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# Productization of Industrial Side Streams into By-Products—Case: Fiber Sludge from Pulp and Paper Industry

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Received: 9 November 2020; Accepted: 8 December 2020; Published: 10 December 2020



**Abstract:** The increasing pressure on natural resources and the climate has been noted by businesses and governments worldwide, who now face the difficult task of integrating paths of environmental sustainability and economic growth. One promising approach to sustainable development, reducing the pressure on natural resources and solving waste problems is circular economy. From different ways of implementing circular economy, this study focuses on the productization of industrial side streams, which carry a great deal of underutilized potential. In this article, the productization of pulp and paper industry side stream, fiber sludge, for commercial use as a dust-binding agent is studied via a descriptive, in-depth case study. Apart from inconsistent quality, fluctuating supply, cost of storage and logistics, what makes industrial side stream utilization challenging is the lack of knowledge that stakeholders have about side streams and their utilization and the lack of new value chain development for their commercial use. Therefore, it is essential for all parties involved to have a clearer vision of what is being sold for what purposes, through productization. This study found that the productization of side streams follows the same steps as the productization of any other traditional product, and the productized side streams can be added to the company's product portfolio as by-products.

**Keywords:** circular economy; industrial by-product; industrial side stream; productization

## 1. Introduction

Today, climate change, scarcity of natural resources, the amount of plastic waste in the world's seas and other issues related to the environment and sustainable development are constantly the focus of attention in different media. The increasing pressure on global resources and the climate due to human activity and population growth has also been noted by businesses and governments worldwide [1], who now face the difficult task of integrating paths of environmental sustainability and economic growth [2]. From a business point of view, the less secure availability and supply of resources, coupled with price volatility, causes operational challenges [3]. Therefore, new solutions and alternative ways of doing business to reduce emissions and the amount of waste and to improve resource-efficiency are needed. One promising approach to sustainable development, reducing pressure on natural resources and solving waste problems is circular economy, which has gained a great deal of popularity in recent years among scholars and practitioners (e.g., [1,3–6]).

The current economy is still mainly based on linearity [3,4,6,7] and the availability of natural resources is taken for granted [2]. Circular economy aims to overcome this dominant linear economic model by increasing the lifecycle of products and materials, maintaining their utility within the economy

for longer and thus maximizing the utilization of value in them while simultaneously minimizing waste generation [3,6]. Circular economy utilizes waste as a raw material in a similar way as nutrients circulating in nature, where the concept of waste does not exist [4,8]. There are different means of implementing circular economy, of which this study focuses particularly on the utilization of industrial side streams.

In today's highly competitive markets, the future successors are able to find new revenue streams through, for example, industrial side stream utilization. There is a lot of underutilized potential in industrial side streams, which are still often treated as waste even though they could provide value in the form of re-used raw material or energy [9]. The effective utilization of industrial side streams often requires the cooperation of multiple actors, from side stream producer to user and the creation of a business ecosystem around utilization [10]. Apart from inconsistent quality, fluctuating supply, cost of storage and logistics, what makes industrial side stream utilization challenging is the lack of knowledge that stakeholders have about side streams and their utilization and the lack of new value chain development for the commercial use of them. For example, the lack of quality standards and product descriptions imposes challenges to side stream producers and users as well as authorities and legislators. The insufficient knowledge of side streams makes, for example, the assessment of long-term environmental impacts of their utilization difficult, causing rigidity of legislative decision-making and, according to Pajunen et al. [2], legislation is one of the main obstacles to side stream utilization, and improving the knowledge of operators is required to bridge institutional barriers. Therefore, it is essential for all parties involved to have a clearer vision of what is being sold for what purposes, through productization.

Overall research in technology development has contributed excellent technological advancements for circular economy. In several cases, the potential has been verified in public research laboratories. However, numerous technologies invented are still lacking practical utilization or the benefits have not been realized as planned. One of the reasons is that these technologies have not been planned on operative conditions, real-life processes and value chains. The economic sustainability has not been considered in the creation of these technologies and, as a result, we have in several cases a huge amount of industrial side stream and a theoretical notion of how to utilize it (e.g., [11–13]). Without economically viable value chain and operators (companies) in the value chain, it is not possible to achieve economic sustainability. Specific companies need to have business interest to process the side stream into a commercial (by-)product or, more accurately, for a sales item to be able to operate. An additional challenge in ramping up novel value chains is that it may require the initiation and creation of several new businesses and operators. Organizing economically justified business requires productization. In productization, a company's offering is defined commercially and technically to enhance the company-wide understanding about what is sold and how the offering is produced [14–17].

Against the above-mentioned background, the purpose of this study is to find methods for productizing potential industrial side streams into by-products in order to create new value chains for their commercial use. In our definition, industrial side streams include everything that comes out of a production process that is not the main product of the process. Our scope is to provide a concept for productizing these types of side streams into by-products for the circular value chains. First, a theoretical framework is created through a literature review on circular economy concepts and cornerstones of productization to synthesize elements relevant to productizing industrial side streams. In addition, the legislation on waste, side streams and subsequent by-products is studied. Then, an analysis of a potential side stream produced by the case company is made to productize it for commercial use. The research questions (RQ) for the study are set as follows:

*RQ1: What are the specific challenges of productizing industrial side streams?*

*RQ2: How to productize an industrial side stream into a by-product?*

## 2. Literature Review

### 2.1. Waste and By-Product

The European Waste Framework Directive 2008/98/EC defines waste as “any substance or object which the holder discards or intends or is required to discard”. The Directive 2008/98/EC also sets out a five-step hierarchy for waste management according to which the most favorable option is to prevent waste generation altogether, followed by reuse, recycle and recovery, which, for example, means recovering the energy contained in waste by burning it. The least favorable option is disposal, i.e., landfill [18].

The European Waste Framework Directive 2008/98/EC defines by-product as “a substance or object, resulting from a production process, the primary aim of which is not the production of that item.” A by-product is considered not to be waste if “(a) further use of the substance or object is certain; (b) the substance or object can be used directly without any further processing other than normal industrial practice; (c) the substance or object is produced as an integral part of a production process; and (d) further use is lawful, i.e., the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts” [18].

In addition, the Directive 2008/98/EC sets criteria for end-of-waste status, which means that waste shall cease to be waste when it has “undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions: (a) the substance or object is commonly used for specific purposes; (b) a market or demand exists for such a substance or object; (c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and (d) the use of the substance or object will not lead to overall adverse environmental or human health impacts” [18].

Directive 2018/851 makes some important amendments to the Directive 2008/98/EC, making it better reflect the Union’s ambition to move to a circular economy. Regarding by-products, Member States are encouraged to take appropriate measures to recognize by-products in order to promote circular economy, sustainable use of resources, by-product use and industrial symbiosis [19].

By-product and end-of-waste status are important to define as replacing the waste status of a material like industrial side stream can be crucial for its subsequent recovery and realistic utilization possibilities [2,11]. However, these definitions are hard to pinpoint [20] and removing the waste status of a material can be a long and expensive process for all actors involved [2]. Legislation can be seen as one of the main drivers in improving material efficiency and contributing to the increased recovery and safe disposal of waste [2]. Tightening environmental legislation and the rising cost of landfilling have reduced the environmental load of landfills and encouraged the development of new waste treatment methods [21]. In many cases, legislation has also become one of the main barriers to side stream utilization, and Pajunen et al. [2] argue that less emphasis should be placed on regulatory procedures if an industrial system is proven to produce useful outcomes. According to Husgafvel et al. [11], the utilization of industrial side streams in new products “supports recycling of materials, decreases the use of primary materials, contributes to reduction of waste generation and aims at ensuring a high level of environmental protection.”

### 2.2. Industrial Ecology and Circular Economy

Industrial ecology considers industrial environments as natural ecosystems where material, energy and information circulate. In industrial ecology, the aim is to understand how the industrial system works, how it is regulated and how it interacts with the biosphere [22]. According to Bocken et al. [1], in industrial ecology, the aim is to achieve an ideal state that most resembles nature. Industrial ecology can also be seen as a comprehensive framework aimed at guiding the transformation of the industrial system to a sustainable level [23].

Circular economy can be seen as a concept in industrial ecology [24]. There are many different definitions and principles for circular economy. According to Bocken et al. [1], the foundations of circular economy thinking are “the recognition of the limits to planetary resource and energy use and the importance viewing the world as a system where pollution and waste are viewed as a defeat”. In contrast to linear economy, where a product is discarded after use, circular economy aims to replace these practices with circular designs where the value and potential of the products are reused for as long as possible [3,4]. The contrast to optimized linear systems is significant; in those systems, returning or repairing products for reuse causes disturbances and creates additional costs [4]. Fogarassy and Finger also talk about sustainable closed-loop resource systems and add that, instead of value chains, in a circular economy, there are circular value circles, where a product or a service is not only delivered but its remnants, like material and energy, are also transported back into the system [25].

Circular economy has similarities with the characteristics of nature: no waste is actually generated in nature, as the “waste” generated in nature is merely a resource for other organisms [4,8]. This type of close cooperation of businesses is called an industrial symbiosis, which Chertow [26] defines as follows: “industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity”.

According to Schulte [4], business based on circular economy can be built on five simple principles: 1. Minimizing waste in product and system design: the rational use of materials, maximum standardization of manufacturing and designing a product for easy disassembly and recycling are taken into account; 2. Understanding the entire business ecosystem: taking into account the entire life cycle of the product and its different stages and improving the transparency and interaction between these stages; 3. Maximize flexibility through design: designing products so that they can be easily repaired and modified to accommodate changing requirements; 4. Using renewable energy sources instead of wasteful exploitation of fossil fuels and 5. Maximizing energy efficiency by minimizing the total energy content of products and services.

### *2.3. Open Innovation and Industrial Side Stream Utilization*

The concept of open innovation can be used to accelerate innovation in the value chains of industrial side stream utilization. Companies cannot survive without innovation and new business model development, meaning that they need to continuously and creatively recombine technologies and the market into new business models [27]. Introducing new business models or changing existing ones according to the requirements of the environment is a way by which companies can adapt and survive in the dynamically changing market [28]. One such new requirement is sustainable development and innovations to reduce emissions and the amount of waste and to improve resource-efficiency are needed.

The effective utilization of industrial side streams often requires the cooperation of multiple actors [10], from side stream producer to user and from public actors to research organizations. Institutional openness and inter-organizational relationships can enhance value creation and allow innovation work to be divided among multiple actors in the value chain [29]. Yun [27] discusses customer supply chain open innovation and emphasizes the importance of carefully listening to the requirements of customers, the input of suppliers as well as other actors in the supply chain. According to Yun and Yigitcanlar [28], very diverse open innovations exist in value chains. These include user open innovation, customer open innovation, common profit community, together growth community and inner open innovation.

In industrial side stream utilization, the perspective of user open innovation is highlighted as the company producing industrial side streams is rarely the company utilizing it. For the company producing side streams, it is essential to cooperate with other companies and actors in order to find new utilization possibilities for their side streams that otherwise only accumulate costs through storage

and disposal. With open innovation, the work of innovating new solutions is no longer the sole responsibility of the side stream producer.

#### 2.4. Productization

##### 2.4.1. Business Case Analysis

Business case analysis is a method to determine whether a certain business opportunity, investment or a product, etc., should be selected or rejected [30]. Companies have limited financial resources and personnel at their disposal, which means that not all new ideas can be implemented [31]. Therefore, each business case must be critically evaluated before any investment decision is made. Many projects are implemented without necessary analysis, which means that they take away resources from other projects and keep creating unnecessary costs the further they advance, if they eventually end up getting dropped [31,32]. According to Kinnunen et al. [32], the business case analysis consists of market assessment (market potential), technical assessment (technological feasibility), financial analysis, evaluation of strategic fit and decision-making. Business case analysis can be seen as the first step to the productization of industrial side streams as it answers the question of whether or not a side stream should be productized in the first place and whether the material is primarily treated as waste or as a by-product.

##### 2.4.2. Products and Productization

People use products to satisfy their needs and desires. A product can be anything with which these needs and desires are satisfied. It may be, for example, physical goods, services, events or experiences [33], or a combination of various tangible and intangible elements [14], which can be sold and delivered and, on this basis, invoiced [34]. From a company's point of view, a product is the thing that generates turnover for the company and thus also determines the company's existence: without a product, the company has no customers and hence no reason to exist [35].

The nature of a product varies between different product types. A tangible product is a product that can be touched. A service product is defined as a process in which sub-processes completed in a sequence form a final service product. An intangible product is defined as a product that is not a service product either, such as a computer program [36].

In order for a product to be marketed and sold to a customer, the seller must have something concrete to offer to the customer [37]. However, companies do not seem to have a consistent, company-wide understanding of what the company's offering consists of [17,38,39]. A consistent understanding of a company's products can be achieved by productization. Productization is often confused with commercialization. Commercialization relates to converting and developing ideas into products, and productization can be seen as an essential condition for commercialization [40]. Suominen et al. [41] define productization as a larger entity, while commercialization is only part of productization in the final phase.

In productization, a suitable set of tangible or intangible elements is combined into a standardized and repeatable offering that is easier to buy, sell and market [14]. A productized product can be given a name, and its contents can be presented clearly [37]. A well-productized offering is more attractive to the customer and is more efficient to deliver [40]. Productization has the role of clarifying an offering, which is particularly important in a service business, where the product is not a tangible asset but something more abstract [14,37]. Having a clear understanding of the product enables setting the price for and calculating the cost of the product, thus making productization a precondition for product-level profitability calculations [39].

##### 2.4.3. Product Structure as Means for Productization

According to Kropsu-Vehkapera et al. [42], companies should, especially if the number of product variations in their product portfolio is large, examine their product portfolio on a top-down basis,

i.e., from larger entities to smaller entities. In this way, the company can clarify its offering and, at the same time, understand what different products actually consist of and how they should be handled on this basis. ElMaraghy et al. [43] add that, even from a customer perspective, a large number of product variations is not always good but can confuse the customer, and an unnecessarily large number of product variations entails high costs for the company—for example, in terms of product design, manufacturing, warehousing, sales and service.

Companies can facilitate the modeling of their offerings by forming a generic product structure for each individual product, describing the product and related information as well as the relationships between the product and its components [44]. According to Saaksvuori and Immonen [33], a product structure consists of parts and components, assemblies and documents related to the product and each other and may also include service elements related to the product. A common term, bill of materials (BOM), is often used for a detailed description of the materials, parts and components required to manufacture a product [45]. The generic product structure, also known as the configurable BOM, includes all the variation possibilities of the product in a single description from which the final customer-specific configuration is generated [46]. This prevents exponential growth of data by eliminating the need to create a specific product structure for every single product variant [47]. The generic product structure shows in a consistent way how the individual products of the company are constructed. A generic product structure is seen as helping to formalize the individual products of the company and how they are understood at different levels of the company [44]. Different departments of a company can fulfil their information needs by examining only the part of the entire product structure related to their own activities [43].

As productization deals with the commercial and technical aspects of the products, the product structure should acknowledge them [48]. The commercial side of the product structure consists of items that can be sold to the customer, such as product families, configurable products and sales items, and thus all variable features and functions that the customer can choose should be seen on the commercial side as separate items [49]. By examining the commercial portfolio, it is possible to see where the company's sales turnover comes from. At the company, the sales and marketing and the product management departments in particular operate on the commercial side, which means that managing a commercial portfolio always involves costs. In addition to the company itself, the commercial portfolio and its changes are also visible to customers [50].

The technical side consists of items that are used to create the sales items, such as version items, assemblies/processes/programs, sub-assemblies/sub-processes/modules and components/tasks/functions for physical products, services and software, respectively [51]. At the company, the technical side is examined especially by product development, production, testing, procurement, logistics and subcontracting. By reviewing the technical portfolio, it is also possible to see what the cost structure of the company consists of, in addition to the sales and marketing and product management departments and the commercial portfolio. By examining and modifying the technical portfolio, the company can find ways to reduce the costs of manufacturing and delivering the product in different ways [50].

### 3. Materials and Methods

#### 3.1. The Research Process and Methods

The productization of industrial side streams was studied via a descriptive, in-depth case study [52]. Figure 1 illustrates the research process and the utilized research methods. The study was initiated by creating a theoretical framework based on a thorough literature review on productization, industrial side streams and by-products and circular economy concepts, as well as on the related legislation, to which later empirical studies could be compared to. The empirical data collection included first an analysis of the case company's public documentation on the production and side streams. Then, an interview with a case company representative was conducted where the current state of case side stream production and utilization were discussed, followed by an interview with a researcher

studying pulp and paper industry side streams who also had studied the possibility to utilize the case side stream as a raw material for a dust-binding agent. Interviews were semi-structured and the research questions were based on the conducted literature review and experiences from earlier circular economy projects. Lastly, a workshop session was organized with eight researchers and industry experts, including the researchers conducting the study. In the workshop, the practical limitations and other challenges of case side stream utilization were analyzed, and the business potential of the business case draft proposed by the researchers was evaluated from both the side stream producer’s and user’s perspectives. The information available on the website and reports of the case company, as well as project reports and other documentation from earlier research and development projects regarding the case company and projects regarding similar circular economy subjects, were utilized in drafting the productization of the case side stream. These reports included a great example of using open innovation to find new industrial side stream utilization possibilities as the case side stream was one of the case materials given to students in a circular economy innovation contest, where teams were assigned the task of creating a new business from currently underutilized local industrial side streams in cooperation with case companies and researchers. Finally, based on the feedback from the workshop session, a conclusion was drawn about how to productize the case company’s potential side stream for commercial use and to answer set research questions based on the results of the case study and conducted literature review.

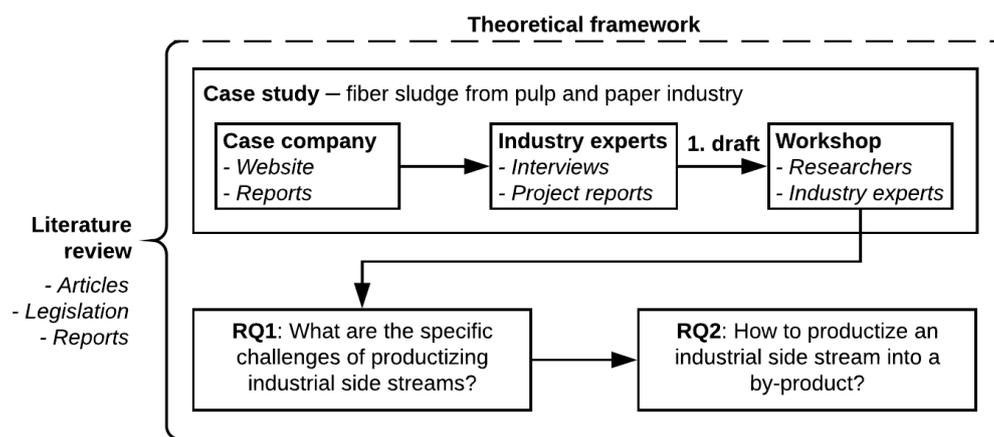


Figure 1. The research process and methods.

### 3.2. Description of the Case Company and Its Side Stream

Stora Enso and its side stream, fiber sludge, were selected as the case example for this study. Stora Enso is a Finnish–Swedish forestry company, which was formed in 1998 when the Finnish company Enso Oyj and the Swedish company Stora Kopparbergs Bergslags AB merged. It operates in more than 30 countries, with around 26,000 employees. The group’s net sales in 2019 totaled EUR 10.1 billion. Its business operations are divided into six divisions: packaging materials, packaging solutions, biomaterials, wood products, forest and paper [53].

This study examines the side stream of pulp production, fiber sludge. Fiber sludge is also called primary sludge, as it is produced at the primary wastewater treatment plant, whose main purpose is to remove large particles such as bark, sand, suspended and floating solids, fiber, fillers, pigments and coating materials and organic materials. Fiber sludge consists mainly of wood-based fibrous material such as lignin, hemicellulose and cellulose fibers and organic binders from the pulping process [9]. A total of approximately 750,000 tonnes of fiber sludge is produced in Finland each year [13]. More particularly, Stora Enso’s Oulu plant serves as the case company, where approximately 5.5 tonnes of fiber sludge (as dry matter) is produced per day [54]. According to the interview expert, the structure of fiber sludge may vary slightly depending on the process in which it is created, but these variations are not significant when considering its utilization from a circular economy perspective.

Forest industry wastewater treatment sludges like fiber sludge have traditionally been incinerated as part of a mill's energy production or disposed of by landfilling. However, burning fiber sludge into energy is relatively inefficient due to its high humidity [9]. In terms of the utilization of waste materials in the current EU strategies, circular economy and material efficiency are the main priorities in the treatment of waste. Priority should be given to reuse and recycling, and only then should the burning of waste be considered. The burning of waste is, however, a more favorable option compared to landfill, in which the case companies involved have to pay taxation according to their country's legislation.

Different uses of fiber sludge have been charted from the perspective of circular economy. Potential applications for fiber sludge include ethanol and biogas production [12] and use as a soil amendment agent and a fertilizer product [9]. According to the interviewed researcher studying pulp and paper industry side streams, fiber sludge could be used as a binding agent for dust, as a binding agent for pellets and granulation and as an additive for construction materials. This study focuses on the further utilization of fiber sludge as a binding agent for dust from the perspective of productization. The productization of the case side stream can be approached from two perspectives: the perspective of the side stream producer and the perspective of its user. In this study, the side stream producer is the Stora Enso Oulu plant, and the user is a company planning to produce a dust-binding agent from modified fiber sludge.

### 3.3. Use of Fiber Sludge as a Dust-Binding Agent

In general, dust refers to small, slowly descending particles with a diameter of 1–100 micrometers that have ended up in the air either as a result of natural forces (e.g., wind or volcanic eruption) or otherwise mechanically, such as crushing, grinding, drilling or sweeping of various materials [55].

Road dust (or street dust) consists mostly of finely ground asphalt and sand. In addition, it may contain soot particles as well as material detached from various parts of cars (e.g., tires and brakes) and soil microbes [56]. Road dust is a problem especially in urban and industrial areas [57], and in cities with busy traffic, road dust can be continuously present in the air [13]. In addition to dust generated on roads, dust is also produced in industrial areas, for example, in the handling of soil masses and demolition waste as well as in mines at quarrying and crushing sites.

Dust in the air causes various problems. For people, for example, road dust causes various irritation symptoms, such as itching and burning of the eyes as well as congestion and coughing. Particularly sensitive population groups include asthmatics, small children and people with pulmonary obstruction, coronary artery disease and heart failure [56]. Khan and Strand [57] found road dust to have adverse health effects, especially for the respiratory system, and exposure to some compounds found in road dust, such as lead, can have serious health risks. Kuokkanen et al. [13] add that the health effects of fine dust particles in the air can be difficult to study because road dust is not the only type of pollution reducing air quality. Road dust is not only a problem for large cities, but high particle concentrations may also occur in smaller municipal centers and urban areas [58]. The composition and concentration of road dust is influenced by traffic and industrial plants present in the area and also seasonal variations [57]. Besides effects on human health, dust can be a safety hazard for road users and cause additional wear and tear in vehicles [59].

There are some solutions to the above problems caused by dust. At its simplest—for example, for road dust—mere water can be used as a binding agent. Currently, one common dust-binding agent for road dust is road salt, i.e., calcium chloride ( $\text{CaCl}_2$ ). The use of calcium chloride as a binding agent is based on its ability to absorb moisture from the air. As a result, the road surface becomes wet and the particles of the dusty material remain attached to the road surface. The use of road salt works with road dust binding, but its disadvantages include dissolving in rainwater and thus draining all the way to groundwater [59]. Calcium chloride also causes corrosion of cars and bridges [60].

Fiber sludge contains various wood-based substances, such as long fibers, lignin, cellulose, hemicellulose and peel pulp. Of the elements, fiber sludge comprises mostly carbon, hydrogen, oxygen and nitrogen. In addition to this, there are small concentrations of nitrogen, phosphorus

and potassium, which, for example, affect the utilization potential of fiber sludge as a soil improver. Correspondingly, when considering burning fiber sludge in order to produce energy, the most important characteristics are, in particular, the content of organic matter and ash [61].

The efficiency of biotechnologically modified fiber sludge as a dust-binding agent is based on flocking, in which the dusty material is assembled into larger entities using chemical reactions. From a chemical point of view, the power of fiber sludge is based on the following: road dust is mainly composed of rock material that contains a large amount of silicate compounds. These silicate compounds contain hydroxyl groups with which the free hydroxyl groups of modified fiber sludge form hydrogenous and other chemical bonds. As a result, larger chemical particle clusters are created, which, due to their size, do not dust as much. When fiber sludge is enzymatically modified, the fiber bundles within it open, maximizing the reaction surface for aforementioned flocking to happen [13,59].

## 4. Results

### 4.1. Productization of Fiber Sludge from the Producer's Perspective

The Stora Enso Oulu paper mill currently produces approximately 5.5 tonnes of fiber sludge per day. For Stora Enso Oulu, it is worth giving the fiber sludge away for free because they have a problem with storing all the fiber sludge produced, and the disposal of it results in costs for the company. In addition, the company can benefit from the utilization of their side stream by constructing their image as a promoter of the circular economy. Stora Enso Oulu is currently offering fiber sludge free of charge delivered up to 25 km from the factory. Apart from drying the fiber sludge, Stora Enso Oulu does not make any efforts in making the produced fiber sludge more suitable for different utilization possibilities.

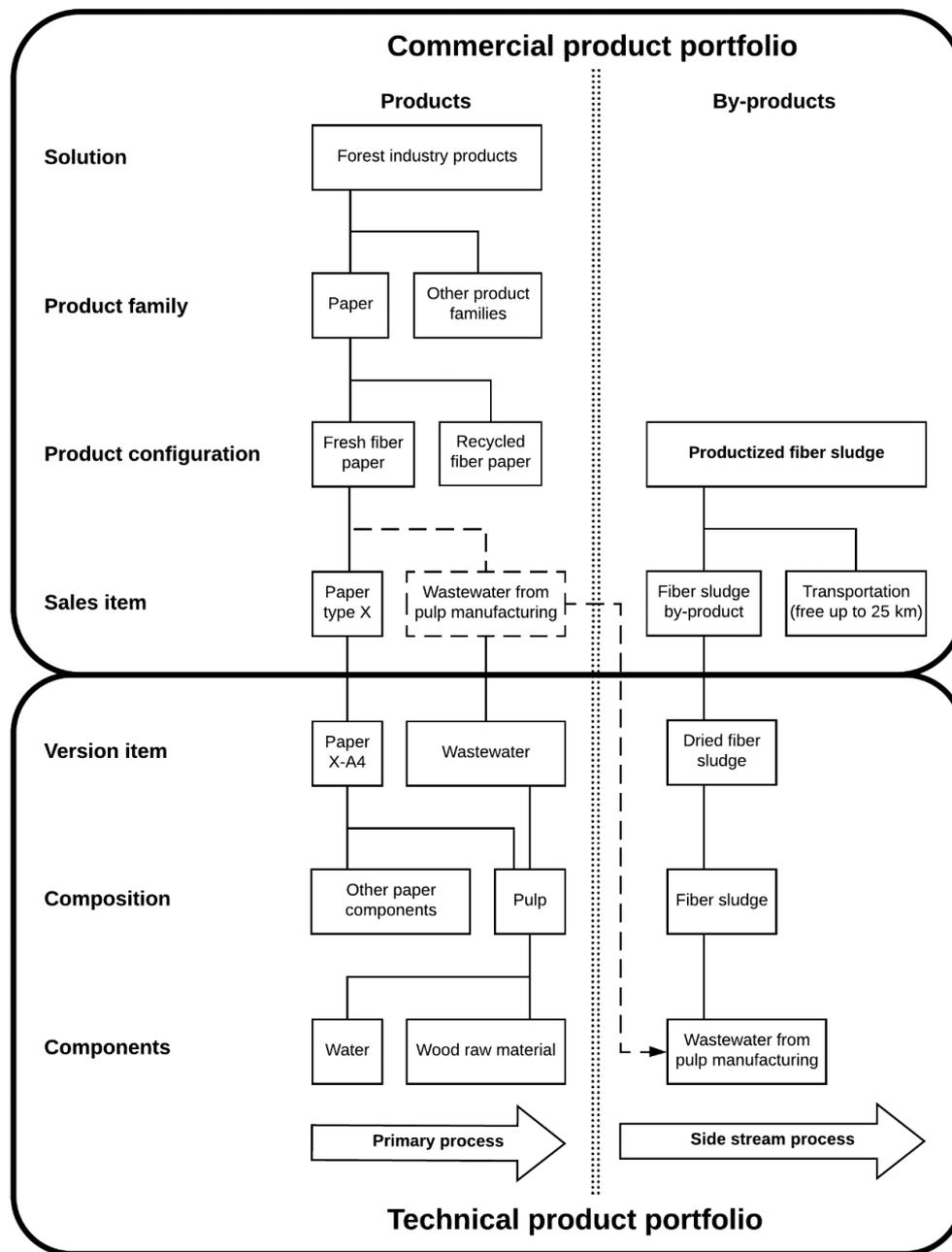
From Stora Enso Oulu's point of view, the greatest advantage in the productization of the fiber sludge is the fact that the fiber sludge is produced steadily, the variation in its quality is not significant in terms of further processing and there are multiple applications present for its utilization. The major challenge is the vast amount of fiber sludge produced and it is problematic to sell even if there are potential users like dust-binding agent manufacturers. The problem is that the companies making use of fiber sludge can be small in size, and the amount of fiber sludge that they need for their operations can be too small to be significant for the Stora Enso Oulu in terms of lowering disposal and storage costs.

The productization of side streams is not part of Stora Enso Oulu's core business and thus they must carefully consider the amount of resources that should be used to productize the case side stream. The focus in productization can be shifted more during the final stage, i.e., how the side stream can be sold or handed over to others without high costs, as the value of the side stream is reasonably low or even negative due to the disposal and storage costs. In this case, it is not appropriate to commit a great deal of resources to product development and to modifying the material after it has been produced. In the best-case scenario, the Stora Enso Oulu could sell all the produced side streams immediately as such. Another option would be to establish a new subsidiary company whose core competence and business could be utilizing industrial side streams produced by the Stora Enso Oulu.

In the future, Stora Enso Oulu or the established new company could start modifying produced fiber sludge to be readily better suited for different utilization possibilities like biogas refining, soil amendment agent, fertilizer product, binding agent for pellets and granulation, additive for construction materials and dust-binding agent. Then, at the latest, the company should start charging customers and find a new revenue stream from fiber sludge. In the past, Stora Enso Oulu has already productized the raw tall oil produced in pulp production as a side stream in a very traditional way. Fiber sludge, on the other hand, is not quite as unambiguous in terms of productization, as it is much lower in value compared to raw tall oil and it is produced in much higher quantities.

Fiber sludge could be added to the product portfolio of Stora Enso Oulu as a by-product sold to the customers. Figure 2 illustrates how Stora Enso Oulu's product portfolio could be with respect to the aspects relevant to productization of fiber sludge. Figure 2 is not an accurate presentation of

the case company’s product portfolio and serves more as a generalization of how a company could productize their side streams and add them to their product portfolio as by-products.



**Figure 2.** The product portfolio of Stora Enso Oulu with respect to aspects essential to production of fiber sludge. Wastewater from primary process is an input to side stream process and as such is marked as a sales item of the primary process. If the side stream process were to be operated by another company—for example, subsidiary of Stora Enso Oulu—wastewater would actually be sold as a sales item.

#### 4.2. Productization of Fiber Sludge from the User’s Perspective

For the potential manufacturer of the dust-binding agent, fiber sludge has been found to have many advantages as a dust-binding agent from the perspective of productization. The main advantage is that, in this case, the dust-binding agent manufacturer would likely receive fiber sludge for free from Stora Enso Oulu. Costs could arise from transportation if the distance from the Stora Enso Oulu plant

were to increase to more than 25 km. For the manufacturer of the dust-binding agent, fiber sludge serves directly as the main raw material. Other advantages for the fiber sludge user include the availability of fiber sludge being guaranteed as it is produced steadily during pulp production. The variations in quality are small and not significant when it comes to using fiber sludge as a raw material for dust-binding agent. There are some variations in the quality of fiber sludge between different pulp and paper mills due to the used processes. According to an interviewed expert, despite these differences, fiber sludge from any pulp and paper mill in the world is essentially applicable for the dust-binding agent use described in this article. The process of modifying fiber sludge for dust-binding purposes is simple and the other components needed are cheap and readily available. From a legislative point of view, the use of fiber sludge as a raw material for a dust-binding agent does not seem to have any major legislative barriers in place. Pöykiö et al. [21] found that the heavy metal concentrations in the fiber sludge were lower than the Finnish heavy metal limit values for fertilizer products. These limit values are not applied in closed industrial sites where concentrations can be even higher, so it is safe to say that modified fiber sludge can be used safely for dust-binding in these sites [20]. The interviewed researcher agrees that, in many cases, separate environmental permits might not even be needed. The organic material in fiber sludge can, however, cause some restrictions to its usage in certain cases where, for example, eutrophication might be a problem. From a marketing point of view, modified fiber sludge can be marketed as an environmentally friendly alternative to, for example, the currently commonly used road salt. The main challenge is to find the right channels and value chains through which one should start marketing, selling and distributing the new dust-binding agent. A dust-binding agent is generally a business-to-business (B2B) product, meaning that other companies and organizations are the customers. For this reason, the marketing of the product should be examined from the B2B perspective. Contacting individual companies and making deals with them is highly inefficient in the long run but, on the other hand, can provide much needed reference cases in the beginning. The initial discussions with potential customers have revealed that the attitude towards such waste-derived products in this context are all positive and they consider modified fiber sludge as an ecological alternative to their currently used dust-binding solutions as long as the effectiveness of the agent is proven and the required dust-binding properties are achieved. The laboratory tests carried out on the effectiveness of fiber sludge as a dust-binding agent have been promising and it has been found to also work in field conditions as a dust-binding agent for roads [59]. However, the effectiveness of the agent has not yet been tested in industrial environments, such as mines or large industrial factory sites. Without concrete evidence and successful references, it can be difficult to persuade customers to change their current dust-binding solution to a new, yet unproven alternative based on just promising results in laboratory conditions. Preliminary investment and profitability calculations for the production of the dust-binding agent have also been made by the company planning to produce dust-binding agent from fiber sludge and, on the basis of these calculations, the productization also seems promising from an economic point of view.

## 5. Discussion

The general challenges of productizing industrial side streams are related to the material itself (e.g., volume, quality, availability), the profitability of productization (e.g., cost of disposal, storage and logistics) and to external stakeholder activities such as legislation and environmental permits. This study found that the challenges in the productization of fiber sludge, from both the producer's and the user's perspective, are mainly in the downstream activities of productization, i.e., marketing, sales and distribution. Table 1 summarizes the specific challenges of productizing industrial side streams and their significance in the case of productization of fiber sludge from both the side stream producer's and user's perspective.

**Table 1.** Challenges of productizing industrial side streams and their significance in the case of fiber sludge.

Challenge	Fiber Sludge Producer	Fiber Sludge User
Volume of side stream	Volume too high to be fully utilized in current utilization applications.	Volume more than enough for user’s productization and operations.
Quality of side stream	Not significant variations in quality.	Variations in quality not significant in terms of further processing. Fiber sludge from other paper mills also applicable.
Availability of side stream	Steady and predictable production.	Guaranteed availability. Transportation provided free of charge up to 25 km.
Side stream processing	Low value by-product worth giving away for free. Further processing is not worth committing resources to.	Process of modifying fiber sludge for dust-binding purposes is simple and other components needed are cheap.
Profitability of productization	Productization of fiber sludge is profitable due to high alternative costs in storage and disposal (negative value).	Main raw material for user’s dust-binding agent received potentially free of charge. Preliminary investment and profitability calculations are promising.
External stakeholder activities	Fiber sludge users responsible for applying for environmental permits if needed.	No major legislative barriers in place. Separate environmental permits might not be needed.
Marketing, sales and distribution	Multiple identified buyers but difficult to sell in high quantities. Best-case scenario is to sell or hand over side stream immediately as such without high costs. Image benefit from side stream utilization.	Modified fiber sludge can be marketed as an environmentally friendly alternative. Problem is to find right B2B channels to market, sell and distribute. Effectiveness of new solution needs to be proven with successful reference cases.
Focus on core business	Not part of core business. Establishing a new subsidiary company worth considering.	Side stream utilization is part of user’s core competence and business.
Value chain creation	Multiple utilization applications present with existing value chains.	New product replacing existing dust-binding solutions in value chains.

In terms of validity [62,63], the descriptive, in-depth case study method applied here produced the desired results. However, more individual cases from different fields of industry would result in a more comprehensive view on the productization of industrial side streams which would have increased the reliability of the research. If this study were to be conducted in a different setting, by different researchers and by analyzing the productization of a side stream from a vastly different industry than pulp and paper manufacturing, other aspects of industrial side stream productization could have been emphasized. As further research implications, more similar studies should be conducted on the productization of industrial side streams. These individual cases could be cross-referenced, which would reveal more information about the productization of industrial side streams as a phenomenon. This would enable companies to better assess the productization of their side streams.

**6. Conclusions**

Despite the additional challenges associated with the productization of industrial side streams, the productization of side streams as a process can be seen to follow the same steps as the productization of any other traditional product, and the productized side streams can be added to the company’s product portfolio as by-products along with their technical and commercial product structures, as demonstrated in this article. Therefore, companies should start considering the productization of side streams with the same level of seriousness as they would the productization of main products. One aspect differentiating the productization of side streams from the productization of traditional products is the fact that the productization of side streams is not part of their producers’ core business, which is why establishing a new subsidiary company whose core competence and business could be utilizing industrial side streams produced by the parent company is an option worth consideration.

Also worth noting is that there might not be existing value chains for by-products, which means that new value chains for their commercial use have to be created.

**Author Contributions:** Conceptualization, T.L. and E.M.; methodology, T.L. and E.M.; validation, M.K. and P.T.; formal analysis, T.L. and H.S.; investigation, T.L. and H.S.; resources, M.K.; data curation, T.L.; writing—original draft preparation, H.S.; writing—review and editing, T.L. and E.M.; visualization, T.L.; supervision, P.T.; project administration, T.L. and P.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflict of interest.

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