Understanding forest-based value creation in a regional context[1]

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Abstract

This chapter gives a short overview of important forest-related residues and side streams and examples of their valorisation. We apply a comparative case study approach for studying the valorisation of forest-industry residues and side-streams across three forest-industry clusters in Norway. The three cases of forest-based industry clusters have shown that it takes a lot of time to build up new industry after the crisis in the pulp and paper industry. The three cases show very different stages of maturity. The exploitation of residues and side streams from forestry industries mostly goes in traditional pathways, such as the use for production of pulp or of particle boards. However, also more advanced valorisation pathways have been explored. And here other types of industry players outside the traditional forest-based industries come in, such as producers of fuels or producers of metals, which can replace fossil resources by forestry residues and side streams.

Keywords

forest-based industry; residues; side-streams, regional clusters; valorisation pathway; Norway

1.1. Introduction

This chapter explores forest-based value creation in a regional context. Since this book is about the circular economy we concentrate here on value creation based on valorisation of side-streams and residues from forestry and forest-based industries.

The empirical background for this chapter is a comparative analysis of three forest-based industry clusters in Norway: Forest Industry in Trøndelag, Treklyngen in Buskerud, and the Norwegian Wood Cluster in Hedmark and Oppland. The cases have been studied by a mixed method approach, building on interviews, workshops and a comprehensive media analysis. For a more detailed presentation of the comparative case study see Klitkou, Capasso et al. (2019).

In order to understand the sustainability challenges and opportunities in different Norwegian forest industry clusters, we draw on the literatures on the circular economy and on industrial symbiosis. The goal of promoting a circular economy is the decoupling of environmental pressure from economic growth (Ghisellini, Cialani et al. 2016). Life cycle assessments have addressed the sustainability or carbon footprint of new products and processes. However, from a life cycle perspective it is important to assess sustainability outcomes also in connected upstream and downstream processes, not just inside a company (Royne, Hackl et al. 2018).

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Value creation based on forestry is one of the main avenues for the bioeconomy in Norway. Export of timber has been important throughout the history of Norway, but also domestic value creation through the production of pulp and paper and through the wooden construction industry.

The Norwegian pulp and paper production has processed a high share of forestry residues and side streams. With the decline of the European pulp and paper production in the last decade there exist other market possibilities for forestry residues. Those valorisation pathways include the wooden construction industry, wooden furniture manufacturing, the production of bioenergy, including solid bioenergy and liquid biofuels, and the production of lignocellulosic chemicals and materials. In this chapter we explore how important the valorisation of forestry residues and side-streams in the three forestry-industry clusters. The three clusters differ regarding there background and history, their specialisation and their valorisation of residues and side-streams.

In this chapter we will answer the following research questions:

1. What are the main characteristics for the three forest-based industry clusters in Norway?
2. How do these clusters valorise side-streams and residues?

We use a comparative case study approach for comparing the valorisation of forest-industry residues and side-streams across three forest-industry clusters in Norway. The main empirical sources for the study are media analysis, document analysis, 13 interviews conducted from March 2016 to January 2019 with representatives of the main actors in the three industry clusters Forest Industry in Trøndelag, Treklyngen in Buskerud, and the Norwegian Wood Cluster in Hedmark and Oppland and with the national forest owner association, the participation in and organisation of workshops and seminars, and site visits. We used the interviews as a check on the media analysis, but here they are not included as citations.

The main characteristics of the three clusters will be shortly presented to answer the first research question. Here we concentrate on the background, history and driving forces of the cluster, some core economic indicators for their main members and main activities. Then we focus on how these clusters valorise side-streams and residues by first giving an overall picture and then present some examples of good practice in more detail.

The paper is structured as following: after the introduction follows a section on valorisation of side-stream and residues in forest-based industries. The third section gives an account of the empirical cases and discusses the results in the light of the research questions. The last section draws some conclusions.

1.2. Valorisation of side-streams and residues in forest-based industries

In this section we give a short overview of important forest-related residues and side streams and examples of their valorisation. There are three main groups of residues and side-streams from forestry and forest-based industries which can be valorised

1. *Primary residues:* leftovers from cultivation, harvesting or logging activities from trees within and outside of 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.

FAO has assessed the shares of residues in the industrial processing of a tree as following (FAO 1990):

Forestry operations, including harvesting and logging of a tree cause following residues, often left in the forest:

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

Operations at the saw mills bring about following residues and side-streams:

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

Only about 28% of the tree end finally as sawn timber. Therefore, the valorisation of the remaining residues and side-streams is so important. Forestry residues are expensive to collect and to transport, particularly in the high-cost Norwegian society, where the forestry sector is struggling to stay competitive in the global market (Talbot and Astrup 2014).

FAO has pointed out that bark, leaves and thinnings are often left behind in the forest, to avoid depleting nutrients in the soil (1990). However, often the bark will be removed first at the plant and then it is used as a fuel for other operations. The moisture content of a logged tree is different in different seasons and differs also across species. The wood can have a moisture content of about 50% (FAO 1990). This has an impact on the heating value of the residues and also on the volume of the residues. This has percussions on the storage of residues: need for area and monitoring and even coverage. Low transport costs of residues and side-streams implies to select short distances. Therefore is a co-location of different valorisation pathways most valuable.

Beside the primary and secondary residues and side-streams there are also the tertiary residues which have to be valorised. The construction and demolition waste contain both wood, metals, concrete, minerals and other substances (Dahlbo, Bacher et al. 2015). It can be distinguished between (a) construction wood waste, which is rather pure wood and can be sorted and recycled easier if contamination and exposure for weather can be avoided and demolition wood waste, which requires a difficult recycling process (Arm, Wik et al. 2017).

We want to highlight opportunities for valorisation of these residues and side-streams in the manufacturing of wooden construction materials and furniture, in bioenergy production (solid and liquid), in manufacturing of pulp and paper and in manufacturing of lignocellulosic chemicals, lignin-based products, textiles and other material. Valorisation strategies include reuse to maximise the lifespan of the resource, recycling and energy recovery, following the principles of cascading use of biomass. However, there are also differences in reuse: the potential for carbon sequestration is highest in structural building constructions (Rose, Bergsagel et al. 2018). Therefore, there is a clear difference between reusing secondary timber in structural applications and using them as resource for particle boards.

Wooden construction materials and furniture

Sawmill residues can be applied as mulch, firewood, hog fuel, animal bedding, in particle or strand boards, and for pulp recovery (Krigstin, Hayashi et al. 2012). They are especially useful for panel and pulp manufacturers, upgraded into various wood-based materials. Markets and valorisation of such products depend on the location of the sawmills and of the local forest industries.

In Finland there have been made some analyses on the cascading potential of recovered solid wood (Husgafvel, Linkosalmi et al. 2018). There are some examples of reuse of wood packages and wooden furniture, but the reuse of construction wood is still less developed and requires more political incitements (ibid.). The recycling of construction and demolition wood waste to produce particle boards was tested and the test results showed that such resources can be used as a resource for the inner layer of medium density particle boards (Azambuja, de Castro et al. 2018). Recently UK researchers tested in small-scale laboratory experiments the recycling of secondary timber in the production of cross-laminated timber (CLT) (Rose, Bergsagel et al. 2018). The tests were promising but further tests are necessary, and the researchers suggested to combine CLT from primary timber and CLT from secondary timber in structural applications (Rose, Bergsagel et al. 2018).

Bioenergy

We distinguish between solid bioenergy, liquid and gaseous bioenergy. A possible valorisation pathway for *sawdust* is the production of wooden briquets from sawdust. More technologically advanced is the production of biochar pellets from residues using patented steam explosion technology as proposed by Arbaflame. *Edgings and slabs* from sawmills can be used for fire wood.

There exist different technological pathways to produce wood-based biofuels including also residues, but mostly they are integrated with the production of other products in biorefineries (Gregg, Bolwig et al. 2017). There is an *anaerobic digestion pathway* to produce biogas, a *thermo-chemical pathway* for biodiesel or bio-oil and a *bio-chemical pathway* to produce bioethanol (Fevolden and Klitkou 2016),

Bioethanol is produced commercially by Borregaard for many years, but not in big volumes (annually 20 million litres, see Johansen 2009, p. 4). The first commercial production of wood-based *biodiesel* started at UPM in Lappeenranta, Finland in 2015. The biodiesel production is based on crude tall oil, a residue from UPM's pulp production (UPM 2019). Beside the biodiesel also wood-based naphtha is produced, which gets converted into renewable resins to produce bioplastics, deployed for coating of wood-based beverage cartons in cooperation with Norwegian ELOPAK (ELOPAK 2018).

The reuse and recycling of *demolition wood waste* is challenged by the contamination of this wood with chemicals due to earlier treatment of the construction wood, biological degradation and mixture of the wood with metals. The metal can be recovered by magnetic separation, but the demolition wood waste remains a feedstock with defects and reduced feedstock properties (Rose, Bergsagel et al. 2018). Therefore, in the Nordic countries this type of resource mostly has been incinerated avoiding landfills, in Finland sometimes even without energy recovery (Arm, Wik et al. 2017).

Pulp and paper production

The pulp and paper industry produces substantial amounts of waste: about 40-50 kg of dry sludge in the production of 1 tonne of paper and 300 kg from processing 1 tonne of recycled paper (Najpai 2015). Papermaking from recycled paper requires many cleaning processes resulting in waste, especially deinking sludge composed by cellulose fibres, printing inks and mineral components (Monte, Fuente et al. 2009). Waste from mechanical pulping includes rejects, 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 from rejects from stock preparation and sludge from chemical pre-treatment, from clarification, biological treatment and chemical flocculation.

Wastes can be valorised, so landfilling is largely eliminated. One of the most common waste treatment methods in the European pulp and paper industry is the incineration of both rejects and sludge with power and steam generation (Oral, Sikula et al. 2005, Monte, Fuente et al. 2009). 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 also used as soil improvers, through anaerobic digestion converted to biogas and biorest (Monte, Fuente et al. 2009).

A Finnish study tested the technical feasibility of pulping contaminated wood waste from the construction industry (Rautkoski, Vaha-Nissi et al. 2016). The produced pulp can be used for fibre-based products outside of the traditional paper industry, such as for wood fibre filaments and thick foam formed panel structures.

Lignocellulosic 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 most cost-effectively. Integrated biorefineries produce a wide spectrum of products such as fuels, platform chemicals and materials of various types including plastics and textiles (Bauer, Coenen et al. 2017). An economic risk analysis of different biorefinery concepts is in favour for upgrading bioethanol to higher value-added chemicals (Cheali, Posada et al. 2016).

One of the main issues in processing lignocellulosic materials in biorefineries is how to handle *lignin*. Lignin was earlier *the* main residue of paper production and represents ca. one third of the dry mass of wood. Lignin had to be removed from the pulp to get a better quality of the paper. Traditionally it has been used as a source of energy, but there it is possible to use the lignin for more valuable products: as an additive to concrete, in the production of high-performance products, of dispersants, or emulsion stabilizers. A company specialised in valorisation of lignin is Borregaard in Sarpsborg, Norway. Borregaard is producing high-performance products, such as vanillin and high-performance food additives and ingredients for the animal feed industry, such as bypass proteins and pelleting aids all produced from lignin, and water soluble specialty lignin products (Borregaard 2018).

Production of textiles from lignocellulosic material

Another option for valorising lignocellulosic side-streams and residues is the production of textiles from cellulose. Traditionally, cellulose has been used for producing viscose, but here highly toxic carbon disulphide is used a solvent which makes the production process less sustainable and potentially health damaging (Jhun, Yim et al. 2003, Ku, Huang et al. 2003). Recently, a new technological pathway has been developed at Alto University in Finland. Here cellulose from a broad range of cellulose resources, including also recovered packaging material, newspapers and recovered textiles, are treated with Ioncell solvent and the resulting fibre can be used for creating textiles (Sixta 2018). The Ioncell solvent can be recovered and reused, and it is not toxic. Currently, the process is still not commercialised, but this type of valorisation could be combined with a lignocellulosic biorefinery.

1.3. Empirical cases

1.3.1. Forest industry in Trøndelag

In 2004, the cluster Forest industry in Trøndelag (Arena SIT) was established. Since 2004 Arena SIT has tried to improve the framework conditions for a better forest industry value chain cooperation in Trøndelag. Focus was on improved efficiency and reduced costs, restructuring of the industry, and development of joint initiatives. In 2015, this work culminated in a joint Arena proposal which did not get funding. However, the first proposal was improved in the following round in 2016, answering on the feedbacks from Innovation Norway and received funding.

Arena SIT has the goal to maximize the value creation of the cluster based on the use of wood and wood fibre by taking up leading positions in existing and new national and international growth markets. Arena SIT has focus on three areas: (1) The use of wood and wood fibre in new product areas and value chains, such as wood-fibre based fish and animal feed, wood-fibre composites, and new high-return markets for packaging, hygiene and absorptive tissues. (2) increased use of wood trough standardized products and solutions for the construction industry. (3) Increased felling activities in Trøndelag and more effective logistic systems to ensure a stable supply of raw materials both long term and short term.

There are 15 core members in Arena SIT, 10 cluster companies and 12 R&D organisations. The core members can be grouped into three types of companies: seven wood processing industry companies, three forestry entrepreneurs, four forestry companies and an intermediary organisation. The largest industry companies are two pulp and paper plants, one specialised in newsprint, and the other is owned by Austrian company and is specialised in high-quality mechanical pulp used for carton board and absorbent products. About 1250 employees work in these core members of the cluster, and the core members achieved a negative result of -173 million NOK in 2017. This is mainly due to the situation of one of the largest industry companies, but also the entrepreneurs at negative results.

Beside the core members of the cluster there are ten cluster companies. They include two industry companies, one specialised in glued laminated timber, the other in producing preproduced private houses, a bioenergy company, a construction entrepreneur, a producer of forest plants, three intermediary organisations. The large number of well-known R&D organisations give a certain strength to the industry cluster: they include two universities and several research institutes.

What have been the main activities in the cluster so far? Arena SIT is grouping its activities in four main fields: forest, infrastructure, wooden building, and fibre. In each of these fields collaborative development projects have been conducted. Those include the development of service packages for forest owners, guidance of forest owners for improved production, a guide for forest roads, a bottleneck analysis of transport network, further education in wooden construction, development of new wooden construction elements, introduction of new sensor-based energy efficiency measures in pulp and paper production etc.

How does SIT valorise side-streams and residues? There are many examples of using wood chips and leftovers for producing heat, even a heat distribution network has been developed locally. Sawdust and wood chips get also delivered to Sweden to be processed in a biorefinery. In the pulp and paper companies they valorise the whole tree, not just the timber. In 2018 the cluster mapped the availability of available by-products and biological sludge for further valorisation. For that purpose, the cluster wants to cooperate with another cluster, specialised in aquaculture, the NCE Aquatech.

For the valorisation of biological sludge from the pulp and paper industry and from aquaculture comes here an example of good practice in more detail. This example is a result of collaboration between one of the core partners of the cluster, a pulp and paper plant and one of the cluster members specialised in bioenergy. The bioenergy company is specialised in valorising residues from the Norwegian aquaculture industry, producing biogas and a bio-residual used as fertilizer for farms. The pulp and paper plant owns a large industry area where parts are not used yet and where infrastructure is located: for transport quays, rail roads and roads, but also access to clean water and renewable energy. The bioenergy company bought a part of this industrial area close to the paper plant complex, got access also to the quays to get delivered the aquaculture residuals by ship and built the plant from 2015 to 2018. . The company started operation last autumn.

The collaboration targets the valorisation of the biological sludge at the pulp and paper plant, delivered directly through waste water pipelines to the biogas plant which receives category 2 residues from salmon aquaculture collected from the Norwegian coast line. Category 2 residues include all sick and clinical dead fish. For the delivery of the aquaculture residues the bioenergy company has signed contracts with suppliers of the aquaculture residues. At the final stage the biogas gets upgraded to liquified biogas (LBG). The LBG is sold to a big international supplier in the field of fuels. Then it is used for fuelling the regional public busses.

After the biogas process the bioenergy plant delivers water back to the pulp and paper plant and a dry bio-residual is delivered to local farmers to upgrade the soil.

1.3.2. Treklyngen in Hønefoss, Buskerud

In 2012, a large pulp and paper mill at Follum nearby Hønefoss in Buskerud was closed and sold by Norske Skog for 60 million NOK to the forest owner association Viken Skog under the condition that the paper production had to be stopped and the equipment had to be dismounted. The forest owner association established a subsidiary, Treklyngen to develop new possibilities for value creation in a forest-based industry in the region around Hønefoss in South-eastern Norway. The explicit goal was to establish a forest cluster with several firms exploiting forest resources differently, sawmills, wood-based construction materials, pulp mill, biorefinery and biofuel production.

Access via main public roads and close connection to the main national airport at Gardermoen and the capital Oslo are location advantages of the cluster. The forest owner asociation will continuously operate a timber yard, a timber dry-cleaning plant and a multi fuel boiler to deliver heat to households in Hønefoss in close cooperation with the local district heating company.

Over the years, national wood chips guaranty 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 the forest owners to find a market for their pulpwood: 2.6 million m^3 of pulpwood lost their domestic market. The cluster planned to exploit 3-5 million m^3 timber annually in the future - about half of today’s national felling volume. These plans involve complementary businesses of different size, exploiting all parts of the raw material, including residues, for value creation at Follum.

The demand for pulp wood even decreased further with the closure of the next pulp and paper plant in Southern Norway: In 2013 Swedish Södra Cell decided to close Tofte and instead to import pulpwood and timber from Norway to their Swedish pulp and paper plants. With the closure of Tofte the development of Treklyngen became still more important for the forest owners because the cluster plans to exploit the whole log in an integrated process with three steps: (a) production of saw logs for house construction industry, (b) valorising waste and pulpwood for producing cellulose, lignin and sugar in a biorefinery, (c) valorising rest streams for solid or liquid bioenergy.

The main activities to develop the cluster were concentrated on two areas: the development of infrastructure and the search for industry projects.

An important activity for developing the cluster was the improvement of the infrastructure. In February 2015, the new timber terminal at Follum was opened. The Follum timber terminal deploys new technology for measuring and analysing the incoming timber, so-called photo-web.

The cluster decided to look for industry projects which deploy relative mature technology avoiding failure caused by technological problems. Treklyngen explored different possibilities for industrial projects trying to involve also companies outside the traditional wood-based industries. Beside larger industry projects Treklyngen founded together with some partners an incubator to support the development of start-up companies. Here smaller companies were developed. The following list shows just the larger industry projects which were made public:

- Since 2012, the cluster explored in cooperation with the state-owned operator of airport in Norway possibilities for the production of bio-jetfuel based on pyrolysis were explored but the technology is still not mature enough.
- In 2014 the cluster collaborated with two companies producing wooden construction materials, one for insulation and another one for wooden construction elements. Both companies went to other locations. In 2014, the cluster and a biochar company signed an agreement and plan for a production plant for a new type of biochar pellets at Follum. Biochar pellets are to replace fossil coal and will be manufactured with unique Norwegian technology.
- In 2016, the cluster established a collaboration with a large metallurgic company, the airport operating company and the local energy company to develop a new value chain for producing biochar and biooil at Treklyngen. The envisioned «Norwegian Wood» had the goal to exploit the whole timber. Because the airport operating company cancelled the plans to produce bio-jetfuel at the cluster, the production of biochar had to put on hold because the production of biochar requires a possibility to use the excess heat for other industrial production and therefore a kind of industrial symbiosis with neighbouring industry plants.
- In August 2016, a bioethanol company with headquarter in Finland signed a letter of intent on building a bioethanol plant at Treklyngen. The plant will be in operation from 2021 and will produce annually 50 mill litres of bioethanol from 500.000 m^3 saw dust from sawmills and low-quality timber. The required investment will be about 1 billion NOK. It is planned to produce bioethanol from spruce and pine, and to extract lignin from the wood which will be used for producing heat.

Altogether, in 2017 the established companies in the cluster had an operating profit of about 29 million NOK and about 200 employees, but this is due to good results for the forest association. Most of the firms established in the cluster are either small and have not managed to become profitable yet or they have not started their production yet, such as the biochar company and the bioethanol company.

However, the search for new industry projects at Follum got competition from other regions in Norway: the construction material companies left the cluster and started production in other places. Södra and Statkraft signed a letter of intent for producing biofuels at Tofte. International competition for building advanced biofuel plants became also stronger, such as UPM in Finland, Licella in Australia, Shell in Houston, USA, and Solena Fuels in Essex, UK.

1.3.3. Norwegian Wood Cluster in Inland

The Norwegian Wood Cluster (NWC) was established in 2017 and is located in Inland in the former counties Hedmark and Oppland in South-eastern Norway. Inland has access to 40 % of Norwegian forest resources. The main focus of this new cluster is to become an internationally leading cluster for industrial and sustainable wooden construction.

There had been earlier attempts to build up a forest-industry cluster in the region. First, the Arena Bioenergy Inland in the period 2008-2010 with a focus on small-scale bioenergy and which was assessed as a failure (Lerfald and Arnesen 2012), and later, an unsuccessful proposals coordinated by Tretorget for an Arena Wood cluster (Kløvstad 2016). The new cluster organisation is not funded by this Arena programme but financed mainly by the private financial means of the cluster members: three forest owner organisations, five industry companies and one university. Altogether the cluster had an operating profit of about 700 million NOK and over 5.400 employees. These positive indicators are mainly influenced by the largest industry company in the cluster, but none of the companies had a negative result in 2017.

There are three forestry companies: two cooperatives and a state-owned company, which is also a member of Arena Skog. Then, there are five industry companies processing wooden resources: the biggest company is a Norwegian-Swedish business group with headquarter in Inland with 28 subsidiaries, processing 4.2 million m^3 forest resources annually and producing industrial timber, laminated timber, wood-based construction products, modular buildings, and providing services to construction industry); a timber processing company, a company producing particle boards for construction industry and for furniture industry, and I-beams; a company specialised in wood-based insolation ; and a company specialised in prefabricated houses and cabins. As a R&D partner the cluster has connected to the Department of Manufacturing and Civil Engineering at the Norwegian University of Science and Technology (NTNU) in Gjøvik. At the department is the Norwegian Manufacturing Research Centre, which is planned to have an impact on the development of the wood-based manufacturing industry in the cluster. NWC can gain synergies by cooperating with other industry clusters which have been developed successfully in the region, such as the Norwegian Centre of Expertise NCE Raufoss with focus on automated production processes and coordinated by SINTEF Raufoss Manufacturing AS and the NCE Heidner Biocluster which is specialised in sustainable food production.

What have been the main activities in the cluster so far? Important planned activities of the industry cluster are the advanced production of wooden construction elements, X-ray technology for measuring timber value, the traceability from stump to plank, and hopefully the new Mjøs bridge. Automation, sensors and robotization of the whole production process are going to facilitate these plans. The cluster is now developing first joined projects to strengthen the interaction and also to show the value of such cooperation. There is a high potential for the cluster to improve the coordination in the value chains from precision forestry to digitalised sawmills to automated industry processing to the customer and finally the recycling again. This includes optimisation of logistics, transport and storage of sawdust etc., but also the exploitation of huge amounts of data to improve already forestry and using the right resource for the right purpose.

How does NWC valorise side-streams and residues? At the moment the cluster members are not co-located but spread throughout the Inland, which does not facilitate industrial symbiosis. However, several of the partners are connected through value chains, especially with regard to side-streams and residues: beside the delivery of timber from the forestry companies to the sawmills and then to the industry companies and there is the delivery of residues for valorisation purposes, such as the largest company is delivering sawdust and pulpwood to its Swedish branch. The company has even plans to valorise the side streams in a biorefinery located in the region (Venn 2018, Venn 2018).

There is an example of good practice for exploiting residues: The construction insolation company has specialised in producing a range of construction elements and insolation products from wood fibre such as wood chips, sawdust and off-cuts from sawmills. The firm has developed a concept where the manufacturing of construction elements is combined with services and competence upgrading of local entrepreneurs. The company is still collaborating 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 nearby their first plant in Gjøvik. This new plant has started in 2018 and is located at the Skjerven Industry Park, for which the municipality of Gjøvik and several industry partners tried to receive funding from Innovation Norway for developing a bioeconomy smart industrial park. The planned industry park has a focus on exploiting synergies in the co-location of several industry actors, exploiting side-streams and excess industry heat (Rognerud 2018). The proposal had no success so far but shows that there are more actors who want to develop the forest-based bioeconomy in the region. The cluster received for 2018 0.7 million NOK from the county council as a follow-up of the county's bioeconomy strategy.

1.4. Discussion

In the following we discuss what and how exogenous elements, such as path dependencies and geographic issues but also changes in markets, in regulations and in policies have been important for implementing innovations for valorising forestry residues.

The three cases have to address quite different challenges due to spatial particularities and local path dependencies. All the cases can deploy new technologies to change the physical properties of the residues and side streams, but the regional path dependencies lead to different strategies of the involved firms to address changes in the markets and to exploit institutional changes. Changes in the market are mainly the decreasing demand for newsprint paper, the increasing demand for wooden construction solutions and the introduction of new regulations favouring advanced biofuels like lignocellulosic bioethanol and LBG.

The valorisation of residues and side streams from the forestry sector has to achieve not just economic profit but also new jobs and is has to contribute to more sustainability. The three cases show rather different points of departure for achieving those goals due to path dependencies, access to R&D capabilities, effects of the economic crisis and financial constraints. Those differences have an impact on the behaviour of investors, being it domestic or foreign investors.

The Arena SIT cluster is located in a region with very diverse industry, including not just forest-based industries but also maritime industry, aquaculture and petroleum industry and a lot of R&D capabilities. This has attracted also foreign owners to take over and to invest in a Norwegian pulp and paper plant, including also new expertise and established international value chains. The synergies between forestry-based industry and the aquaculture include not just the production of biogas and LBG from aquaculture residues but also plans for the production of new types of feedstock for aquaculture from forest residues. In that manner the cluster solves important environmental issues related to the residues, creates new jobs and can achieve profit.

The Treklyngen cluster has to overcome a high path dependency into newsprints, a high number of job losses in the old industry and rather few local R&D capabilities. It might also be a problem that the capital Oslo is not near enough to convince investors to focus on this cluster. The competition with other Norwegian locations has been critical for several of the industry projects and highly competent workers find jobs in the capital region. Often other locations can offer still better conditions and therefore projects get realised there. Changes in public policies related to biofuels have created better market possibilities, but the industrial projects are hampered by the lacking maturity of the technology. The industrial project for producing biochar has received considerable public funding, but the company still lacks a market and therefore investors. Therefore, the goal of the cluster to create many new jobs is still not achieved, the residues of the forestry sector are only partly valorised locally, without deploying advanced technologies and they get rather shipped to Sweden. The planned industrial cooperation is also hampered by the delays of the different projects.

The cluster in Inland has a path dependency in wooden construction and bioenergy through its long tradition in forest-based industries. However, the cluster includes one of the biggest companies in the field of wooden construction in both Norway and Sweden and has access to R&D capabilities through the local branch of the Norwegian technical university (NTNU) at Gjøvik. The region is not suffering as much as Buskerud under the crisis of the pulp and paper industry but is profiting from a change in public environmental policy supporting the construction of wooden houses and bridges. In that way the companies can make profit and can establish new jobs. However, the cluster is still not really in a cooperative mode since the cluster started just in 2017.

1.5. Conclusion

The three cases of forest-based industry clusters have shown that it takes a lot of time to build up new industry after the crisis in the pulp and paper industry. Financing for new industry is difficult and often just possible if foreign investors or owners get an interest, as the examples of all three cases have shown. Companies which have not such a backup have to look for public co-funding and private investors, such as the biochar company in Treklyngen.

The three cases show very different stages of maturity: while the forest industry in Trøndelag has developed over 14 years now, the two other cases are much younger and face certain challenges. For the forest industry in Trøndelag collaboration projects are on the agenda and have shown the usefulness of co-location and industrial symbiosis. For the development in Inland this is still in the far future, companies work more separately, and exploitation of residues is realised more through traditional supply chains. In Treklyngen the plans are made for achieving synergies through collocating and connecting the different businesses at Follum, but this has not materialised yet due to financial constraints.

The exploitation of residues and side streams from forestry industries mostly goes in traditional pathways, such as the use for production of pulp or of particle boards. However, also more advanced valorisation pathways have been explored. And here other types of industry players outside the traditional forest-based industries come in, such as producers of fuels or producers of metals, which can replace fossil resources by forestry residues and side streams.

Traditional wooden construction industry is developing in new directions, going for building multi-storey houses and other large wooden constructions such as bridges and office buildings etc. Here the need for insolation and other construction elements invites the valorisation of residues as well.

We have seen that there exists certain competition for the best industry projects in the three regions, but there exists also collaboration across the three geographical conglomerations: either through ownership or through project collaboration or value chains.

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