# POSSIBILITY TO REUSE AND RECYCLE WOOD WASTE AND CDWW*

– *CONSTRUCTION AND DEMOLITION WOOD WASTE

MSc in Resource Recovery
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**Abstract**
This essay will address if and how it is possible to reuse and recycle wood waste and CDWW (construction and demolition wood waste). The background will have a short introduction and then be divided into 3 sections. The first section addresses similarities and differences between linear vs. circular economy. The second section will take up bioeconomy and how it is managed in the different countries in the world, and the last part takes up wood waste management.

The purpose of this thesis is to investigate from literature if it is possible to reuse and recycle wood waste and CDWW. By reviewing case studies, see if it is possible to implement a practical sustainable recycling worldwide. There are four questions that will be answered to see if it is possible. Those are: 1, Are there enough volumes of wood waste for it to be worth to reusing/recycling it? 2, What opportunities does it provide and how can it affect society, economy, and the environment? 3, Is it worth investing in facilities that only accept wood waste and reuse/recycle the material? 4, How have the trends with wood waste been according to the data collected?

The methods that have been used are literature study, qualitative and quantitative methods. Qualitative as an interview has been conducted, and quantitative as data for wood waste in Borås has been compiled.

The result showed that there exist enough volumes for it to be worth reusing and recycling, however, the volumes has gone down significantly and are not stable, though this could be argued due to the COVID-19 pandemic and will most likely change and go up in volume within the next few years. There have not been any studies on how the society could be affected by reusing and recycle wood waste, although from an economic and environmental perspective it shows a positive outcome, such as new jobs get created and less deforestation and less reduction of biological diversity. Depending on the type of wood waste the facility receives, it can affect whether it is profitable or not, as the more hazardous chemicals exist in the wood residues, the more difficult and expensive the treatments and recycling becomes.

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# Abbreviations

CCA = Copper chromium arsenic
CDW = Construction and demolition waste
CDWW = Construction and demolition wood waste
CE = Circular economy
C&D = Construction and demolition
C&I = Commercial and industrial
EU = European Union
EWP = Engineered wood products
EWW = Engineered wood waste
GDP = Gross Domestic Product
GHG = Greenhouse gases
kt = Kilo tones
LOSP = Light organic solvent preservatives
LVL = Laminated veneer lumber
MDF = Medium-density fiber board
MT = Mega tons
OSB = Oriented strand board
R&D = Research and Development
SDG = Sustainable Development goals

# 1. Background and problem description

The background consists of four parts, where the first part has a short introduction and background. The second part takes up what linear vs. circular economy is, their differences and how it can be emphasized for a more circular economy. The third part consists of bioeconomy and explores from a more legislative and governance point of view. The last part deals with wood waste management, what kind of wood products are available, as well as wood for construction and what type of wood waste can occur from that sector.

## 1.1 Introduction

As climate change is occurring, one cannot expect that the earth will be able to continue to produce as much raw materials as is exploit today [1, 2]. At the same time, our residues are not getting less by the year as the human population is increasing and is expected to reach 9 billion around 2037 [3]. Using residues as raw material is a way to decrease the pressure on the globe and the earth's resources. This can also help to convert the linear economy that most of the society have, to a circular economy. By having a circular economy, more jobs could be created as well as be more sustainable and profitable for all form of startups and small businesses, to big industries [1].

During the 18$^{th}$ century, Britain had the first industrial revolution where the production of textile, coal and iron where the driving force. As time went on, the focus was on labour productivity than resource productivity. After World War 2, the "green revolution" in agriculture took place and there became nearly a doubling of crop yields since 1960. By using pesticides, more land (twice as much), fertilizer as well as using machines running on fossil fuels instead of workers, it takes 10 kcal of fuel to produce 1 kcal of food. As the human population is growing, the land would be exposed to more pressure as infrastructure would increase (home, roads, energy provision, water and sewage pipelines etc.), and the land to cultivate food would reduce [1].

Using renewable resources, the pressure on the globe can be reduced, if done in a reasonable and responsible way. By building a house of wood, where the trees took 80 years to grow, the house should withstand at least 80 years, if not more, to have a neutral to positive effect on the globe [1, 2]. Investigations show that products from virgin material uses 1,4 tones carbon footprint more per ton of products, compared to products made from recycled resources on average. Even though products are made from resources that are recyclable, it is estimated that out of 92.8 billion tons of material only 8.4 billion of them are recycled. Meaning that only roughly 9% of all the materials gets recycled and circulated [4].

Wood is considered as a renewable and reusable material, as it is biodegradable, grows promptly compared to other equivalent products and have a renewable origin, as well as it can change shape during the wood's lifetime. Different products could be made from wood, such as construction material, furniture, utensils etc. Compared to other equivalent products from fossil or inorganic material, the environmental impact that wood have during its production and end-of-life phase is much lower than fossil and inorganic originated materials. Therefore, it is expected to be a greater demand for raw wood materials to minimize the climate footprint in the future, and there is a chance that the demand will not be met by 2030 in Europe [5]. By utilizing wood residue, the pressure and demand for virgin wood could be reduced and get a chance to meet the demand.

## 1.2 Linear vs. Circular Economy

The linear economy is based on "take, make, waste" which is illustrated in figure 1. As a result, the human population consumes 1.75 planets if not more. Consequently, 60% of the planet's

ecosystem has been either degraded or destroyed completely. That includes pollution of soil, air, water as well as deforestation, burning of fossil fuels and industrial agriculture which releases an unsustainable amount of GHG (greenhouse gases). This in turn has created constraints on resources (both renewable and non-renewable) [1].

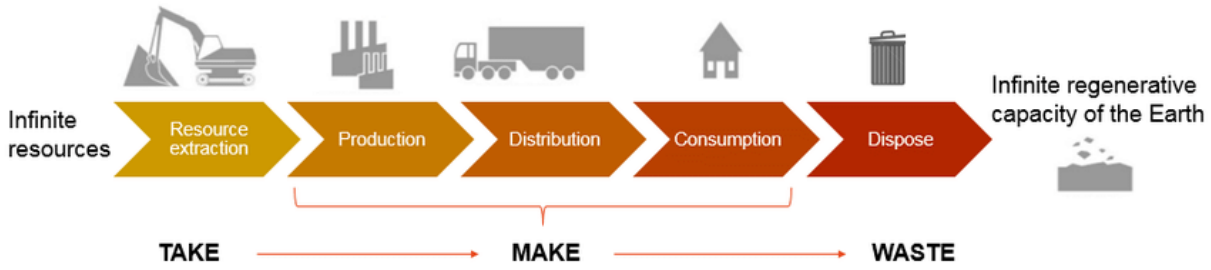


*Figure 1: Illustration of a linear economy [6]*

There are four 'linear business practices' that defines the liner economy to some extend [1]:

- Using materials with no thought if its renewable or recyclable
- Producing products with a short lifespan to sell more.
- Not giving out information about the product and no collaboration or partnership with other business.
- Not adapting to the future market or/and adapting to their own system.

Whereas the 'circular business practice' are [7]:

- There is no waste, only resources.
- Use durable or disposable material, e.g. biodegradable products are disposable whereas metals can be reshaped and thereof a durable material.
- Have collaboration and sharing information.
- There is no costumer or consumers, only users that use the materials for a time.
- Utilize innovation and adaptation.

As liner economy is about a liner way for the product, the circular economy focusses on the loops that connect to each other as seen in figure 2. Depending on what loop the material are in, indicates the value of the material. The smallest loop (reuse) has the greatest value and efficiency, whereas the largest loop (recycling) has the least efficiency and value of the material [1].

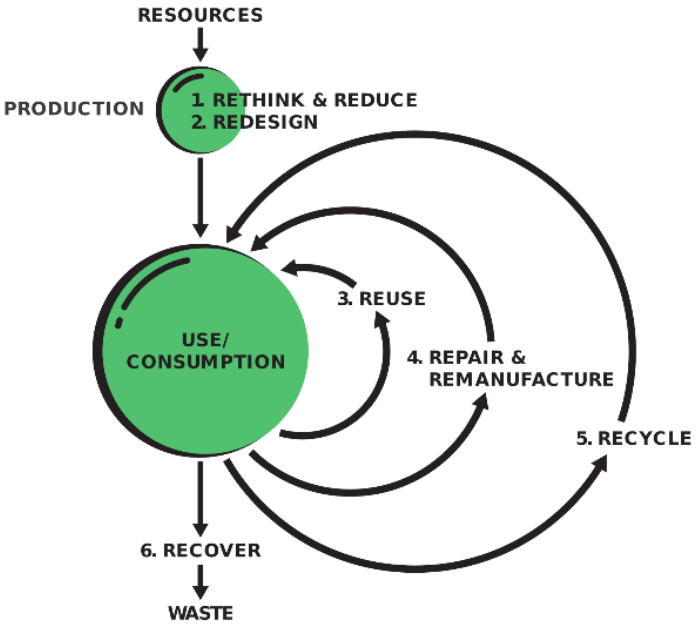


*Figure 2: Illustration of a circular economy [8]*

But how is it possible in practice to convert from linear economy to a circular one?

By engaging with the end consumer, there could be clues to how to maintain the product, make it easier for reparation or just refilling. By finding a way to recycle, remanufacture or refurbish, where the latter has the highest priority as it has more value and least climate impact. Moreover, find new customers and engage new partner to trade products that they do not want, i.e. by-products or residues [1].

By taking/using inspiration from industrial engineering, like SixSigma, one of the authors of "a circular economy handbook, 2nd edition" has created a list of 8 different design principles for the supply chain. This is called the '8 sustainability principle' (8S) [1].

1. Simplify, the number of materials on the product should be as few as possible and more natural, and the design of the product should be so easy to separate the different materials without much energy or cost [1]. By using materials that are readily available and that are easy to recycle or biodegrade, contributes to a circularity in comparison to mixed materials, where the risk of downcycle is greater or if even possible.

2. Standardize design, where the design of the product is the same and can be upgraded or repaired later during the product's lifetime. In this way, modular design can help with repairs, large and small, remanufacturing and in the future, possibilities for upgrading the product. By optimizing clear design principles and modular approaches, it is possible to streamline production and products that can be created in the future.

3. Security of supply, to ensure that there is availability for materials and suppliers, also for future production and possibly review where the optimal geological location is for any new construction of a factory. As several companies focus on where the lowest labor and supplier costs are, several uncertainties can occur - e.g., that the raw material is to be sent from Egypt to China for production, and then transported to Sweden to be sold. In between, transport logistics can have several uncertainty factors, i.a. geopolitical

disturbances or that a blockage on the transport route occurs, - e.g. such as the blocking of the Suez Canal in 2021. Another advantage is also minimization for geopolitical events, such as labor strikes or climate/weather impact (storms, earthquakes, etc.)

4. Less is more, by reducing geographical spread and scale it becomes easier to customize for the local market. As energy prices have increased and the requirement to reduce $CO_2$ emissions is becoming more and more strict and regulated. Companies are adapting to a more decentralized distribution model, as is shown in figure 3. This means that the lead times from finished product to customer are shorter.

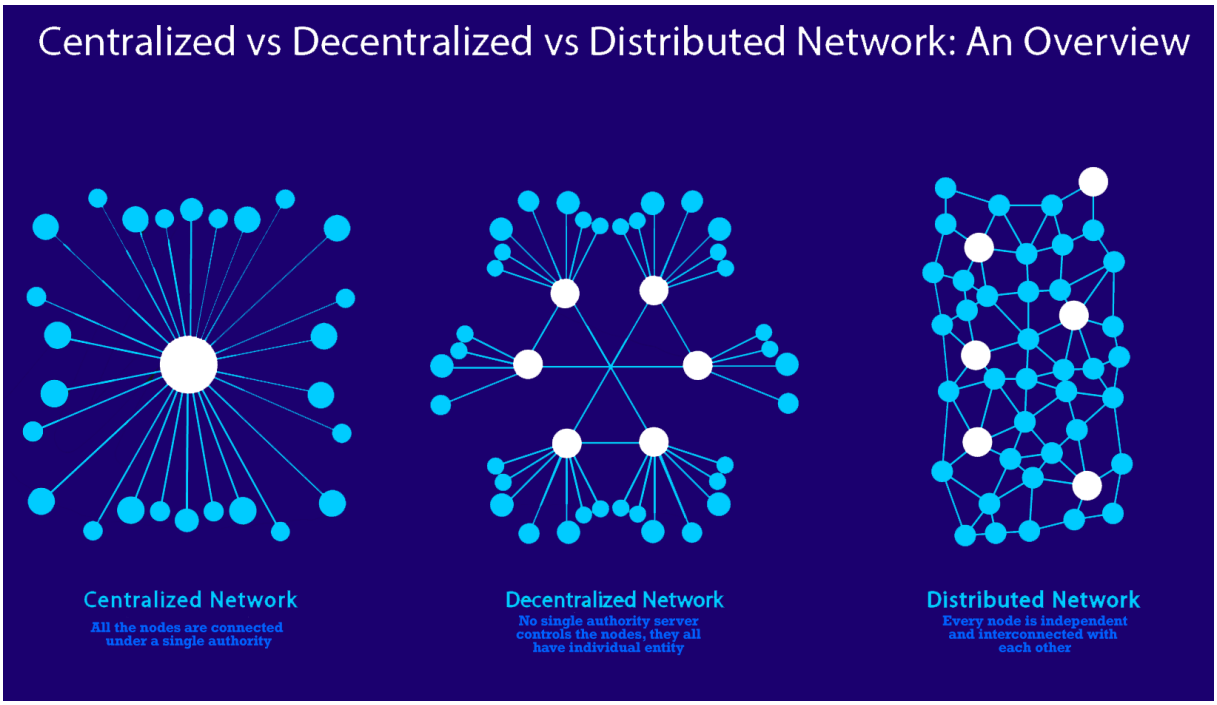


*Figure 3, illustration of different types of network [9]*

5. Shared approaches, by having a shared structure, it can benefit the entire supply chain. It can be through infrastructure, buildings and equipment, symbiotic flow, information to supplier and customer. By sharing infrastructure such as exchanges and platforms, response time can be increased, and costs can be reduced. The same applies with shared equipment and buildings. If there is a lower demand for a product that one company makes, another company may have an increased demand and thus use of the equipment. With a symbiotic flow, the "garbage" can be transformed into a by-product of one company and become raw material for another.

6. Service and performance models are somewhat more complicated, where products that have a high wear and tear damage can occur, e.g., mobile phones. As a cracked screen on the mobile can render it unusable as the user cannot see the screen but can be an easy repair (if everything else works). For larger products such as machines, the question would be how easy it is to get access to a mechanic who can go to the site and repair the machine. How should these products be returned when they are no longer useful, without the materials and functionality themselves decreasing in value.

7. Stewardship increases over time and becomes increasingly common, i.e., that the producer takes responsibility for the entire life cycle of the material and product. Then questions arise such as, how should the company that manufacture the product, design

and organize the supply chain. Should the products go directly to the factory where they were created, or should an external partner be responsible for the process of dismantling and recycling the various parts.

8. Streams for new circular and symbiotic flows, co-products and by-products will be increased in the supply chain. As the different products and flows will have different types of logistical demands, such as temperature sensitivity, bulk transport or even a dangerous substance where laws and regulations must be provided. This makes it more complicated to plan the different flows which each has different challenges. It is important to ensure that the value of the material does not decrease with the course of the stream. It becomes more beneficial if the material has a high value for as long as possible.

By question these principles and see how they should and could be applied in the company structure and organization as good as possible, the path from a linear economy to a circular one is manageable *"…getting involved in product and process design means you can help generate ideas for new flows and markets, and flag benefits or issues for the different options."* [1]. Going forward, these point will automatically take priority of recycled or renewable material, to achieve 'zero extraction'. Acquiring a team with a focus on accelerating the transformation from linear to circular production can ensure future resources and improved quality of the materials. As more recovery loops will arise from the transformation to a circular economy, especially within the repair and remanufacture loop, new businesses, partners and relationships can arise to cover these loops that were not utilized before [1], as could be seen in figure 4.

As the entire flow changes from linear to circular, the measurement of success also need to be changed. Instead of measuring "return on capital employed" (ROCE), where the measure is used to compare the relative profitability after considering the amount of capital used, the measurement should be on RORE, "return on resources employed". Then the measurement is on how much of the material's value, water and energy are used, is in focus. Buying raw materials and other additives to produce a product, and then throwing away the by-products they consider waste, where in some cases a charge may be added to manage the waste, makes the value of the material go down and is thus a bad deal [1].

By approaching circular economy, redesigning and rethinking the complex system of how the ways used to be are needed. By increasing the engagement downstream and upstream, the scale and scope could change more easily and smoother than forcing it, as can be seen in figure 4. As it will change profoundly whether anyone wants it or not. Looking for opportunities of circular approach in the supply chain could give businesses a head start in the future. These opportunities could be shared equipment, create value of residues etc.

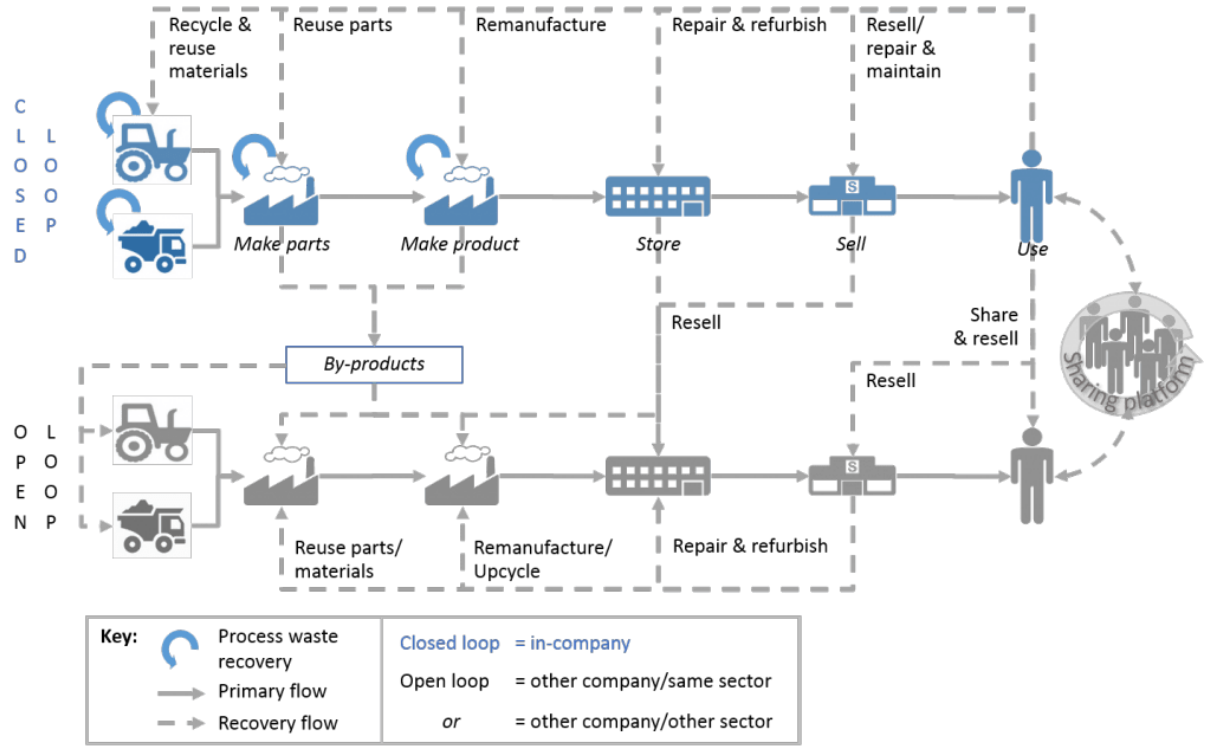


*Figure 4, Illustration of open and close loop material flow [1]*

## 1.3 Bioeconomy

Bioeconomy is a term that sees renewable biological resource matter as building blocks for energy, chemicals and materials [10]. As there are multiple ways of applying and utilizing biotechnology, it has been divided into 7 groups to distinguish the different methods and the main areas from each other. White or industrial biotechnology focuses on using micro-organisms or enzymes for making products that are bio-based which could be textiles [11], bioenergy [12], food and feed [13] and chemicals [14]. A group that was previously connected to the white biotechnology, though have become their own group, is grey biotechnology. Grey biotechnology uses the same source (enzymes and micro-organism), though its application is in the usage to protect the environment, and not for creating requested products. Scenarios could be such as cleaning of sewage water and oil spills [10].

Developing genetically modified crops (GMO) in agricultural processes is an example of what green biotechnology is about. Anything that have with processes in agriculture with the usage of life science, is in this group. Wood would fall on the green biotechnology, as it is cultivated, and research have been done in how to grow trees faster [15]. As for the aquatic and marine application, they belong to the term blue biotechnology. Whereas red biotechnology relates to the pharmaceutical and health sector. The final and newest term is modern biotechnology, where the conventional focus is fermenting and breeding of microorganism. For the more technical aspect, cell fusion and genetic engineering [10].

### 1.3.1. Bioeconomy worldwide

To reach the different types of Sustainable Development Goals (SDGs), implementation of bioeconomy could be a way of achieving them. By using sustainable resources that are bio-based and some innovation, different economy sectors (i.e., textile [11]) could develop and in turn improve the environmental, social and economic standpoints [16].

It is found that 41 countries have some type of political strategy for bioeconomy, and they have their own way to promote and expand their view of this model [16]. As bioeconomy is one way to tackle the current climate change crisis [17], it has been emphasized from recent studies that on a social, technical and economic standpoint, that being depended on bioeconomy cannot provide a fast solution to create a sustainable society and in the view to tackle the climate change [18]. Therefor experts recommend and demand that the government makes more structural framework and rules to make a smooth transition for the bioeconomy framework and that the frameworks is actually an improvement and making an climate neutral/positive impact [19, 20]. As industrial countries commonly have a more integrated system with fossil fuel and a pre-biotechnological production process, there could be some conflict of interest during the conversion to a more bioeconomy system [16]. Thereof, depending on the way that the politics are supporting bioeconomy is very crucial. Too fast of a transformation to bioeconomy could result in a higher conversion cost, and if not enough research and development strategy is investigated, could potentially lead to a negative consequence and devastation for the society and the climate [16].

An example of this is the ethanol production in South America. As bio-based vehicle fuel was attractive as an alternative to fossil fuel, ethanol became a highly demanded product. In consequence of this, a lot of deforestation happened in Brazil and contamination of the soil, as well as a competition of food vs fuel to name a few of the consequences by the cultivation of sugar cane to produce the ethanol [21]. Hence the importance for the government to invest in research and development in the bioeconomy questions, and not for only economical gain purposes. Other ways for the government to implement the bioeconomy easier, is to market, enhance and gild products that are bio-based and sustainable. In this way, the awareness and the societal participation could grow and become more responsible and change their pattern for a more sustainable consumption. As a aftereffect, those companies could grow and expand their businesses and produce more sustainable products [16]. Though problem could still arise after becoming a more bioeconomy-based society, as there could be or become goal conflicts for the SDGs.

The earliest and most common conflict for transforming to a bioeconomy society (and still is), is the debate of “food vs. fuel” as mentioned before with biobased ethanol [21]. Though it has become more focused on other aspects, such as land use change, water scarcity, land degradation and global equity concerns. Thereof a political effective management that searches for such conflicts and solution would be essential to tackle the development and the challenges for a sustainable bioeconomic framework [16]. As it is investigated, many countries have developed goals and are willing to give the support that are needed for their definition and goals of bioeconomy. Although as mentioned before, goals that conflict each other have not been as thoroughly investigated and got the attention compared to the bioeconomy implementation [16]. A minority that are implementing and having a bioeconomy strategy, acknowledge that there could be a conflict of interest and a negative consequence by doing the transformation for a more bio-based sustainable development. As a result, they have a softer political approach to be able to manage these conflicts, and to make as smooth of a transition as possible to reduce the costs, as mentioned before that can arise if the transition goes too fast [16].

Even if there could be negative consequences of transforming and using bioeconomy, current literature does emphasize the potential that the bioeconomy could give to the society, economy and to reach the different SDGs. Though they do not idle dismiss the negative consequences, and brings the different problem into light, the positive effect would be much greater if applied

in the bioeconomy correctly [16]. It is also brought up by some researcher that the political and the economic growth is the primary cause for the hardship of transformation to a bioeconomy. Before the bioeconomy paradigm became a thing, the politicians, economics and society created an economic system and infrastructure that did not consider the transformation for an environmentally friendly society. Thus, the sustainability and environmental friendlier solutions got cut back if it costs less to carry out a different infrastructural project or products [16]. Thereof it is harder today to remake the infrastructure in many societies as multiple obstacles will arise.

The problem does not only align in the earlier politicians and societies choices, but also on the industries today. As of today, majority of the value chains and industries have adapted their product and production on fossil-based resources. This makes the conversion to a more biotechnology production process harder, as the quality, quantity and the process itself differentiate compared to earlier and todays fossil-based design [16]. This also applies, as mentioned before, in current infrastructure like transport system and the need for bio-based vehicle fuel. Even if companies want to change and adapt to a more bioeconomic process, there is a risk that they lose their competitiveness. As the chances and risks are that the cost of production increases and depending on the quality of the product is, if it does not deliver up to the standard that consumers expect, they can turn to their competitors and thus the company that wants to develop can or will go bankrupt. Even in the long run the bio-based conversion offer a sustainable gain, many companies still do not dare to take the risks [16].

If the politicians set laws and regulations for producers, it does not automatically mean that consumers will change their cognitive behavior. Therefore, it is important that the right information reach the population as well as getting knowledge about the new products/society structure. Giving the population a timeframe to change their consumption patterns, and not change everything over one night would be beneficial. As less misplacement and misunderstanding would occur, but also give time to see if there will appear any faults during the transformation. If any fault appear, it is in general easier to fix in the early stage [16]. Compared to economic, political and industrial changes, the human behavior is harder to change during a shorter time in comparison the three last mentions.

In summary, it could be said that there are three main reasons for the difficulty of converting into a more bioeconomic structure, namely politics, economy/industry and the human behavior. In general, the politics and industry shaped the current infrastructure with fossil-based resources. Moreover it is the human behavior as well as the framework made by the politicians that regulate the industries, will affect the future transformation to a sustainable bioeconomy [16].

### 1.3.2. Bioeconomy Strategies

There are 4 main overall strategies that are commonly brought up and used by the politics to transfer into a bioeconomy. (1) using raw material that are bio-based instead of originated from fossil fuels; (2) increase productivity in the bio-based primary sector; (3) utilize and increase the efficiency of the biomass; (4) separated from large-scale biomass production, create value and addition by application of biological principles and processes. However, using one or all of these strategies, does not mean directly that it will create a positive impact and a closer achievement of the SDGs [16].

Evidently, most of the countries with a bioeconomy strategy does have a define way of the implementation, either using three or all four of the mentioned strategies. They plan and invest

in R&D with the aim of increasing the competitiveness of their bioeconomy. Not only do they invest in R&D, as mentioned earlier with industries that have a hard time to change to a bioeconomy production in fear of going to bankruptcy, governments in the different countries and institutions, seek for policies for the improvement of the different industries that are bio-based. Subsequently, to improve acceptance for the implementation of bioeconomy, educational and information campaigns would be pursued [16]. Basically, it is possible to say that within a few years, there will be a momentum where a change for a more bioeconomy will happen.

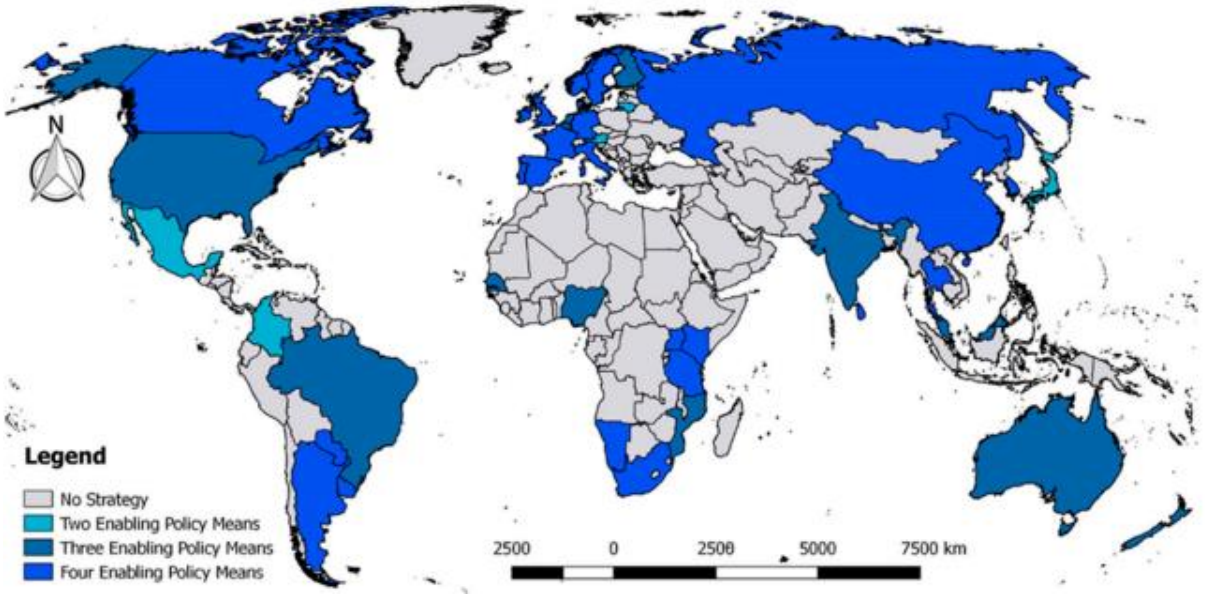


*Figure 5, Countries that are implementing opportunities and enabling political means for a national bioeconomic strategy [16]*

### 1.3.3. Regulations of Bioeconomy

It has been brought up before that majority of those that are using and implementing a national strategy for a bioeconomy, does not consider nor pay attention to the SDGs conflicts (26 of 41 countries) [16]. In general, the countries that shows the most potential risks, SDG conflicts and political sensitivity are the European countries. On the opposite side, those that does not consider the risks and have the potential for an extensive bioeconomy, is for instance Argentina, Brazil, Russia and USA. In between lies a few African countries and China, as they do recognize the importance of doing calculation of risks and the influence political decision have on the shaping for a sustainable bioeconomy [16].

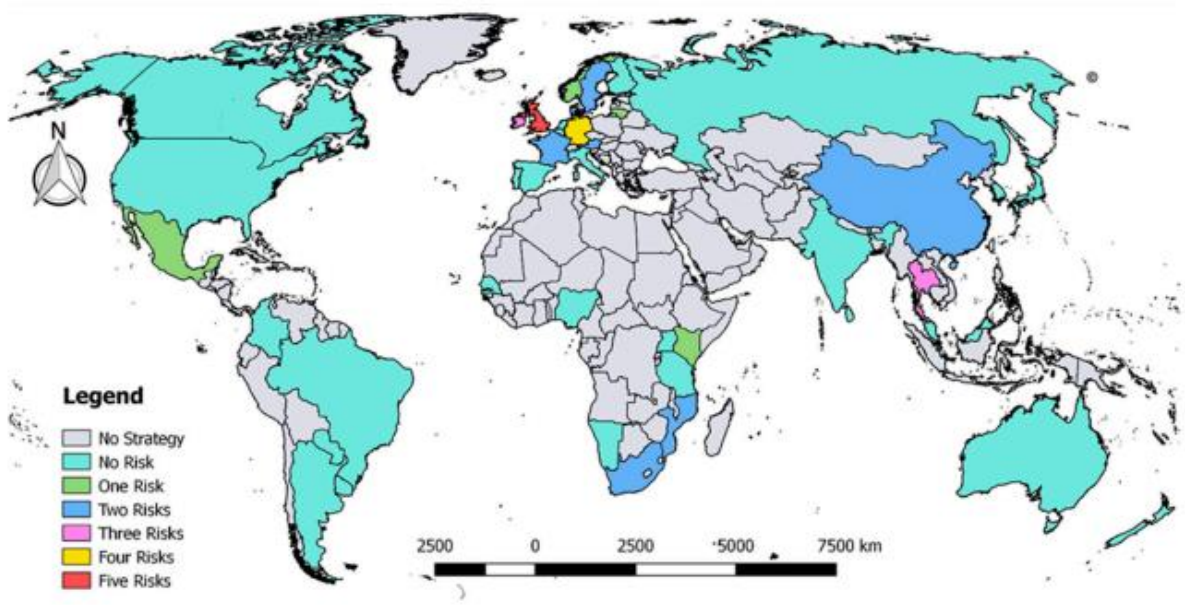


*Figure 6, Risk analysis of the countries that are implementing a national bioeconomy [16].*

Table 1 summarizes what the different countries have defined as potential conflicts for their national bioeconomic strategy. Most of the concerns are about their own land resources, closely followed by; how much nutrition is available for growing crops [16].

*Table 1, Identification of different potential conflicts that could hinder to reach the SDGs [16].*

| Country | Nutrition | Poverty/Inequality | Nat. Res. (Air) | Nat. Res. (Forests) | Nat. Res. (Land) | Nat. Res. (Water) | Health | Climate |
|---|---|---|---|---|---|---|---|---|
| Austria | ● | | | | ● | | | |
| Denmark | ● | | | | ● | | | |
| France | ● | | | ● | ● | | | |
| Germany | ● | ● | | ● | ● | | | ● |
| Ireland | ● | | | | ● | | ● | |
| Kenya | | | | ● | ● | ● | | |
| Lithuania | | | | | ● | | | |
| Mexico | | | | ● | ● | ● | | |
| Mozambique | ● | | | | ● | | | |
| Norway | | | | | | ● | | |
| South Africa | ● | | ● | | ● | ● | | |
| Sweden | ● | | | | ● | | | |
| Thailand | ● | | | ● | ● | | | ● |
| United Kingdom | ● | ● | ● | ● | ● | ● | ● | ● |
| China | ● | | | | ● | ● | | |
| Total | 12 | 2 | 2 | 6 | 15 | 7 | 2 | 3 |

In table 2, it is shown that multiple countries usually are dependent on soft regulation to handle risk that are related to bioeconomy, i.e., self-regulation such as certification and private standards. Because of this countries advocate for a comprehensive regulation to avoid conflicts of SDGs goals and enhance cooperation on an international level [16].

*Table 2, Regulatory mechanism by contries [16]*

| Country | State Regulation | Creation of Positive Incentives by Governments | Private Standards and Certifications | International Cooperation | Total |
|---|---|---|---|---|---|
| Austria | | | ● | | 1 |
| Denmark | | | ● | | 1 |
| European Union | | | ● | | 1 |
| France | ● | ● | ● | ● | 4 |
| Germany | ● | ● | ● | ● | 4 |
| Ireland | ● | ● | ● | ● | 4 |
| Kenya | | | ● | | 1 |
| Lithuania | ● | | ● | ● | 3 |
| Mexico | | | | | |
| Mozambique | | | ● | ● | 2 |
| Norway | | | ● | | 1 |
| South Africa | ● | ● | | ● | 3 |
| Sweden | | | ● | ● | 2 |
| Thailand | | | ● | ● | 2 |
| United Kingdom | ● | ● | ● | ● | 4 |
| China | ● | ● | ● | ● | 4 |
| Total | 8 | 6 | 14 | 10 | |

### 1.3.4. Development at Regional levels

In the previous sections, a few strategies that countries take up in their policies and in their attempt to implement bioeconomy were reviewed. This section summarizes a more detailed overview of what the different regions are doing.

The African continent have the least number of countries that does not have any kind of bioeconomy strategy or implementation. Nevertheless, in the southern part of African some few countries exist that are showing potential for the implementing bioeconomy in their states, where they also include some framework and regulations [16]. Mozambique and South Africa are some of the countries to which this applies. As many African countries do not have a strong infrastructure, industries and society linked to fossil raw materials, there is the potential to easier develop a sustainable society with the help of bioeconomy.

Australia and Asia have many large countries such as Russia, India, China and Australia itself that have developed an advance strategy for their bioeconomy, though for some of them the risk analysis is minimal or missing completely. There are Asian countries that have not enabled a bioeconomic strategy at all, nevertheless Thailand and China have shown attention for the potential sustainability risk of implementing and the risks of a bioeconomy [16]. Europe have shown clearly that they have one of the most advanced strategies for implementing a bioeconomy. This may be due, among other things, to the fact that the European Union (EU) makes an active choice to market their transformation and environmental awareness. Unfortunately, this does not apply to all countries in Europe. There is a clear picture that the eastern European countries have not come as far, or shown no development at all, in implementing bioeconomy in their country. Hence there is a large gap between the different countries, despite the fact that they have an international cooperation between the different countries and societies [16].

In North and South America, there is a similar depiction of the development between the various countries and states as in Europe. Where some countries and states have a well-developed framework of bioeconomic implementation, while others have none. The biggest difference between Europe and America, is that in America there is no common organization and structure compared to Europe. Although they both have gaps between the different neighboring regions, EU forms a basic structure and risk analysis, and can therefore more easily help countries with the transformation into a bioeconomy. Whereof America have not and runs a great risk of falling into sustainability risks as it has not been investigated, or that the information they receive cannot be amplified in their specific region [16].

### 1.3.5. Summary of bioeconomic strategies

It can be seen that there is a clear trend where more and more countries plan and structure for a bioeconomic society. Overall, the countries are willing to provide political support in the form of financial funds and investment in R&D departments, as well as a framework so that industries can develop on the same playing field. Although countries have done the analysis of bioeconomy in their implementation to varying degrees, there are many who have not analyzed the risks and conflicts to achieve the various SDGs that may arise with the implementation. Those countries that use comprehensive approaches to a bioeconomy rely more on a softer policy for risk reduction and resolve conflicts when it arises. To create an effective governance arrangement, methods that can assess and measure bioeconomy are required. Under- or overregulation could be created if not impact analysis and monitoring are performed. Today's business with fossil-based economy requires to be confronted and the risks to be analyzed. As the opportunity to develop and implement bioeconomy in industries, it requires a careful assessment if conflicting goals arise as well as risks and how they can be avoided. A material that is largely related to bioeconomy and bioeconomic strategies in several countries is timber, which will be discussed more in the next chapter.

## 1.4 Wood waste management

Forests provide livelihoods and goods as well as having a ecological and economical function. Wood is a product that is accessible and possible to cultivate through forest management [22]. Timber industries get their products primarily from forest, where the trees are chopped down [22, 23]. By cutting the wood in different size and shapes, it could be supplied for different industries to produce products such as sawn timber, round wood, engineered wood products (EWP), wood-based panels, furniture, wood-based utensils, pulp, paper, and other alternative products to increase the global economy [22, 24]. There are different types of wood that each of them has different types of characteristics. Depending on what type of tree the wood comes from, the tree will grow in specific climate and speed. Oak is slow growing, though sturdy and a compact material, whereas pinewood is less compact and grows quicker. EWP, wood-based panels and framing are the primary products that are used in the construction industry. By using and harvesting wood from the forest is a way to improve the national economy, though it can also have a severe impact on the environment as biodiversity can be reduced or lost completely. To minimize this risk, using and implementing circular economy concept could be a way to minimize the pressure and the demand for virgin material. More than 20 years ago, the earth had around 3870 million hectares of forest, which cover 30% of the land mass [22]. The countries that produce and export wood the most in the world is seen in figure 7.

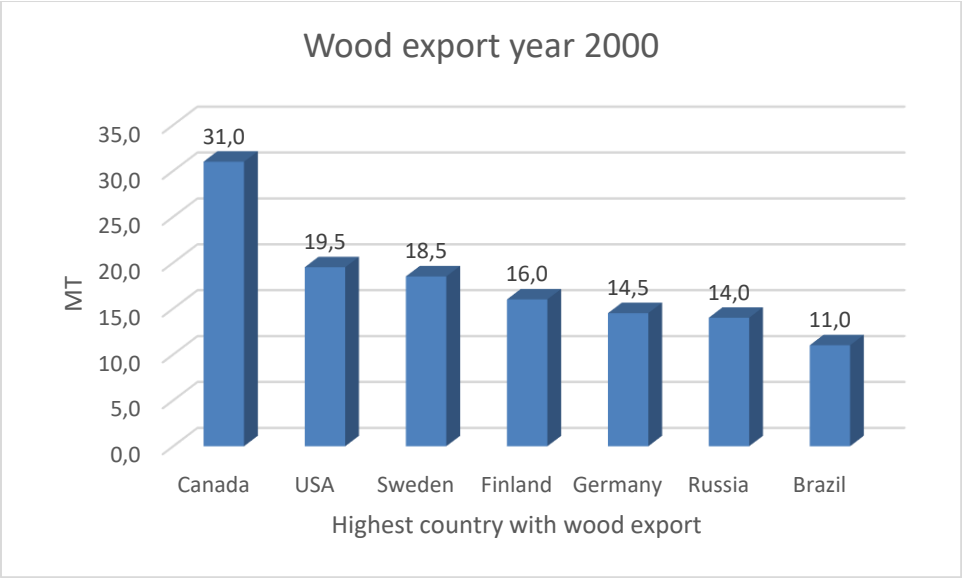


*Figure 7, Most production and export in wood [17]*

### 1.4.1 Wood Waste

Wood waste or wood residues can come from multiple different sectors, of which the construction and demolition section will be addressed and examined. Other sectors and products could be furniture, disposable pallets, wooden packaging and waste wood from sawmills.

### 1.4.2 Construction and Demolition (C&D) waste

Construction and demolition waste (CDW) is waste in solid state, that could be concrete, rubble, bricks, aggregate, timber, steel, mixed materials and building debris from the renovation industry or C&D [25-27]. Through renovation of buildings, industrial site clearings, demolition or commercial, residential, construction, land excavation is the most common categories that generate CDW [28]. One of the significant economic sectors that enrich the regions gross domestic product (GDP) is the construction industry. The construction industry does though create a significant impact on the environment, as it consumes enormous volume of natural resources and releases pollutants and impurities, such as greenhouse gases (GHGs) and other solid and liquid materials [27, 29-31]. It is measured that approximately 30-40% of the waste are generated globally from CDW every year [31]. As it is an extensive waste that gets created every year, and affect the environment, implementing a circular economy with the reduce, reuse and recycling mindset worldwide is essential for the CDW to not create more damage for the environment [22].

### 1.4.3 Construction and demolition wood waste (CDWW)

During construction, renovation and demolition, enormous amounts of wood waste is generated throughout the world. CDWW stands for 20-30% of the total CDW, which makes it the second leading stream [22]. Table 3 shows a summation of different regions CDWW. 10-15% of timber material is estimated to go to waste that is used in new construction. It is estimated globally that 10% of waste material that ends up in landfills is CDWW [22].

*Table 3, Summary of generated CDWW in different countries*

| Region | CDWW (MTon) | Year | Reference |
|---|---|---|---|
| USA | 55,75 | 2020 | [32, 33] |
| Australia | 2,311 | 2018-2019 | [34] |
| Hong Kong | 20,72 | 2020 | [35] |
| EU – 28 countries | 50,2 | 2018 | [36] |
| UK | 4,5 | 2020 | [22] |
| Germany | 3,53 | 2015 | [22] |
| Sweden | 0,571 | 2020 | [See footnote] |

In 2020, USA produced approximately 55,75 mega tone (MT) of wood waste [32, 33]. Another report presented that Australia produced 2,311 MT of wood waste in 2018-2019, where C&I was the largest producer and stood for 64.3% (1,524 MT) of the wood waste, whereof C&D stood for 25.8% (0,799 MT) [34]. In Hong Kong during 2020, it was found that they produce 20,72 MT CDWW [35]. In Europe (EU- 28 countries), it is found that they account for approximately 50,2 MT of wood waste production [36]. Looking closer in Germany, in 2015 around 11,9 MT of wood waste was generated, whereas 29.7% (3,53MT) of it came from CDWW. In the UK, roughly 0,5 million of their wood waste ended up on land fill, whereof the generating of wood waste was 4,5 MT in 2021 [22]. According to the Swedish Environmental Protection Agency, Sweden generated during 2020 14,6 million ton of C&D, where of 0,571 MT was wooden material[1].

It is predicted that roughly 20-30% of all construction and demolition waste (CDW) is recycled globally and not transported to landfill [22]. The data of CDW recycling for some different countries are presented in figure 10. Wood that are contaminated are costly and complicated to recycle, whereof could be a reason that no one have accomplished 100% recycling of CDW.

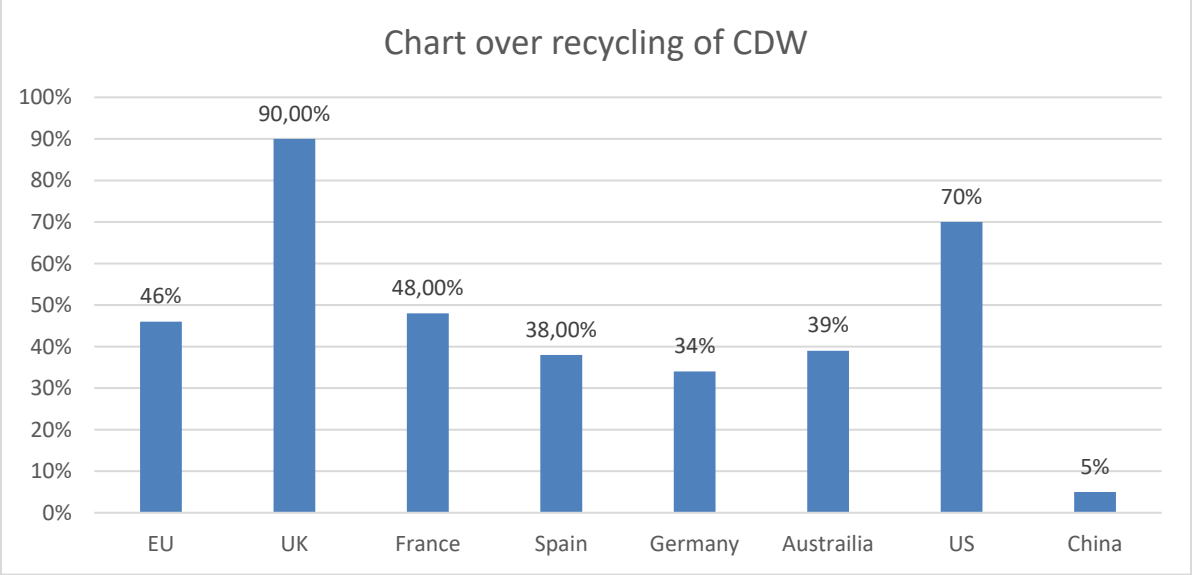


*Figure 8, Chart over recycling of CDW [37-40]*

Multiple literature explains different ways of recycling and reusing steel, aggregate and concrete individually [41-44], but it is only lately that CDWW have become of more interest

[1] Olof Dunsö, Case manager in Swedish Environmental Protection Agency, e-mail conversation 15th may 2023

[45]. Even if research in reuse and recycling CDWW have increased, concrete and steel are still two of the leading materials that are recovered and recycled (82% and 98% respectively). It is clearly stated and shown through different literature that there is a large amount of CDWW produced yearly. As wood is an organic material, when it is landfilled, an anaerobic process starts to decompose the wood. The consequence of this is that a large amount of GHG is released, which in turn contributes to global warming [46].

Consequently, it have become a global interest and challenge to handle the extensive amount of wood waste from C&D [22]. During the pandemic (COVID-19), there was a deficiency of virgin wood, which could have been prevented by having a befitting management plan of wood waste. There of the importance of a circular and life cycle of CDWW [22]. By develop a circular flow of wood (waste), it could assist of conserving and protect forest supply as well as conduct a sustainable development [47, 48]. Hence a CE policy and management could be a way of reducing CDWW, and contribute to the social, economic and environmental benefits [22].

### 1.4.4 Categories of Wood Waste

There are three categories of wood waste. Namely, untreated wood, engineered wood and lastly painted or preserved-treated wood. These three types of wood wastes are acquired from renovations, constructions, and demolition operations [22].

#### 1.4.4.1 Untreated wood

Untreated wood is wood that have not gone thru any type of chemical treatment that could help with preservation of the wood. This wood is the cleanest type of wood of all the categories as it is do not contain any added chemicals. The streams could contain such as boards, wooden boxes, wooden pallets, production waste or other wooden packaging. It could also be timber from building frame, which is usually made of ‘hardwood’ or ‘softwood’ and are in high quality [49]. Hardwood is obtained from trees such as walnut, eucalyptus and oak, or general trees with broad leaves. While ‘softwood’ derives from firs or pine trees [22].

#### 1.4.4.2 Engineered Wood

Engineered wood are products such as oriented strand board (OSB), glue-laminated timber, medium-density fiber board (MDF), laminated veneer lumber (LVL), particle board and plywood, that are commonly used in constructions [50]. They are manufactured by using chips, veneers, flakes, or fiber. To produce various products, it is common to use adhesive or resin to connect the different elements [49]. As engineered wood products (EWP) are vastly and commonly used in the construction industry, consequently, largely amount of engineered wood waste (EWW) are formed [22].

#### 1.4.4.3 Painted or Preserved-treated Wood

By using a paint or some kind of chemical treatment, the longevity of the wooden material could be significantly longer than not be treated at all. The treatment of the wood could prevent from any biological violation to happen, such as animals, fungi or insects attack. It can also help against the weather elements that could hasten the biological degradation or protect from moister damage [22]. The most common used chemicals to make wooden products more durable is the use of alkaline copper quaternary (ACQ), copper chromium arsenic (CCA), light organic solvent preservatives (LOSP), or creosote [50]. Softwood is commonly treated with CCA. However, a small portion of hardwood could also be treated for various reasons, though less frequent. It is further common for wood to be painted with lead-based paint, which has been found to be incredibly toxic to the environment, nevertheless could still be found in

CDWW flows [22]. Examples of this type of residues could be railway sleepers or infrastructure poles (power line, telephone).

### 1.4.5 Appearance of Wood Waste

Wood waste from C&D could come in different size and shapes, such as sawdust, bars, shavings, slabs and off-cuts [51], as demonstrated in Figure 5. In these wood waste flows, it could contain small amount of metal and fastenings such as bolts, staples, hinges, framing anchors, nails, or nail plates [22]. Example of the size of the wood could be from sawdust particle to larger wood shavings, as well as irregular off-cuts wastes that could be hard and not suitable for reuse. Particles of sawdust could become a health hazards, as the size could vary from flour size to coarse particle [51]. As the sizes of the wooden waste can be incredibly variable, it is difficult to logistically collect, store and transport it in the optimal way in larger volumes [22]. Another concern of CDWW management is wood that is preservative treated. These materials are difficult to treat and are usually hazardous as well as require a separate management system that could rapidly become expensive. This makes wood that is considered hazardous more difficult to recycle and is a complicated process [50].

*Figure 9, Image of different appearances of wood waste [22].*

### 1.4.6 Wood Waste and CE

The global demand for wood has increased hugely over the past century [52]. The cause of this increased demand could be argued to have occurred because of accelerated growth of population, urbanization, and the development of industries worldwide. Consequently, more attention needs to be paid on consumption of virgin materials, energy usage, and management of waste. As wood is not completely circular compared to metal, as it can't be reshaped or change in shape when it has been cut down. Therefore wood is a linear process and one way or another becomes to an end-of-life disposal [22]. Hereof the importance of implementing a CE into the wood's life cycle to reach a sustainable development. As described earlier, CE is a model that implement and utilize the 3R (reduce, reuse, recycle). By implementing CE, virgin

material, emissions, energy usage, and waste generation could be minimized [22], which is illustrated in figure 9. By closing the loops, a system that is regenerating is created. By designing the product to be able to be recycled, get repair and reusable as well as maintainable, will in turn reduced and prevent for energy leakage, emission and waste generation [53].

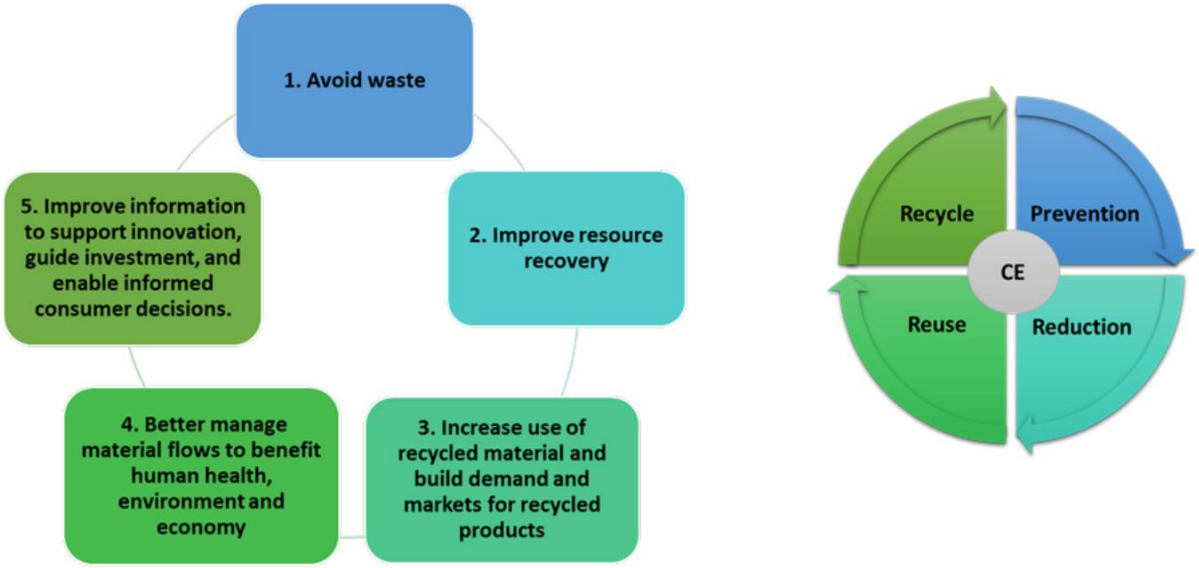


*Figure 10, Ilustrations of CE [22]*

# 2. Purpose and limitations

The purpose of the project is to make a literature study to see if it is possible to recycle wood waste from C&D, and if it is possible to make it more circular. Explore how the different wood products relate to each other and how they can be circulated according to their properties. The work will also address different methods to minimize wood waste and which types of replacement methods would be possible, as today the result focus on financial gain. As it is not uncommon for wood waste to be incinerated or landfilled.

The research will also analyze data from companies and discuss how the trends have changed over the last few years. A case study will be implemented in form of an interview and parallels will be drawn from the literature study.

Questions that will be addressed in this thesis are:

- Are there enough volumes of wood waste for it to be worth to reusing/recycling it?
- What opportunities does it provide and how can it affect society, economy and the environment?
- Is it worth investing in facilities that only accept wood waste and reuse/recycle the material?
- How have the trends with wood waste been according from the data collected?

The limitation of the work is that the case study data is collected in Borås and does not provide an overview of how it looks in general over Sweden or in other countries. Methods for recycling wood are not discussed on a chemical level.

# 3. Description of method

The methods that are used is a mix of literature study and collected data from Sobacken, Borås as well as a qualitative interview with 'Åter-i-Bruk', Borås. By finding literature, the search engine 'google scholar' have been used and searching titles such as "wood recycling", "construction and demolition circular economy", "construction and demolition wood waste", "circular economy wood" have been used. Also, physical literature has been viewed and studied.

# 4. Result

This segment is divided into four sections that will discuss 'Construction planning',' Today's management and opportunities', 'Environmental, economic and social impact' and lastly 'Case study 'Åter-i-bruk' and Sobacken'.

The first segment focuses on how to make construction more circular from a material perspective for the future. This could be from new construction, renovation or simply demolition. The second segment brings the possibility to use wood waste and CDWW material in today's society, as well as some difficulties that may arise and how to potentially overcome them. The third segment brings up the environmental, economic and social impacts that CDWW and wood waste could have. Such as, does it cause a negative environmental impact, or is it possible to reverse the impact and make it positive. Is there a possibility for economic growth and gain, as well as what kind effect CDWW could have on the society. The fourth segment brings up data from Sobacken, Borås and a case study from 'Åter-i-bruk', Borås. Sobacken is a waste facility that takes care of Borås municipality's waste, as well as the waste of certain industries in the surrounding area. 'Åter-i-bruk' is a municipal organization that has two second-hand shops and a joinery. They hire people who are far from the labor market to give them a chance to get back into the society. They take in certain materials from construction waste (such as wood waste) to carve a new product in the joinery, and later sell it in the secondhand store.

## 4.1 Circular Construction Planning

As constructions are supposed to last for several decades, it takes time before all buildings are made of materials that can be reused and recycled. As countries have made new or changed legislation about what type of construction material (of wooden origin) is legally to use, it does not mean that earlier wooden building materials have been replaced. Therefore, it takes time before all the old and non-circular wooden material is removed from society. As found in literatures [22], by utilizing and using the CE principles, a high amount of unwanted waste and emission could be minimized. To achieve this circularity, it begins before the construction even starts. In this section, different approaches and step by step construction progress will be discussed to make the CDWW more circular, although it could be applied in general for other building materials as well.

### 4.1.1 Pre-construction phase

The pre-construction phase could plan how the materials would be handled when the demolition or renovation will happen, as well as the management of the material. It's the first step to plan and work towards a CE in the C&D. Thereof it is a crucial stage that contributes to a reduction of materials, prevention of waste as well as creating an effective waste management plan for

timber [37, 54]. Today there is no such targets from the government, hence the architects and engineers for the construction projects have a bigger responsibility to enhance minimizing of waste generation as well as have a meticulous amount of material that is counted to be used during the construction. In that way, less demand and over exposure for virgin material would consequently lessen the pressure on the environment [22].

### 4.1.2 Building information modeling (BIM)

By implementing a BIM during the early design stage, it could help to measure accurately how much waste could accumulate during the project as well as a detailed composition of the materials [38, 55-57]. If BIM is applied correctly during the design stage to know how much waste would be generated, the waste management could be easily handled and more materials could be recovered, reused, recycled during the end-of-life stage. Another positive consequence by using a BIM would be the ability to see the buildings' life cycle. Which includes the demolition stage, reuse and recycling, which helps to implement a CE [57].

### 4.1.3 Prefabrication

By prefabricating wood and different types of elements for construction, a certain amount of waste could be minimized and thereof has become a popular method and term to use [58-60]. By utilizing prefabrication, the products and materials are prefinished from the factories and therefore takes a higher incentive for the labors when it comes to the construction site. Nevertheless, it becomes an effective approach to minimize streams of waste that could arise, compared to if the prefabrication was not made [37, 61]. Most of the contemporary residential buildings consist of timber-framed construction that contain broken veneers, such as studs, wall framing, rafters, roof trusses, and joints that are prefabricated. By using prefabricated materials, health issues and labor cost could be reduced as well as waste such as sawdust, off-cuts and shavings, as well as reduce timber waste from 65%-80% [37, 61].

### 4.1.4 Construction and operation for waste management

By applying a site waste management plan that consists of storing, collecting, sorting and monitoring of waste could be a way of subsequently come closer to a CE. In this way, material could be reused, recycled and in general reduce the waste accumulation [62-64]. As wood is an organic material, it will naturally decompose rapidly. Thus, the challenge aligns to obtain wood waste material that are durable with a long-life cycle. Different compositions and qualities also occur in CDWW, such as engineered wood, treated, untreated wood and wood contaminated with other types of materials and chemicals [49]. By having a standardized and legitimate management and monitoring of the wood waste stream, the quality of the materials that are sorted and recovered could be easier to use. Though it does take up substantially of space and labor, which could be a hindrance [22]. Various procedures and techniques have evolved to sort wood waste, such as online sorting (fluorescent, x-ray, laser-induced breakdown spectroscopy) or the old fashion way, manual sorting. Several research papers have not found or described an effective and cost friendly processes to separate wood waste from other impurities/chemicals that could reside in the wood waste [22]. Plastics, metals and cementitious materials could be significant percentage constituents that could remain in the wood residues, which could affect the quality for the reuse or the recycling procedure [47]. Thus, it is important to develop a competent sorting procedure to secure the quality of the wood waste for the recycling process and further use and reusage.

### 4.1.5 Demolition or Renovation Phase

The demolition sector contributes to the most of the CDWW. As wooden building materials have received a higher demand compared to a decade ago, it could be a reason why less wood

waste from demolition sites goes to waste facilities, as it becomes more reused and utilized. As wooden materials demand has increased, the request for wood can't always be meet [22], or becomes too expensive. In USA, wooden materials are utilized in building construction and stands for one-fourth up to two-thirds of the total building material [65]. Whereas projects such as deconstruction and demolition have been found to generate 10 times more general waste compared to during the construction phase [66]. During the deconstruction and demolition phase, it is often mixed material that goes to the same waste container and is not separated as it takes time, labor and energy. Or they are separated in different material categories such as a 'wooden container', 'metal container' etc. Although it does not stand of what type of wood it is for the specific container (non-treated, painted, pressure impregnated etc.), which in turn makes it harder to separate the quality and the contamination type. The same problem goes for renovation projects.

There could be engineered wood waste involved, where the quality and category could vary, which gives a challenge for the separation and sorting process [67]. Some of the engineered wood waste could also contain hazardous chemicals, which leads to an expensive and difficult process to recycle it [68]. Consequently, a lot of the material is landfilled or dumped that contributes severely to GHG and provides a negative environmental impact. By sorting the demolition waste during the process where the materials get moved from the demolition site to the waste container, it could be a way to effectively collect timber from these constructions. Components from houses could be extracted and reused in a new building that is constructed, such as doors, window frames, wooden moldings, timber beams, cladding, flooring and roofing. To guide and contribute into a successfully CE could be done by doing a demolition analysis, planning and demolish selectively by labelling threats, proper sorting, hazardous waste or untreated contamination [55, 64, 69, 70].

## 4.2 Today's management and opportunities

This section will bring up how some countries manage the CDWW and wood waste, pros and cons for the different area and which is more beneficial.

### 4.2.1 Wood waste reusage and recycling

Reusing material from wood waste and CDWW is the best way to promote as well as a cost effective and environmentally friendly of recirculation and waste management in the CE [55, 56, 71]. It has been proposed that plywood, MDF and OSB residues can be reused and reformed into tchotchke [72]. As tchotchke and decorative does not have any standard in quality, building materials does. Thereof a direct reusage of those material could be doubtful for new construction owners and not live up to these standard measurements compared to virgin materials [38]. There are exceptions on materials that are reused in construction, such as pallets, wood beams, doors, wood-frame structures e.g. window framing etc. [37]. By including and engaging stakeholder like consumers, contractors, architects, engineers, demolition, and renovation companies, they could contribute to develop a standard template for reusable material, as it could be a key to implement CE.

It is essential to reuse or recycle wood to highlight and promote for a circular economy, as well as a bioeconomy. By reuse or -recycle the wood, it could potentially take less energy to produce a product, compared to if the product was made of virgin material. It would also lessen the demand and pressure for virgin material and alleviates social, economic and environmental strain. Compared to steel and concrete, wood is highly desired as a structural material in the construction industry, such as wood beams. Off cuts does stand for a compelling percentage of the CDWW stream. These bits could be pretreated to discard impurities [73]. The remains are

later entered into a suitable recycling process (e.g., closed, semi-open or open loop, see figure 4) where a new material or product is developed.

The stream that is currently present for recycling of CDWW, is not efficient enough to provide a positive financial return, which consequently have led to that a substantial amount of material have been discarded into landfills, or worse case, illegally dumped (with no overview of the emissions that's get released into the environment) [64]. A product that contributes an extensive amount to the CDWW stream is engineered wood products (EWP) [50]. Chances are high that EWP contain CCA, LOSP, boron and lead. These chemicals are hazardous for living beings and the environment, and they are tough to remove during a recycling process [50, 68]. A few studies have recommended a cost-efficient way on an industrial scale for decontamination, where it could be implemented [67]. Recycled or reused materials from CDWW should have a standardization of the quality of the new product. In that way, the customer that wants to buy the product knows the durability and sustainability of the said product. [22].

### 4.2.2 Recovery of energy

Transforming wood waste into liquid or gaseous fuel as well as combustion is a way to maneuver the materials that are not reused nor recycled. This could in turn produce power or energy without being dependent of virgin wood [74]. There are several ways to convert waste-to-energy, such as thermochemical- and biochemical processes. Thermochemical technology uses higher temperature to constitute different chemical reactions, such as gasification, pyrolysis and incineration. Whereas the later technology uses lower temperatures to perform physicochemical technology, carbonization etc. [22]. Netherlands is one of bountiful countries that uses an enormous supply of CDWW for heat generation as well as for power plants [26]. Furthermore, Canada export roughly a million tons of wood pellets made of wood waste to EU for the same usage as Netherlands as well as hot water generation [75]. To generate steam for turbines, Scotland uses wood waste as a fuel for the boilers [76]. Using wood waste as a fuel to an electricity generator could also be a possible way. Nonetheless it is found that electricity generated from wood waste create a higher GHG emission compared to electricity made from biogas. The difference could be 55% higher emission by using wood waste. Thereof is wood waste not a recommended material to use as a fuel to produce electricity [47]. As a conclusion for an energy production in a CE concept, in order not to create more GHG emissions and pollutions more than necessary, there are opportunities of development by using wood waste as a source for electricity. Though in this day and time it is not recommended to use wood waste for this purpose. Thus, it is better to use wood waste for energy and heat generation, like district heating.

### 4.2.3 Landfill

In the case of cradle-to-grave, landfill is the final stop and hence the grave. A natural biodegradation of the wood occurs during this stage. The chemical composition of wood is mainly lignin, cellulose, and hemicellulose. These molecules are easily and quickly decomposed, except for lignin in an anaerobic environment as it can last for extremely prolonged time [77]. During degradation, carbon dioxide, methane and nitrous gases are released and contribute to the GHG emissions. As for EWW, they do contain additives that could be hazardous, such as lead-based paint, chromium or CCA, which could consistently constitute environmental poisoning as well as a threat to human health. For these reasons, wood waste is not merrily sent to landfill as the poisons from the additives are not desired to be released uncontrolled [50, 76]. To implement a CE, landfilling wood waste needs to be limited. These materials can instead be used for energy production or other reuse/recovery streams. Countries that have not banned wood waste landfills have introduced a tax on landfilling wood

waste, while several countries have already banned it altogether, such as Austria, Germany and Sweden. [22, 78].

### 4.2.4. Transportation

If a landfill is cheaper compared to a location that can recycle, recover or reuse the material, the stakeholder might potentially select the cheaper option, even if the latter is more environmentally beneficial. Therefore, the location of the recycling station plays an important role, so that it can benefit more economically to transport there [22]. Even if it is cheaper to landfill, if the distance and transportation cost gets higher compared to the recycling center, so that the total cost of transportation and reception is cheaper than the landfill, it could be more persuasive for the stakeholders to change the end destination for the wood waste. In turn, it would contribute to more secondary products that could be reused in the construction industry [22].

### 4.2.5 CDWW developed material and marketability

By reusing, recycling or practicing an energy recovery from construction or demolition wood waste, it could be recovered and used for other industries. In the circular economy concept, recovered wood products or recycled wood have different usage for the development of sustainable activities [22]. As engineered wood products have developed and progressed for a longer longevity, it has also advanced as a more environmentally friendly material. Bedding material, animal bedding material, pallets, pressed wood pellets, fibers for composite board products, EWP, and other building materials are examples of markets for reused and recycled wood. A sustainable product design must be considered and emphasized for wood waste to be included in a circular economy. As different types of wood waste can have different types of properties, qualities and areas of use [79]. There are three main areas where CDWW material can be used as a raw material, namely, materials development from CDWW research, recycled and recovered materials and lastly, innovation.

## 4.3 Environmental, economic, and social impact

This sector will bring out the environmental, economic, and social impacts that wood waste and CDWW could bring.

### 4.3.1 Deforestation and reduction of GHG emissions

As deforestation becomes a larger problem and biological diversity reduction, by reuse and recycling wood waste instead of demanding virgin wood can reduce the deforestation and the biological reduction. By reducing the consumption of virgin wood material, the emissions of GHG emissions could also be reduced. Reusing and recycling wooden materials could provide social and economic benefits as well as reduce the demand of virgin wood, [39]. It is shown in multiple research projects that carbon dioxide has increased exponentially over the last few decades. It was estimated during 2017 that the concentration of carbon dioxide was 405 ppm, and it is estimated that in 2050 it will increase to 450 ppm, and in the year 2100, 750 ppm [22]. By reducing climate change and the $CO_2$ emissions, it is beneficial to use wood waste for biofuel production as well an approach to develop a bioeconomy, as several studies have affirmed that deforestation contributes to around 20% of carbon emissions, including wood harvesting [36]. Hence, it's better to use the wood waste instead of virgin wood, if it's possible, from a deforestation view.

### 4.3.2 Climate change mitigation

There are numerous studies that imply that to lower the GHG emissions, new products developed from wood waste could help largely [80, 81]. It has been observed and concluded

from other literature that by utilizing wood waste to develop new valuable products, consumption and demand on natural resources reduces as well as it reduces the impact on the environment and the climate change [82, 83]. To increase the circulation (like in figure 4), creating new products from wood waste materials and extend as well as increase the market, less chances for biodiversity loss and the health of the forest would increase. This could be a healthy way of reducing the environmental impact as well as reduction of wood waste ending up in landfills [84]. Hence, it is recommended from the results and the literatures to use and apply CDWW for a CE, to consequently reduce the demand and pressure for virgin wood and reduce the amount of wood waste ending up in landfill [85].

### 4.3.3 Economic benefits

There is research that shows it could be economically beneficial and give an ecological benefit by using CDWW [86]. By recycling wood waste and producing new products, it has been demonstrated that there is a possibility for an economical gain and is technical feasible [86]. Opportunities becomes open for employment to enhance economic growth with the help of recycling wood waste, as it could be a low-cost material source that is renewable. Some of the materials from CDWW that end up in landfill, could potentially be used to produce products that have a value-added element [22]. This could in turn lessen or eliminate the CDWW landfilling and consequently decrease the space cost as well as landfill cost. As mentioned before the sustainability of the environment and forest reserve, by using CDWW and the government supporting a supply chain, an expanding market opportunity for new products made from waste wood could arise. This could give economic opportunities as well as enhancing a CE [22].

### 4.3.4 Social benefits

Until now, there have not been any scientific study of how the reuse and recycling of CDWW would contribute to the society. The research has focused on either the economic, environmental or both benefits. For the construction fraction to achieve a sustainable development, it requires to involve, integrate and collaborate with three significant dimensions; namely the environment, economic and the social dimension [87]. Those who participate in the construction industry are required to engage in waste management as well as give attention to economic, ecological and social perquisition and concerns. Those who are the most involved in waste management, from a social point of view, could be divided into two groups. The first group participates with the main contractors, subcontractors and the project client. These parties tend to focus and priorities the economic gain from the different projects, and less about managing the construction waste and what the benefits could be. The second group involves the public, authorities and NGOs. These parties gravitate to reduce the waste generation from construction to give a better social and environmental impact [25]. As there have not been any scientific study of how the environment in a waste management workplace could affect the long-term health for the workers, operatives' safety as well as the physical working atmosphere, it is a necessity to approach these subjects to find breaches that could potentially become dangerous. This should be developed side by side with the environmental and financial aspects to create sustainable waste management in the C&D industry [88].

## 4.4 Case study 'Åter-i-bruk' and Sobacken

This section will bring up two parts, where one part is about the company Borås energy and environment, and their facility Sobacken, as well as how much wood waste they have received and an analysis of the data. The second part will cover 'Åter-i-bruk' and their business and how they manage wood waste to have a functioning business.

### 4.4.1 Borås energy and environment, Sobacken

The company Borås energy and environment have a large facility that is responsible for all waste that the municipality and the population throw away, as well as external companies that have their operate in or around Borås municipality. They have provided data on how much and what type of wood waste they have received between the years 2018-2022, which can be seen in figure 11.

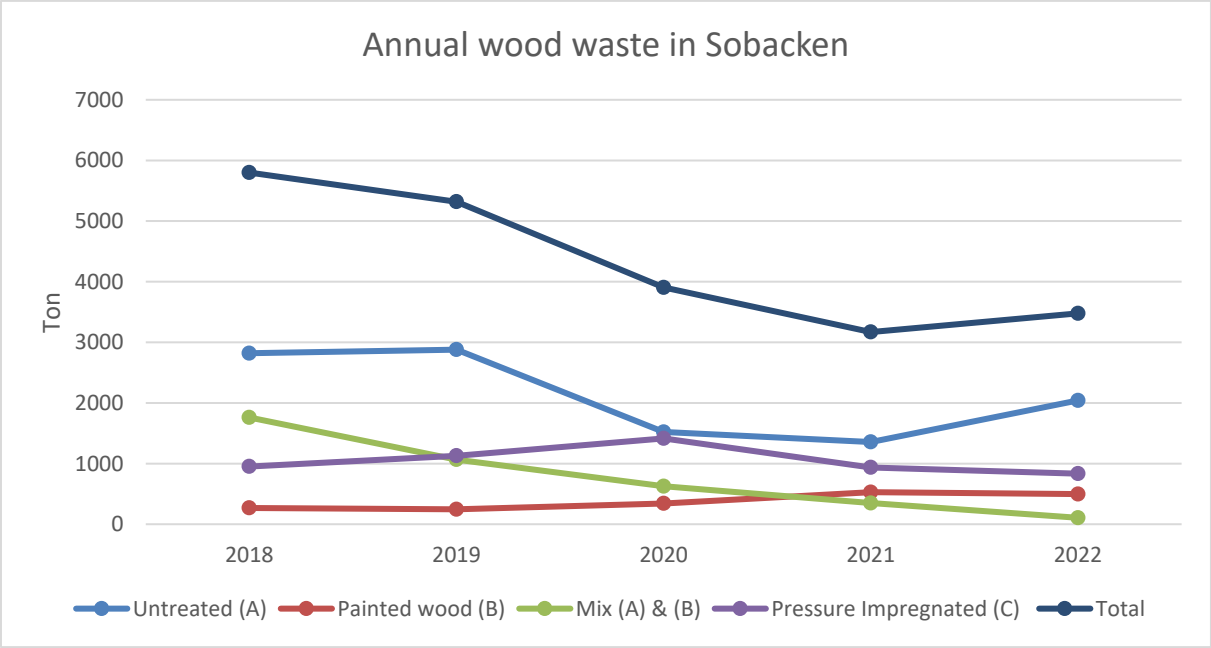


*Figure 11, Annual wood waste collected at Sobacken, Borås*

It is clearly seen that the total amount of wood waste has decreased since 2018, and a reasonable argument could be because of the COVID-19 pandemic. Many construction projects were canceled or on hold until the pandemic was over, and materials from other countries could not be transported or arrive on time. Apart from the general decreased in total wood waste, it is shown a general trend that mixed containers with untreated and painted wood that arrives to Sobacken becomes less frequent. Untreated wood has also decreased significantly, which may be for the same reason as mentioned before with COVID-19. There has been a slight increase with painted wood and pressure impregnated wood during year 2020, which could be caused by more people working and had their vacation at home. They started to make their own building projects such as building or upgrading their balcony, facade or plainly expanding their home where these types of material are used. The untreated and the painted wood which is collected at Sobacken are used as fuel to produce heat. The impregnated wood is transported to another facility for further treatment. Table 4 shows a detailed description of how much of what type of wood arrived at Sobacken from 2018 to 2022.

*Table 4, Annual wood waste collected at Sobacken*

| Ton | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Combustible (A) | 2819.78 | 2879.14 | 1521.28 | 1355.78 | 2041.3 |
| Painted wood (B) | 267.88 | 246 | 341.78 | 528.66 | 496.62 |
| Mix (A) & (B) | 1760.53 | 1065.82 | 626.14 | 349.3 | 106.12 |
| Pressure impregnated | 951.78 | 1128.28 | 1415.12 | 935.82 | 833.69 |
| Total | 5799.97 | 5319.24 | 3904.32 | 3169.56 | 3477.73 |

### 4.4.2 Åter-i-Bruk

All information have been obtained through an interview with Anders Smedberg who works as a manager in 'Åter-i-Bruk'.

"Åter-i-Bruk construction and secondhand shop" is an organization in Borås, Sweden, where their number one priority is to get people i.a. addicts rehabilitated. In this way, it gives a chance for people to become independent, return to society and get a temporary job. Thereof it was important when they started in May 2008, that the workplace was a job that contributed to society, and that the workers could see that their time and effort paid off, and not just an obligation to get a salary at the end of the month. In this regard, involving recycling and circularity became a start to give these people a job that was enriching, and contributed to the environment. The organization consists of three units, two secondhand shops and one joinery that is separated and self-sufficient. The majority of 'Åter-i-Bruk' furniture that they have in their workshops and shops, is furniture that would otherwise be thrown away from renovation site at e.g., schools and other communal premises.[2]

The first secondhand shop sales ordinary goods except for textiles and clothing's, while the second one sales material that could classify as 'building materials/equipment', such as screws, doors, windows, wood parts, equipment etc. The building secondhand was established 2016, where they first started to only have workers with disability and used the time as a 'daily activities', but later changed and now only take people who goes thru rehab or similar processes. The materials that arrive could be leftovers from construction, renovation or demolition projects. The third one is a joinery where pieces of wood that cannot be sold are reused in their carpentry, which is a separate department but interacts with the secondhand shops. The carpentry uses wood material that is not sold or cannot be sold and reuses to make new products such as cutting boards, boxes, flowerpots, flower pedestal, rolling pin (see appendix A). Everything that comes from the joinery is 100% reused wood. If they get a high quantity of one type of wood, it is sold directly in the secondhand shop. If there are many small pieces and different types of wood and qualities, it goes to the carpentry shop to create new products. Within the carpentry and the two secondhand shops, wood accounts for approximately 1/5 of all material that comes in. It has also become an increasing trend for construction companies that are going to demolish or renovate buildings to ask for a calculation of how much of the material they use, or demolish, that can be taken and resells. Then the companies can send this calculation to their environmental department and get a better corporate image.

'Åter-i-Bruk' does rarely receive large quantities of wood compared to what they received before covid-19, as it has become an increasingly expensive product and more people keep the

[2] Anders Smedberg, Manager at 'Åter-i-Bruk', interview 4th mars 2023

materials and sell them instead of giving them away for free. Though, the demand has always been great and has grown over time. Roughly 90% of all material and products they receive is picked up by them. Reasons can be deathbed, renovations, moving or outright wrong ordering of material. They pick the material from both private individuals and companies. They also collect a lot from within the municipality's organization, such as schools that are being renovated. As they don't have any 'qualification' of what material and products they accept, they could receive virgin to old materials. They have discovered a big difference in just 5 years, that more and more people who build and architects take advantage of materials that are already on site and reuse the materials in the new building. This was not common 5 years ago. There is thus a positive trend about circularity and reuse of materials. They do not take in creosote, CCA or extremely toxic treated wood, as it can be a health hazard if it is not handled correctly by the staff and the buyer. They are concerned that older material cannot be resold, even though it is in good condition because the risk of high poison levels.

This business is an exemplary example of how implementing CE and contributing to society and the environment can be. It creates new jobs, gives the opportunity for those who are not able to get an ordinary work to get a job and get more independent, and resell or reuse materials that would otherwise have gone to incineration or other lower value usage. If similar types of emerges, it can provide jobs for those who have difficulty entering the labor market, such as the young, the elderly, the sick and those who are trying to get back into society. Instead of having one large operation, it would probably be more beneficial to have several smaller ones spread out in different areas/villages. Then for those who live on the outskirts or some distance from town with poor public transport, they can still get a job or buy things that can be found second hand. It can also give a positive village feeling and togetherness, as well as a visual image that materials that you have that do not provide any benefit, provide benefit to someone else.

# 5. Discussion

In order to summarize the thesis and see if the questions have been answered, they will go thru one by one:

- Are there enough volumes of wood waste for it to be worth to reusing/recycling it?

It could be seen from the data collected from Sobacken, Borås that there is a declining trend of wood waste from the last few years. Though this could not be taken for granted that it will continue to decline, rather could be argued the opposite as the pandemic is coming to an end. Though it could happen that the same amount or less wood waste would go to Sobacken as it is today, as more companies are utilizing and collecting wood spillage (like in prefabrication) to produce new products such as wooden pellets.

- What opportunities does it provide and how can it affect society, economy and the environment?

As it is discussed in section 4.3, there is no scientific study of what kind of social benefits it could give. As for economic and environmental opportunities, there has been more research. It have been demonstrated in section 4.3 (and in other sections) that reuse and recycle wood waste would have a positive outcome and opportunities from an environmental and from a deforestation view. As a result of reusing and recycling wood, new jobs and business opportunities could emerge.

- Is it worth investing in facilities that only accept wood waste and reuse/recycle the material?

As of today, there are facilities that acccept wood for reusage or recycling purposes. Although the higher the contamination, the more expensive the treatment becomes, and in some cases, it could not be reused nor recycled. So, depending on the type of wood and the quality of the wood products, it may be worth investing in a facility that receives wood waste.

- How have the trends with wood waste been according to the data collected?

As it has been discussed earlier from section 4.4.1, the general trend in Sobacken, Borås has shown a decline over time, though it could be argued to have occurred of the COVID-19 pandemic. It should not be taken for granted that the trend will continue linearly downward, as there are possibilities that it will go up again now when the pandemic is over.

As circular economy is a big core in emphasizing recycling and circulation of materials, it will be discussed more hereafter. Having a decentralized network, as shown in figure 3, to leave wood residues would create easier access to the material and can be purchased in the local area. This in turn makes the lead times not prolonged due to the goods not being available, or it is transported from abroad and has been stopped or slowed down for unforeseen reasons. It would also become easier to collect and sort what can be reused, resell and what should be recycled into e.g., wood pellets.

By having these network locations, it will indirectly be a quality control. This can lead to increased confidence for customers to buy wood residues from CDWW and from other sectors. Depending on what area of use the customer intended to use the wood, it may not need to be of the highest quality. This also partly secures the supply of certain wooden material. By minimizing uncertainties of supply, it is possible to use wood residues found in the immediate area instead of virgin material. The risk is that the material would not be 100% pure, but on the other hand, the prices for the material can become more stable and cheaper, and thus the final price not so volatile and the customers can rely on the price.
To utilize wood waste and CDWW for new business and create new open loops, as shown in figure 4, also helps to highlight and get a more bioeconomy into the society with a smooth and soft transition. A side effect can be opportunities to collaborate with other sector and possibly create products that are wanted, such as wooden boxes, flowerpots e.g., like ‘Åter-i-Bruk’ are doing. It also helps to see which wood products are sustainable and which cannot be recycled, and accordingly determine laws and regulations to achieve a CE.

By sharing information with the end user or customer about the type of material, the origin of the raw materials, supplier certifications, supply chain impact, footprint etc., the customer can more easily see what impact the product has on the earth and thus make their choice. This can be beneficial for those companies that already share this type of information in comparison with their competitors who may not do so. The customers may suspect that they are hiding something and choose the product where the information is available. As mentioned earlier, shared information with the supplier can help with efficiency both for production, but also for the supplier. By sharing data on forecasts for future demand, the supplier can adjust its availability accordingly. If they do not have that capacity, it is possible to search in time for other partners who can deliver the missing volumes.

By having fewer and local suppliers, communication, transparency and understanding between the different sectors becomes clearer, which in turn can lead to the discovery of potential supplier problems that would otherwise not have come up for discussion. As the suppliers usually only deliver the goods, without understanding how the material will be transformed in production. Keep in mind, however, that having a larger supply network within several different regions means that alternative replacement materials or components reduce the risk of delivery errors and increase resilience in the event of reduced supply.

# 6. Conclusion

It can clearly be seen that the reuse and recycling of wood waste and CDWW can be significantly improved and has a potential gain in both economic, social and environmental terms. By emphasizing and giving the opportunity to buy wood as a secondhand form can be a way to get private people more involved in circulating wood residues. Private individuals usually do not have the same requirements for wood quality compared to construction companies, where the material must live up to a high standard and guarantee. Also depending on the accessibility of leaving wood residues, likewise, getting wood residues plays a virtual role.

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# APPENDICES

Appendix A

Flower pedestal

Flowerpots/basket

Wooden Boxes

Cutting board

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