there is also evidence of a contradictory policy environment. The Swedish biofuel sector is characterized by industrial convergence processes, so it is also linked to a multitude of policy domains and government agencies. Thus, biofuel development is at the intersection between, for instance, energy policy, economic policy, and climate policy, which in turn can be attributed to several ministries at the national level (e.g., Ministry of Finance, Ministry of the Environment, Ministry of Enterprise and Innovation). There has over time been a lack of coordination – and even of mutual understanding – among government ministries and agencies, as well as various regional authorities.\(^2\) This has negatively affected progress from the pilot and demonstration phase to commercial application, not least since the required policy instruments are not within the realm of a single ministry or authority. Specifically, during the pilot and demonstration phase, public R&D support has played an important role for reducing technical and product-related risks, but the relevant actor networks have only had a limited (and mostly an indirect) influence over the institutional and market-related risks. For instance, while the Ministry of Enterprise and Innovation resides over public support for energy R&D, the Ministry of Finance resides over fuel (including carbon dioxide) taxation issues. This type of policy inconsistency has added to the inherent bias towards biofuel value chains that build on incremental innovations and a reliance on business models that are aligned with the interests of the incumbent actors.

Finally, existing regulations have also added to the policy uncertainties facing biofuel developers in Sweden. These include the EU state aid rules, which set limits on public funding for industrial projects. In fact, a few actors also express concerns that two different government agencies in Sweden (i.e., Vinnova and the Swedish Energy Agency), both of which fund demonstration plants, tend to interpret EU state rules regarding funding levels and project classification differently.\(^2\)\(^6\) Yet another regulatory barrier to biorefinery investment has been the environmental permitting process, which has been claimed to be unpredictable, subjective, too slow, and subject to a lack of coordination across different regulatory authorities.\(^5\)\(^6\),\(^5\)\(^7\)

**Discussion**

Figure 5 is a **generic** illustration of the emergence of various incumbent value chains in a converging industrial landscape, i.e., a framework that should be useful also in other empirical contexts involving a mix of incumbent firms and new industrial actors (e.g., biofuel development in other geographical regions). This framework highlights the three different levels, i.e., organizational, actor network, and policy, at which the actors face several transformation challenges. To manage these challenges and enhance absorptive capacity, incumbent industries could establish cross-sectorial collaborations, i.e., joint business ventures that can help capitalize on knowledge and resources from different incumbent actors along the old and the emergent value chains.

The specific experiences from Swedish biofuel development show how the transition for incumbent industries is manifested in different parts of the value chains depending on industry / sector. This holds implications for the challenges that are encountered. For example, the forest industry is familiar with biomass handling and processing but typically lacks the knowledge related to end-user demand and the distribution of biofuels. By contrast, the refinery industry holds knowledge about demand and the distribution of fuels but has deficient knowledge about the upstream parts of the biofuel value chain. Furthermore, the Swedish case has also highlighted the role of the pilot and demonstration plants as collaborative innovation arenas where actors with different competences and resources can meet and interact across the value chains.
In the case of developing advanced biorefineries, the pulp and paper and the chemical process industries, in particular, are shown to have a significant, and increasing, number of intersections. In practice, biorefineries producing the same products, such as biobased methanol, lignin-based phenols for resins production, could be introduced both in the pulp and paper industry as well as in the chemical process industry. As not all alternatives are equally interesting for all industries, the constellation of actors will have a significant influence on the future development of the biorefinery innovation system and its institutional setting, not least with respect to the platform technologies and associated fuels that will be given priority.

This has led to the emergence of new types of value chains and an expanding Swedish biofuels industry over the last decade. However, as noted above, this development has been associated with several challenges at the organizational level, the actor network level, and the policy level. The overall picture is complex with several (inter-related) biorefinery initiatives. There is a clear bias towards incremental innovation in which the incumbent industries have strong incentives to prioritize development paths that do not come into conflict with core skills and practices. This has made it difficult to pursue more advanced and less mature biorefinery trajectories, which build on the use of by-products with favorable sustainability performance. This attempt to achieve ‘transition from within’ can in turn likely explain the so-far relatively limited expansion of Swedish biofuel production based on domestic feedstock.

The further progressing of Swedish biorefinery development requires change at all three levels; as emphasized above, industrial initiatives such as improving absorptive capacity and strengthening new actor networks to help build up the future value chains are needed. However, we cannot expect more fundamental changes at the organizational and actor network levels unless a coherent and consistent policy mix is put in place. The sustainability transitions literature often argues that, in order to propel the development of new industrial niches – such as the ones needed for the transition from a fossil-based to a bio-based economy – strong governmental industrial policy is needed, protecting and nurturing the niche until it can compete on its own. At a general level, there is a need for a green industrial policy mix that is based on three broad categories of instrument: (i) technology-push instruments (e.g., public R&D support); (ii) demand-pull instruments (e.g., the reduction quota); and (iii) systemic instruments, such as providing infrastructure and pursuing various network management activities.

However, the complexity of biofuel development, not least with different value chains of different maturity emerging in parallel, implies clear challenges for policy makers. One particularly important task is designing and implementing a policy mix consisting of instruments that complement each other. Nevertheless, in the Swedish case as well as in other countries, the technology-push and demand-pull instruments tend to target different technological fields of various maturity. Specifically, the reduction quota has so far mainly been met through imports, while the government’s R&D efforts instead have focused on less mature technologies relying on by-products from the forest industries. This policy inconsistency has, as noted above, also led to incoherence in the network management activities pursued by the Swedish government agencies. For instance, the lack of a clear strategy and vision for the country’s biorefinery development tends to imply diverging interpretations and priorities among actors, in turn leading to the emergence of a large number of relatively small and competing actor networks, primarily pursuing incremental innovation.
Hence, there is a need for policy to recognize that different technological pathways and value chains differ in terms of maturity and therefore require different types of policy support, and then design clear and transparent strategies based on this fact. This, in turn, requires increased policy integration and alignment across the various policy domains (energy, economy, forestry, agriculture, etc.). Biofuel development is complex, involving both incumbent and new actors, as well as bridging various policy areas.

Concluding remarks and avenues for future research

This paper investigated the transformation challenges of the incumbent actors in the empirical context of Swedish biorefinery development and its emerging biofuels industry. These actors include the pulp and paper industry, the oil refinery sector, the chemical process industry as well as the heat and power sector. Intersections and convergence between these incumbent industries have been frequent in biofuel development. The paper identifies three overall transformation challenges: (i) inertia and a lack of absorptive capacity, which create inertia at the organizational level; (ii) weak and inefficient actor networks at the industry/network level; and (iii) contradictory policy instruments and a lack of coordination at the policy level.

The analysis illustrates that there is a need for industrial initiatives that improve absorptive capacity and strengthen novel actor networks to help build-up the future value chains needed to realize the emergence of a sustainable biofuels sector. At the policy level, there is a need for instrument mixes that can stimulate the emergence of more disruptive innovations, in turn relying on policy integration and alignment across the various policy domains as well as the instruments in the policy mix. If this cannot be achieved, there is a risk for additional bias towards incremental innovation, and the development may become too scattered across small and competing actor networks with limited abilities to further develop the most promising biorefinery concepts.

Finally, there should be plenty of scope for more in-depth conceptual and empirical work. First, this paper has focused on the transformation challenges facing the Swedish biofuels sector, with emphasis on the incumbent actors. Comparisons with the corresponding developments in other countries with similar ambitions in biorefinery technology (e.g., Finland, Canada) should be relevant and allow for more generic conclusions and implications. Second, another interesting avenue for future research is to study the dynamics of industry convergence processes further on the one hand and policy on the other, thus explicitly recognizing that the incumbent and new actors do not only passively respond to policy changes, they will also be active in shaping and directing such change.

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References

1. European Commission (2018). A sustainable bioeconomy for Europe. Strengthening the connection between economy, society and the environment. Updated bioeconomy strategy, Brussels.
2. Hellsmark H, Mossberg J, Söderholm P and Frishammar J, Innovation system strengths and weaknesses in progressing sustainable technology: the case of Swedish biorefinery development. J Clean Prod 131(10):702–715 (2016a).
3. Bauer F, Coenen L, Hansen T, McCormick K and Voytenko Palgan Y, Technological innovation systems for biorefineries: a review of the literature. Biofuels Bioproducts Biorefining 11:534–548 (2017).
4. Brown A, Waldheim L, Landälv I, Saddler J, Ebadian M, McMillan JD et al., Advanced Biofuels – Potential for Cost Reduction. IEA Bioenergy Task 41: 2020:01. International Energy Agency (IEA), Paris (2020).
5. Hellsmark H, Frishammar J, Söderholm P and Ylinenpää H, Role of pilot and demonstration plants in technology development and innovation policy. Res Policy 45(9):1743–1761 (2016b).
6. Sick N, Preschitschek N, Leker J and Bröring S, A new framework to assess industry convergence in high technology environments. Technovation 84–85:48–58 (2019).
7. Bento N and Wilson C, Measuring the duration of formative phases for energy technologies. Environ Innov Soc Trans 21:95–112 (2016).
8. Hedeler, B., Hellsmark, H., Söderholm, P., Donner-Amnell, J. (2020). Dynamic between policy mixes and the emergence of sustainable value chains: comparative perspectives from biofuel development in Finland and Sweden. Paper presented at the 2020 International Sustainability Transitions (IST) Conference (online), 18–21 August, 2020.
9. Bauer F, Hansen T and Hellsmark H, Innovation in the bioeconomy – dynamics of biorefinery innovation networks. Technol Anal Strateg Manag 30(8):935–947 (2018).
10. Hellmark H and Hansen T, A new dawn for (oil) incumbents within the bioeconomy? Trade-offs and lessons for policy. Energy Policy 145:111763 (2020).
11. Geels F, The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ Innov Soc Trans 1:24–40 (2011).
12. Hansen T and Coenen L, Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. Technol Anal Strateg Manag 29:500–513 (2017).
13. Kiltkou A, Bolwig S, Hansen T and Wessberg N. The role of lock-in mechanisms in transition processes: the case of energy for road transport. Environ Innov Soc Trans 16:22–37 (2015).
14. Geels F. Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. Theory Cult Soc 31:21–40 (2014).
15. Nikoleris, A., Åhman, M., Nilsson, L. J. (2012). Sustainability transition in basic industries – the forgotten sector. Paper presented at The International Conference on Innovative Methods for Innovation Management and Policy (IM2012), Beijing, China.
16. Bower J and Christensen C. Disruptive technologies: catching the wave. Harv Bus Rev 73(1):43–53 (1995).
17. Christensen C, The Innovator’s Dilemma – When New Technologies Cause Great Firms to Fail. HBR Press, Boston, MA (2016).
18. Spåth P, Rohracher H and von Radecki A, Incumbent actors as niche agents: the German car industry and the taming of the Stuttgart e-mobility region. Sustainability 8(3):252 (2016).
19. Smink M, Hekkert M and Negro S, Keeping sustainable innovation on a leash? Exploring incumbents’ institutional strategies. Business Strategy Environ 24:86–101 (2015).
20. Smith A and Raven R, What is protective space? Reconsidering niches in transitions to sustainability. Res Policy 41:1025–1036 (2012).
21. Rodrik D, Green industrial policy. Oxford Rev Econ Policy 30(3):469–491 (2014).
22. Smith A, Stirling A and Berkhour F, The governance of sustainable socio-technical transitions. Res Policy 34:1491–1510 (2005).
23. Stiglitz N, Digital dynamics and types of industry convergence: the evolution of the handheld computers market, in The Industrial Dynamics of the New Digital Economy, ed. by Christensen J and Maskell P. Edward Elgar, Cheltenham (2003).
24. Simms C, Frishammar J and Ford N, The front end in radical process innovation projects: sources of knowledge problems and coping mechanisms. Technovation (in press).
25. Lamberti L and Lettieri E, Gaining legitimacy in converging industries: evidence from the emerging market of functional food. Eur Manag J 29:462–475 (2011).
26. Frishammar J, Söderholm P, Hellmark H and Mossberg J, A knowledge-based perspective on system weaknesses in technological innovation systems. Sci Public Policy 46(1):55–70 (2019).
27. Mossberg J, Söderholm P, Hellmark H and Nordqvist S, Crossing the biorefinery valley of death? Actor roles and networks in overcoming barriers to sustainability transition. Environ Innov Soc Trans 27:83–101 (2018).
28. Mossberg J, Frishammar J, Söderholm P and Hellmark H, Managerial and organizational challenges encountered in the development of sustainable technology: analysis of Swedish biorefinery pilot and demonstration plants. J Clean Prod 276:124150 (2020).
29. Fossil Free Sweden, Roadmap for Fossil Free Competitiveness. Summaries 2018–2020. Fossil Free Sweden, Stockholm (2020).
30. Drivkraft Sverige (2020). Andel förnybara drivmedel i transportsektorn. (Accessed January 2020). https://drivkraftsverige.se/statistik/andel-fornybar-l-transportsektorn/
31. Swedish Energy Agency. (2020). Drivmedel 2019. Redovisning av rapporterade uppgifter enligt drivmedelslagen, hållbarhetslagen och reduktionsplikten. ER 2020:26, Eskilstuna, Sweden.
32. Eurostat (2019), Renewable Energy Statistics. Accessed 15 May 2019. https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Renewable_energy_statistics.
33. Ahlgren, S., Björnsson, L., Prade, T., Lantz, M. (2017). Biofuels from agricultural biomass – Land use change in a Swedish perspective. f3 Report 2017:13, the Swedish Knowledge Centre for Renewable Transportation Fuels f3, Gothenburg, Sweden.
34. BioDriv Öst (2019). Perspektiv på svenska förnybara drivmedel – Utvärdering utifrån miljökvalitets- och samhällsämne samt scenarier för inhemska produktion till 2030. (Accessed December 2020). https://biodrivost.se/Publikationer/Rapporter/Details/2809.
35. Börjesson P, Potential för ökad tillförsel och avsättning av inhemska biomassa i en växande svensk bioekonomi. Environmental and Energy Systems Studies, Lund University, Lund (2016).
36. Wetterlund, E., Falide, M., Pettersson, K., Olofsson, J., Börjesson, P., Lundgren, J. (2017). Be Where – Stakeholder analysis of biofuel production in Sweden. f3 Report 2017:15, the Swedish Knowledge Centre for Renewable Transportation Fuels f3, Gothenburg, Sweden.
37. Ahlgren S, Björnsson L, Prade T and Lantz M, Biodrivmedel och markanvändning i Sverige. Environmental and Energy Systems Studies, Lund University, Lund (2017).
38. SPBI (2018). SPBI Branachsftaka 2018. (Accessed 2 May 2019). https://spbi.se/wp-content/uploads/2018/11/SPBI_branchsftaka_2018-uppdatt-181015.pdf.
39. Drivkraft Sverige (2020). Råvaror till biodrivmedel som används i Sverige 2018. https://drivkraftsverige.se/uppdragarplan/fakta/drivmedel/fornybara-drive-medel/ravaror-i-biodrivmedel/
40. Svebio (2018). Tidningen Bioenergi. No. 5, 30–37.
41. Swedish Climate Policy Council (2020). 2020 Report of the Swedish Climate Policy Council, Stockholm.
42. Acemoglu D, Aghion P, Bursztyn L and Hemous D, The environment and directed technical change. Am Econ Rev 102:131–166 (2012).
43. Cohen WM and Levinthal DA, Absorptive capacity: a new perspective on learning and innovation. Admin Sci Q 35:128–152 (1990).
44. Novotny M and Laestadius S, Beyond papermaking: technology and market shifts for wood-based biomass industries – management implications for large-scale industries. Technol Anal Strateg Manag 26(8):875–891 (2014).
45. Sörensson, R., Jonsson, A. (2014). Företag inom svensk massa- och pappersindustri, 2007–2012. VA 2014:08, Vinnova, Stockholm.
46. Swedish Forest Industries (2015). En hoppfull berättelse om framtid, hållbarhet och den svenska skogens alla möjligheter. Stockholm.
47. Mossberg, J. (2016). Chemical industry companies in Sweden: update including data for competence analysis. VA 2016:04, Vinnova, Stockholm.
48. Newell D, Sandström A and Söderholm P, Network management and renewable energy development: an analytical framework with empirical illustrations. Energy Res Soc Sci 23:199–210 (2017).
49. Musiolik J, Markard J and Hekkert M, Networks and network resources in technological innovation systems: towards a conceptual framework for system building. Technol Forecast Social Change 79:1032–1048 (2012).
50. Peck, P., Grönnkvist, S., Hansson, J., Lönnqvist, T., Voytenko, Y. (2016). Systemic constraints and drivers for production of forest-derived transport biofuels in Sweden. Part A: report and Part B: case studies. f3 reports 2016:9a and 2016:9b, The Swedish Knowledge Centre for Renewable Transportation Fuels f3, Gothenburg, Sweden.

51. Söderholm P, Hellmark H, Frishammar J, Hansson J, Mossberg J and Sandström A, Technological development for sustainability: the role of network management in the innovation policy mix. Technol Forecast Social Change 138:309–323 (2019).

52. Teece DJ, Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. Res Policy 15(6):285–305 (1986).

53. Lundmark R, Anderson S, Hjort A, Lönnqvist T, Ryding S-O and Söderholm P, Establishing local biogas transport systems: policy incentives and actor networks in Swedish regions. Biomass Bioenergy 146:105953 (2021).

54. Nordqvist, S., Hellsmark, H. (2018). The influence of patenting on niche development: the case of publicly funded demonstration plants in Sweden. In Nordqvist, S. Actor Roles, Knowledge Types and the Role of Patenting for Progressing Sustainable Technologies: A Case Study of Demonstration Projects. Licentiate Thesis, Entrepreneurship and Innovation, Luleå University of Technology, Sweden.

55. Söderholm P, The green economy transition: the challenges of technological change for sustainability. Sustain Earth 3:6 (2020).

56. Grahn M and Hansson J, Prospects for domestic biofuels for transport in Sweden 2030 based on current production and future plans. Wiley Interdisc Rev Energy Environ 4(3):290–306 (2015).

57. Swedish Agency for Growth Policy Analysis (2019). Miljölagstiftningens betydelse för stora kunskapsintensiva investeringar. PM 2019:15, Östersund, Sweden.

58. Rogge KS and Reichardt K, Policy mixes for sustainability transitions: an extended concept and framework for analysis. Res Policy 45(8):1620–1635 (2016).

59. Palage K, Lundmark R and Söderholm P, The impact of pilot and demonstration plants on innovation: the case of advanced biofuel patenting in the European Union. Int J Prod Econ 210:42–55 (2019).

60. Furusjö, E., Lundgren, J. (2017). Utvärdering av produktionskostnader för biodrivmedel med hänsyn till reduktionsplikten, Report 2017:17, The Swedish Knowledge Centre for Renewable Transportation Fuels f3, Gothenburg, Sweden.

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