# 4 New path development for forest-based value creation in Norway

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## 4.1 Introduction

This chapter focuses on path development in the forest-based industries of Norway, based on the valorisation of side-streams and residues.

Forest-based value creation is one of the main avenues for the emerging bioeconomy in Norway and the neighbouring Nordic countries Sweden and Finland. Historically, the forestry sector has been an important part of the Norwegian economy, both in terms of GDP and employment. The sector contributed 10.4% of Norwegian GDP in 1845 (Grytten, 2004, p. 254). After the discovery of oil and natural gas on the Norwegian shelf, the importance of the forestry sector has diminished. And over the last decade this negative trend has multiplied.

For decades, the forestry-based industry in Norway has specialised in pulp and paper production, especially newsprint paper. Therefore, huge volumes of forest resources, including residues and side-streams, have been poured into this industry. However, due to changing global market conditions – the massive deployment of the Internet reducing demand for newspapers – and the rise of competitors in other parts of the world, European pulp and paper production has declined significantly in the last decade (Karltorp & Sandén, 2012). This development has had a tremendous impact on the market possibilities of forestry residues, since they can now be processed for pulp and paper to a much lesser degree. Nevertheless, other valorisation pathways exist besides pulp and paper production, such as the wooden construction industry, wooden furniture manufacturing, bioenergy – including solid bioenergy and liquid biofuels – and the production of lignocellulosic chemicals and materials. We want to explore how important these pathways could be in valorising forestry residues and side-streams.

This chapter analyses and compares new path development processes in three Norwegian regions specialising in forest-based value creation. These developments take place in different regional contexts and take different directions regarding choice of technology and the success of these developments. We can distinguish between three pathways and compare three empirical cases: (1) replacing pulp and paper production with an integrated biorefinery which produces chemicals and materials; (2) integrating pulp and paper production with liquefied biogas production; and (3) developing an industrial cooperation of different firms in order to replace pulp and paper production with new forest-based products from logs and residuals, such as bioethanol, biochar, wooden construction materials, etc. In this chapter we will answer the following research questions:

1 What are the main new pathways for forest-based value creation in Norway?
2 How did these new pathways emerge and how is valorisation of side-streams and residues accomplished?

The chapter is structured as follows: after the introduction comes a short section on the valorisation of side-stream and residues in forest-based industries. The third section discusses the conceptual framework for this chapter. The fourth section explains the methodology and data sources applied and gives an account of the three empirical cases as well as applying the conceptual framework; and the final section discusses the results in light of the research questions.

## 4.2 Forest-based value creation with a focus on the valorisation of side-streams and residues

When exploring new possibilities of value creation in forest-based industries it is necessary to understand the different types of residues and side-streams and how they can be valorised. We have to distinguish between three main groups of residues in forestry-based value chains:

1 *Primary residues:* leftovers from cultivation, harvesting or logging activities from trees within and outside forests;
2 *Secondary residues:* wood processing residues and side-streams, such as sawdust, bark, black liquor;
3 *Tertiary residues:* used wood (in household-waste, end-of-life wood from industrial and trade use, discarded furniture, demolition wood, etc.) considered to be organic waste.

In this chapter we will mainly focus on secondary residues and side-streams, as these are especially important from a regional development perspective.

The Food and Agriculture Organization (FAO) has assessed the shares of residue in the valorisation process of a tree as follows (FAO, 1990):

The harvesting and logging of a tree lead to the following residues being left in the forest:

- Tops, branches and foliage: 23%
- Stumps (excluding roots): 10%
- Sawdust: 5%

Operations at saw mills result in the following products and residues:

- Slabs, edgings and off-cut: 17%
- Sawdust and fines: 7.5%
- Various losses: 4%
- Bark: 5.5%
- Sawn timber: 28%

This gives a high potential for value creation based on these residues. Forestry residues are expensive to collect and to transport, particularly in high-cost Norwegian society, where the forestry sector is struggling to stay competitive in the global market (Talbot & Astrup, 2014). If the bark, leaves and thinnings are left behind in the forest, the nutrients in the soil will not be depleted (FAO, 1990). However, often the bark will first be removed at the plant, following which it will become a residue and will be used as a fuel for other operations.

We want to highlight opportunities for the valorisation of side-streams and residues resulting from the manufacturing of wooden construction materials and furniture, bioenergy production (solid and liquid), manufacturing of pulp and paper and manufacturing of lignocellulosic chemicals, lignin-based products, fibres and other material.

### *Manufacturing of wooden construction materials and furniture*

The value chain starts with the processing of the logs harvested in the forest to produce sawn wood. Only about one-third of a tree becomes sawn wood, leaving a vast amount of residue (Parikka, 2004), e.g. sawdust and fines. The efficiency of particular sawmills depends on various factors (e.g. wood properties, types of operations, machinery) and can be measured using special formulas, e.g. lumber recovery factor (LRF) (Keegan, Morgan, Blatner & Daniels, 2010). Sawmill residues can be used individually or combined as mulch, firewood, hog fuel, animal bedding, for use in particle or strand boards and for pulp recovery (Krigstin, Hayashi, Tchórzewski & Wetzel, 2012). They are particularly attractive to panel and pulp manufacturers, and can be upgraded into various wood-based materials. Markets and the valorisation of the products depend on the sawmill location and the local forest industries.

### *Bioenergy production*

We can distinguish between solid bioenergy, liquid and gaseous bioenergy. As examples of solid bioenergy there is a possible valorisation pathway for sawdust, involving the production of wooden briquettes from sawdust. Edgings and slabs from sawmills can be used for fire wood. More technologically advanced is the pathway leading to the production of advanced pellets from sawdust, etc. using patented steam explosion technology.

There exist different approaches to producing advanced biofuels from wooden material, including residues, but these approaches are mostly integrated into the production of other products in biorefineries (Gregg et al., 2017). Mainly we distinguish between an *anaerobic digestion pathway* to produce biogas, a thermo-chemical pathway for biodiesel or bio-oil and a *biochemical pathway* to produce bioethanol (Fevolden & Klitkou, 2016). The *thermo-chemical approach* involves heating the biomass either with oxygen (gasification for producing syngas and later through a Fischer-Tropsch process-created biodiesel) or without oxygen (pyrolysis for producing bio-oils).

### *Manufacturing of pulp and paper*

The amount of waste in the pulp and paper industry is substantial: around 40–50 kg of dry sludge is generated during the production of one tonne of paper while as much as 300 kg results from one tonne of recycled paper (Najpai, 2015). The composition of waste from pulp and paper mills depends on the final products, production methods and equipment. Waste from mechanical pulping includes rejects (bark and wood residues, sand), ash from energy production, green liquor sludge, dregs and lime mud, primary and biological sludge and chemical flocculation sludge. Papermaking using virgin fibres results in waste in the form of rejects from stock preparation and sludge from water treatments (sludge from chemical pre-treatment, from clarification, biological treatment and chemical flocculation). Papermaking from recovered paper requires many cleaning processes, resulting in more waste, especially deinking sludge composed of cellulose fibres, printing inks and mineral components (Monte, Fuente, Blanco & Negro, 2009). Most of these wastes can be used and valorised, largely eliminating the use of landfills.

One of the most common waste treatment methods in the European pulp and paper industry is the incineration of residues (rejects and sludge) by power and steam generation (Monte et al., 2009; Oral et al., 2005). Other thermal processes, such as pyrolysis, steam reforming, wet oxidation or gasification, are also possible but the technologies for sludge application are still being improved. In the cement industry, both material and energy residues from pulp and paper production can be used to improve products and production processes. Wastes and sludge can be used as soil improvers, through anaerobic digestion converted to biogas and humus (Monte et al., 2009). Other interesting valorisation pathways are cat litter and other absorbents from dried sludge, pesticide/fertiliser carriers or conversion to fuel components (Najpai, 2015). Research on waste from the pulp and paper industry confirms useful elements for both value-added products and industry. While some producers ‘capitalise on these opportunities’, current best practices are still ‘far from gaining the maximum value from paper resources’ (CEPI, 2013).

***Manufacturing of lignocellulosic products in integrated biorefineries***

In integrated biorefineries the whole tree is processed and no off-cuts, sawdust, etc. are lost. The bark is used for heating purposes. Energy produced in one operation is reused in other operations, which means that an integrated biorefinery should co-locate a number of plants to enable the symbiotic exploitation of side-streams and residues in the most cost-effective way. Integrated biorefineries produce a wide spectrum of products such as fuels, platform chemicals and materials of various types including plastics and textiles (Bauer, Coenen, Hansen, McCormick & Palgan, 2017). An economic risk analysis of different biorefinery concepts is in favour of upgrading bioethanol to higher value-added chemicals (Cheali, Posada, Gernaey & Sin, 2016).

One of the main issues when processing lignocellulosic materials in biorefineries is how to handle lignin in the production process. Lignin originally appeared as the main residue of paper production and represents *c.*30% of dry mass of wood. Lignin needs to be removed from the pulp to get a better quality of paper. Traditionally it has been used as a source of energy only, but at an integrated biorefinery lignin can be valorised into more valuable products. There is an established practice of using lignin as an additive to concrete, and other industrial valorisation pathways include the production of vanillin, dispersants or emulsion stabilisers.

***Storage and transport of residues***

The storage of residues requires area capacity and monitoring and, in the case of saw dust, even coverage to safeguard losses. The quality of the residues and side-streams requires that they are handled with as little transportation as possible, which means that short distances are preferable. When a tree has been logged the wood has a moisture content of around 50% (FAO, 1990). The moisture content is different in different seasons, and varies across species. High moisture content has an impact on the heating value and on the volume. For these reasons a co-location of valorisation pathways seems the most cost-effective option. Therefore, in our analysis of the three cases we use a theoretical framework which is specially tuned to analyse local/regional path development.

## 4.3 Conceptual framework

In order to understand the challenges and opportunities of the forestry industry in different Norwegian regions to simultaneously diversify into new product groups and minimise waste, we draw on the literature on regional path development. In the following section we describe different types of possible path developments for the three regions included in our study.

Sydow et al. (2009) highlight that the formation of a new path involves several stages and it is during the last stages that the process first gets locked in and becomes path-dependent (p. 691). Therefore, non-predictability and the coexistence of several outcomes are typical characteristics at the start of the process, while inflexibility comes later and inefficiency is typical only of the last stage. This implies that new paths can eventually evolve into barriers for the creation of fundamentally new paths because they bind resources, such as human, economic, institutional and scientific resources. Simmie (2012) has pointed out that in this way a former competitive technology can become the basis of a declining industry (p. 758).

Building on earlier work on the path dependency of technologies and economic activities, more recent scholarly work has highlighted opportunities for developing new industrial paths (Garud, Kumaraswamy & Karnøe, 2010; Martin, 2010). Drawing on evolutionary approaches, these contributions highlight how regional path development is influenced by existing conditions, but may nevertheless take multiple forms (Coenen, Asheim, Bugge & Herstad, 2016). Declining old industrial regions have to develop regional development strategies to 'break out of locked-in paths of development by pursuing innovation, new technological pathways and industrial renewal' (Coenen, Moodysson & Martin, 2015, p. 851). Different taxonomies of possible path developments have been developed, such as the six types defined by Grillitsch and Trippl (2016), who distinguish between path extension, path upgrading, path modernisation path branching, path importation and path creation, or the taxonomy introduced by Isaksen (2015), which distinguishes between path extension, path exhaustion, path renewal and path creation. Of course, these are ideal types, which may combine in reality. Path renewal and path creation tend to require institutional change and the building of new knowledge organisations, while path exhaustion is characteristic of regional industries which are locked into activities that predominantly follow existing technological paths, limiting their opportunities for going in new directions. We use here the taxonomy introduced by Isaksen (2015).

*Path exhaustion* describes a development where the innovation potentials of local firms are highly reduced and these firms are not able to adapt to technological and market changes.

*Path extension* is defined by the continuation of an existing industrial path based on incremental product and process innovations in existing industries and well-established technologies.

*Path renewal* occurs when existing local industries restructure and branch into new, but technologically related industries.

*Path creation* is defined as the emergence of new industries based on radically new technologies and scientific knowledge, new business models or user-driven innovation.

Regional actors and their networks are central to how lock-ins and path development can be addressed. The possibilities of a firm to engage in path development are highly dependent on the firm's organisational capabilities for innovation. Such capabilities include strategies for innovation, prioritisation of innovation, innovation culture, idea management, external linkages, implementation of ideas, system rules, knowledge generation and diffusion in the organisation (Bjørkdahl & Börjesson, 2011). Firms have to decide the main focus of their innovation activities: improvements of existing products and optimisation of existing processes and value chains, which mostly require more incremental innovations, or the development of totally new types of products and processes, which require more radical innovations. Incremental innovation characterises path extension and exhaustion, while radical innovation is necessary for new path creation and also, to some extent, for path renewal. The prioritisation of incremental versus radical innovation varies significantly between industries (Pavitt, 1984), with consequences for the likelihood of different types of development. The incumbent forestry industry has generally been found to prioritise incremental innovation (Hansen & Coenen, 2017; Näyhä & Pesonen, 2014). The more radical innovations tend to be rather costly in the first stages and therefore require more refinements to improve the new products and processes, i.e. radical innovations should be complemented by incremental innovations.

The actors interact through various types of networks, including supplier networks, research and learning networks, or user-producer networks. Actors include machinery and material suppliers, firms specialising in engineering, transport, maintenance and R&D, but also business development organisations and incubators (Novotny & Nuur, 2013). The importance of different types of actors varies according to technological characteristics, and particularly in degree of technological complexity (Hansen, Klitkou, Borup, Scordato & Wessberg, 2017). The focus on the actors is motivated by our interest in processes of agency, which are essential for new path creation (Garud & Karnøe, 2001a, 2001b; Simmie, 2012).

## 4.4 Analysis of empirical cases

We present a comparative analysis of the valorisation of residues and side-streams that can be found and directions in which path development has evolved across the three cases. The main empirical sources for the study are interviews with several representatives of the main industry actors and their collaborators in the three cases (Treklyngen, Skogn and Borregaard) and with the national forest owner association, participation in workshops and site visits. Media analysis, analysis of relevant policy documents and descriptive statistics complement the interviews.

We have selected these three cases because they represent rather different development directions, spanning over a broad range of valorisation pathways, and based in different counties of Norway: Østfold, Buskerud and Trøndelag (see Figure 4.1).

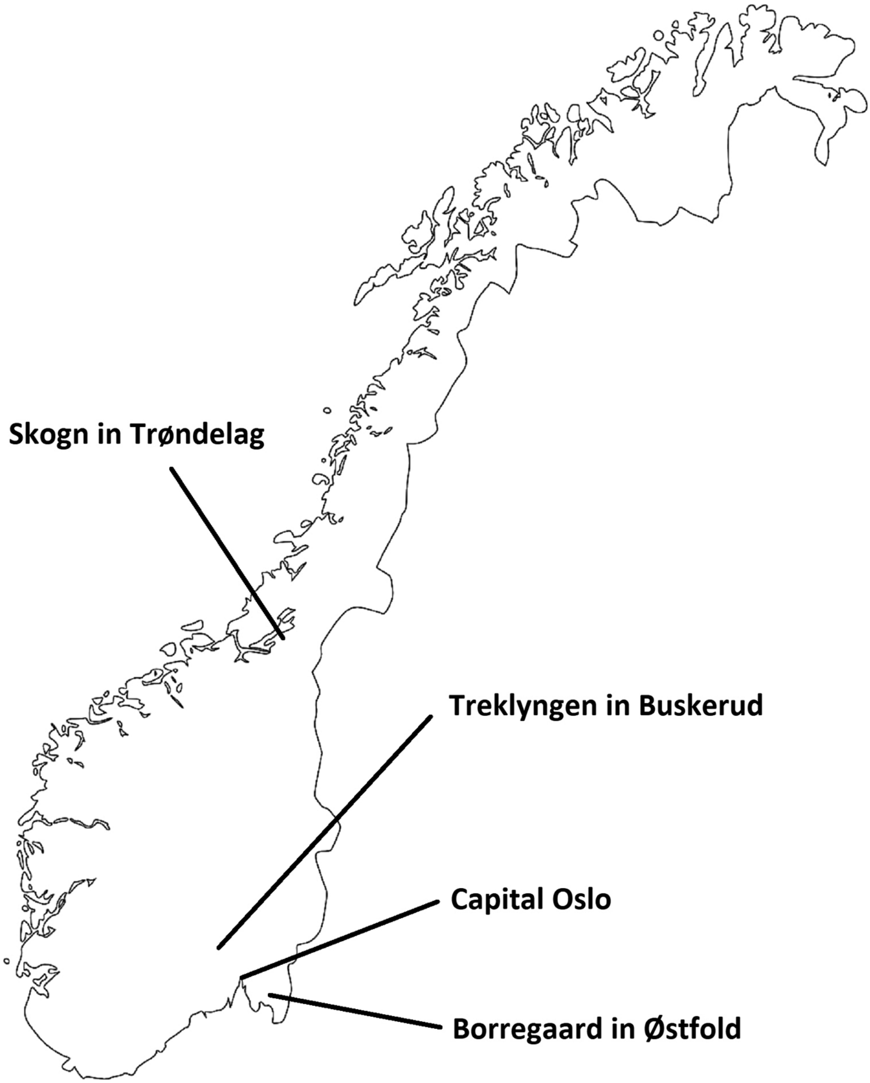


*Figure 4.1* Location of the three cases: Skogn in Trøndelag, Treklyngen in Buskerud and Borregaard in south-eastern Norway.

#### *4.4.1 Norske Skog Skogn at Fiborgtangen, Trøndelag*[1]

Norske Skog has been the leading pulp and paper producer in Norway for many years. It was established in 1962 with its headquarters in Oslo, Norway, and plants in 14 countries. Norske Skog has been highly specialised in the production of newspaper paper and its first newspaper paper plant opened in

Skogn in 1966. Over the years Norske Skog put all its efforts into becoming the world's leading paper producer, acquiring many foreign pulp and paper mills globally and consequently losing a great deal of its economic power as a result of a globally diminished demand for paper. Several of the pulp and paper plants had to be closed, but the one in Skogn has remained open in Norway, with three paper machines in operation.

While the mother company has declared bankruptcy, both Norske Skog Skogn and the other Norwegian plant, Norske Skog Saugbrugs AS in Halden, which specialises in magazine paper, are still in business; indeed they are earning steady incomes and do not fear for the future because of increased demand. While global demand for newspaper paper has declined, the European production capacity has nosedived still more rapidly, leaving a potentially large market share for the paper produced in Skogn. Norske Skog Skogn owns a large area of land in Fiborgtangen where the necessary infrastructure is already in place, such as quays, railways, roads, access to clean water and renewable energy. This allows direct export by ship to the United Kingdom and the Netherlands. Norske Skog uses bark as an input for thermal energy in the production of newsprint paper and the plant recycles newspaper paper in the production of its newsprint paper. Finally, the plant produces waste water, and this is the main input for valorisation as biogas.

Norske Skog Skogn has established cooperation with Biokraft AS, a company launched in 2009 and specialising in producing biogas from residues in the Norwegian aquaculture industry. The company is mainly owned by two shareholders: Scandinavian Biogas Fuels (50%) and Trønderenergi (43%). Biokraft had earlier experience of producing bio-oil from aquaculture residues. Norske Skog Skogn and Biokraft planned to exploit rest resources from pulp and paper production together with the rest resources from salmon aquaculture (category 2) in order to produce biogas and upgrade it to liquefied biogas (LBG). Category 2 rest resources include all sick and clinically dead fish.

Biokraft bought a part of the industrial area at Fiborgtangen close to the paper plant and started building a plant in 2015, opening it in June 2018. Regarding infrastructure, it should be mentioned that Biokraft also has access to the quays, where it takes deliveries of aquaculture residuals by ship. The plant's co-location with Norske Skog Skogn allows the setting up of direct pipelines for the waste water running from the pulp and paper plant to Biokraft.

The main source of success for the biogas plant was the entrepreneurial spirit of both companies, overcoming administrative barriers at the county level concerning public procurement of LBG. A major problem for the project was that Biokraft had to buy all raw materials (the aquaculture residues) in advance and sell the LBG before the project could receive any financing. The cooperation with AGA was key to getting the funding for the plant: AGA bought all Biokraft's LBG for the next 10 years, ensuring the success of the project. AGA is a Swedish company specialising in industrial gases, including biogas, and is part of the international Linde Group. For access to the aquaculture residues Biokraft has contracts with Scanbio and other companies on the delivery of the residues.

At the national level the Biokraft project twice received funding from Enova and once received a loan from Innovation Norway. The government budget in 2014 abolished tax exemptions for LPG, which enabled LBG to become competitive in price. And in 2015 the government introduced an economic compensation scheme for public buses fuelled with biogas. These decisions enabled a long-term market for LBG in the region.

The municipality of Levanger where Norske Skog Skogn is located was very much in favour of the biogas plant and also functioned as an important enabler.

As a result of the collaboration, Biokraft will process waste water from the pulp and paper plant, which is a mixture of biological sludge and water. After processing the waste water together with the fish residues, Biokraft delivers water back to Norske Skog Skogn. A dry bio-residual will be delivered as a fertiliser to farmers nearby through a local entrepreneur. This resource will be useful for upgrading soil. The farmers already know the quality of this bio-residual. Norske Skog Skogn in turn will receive a substrate which will reduce their need for urea. The biogas is chilled down and liquefied, before being sold as LBG to AGA. Following this it is used to fuel the regional public bus transport system. A barrier to the usage of LBG is the lack of extended filling infrastructure for LBG. Norway's focus on electrical mobility has left little attention for the development of necessary filling infrastructure for LBG.

In the case of Norske Skog Skogn we see a dominance of path extension due to the focus on the incremental improvement of their traditional newspaper paper production, which remains their core product. However, we can also see elements of path renewal, since the company has engaged in collaboration with a new industry in order to produce biogas from pulp and paper residues and the waste water, and even co-create future plans for developing totally new industries within the industrial area, such as introducing land-based fish-farming and a biorefinery. Biokraft is interested in expanding its LBG producing business at Skogn.

### *4.4.2 Treklyngen in Hønefoss, Buskerud*

In Hønefoss, the crisis of Norske Skog was the starting point for new development. In 2012, Norske Skog's pulp and paper mill at Follum, close to Hønefoss, was closed and sold for 60 million NOK to Viken Skog under the condition that the paper production had to be stopped and the equipment dismantled.

Viken Skog is a cooperative with a membership of about 11,000 forest owners, which means a very high degree of ownership fragmentation.

Viken Skog established Treklyngen as a subsidiary to establish a forest-based cluster with several firms exploiting forest resources differently to how they used to be exploited at the pulp and paper plant. Other valorisation pathways now came into focus, such as sawmills, wood-based construction materials, biorefinery and biofuel production. Viken Skog developed a vision of Treklyngen creating 1,000–2,000 new jobs, replacing the lost jobs in the forest-based industry in Southern Norway as well as over 350 jobs at Follum. Treklyngen decided that it would not repeat the mistakes previously made by Norske Skog during the failed Xynergo project, which aimed to produce biodiesel: they would exploit the whole tree and not just parts of it to avoid transport problems; they would use more mature technology than Xynergo; and they would develop an industrial symbiosis between several firms co-located at Treklyngen and share infrastructure costs regarding transport and energy. Treklyngen aimed to exploit the whole forest-based value chain from the sawmills/wood-working industry to the modern wood processing industry for processing, for instance, cellulose or biofuel, but would not be in competition with Borregaard in Sarpsborg.

The market for side-streams and residues had diminished. Over the years, wood chips guarantee instruments had been reduced gradually and at the same time low electricity prices were critical for wood-based bioenergy. With the closure of Follum it became difficult for forest owners to find a market for their pulpwood: 2.6 million $m^3$ of pulpwood lost their domestic market. Treklyngen planned to exploit 3–5 million $m^3$ timber annually in the future, about half of today's national felling volume. These plans would involve complementary businesses of different sizes, exploiting all parts of the raw material, including residues, for value creation at Follum. The forest owners at Viken Skog and the regional sawmills dependent on Viken Skog also had to struggle with a reduced market for their residuals because in 2013 the last pulp and paper plant in the region, Tofte, owned by Södra Cell, closed down. The pulp mill at Tofte had processed one quarter of all Norwegian timber. Before the closure Follum delivered 100,000 solid $m^3$ of wood chips a year to Tofte. After the closure the resources had to be exported to Sweden and Germany, often at low prices. Therefore, local valorisation was paramount for the development of Treklyngen. Treklyngen aims to exploit the whole log in an integrated process of three steps: (a) saw logs for construction of houses, (b) collect waste and pulpwood for producing cellulose, lignin and sugar in biorefineries, (c) collect rest streams for solid or liquid bioenergy.

Treklyngen explored different possibilities for industrial projects at Treklyngen, collaborating with: Avinor to produce bio-jetfuel, Arbaflame for a production plant for biochar, Elkem and the energy company Vardar to develop a new value chain for producing biochar and biooil, ST1, to build a bioethanol plant and an international data centre.

The production of solid wooden materials for construction purposes or for energy has been another valorisation pathway. Important projects have been Hunton Fiber, Termowood, Saga Wood and Norwegian Firewood. Several of these companies and start-ups have collaborated with the industry incubator in Hønefoss, Pan Innovation, where Treklyngen is one of the main owners. Pan Innovation functions not only as a local incubator, but as a national incubator for forest-based business development.

Hunton Fiber has specialised in producing a range of construction elements from wood fibre taken as waste chips, sawdust and off-cuts from sawmills. Hunton Fiber collaborated with Treklyngen and the Norwegian Paper and Fibre Research Institute, and would have been ideal for Treklyngen's profile. However, in 2014 the company decided to locate the new plant at another plant, near their first plant in Gjøvik.

In December 2014 Termowood signed a contract with Treklyngen to start production in 2015 at Treklyngen. Termowood developed a technology for wooden construction elements which ensures a fast and effective construction process, high quality, a good indoor climate and low costs. The business idea was based on a patent for building two-storey houses using self-supporting wooden structures with rock wool insulation in between, held together by veneer or wooden dowels. Termowood received support from Innovation Norway, SkatteFunn and Pan Innovation, but needed additional private investors. A year after the agreement with Termowood, in December 2015, Termowood decided to leave Treklyngen and start production in Hurdal, because of a new shareholder. Treklyngen has continued to collaborate with Termowood, but Termowood is not located there.

Saga Wood is a Norwegian company founded in 2015, specialising in wooden construction materials and fully utilising its experience with thermo-treated and linseed oil-impregnated wood. The company has acquired the rights to exploit Thermo 2.0 technology, developed by WTT in Denmark. Production started in autumn 2018.

Norwegian Firewood (now Varma) was established in 2015 as a start-up at Pan Innovation. The company specialises in selling wood and wooden briquettes. In 2016 the company acquired a large contract for selling wooden briquettes via a national retailer. They have developed a production capacity of 600,000–700,000 10-kg packages of wooden briquettes, exploiting sawdust from a saw mill near Treklyngen, Soknabruket.

Treklyngen does not have much manpower, but there are several highly engaged and competent people from outside the forest sector who are also trying to advance the cluster. The main advantages of Treklyngen are the location (near the capital's main airport), the size of the area and its access to infrastructure (train, road, energy). Several of the projects Treklyngen is involved in have received public funding in their early stages, but for commercialisation some of the projects, such as Arbaflame, need more investments. This has been a focus of network and lobbying activities over the last years, both within forest-based industries and with politicians.

Treklyngen has been forced to be open to many different opportunities after pulp and paper production ended. Therefore, we see here a mixture of path renewal – a restructuring and branching into new, but related industries (forest-based industries specialising in different advanced forms of bioenergy and wooden construction elements) – and path creation – aiming for biorefining and attracting an international data centre.

### *4.4.3 Borregaard in Sarpsborg*

Borregaard is a Norwegian company, established in 1889 and located in Sarpsborg in Østfold County in south-eastern Norway. The location is favourable for industry because of access to local hydropower for the production process at Sarpsfossen, Europe's biggest waterfall, to forest resources in south-eastern Norway and to a harbour as necessary infrastructure for delivery of forestry feedstock and export of goods.

Borregaard began by specialising in pulp and paper, and at the end of the 1930s the company started producing chemicals based on timber from spruce as a raw material, exploiting the hemi-cellulose in the feedstock (Klitkou, 2013). Since the 1950s Borregaard has also used the lignin components of the feedstock to produce chemicals.

Borregaard has been working on the development of an integrated biorefinery for more than 50 years (Rødsrud, Lersch & Sjöde, 2012). Borregaard's strategy is directed towards the production of high value-added products from Norwegian forest resources. The rationale behind this strategy is to become a company which specialises in producing chemicals and not cheap commodity products such as pulp and paper or advanced biofuels. This strategy has paid off and pulp and paper plants are not trying to compete with Borregaard, because they have high labour and feedstock costs and low value-added products.

Borregaard has used lignocellulosic feedstock, sulphite spent liquor from spruce wood pulping, as feedstock for many years. The feedstock is provided by the regional forestry industry and is relatively expensive compared to other countries. Borregaard annually consumes around 400,000 tons of spruce (Johansen, 2009). The biorefinery opened in 1938. Annually, the commercial biorefinery produces 160,000 tons of speciality cellulose, 170,000 tons of speciality lignin, 20 million litres of advanced bioethanol, 1,300 tons of vanillin, 200 GWh bioenergy and 30 GWh biogas based on anaerobic digestion (Johansen, 2009, p. 4).

The company acts globally and has plants and sales offices in 17 countries. Since 2012 the company has been listed on the Oslo Stock Exchange; it has over 800 employees and a solid turnover. Today, Borregaard produces a range of products, such as performance chemicals, advanced speciality cellulose, water-soluble specialty lignin products, ingredients for food and flagrance applications and fine chemicals for the pharmaceutical market. Examples of high-performance products are vanillin and high-performance additives and ingredients for the animal feed industry, such as bypass proteins and pelleting aids produced from lignin, and MFC – Exilva – from cellulose.

Borregaard has an additional six production plants around the world which produce lignin speciality chemicals. Borregaard wants to continue being the world's leading supplier of lignin-based chemicals and to improve its position, with bio-ethanol as an important by-product. Therefore, Borregaard has bought up a high-lignin production capacity globally. The company's strategic goal is to build and operate plants in Europe or other places in the world and not become a technology supplier.

For several decades, Borregaard has been interested in optimising its different processes – debarking, pre-treatment, hydrolysis, fermentation and chemical conversion. The most recent developments have been the BALI Pilot plant, where the pre-treatment of feedstock is central, and a plant for producing microfibrillar cellulose (MFC).

The BALI pilot plant is a research plant and does not produce for the market. The plant aims to 'utilize low value biomass and convert it to various competitive products. A goal is to utilize at least 80% of the biomass to produce products, energy excluded' (Rødsrud et al., 2012, p. 52f.). The BALI Pilot is based on the biochemical conversion of lignocellulosic material and produces ethanol; lignin, specialty chemicals; single-cell protein and sugar derivatives. The BALI process is based on chemical pre-treatment, saccharification with commercial enzymes, conventional fermentation of hexoses, aerobic fermentation or chemical conversion of pentoses, and chemical modification of lignin.

Borregaard first installed a pilot plant for developing and testing the MFC technology. The plant is still in operation and is used for testing and demonstrating new applications for MFC. It has a capacity of 100 dry metric tonnes. The MFC plant started its operation in 2016 and is globally the first commercial plant for MFC. It has a capacity of 10,000 metric tonnes of 10% paste (1000 metric tonnes dry) (Borregaard Exilva, 2018).

Borregaard has its own research centre with 70 employees and collaborates extensively with knowledge organisations inside the region, such as the University of Life Sciences in Ås and Østfold Research in Fredrikstad, but also within international networks which are engaged in developing new biorefinery technology. The company has received public funding for various research projects in the field of biorefining, but also for big demonstration facilities. Important national funding agencies were the Research Council of Norway, Innovation Norway and Enova. In cooperation with other companies, Borregaard was central in the development of a national strategy for forest-based industries (Skog 22, 2014). In this project Borregaard focused on the development of wooden fibre and biorefining exploitation. The Fibre Group concluded with three main goals for the fibre-based industry: increased harvesting from Norwegian forests, increased domestic value creation and decreased dependence on exports and, finally, innovation. The short-term focus on export of timber and use of forest resources for stationary energy was assessed as risky and should in the long-term be replaced with a focus on biorefineries and production of advanced biofuels for heavy transport, aeroplanes and ships, on bio-chemicals and special lignocellulosic materials (Rødsrud, 2014).

Borregaard has been very active in European RD&D projects and has received funding from Horizon 2020, among others, under the Bio Based Industries Joint Undertaking.

Borregaard has realised many more of the potentials of path creation than the two other cases. While the other two cases more or less have plans for path creation, Borregaard has realised the transformation of a pulp and paper plant into an advanced integrated biorefinery producing a wide range of products and relying on the development and commercialisation of advanced scientific knowledge. The firm is central in international projects for advancing forest-based biorefineries.

## 4.5 Conclusion

Our first case study, on the recent developments of Norske Skog in the Skogn region, has shown how a successful path extension, reached through incremental improvements of a traditional production line, may have far-reaching consequences for the valorisation of organic waste. Norske Skog Skogn has been able to survive demand swings and financial turmoil because of process innovations, without moving away from paper as a core product. Incremental innovations, devoted in particular to energy optimisation within its paper plant, have enabled not only an extension of the traditional regional path, but even a path renewal by allowing a co-located production of biogas. An industrial symbiosis has emerged where the new biogas plant can employ waste water from the local paper plant as well as residues from extra-regional aquaculture activities. The symbiosis has gone so far as to include an exchange of the dry bio-residual from the biogas plant with a substrate from local farmers.

Attempts to create an industrial symbiosis in the Hønefoss area, which we have studied as a second case, have encountered several difficulties. Before the entrance of Treklyngen, the traditional path based on pulp and paper production at Hønefoss was exhausted, and Treklyngen's efforts to renew this path by branching into other forest-based sectors face an uncertain future. If successful, the current plans for exploiting the whole wood timber in an integrated process could reduce the overall amount of waste, across all the value chains involved, to a minimum. However, in spite of a strong institutional backbone, the region does not offer a firm, or group of firms, that is sufficiently successful in the traditional regional path to provide enough support for regional branching. As a consequence, some of the firms which had considered producing novel products in the area have, in the end, decided to operate in different regions, where incumbents in traditional forest-based industries are operating successfully and could offer fruitful partnerships.

We have witnessed a completely different scenario when studying the Sarpsborg area. Here the incumbent Borregaard has been able, over almost a century, to move from the production of pulp and paper to the production of a vast range of wood-related chemical products. Such path creation has been made possible by the long-term innovation strategy of the firm, directed towards the production of high value-added goods from Norwegian forest resources. An in-house research centre, active in international networks as well as collaborating extensively with knowledge organisations within the region, has indeed enabled the invention of competitive products from underutilised resources, and guaranteed an optimisation of industrial processes. Industrial symbiosis has thus been reached within the firm, by co-locating or integrating different processes pertaining to different business lines.

Summing up our findings from the three cases analysed, it seems that forest-based waste valorisation often originates with the co-location of activities belonging to different value chains. Such activities can be performed by a firm operating in different lines, or by different firms, possibly belonging to different sectors. In both cases, the presence of a strong and innovative private actor in a region raises the region's chances for waste valorisation. Innovation could be directed explicitly towards the development of high-performance products, whose production lines can be harmonised for waste-reducing purposes. On the other hand, a persistent incremental process innovation within traditional business lines could bring waste valorisation about indirectly, by shaping the right regional environment for attracting firms into the region and for creating industrial symbioses. An extension of the traditional regional path would then lead the way to a path renewal, characterised by collaborations with industries new to the region for the purpose of waste valorisation.

## Note

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## References

Bauer, F., Coenen, L., Hansen, T., McCormick, K. & Palgan, Y. V. (2017). Technological innovation systems for biorefineries: A review of the literature. *Biofuels, Bioproducts and Biorefining*, *11*(3), 534–548.

Bjørkdahl, J., & Börjesson, S. (2011). Organizational climate and capabilities for innovation: A study of nine forest-based Nordic manufacturing firms. *Scandinavian Journal of Forest Research*, *26*(5), 488–500. doi:10.1080/02827581.2011.585997.

Borregaard Exilva. (2018). Exilva. Retrieved from www.exilva.com.

CEPI. (2013). *CEPI Sustainability Report 2013. European Paper Industry – Advancing the Bioeconomy. Summary.* Retrieved from www.cepi-sustainability.eu/uploads/short_sustainability2013.pdf.

Cheali, P., Posada, J. A., Gernaey, K. V. & Sin, G. (2016). Economic risk analysis and critical comparison of optimal biorefinery concepts. *Biofuels Bioproducts & Biorefining – Biofpr*, *10*(4), 435–445. doi:10.1002/bbb.1654.

Coenen, L., Moodysson, J. & Martin, H. (2015). Path renewal in old industrial regions: Possibilities and limitations for regional innovation policy. *Regional Studies*, *49*(5), 850–865. doi:10.1080/00343404.2014.979321.

Coenen, L., Asheim, B. T., Bugge, M. M. & Herstad, S. J. (2016). Advancing regional innovation systems: What does evolutionary economic geography bring to the policy table? *Environment and Planning C: Politics and Space*, *35*(4), 600–620.

FAO. (1990). The potential use of wood residues for energy generation. In *Energy Conservation in the Mechanical Forest Industry*. Rome: Food and Agriculture Organization of the United Nations.

Fevolden, A. M., & Klitkou, A. (2016). A fuel too far? Technology, innovation, and transition in failed biofuel development in Norway. *Energy Research & Social Science*, *23*(January), 125–135.

Garud, R., & Karnøe, P. (2001a). Path creation as a process of mindful deviation. In R. Garud & P. Karnøe (Eds.), *Path Dependence and Path Creation* (pp. 1–38). Mahwah, NJ: Lawrence Erlbaum Associates.

Garud, R., & Karnøe, P. (Eds.). (2001b). *Path dependence and path creation*. Mahwah, NJ: Lawrence Erlbaum Associates.

Garud, R., Kumaraswamy, A. & Karnøe, P. (2010). Path dependence or path creation? *Journal of Management Studies*, *47*(4), 760–774.

Gregg, J. S., Bolwig, S., Hansen, T., Solér, O., Amer-Allam, S. B., Viladecans, J. P., … Fevolden, A. (2017). Value chain structures that define European cellulosic ethanol production. *Sustainability*, *9*(118), 1–17.

Grillitsch, M., & Trippl, M. (2016). Innovation policies and new regional growth paths: A place-based system failure framework. *Papers in Innovation Studies*, *26*, 1–23.

Grytten, O. H. (2004). The gross domestic product for Norway 1830–2003. In Ø. Eitrheim, J. a. T. Klovland & J. F. Qvigstad (Eds.), *Historical Monetary Statistics for Norway 1819–2003* (pp. 241–288). Oslo: Norges Bank.

Hansen, T., & Coenen, L. (2017). Unpacking resource mobilisation by incumbents for biorefineries: The role of micro-level factors for technological innovation system weaknesses. *Technology Analysis & Strategic Management*, *29*(5), 500–513.

Hansen, T., Klitkou, A., Borup, M., Scordato, L. & Wessberg, N. (2017). Path creation in Nordic energy and road transport systems: The role of technological characteristics. *Renewable and Sustainable Energy Reviews*, *70*, 551–562.

Isaksen, A. (2015). Industrial development in thin regions: Trapped in path extension? *Journal of Economic Geography*, *15*(3), 585–600.

Johansen, G. L. (2009). *Creating Value from Wood: The Borregaard Biorefinery*. Paper presented at the Biofuels & Bioenergy: A Changing Climate. IEA Bioenergy Multi Task Conference, Vancouver.

Karltorp, K., & Sandén, B. A. (2012). Explaining regime destabilisation in the pulp and paper industry. *Environmental Innovation and Societal Transitions*, *2*, 66–81.

Keegan, C. E. I., Morgan, T. A., Blatner, K. A. & Daniels, J. M. (2010). Trends in lumber processing in the Western United States. Part I: Board foot Scribner volume per cubic foot of timber. *Forest Products Journal*, *60*(2), 133–139. doi:10.13073/0015-7473-60.2.133.

Klitkou, A. (2013). *Value Chain Analysis of Biofuels: Borregaard in Norway*. Retrieved from: www.topnest.no/attachments/article/12/Borregaard_TOPNEST_Case%20study.pdf.

Krigstin, S., Hayashi, K., Tchórzewski, J. & Wetzel, S. (2012). Current inventory and modelling of sawmill residues in Eastern Canada. *The Forestry Chronicle*, *88*(05), 626–635. doi:10.5558/tfc2012-116.

Martin, R. (2010). Roepke lecture in economic geography: Rethinking regional path dependence: Beyond lock-in to evolution. *Economic Geography*, *86*(1), 1–27.

Monte, M. C., Fuente, E., Blanco, A. & Negro, C. (2009). Waste management from pulp and paper production in the European Union. *Waste Management*, *29*(1), 293–308. doi:10.1016/j.wasman.2008.02.002.

Najpai, P. (2015). *Management of Pulp and Paper Mill Waste*. Cham, Switzerland: Springer International Publishing.

Näyhä, A., & Pesonen, H.-L. (2014). Strategic change in the forest industry towards the biorefining business. *Technological Forecasting and Social Change*, *81*, 259–271.

Novotny, M., & Nuur, C. (2013). The transformation of pulp and paper industries: The role of local networks and institutions. *International Journal of Innovation and Regional Development*, *5*(1), 41–57.

Oral, J., Sikula, J., Puchyr, R., Hajny, Z., Stehlik, P. & Bebar, L. (2005). Processing of waste from pulp and paper plant. *Journal of Cleaner Production*, *13*(5), 509–515. doi:10.1016/j.jclepro.2003.09.005.

Parikka, M. (2004). Global biomass fuel resources. *Biomass and Bioenergy*, *27*(6), 613–620. doi:10.1016/j.biombioe.2003.07.005.

Pavitt, K. (1984). Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy*, *13*(6), 343–373.

Rødsrud, G. (2014). *Skog22: Arbeidsgruppe Fiber*. Retrieved from www.skoginfo.no/userfiles/files/Skogforum/2014/5%20Gudbrand%20Rodsrud%20Arbeidsgruppe%20Fiber.pdf.

Rødsrud, G., Lersch, M. & Sjöde, A. (2012). History and future of world's most advanced biorefinery in operation. *Biomass & Bioenergy*, *46*, 46–59. doi:10.1016/j.biombioe.2012.03.028.

Simmie, J. (2012). Path dependence and new technological path creation in the Danish wind power industry. *European Planning Studies*, *20*(5), 753–772. doi:10.1080/09654313.2012.667924.

Skog22 – Arbeidsgruppe fiber og bioraffineri. (2014). *Skog22: Delrapport Arbeidsgruppe fiber og bioraffineri*. Retrieved from www.innovasjonnorge.no/contentassets/920a1e161a494a508f91b7a02344a47e/delrapport-skog22-arbeidsgruppe-fiber-kortversjon-endelig-versjon.pdf.

Sydow, J., Schreyögg, G. & Koch, J. (2009). Organizational path dependence: Opening the black box. *Academy of Management Review*, *34*(4), 689–709.

Talbot, B., & Astrup, R. (2014). Forest operations and ecosystems services in Norway: A review of the issues at hand and the opportunities offered through new technologies. *Journal of Green Engineering*, *4*(4).