Delft University of Technology

Master´s Thesis

Economic and Environmental Impacts of Cascading System Implementation for Waste Wood Pallets in The Netherlands

Outline for a cascaded system towards a transition to waste pallets reuse practices

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EXECUTIVE SUMMARY

In the logistics world, pallets are great features, and they are available in different types. The wooden pallet commonly used, and it is not only important in the world of logistics. Wooden pallets are present in every logistic chain of any product nowadays. As a considerable amount of them join the circulating group every year, a relevant group also leaves the chain as waste. In Europe, pallet pools take care of closing the decks' loop from a product perspective, by recovering a share and executing repair, refurbish, and recycle operations. However, despite this retrieval and immediate revalorization actions, pallets that cannot be recycled any longer, or those that do not get into the pool, are directly sent to landfills or combustion facilities for energy recovery purposes. In this scenario, the waste wood material loses its material value and gets downcycled, instead of being subject to sustainable management practices that allow revalorizing the material by reinserting it into the economic cycle and reuse it as long as its features allow it to before its final treatment as an energy source.

The purpose of this study is to determine and analyse the economic and environmental implications of implementing a circular model for waste wood pallets in the Netherlands, composed of a wood cascades system coupled with advanced biofuels production as energy recovery means. In this regard, the following main research question addressed:

"What are the environmental and economic implications of implementing a waste wood cascading system in the Netherlands with gasification as an energy recovery alternative for the production of biofuels?"

From the main thesis problem, a number of other questions branched out, that the thesis also intends to respond to these questions:

- What is the status of a cascading system and gasification of wood pallets in the Netherlands? (Chapters 2 – 3);
- What are the economic benefits and limitations of implementing a cascading system for waste wood pallets in the Netherlands? (Chapter 4, explicitly in chapter 7);
- What are the environmental benefits and disadvantages of implementing waste wood pallets as input material for syngas production in the Netherlands? (Chapter 7);
- How does the end of life and extension of use of wood pallets compare for different approaches of upcycling, reusing and gasification? (Chapters 7 - 9);
- What outline for a cascaded system can the Netherlands apply to facilitate a transition from current down cycling towards efficient reuse of waste wood pallets? (Chapter 6).

The economic benefits are accompanied by environmental benefits for the wood material industry and biofuels production. This represented by a decrease in the energy use of wood materials

manufacture, which entails a lowered use of fossil fuels by the industry. In addition, Land Use Change effects related to current biofuels production, and a decrease in the use of fresh feed by the wood industry, are some other environmental benefits of using cascaded wood as biofuels input.

The wood cascades also incentive the integration of sustainable practices in energy management, as well as an incrimination of the share of renewables within the wood and biofuels industry, adding up to a reduction of Greenhouse gases (GHG) emissions related to these activities, The performed analysis performed throughout this study points to the economic benefit of achieving growth at a micro-market level, as a result of the new economic model. This growth is embodied by the creation of new businesses, interactions, and commercial networks derived from the development of reverse logistics typical of circular chains. However, the implementation of this new model resulted to be hindered by the lack of proper action, and better structured regulatory instruments especially at middle and lower political levels.

This thesis seeks to execute a qualitative assessment of collected data from literature related to research, early implementations, and experiences from pilot-scale projects, as well as analysing the current situation of wood waste management, and biofuels production in the Netherlands. Additionally, an outline for a cascaded system was designed to lead forward the implementation of wood cascading as an end-of-life alternative for waste wood management. The outline for a cascaded system is structured according to existing policy instruments and limitations of these initiatives in coming Dutch Circular Economy scenarios.

Despite the environmental benefits of coupling both supply chains a major limitation arises, the complexity of coupling both systems in order to cover the feedstock demand of such an intensive sector like that of biofuels. The biofuels sector is composed by technologies that are still struggling with material efficiency in order to harness the largest potential per unit of material, thus in order for this system to work, it would be necessary to study different alternatives as far as energy demand, transportation and infrastructure.

From this main economic limitation that referred to previously, a group of factors is derived, related to infrastructure, material competitiveness, absence of adequate networks, communication between stakeholders, as well as missing public awareness, and for addressing these main issues and limitations, an outline for a cascaded system was structured, in order to organize the different involved elements of a cascaded wood supply chain, as well as defining the necessary interconnections that would impulse the implementation of the proposed system, and thus a Circular Economy in the Dutch wood sector.

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LIST OF ABBREVIATIONS

- PM: Particulate Matter
- CHP: Combined heat and power
- LCA: Lifecycle assessment
- LUC: Land Use Change
- GHG: Greenhouse Gas
- CSR: Corporate Social Responsibility
- CE: Circular Economy
- RED: Renewable Energy Directive
- PV: Photovoltaic
- EPV: Emballage – en Palletindustrie Vereniging
- PEFC: Programme for the Endorsement of Forest Certification
- FSC: Forest Stewardship Council
- ISO: International Organization for Standarization
- EPAL: European Pallet Association
- FAO: Food and Agriculture Organization
- ISPM: International Standards for Phytosanitary Measures
- MB: Methyl Bromide
- UV: Ultraviolet
- HT: Heat Treatment
- EU: European Union
- NL: The Netherlands
- WPM: Wood Packaging Material
- EPF: European Panel Federation
- MDF: Medium-Density Fibreboard
- OSB: Oriented Strand Board
- LAP: National Waste Plan
- MSW: Municipal Solid Waste
- MWe: Electric Megawatt
- DME: dimethyl ether
- SNG: Synthetic natural gas
- FT: Fischer-Tropsch
- ECN: Energy Research Centre / Netherlands
- MBTE: methyl-tertio-butyl-ether
- ABP: Advanced Biofuel Production
- LMC: Land management change
- EPR: Extended Producer Responsibility
- SME: Small and Medium Enterprise
- EREP: European Resource Efficiency Platform
- GPP: Green Public Procurement
- CEBM: Circular Economy Business Model
- IPPC: International Plant Protection Committee
- VAT: Value Added Tax
- VNG: Association of Netherlands Municipalities

CHAPTER 1

INTRODUCTION

An incipient circular management pallet system is starting to take over the pallets industry in Europe. Efforts are being done to augment the sustainability of the logistics business in general and it passes by repairing and recycling the decks to reinsert them into economic activities. However, an important number of used pallets do not get back in stock, and end-up being abandoned, landfilled, or sent to incineration facilities. Likewise, pallets leaving the existing circular loops, or reaching the end of their useful lifetime, are recovered and destined for mulching, or directly used for energy-generating purposes, with a few exceptions in which they are utilized as feedstock for particleboards production or composite materials. Nonetheless, the main trend consists of downsizing waste wood value, which is done without following a sustainable framework where its physical characteristics are taken into consideration to find adequate use according to such.

Current management practices, thus support the existing linear wood cycle of harvest-use-disposal, contributing to the exhaustion of the natural capital of the planet, depletion of biodiversity, and overall opposes the aim of reducing the associated carbon footprint and GHG emissions.

The implementation of a bio economy in which woody biomass plays a central role involves updating mainstream end-of-life management practices and technologies, and adapting them to the new environmental needs while supporting economic growth. The circular management of waste wood pallets coupled with more efficient and flexible energy recovery techniques represent a way to decouple economic growth from natural capital exhaustion.

This research project aims to stimulate the transition towards the development and implementation of sustainable business models in which waste wood pallets are upcycled. Consequently, their value is extended as long as the material permits. The utilization of more efficient and updated energy recovery techniques that could boost the use of advanced biofuels in the Netherlands is also explored and assessed considering its environmental implications as part of the emissions reduction targets.

Additionally, this research project also includes structuring a comprehensive outline for a cascaded system to facilitate the transition towards an efficient material use via wood cascades system, which when coupled to advanced biofuels production, holds the potential of opting for cleaner biofuels. The outline for a cascaded system was designed in a way that can be adapted to other waste materials, emerging as a novel approach at the micro-market level in the Netherlands.

The cascading system shall highlight how its implementation instigates value creation, while also serving as corporate social responsibility (CSR) initiative. Cascading of waste wood pallets would propel an image of the government, which is mindful of the public's interest and wellbeing. This way, a reverse effect can lead the process from the bottom to the top by pushing to create ultimately the required radical policy change to increase the market size and attract more active stakeholders to the emerging industry. Shortly, wood pallets can serve as a "master plan" to the total waste wood in the Netherlands.

1.1 Problem Statement

The Netherlands is determined to become a Circular country by 2050. This implies a reconfiguration of the current linear system in order to achieve this target. The strategy is described in the Green Deal, which sets the bases for the economic transition. In this sense several strategies, aligned with this initiative are being originated in order to advance on sound steps towards a new economy that would, among other things allow the country to grow in a resilient and sustainable way. This would allow the nation to be able to seize its own resources in a way that does not depend to a large extent on imports and external factors, such as raw materials shortages. This statement impels finding creative solutions and fresh approaches to build the new system upon the lessons learnt from the past, so the new approach is directly linked to environmental and economic benefits.

As wood prices are expected to rise, the expected gap between supply and demand will imply higher economic resources to cover if the bases of the economy are not adequate to the new model. This also involves that the current harvest-use-dispose practices typical of the current wood system will no longer support the growth of the wood manufacturing sector nor bio based energy. In this sense, incentives that promote the use of woody biomass for energy purposes and not for material use will be considered obsolete, especially when considering the availability of more efficient ways to generate electricity.

In the Netherlands, a few private initiatives noticed the associated value of waste wood from construction, demolition, and waste pallets related operations creating a new value chain by cascading the same material unit multiple times for diverse applications. Nonetheless, the practice is still not extended to a larger reach. Consequently, one of the main benefits for the wood sector and the micro-economy is the uncover of the potential of waste wood as raw material for upcycled woods by incrementing the material's use efficiency. Additionally, a decrease in the energy input of the sector is also attained.

Biomass is also expected to play an important role in the increasing contribution of renewable energy. The renewable energy target for the Netherlands for 2020 was set at 14% according to European directive 2009/28/EG. Within the power sector only, 10% of the final consumption in 2011 is from renewable sources of which almost 60% is produced from biomass. Dutch regulations continue giving biomass an important role in the energy transition, and it is a major player, though the perspective of use and management demands immediate reconsideration.

This study aims to answer the research question: **What are the environmental and economic implications of implementing a waste wood cascading system in the Netherlands with gasification as an energy recovery alternative for the production of biofuels?**

The main question is accompanied by the following sub-questions:

- What is the current status of a cascading system and gasification of wood pallets in the Netherlands?
- What are the economic benefits and limitations of implementing a cascading system for waste wood pallets in the Netherlands?
- What are the environmental benefits and disadvantages of implementing waste wood pallets as input material for syngas production in the Netherlands?
- How does the end of life and extension of use of wood pallets compare for different approaches of upcycling, reusing and gasification?
- What outline for a cascaded system can the Netherlands apply to facilitate a transition from current down cycling towards efficient reuse of waste wood pallets?

1.2 Objectives

This study targets wood pallets' waste revalorization by introducing a cascading system coupled with the production of advanced biofuels. The target is addressed by relying on Lansink's ladder framework, which serves as the basis for designing a new and appropriate system to manage waste wood more effectively.

The main research question targets the environmental and economic repercussions of establishing a cascading system for waste wood in the Netherlands, based on the Lansink's ladder framework and Circular Economy (CE) principles, such as feedback loops, using gasification as energy recovery step. The main objective is supported by the following specific objectives:

- Evaluate the current waste wood pallets end-of-life management practices in the Netherlands and their economic and environmental situation.
- Identify and analyse the environmental and economic benefits, as well as the limitations behind a waste wooden pallet cascading system implementation in the Netherlands.
- Identify and examine the economic and environmental benefits and limitations of deploying waste wood pallets as input for syngas production in the Netherlands.
- Explore economic possibilities for new business development in the Netherlands derived from the cascaded waste wood pallets system.

1.3 **Outline of Thesis**

The present study is structured as follows: Chapter 2 comprises an overview of the wood pallets sector, as well as a description of the Circular Economy and cascades systems principles applied to waste wood management. Chapter 3 discusses the gasification technology adapted to woody biomass, as well as the products and an overview of gasification projects in Europe and some parts of the world, as well as the production of advanced biofuels.

Chapter 4 that shown the economic perspective, That's because the circular economy permits the system to function in such a way that there is no need for fresh materials, since materials are fully recycled, Chapter 5 includes the followed methodology to analyse the available information, including data compilation and research description, as well as assumptions related to the structure of the present thesis, Chapter 6 comprises the description of the proposed outline for a cascaded system based mainly on policy instruments and studied literature to structure the novel approach. Chapter 7 discusses the insights and finding resulting from the methodology and analysis of the data found in literature and information websites. It also shows the limitations associated to the implementation of the system. Discussed and limitations are stated. Lastly, Chapters 8 - 9 reflects the conclusions of the study and recommendations for further research.

CHAPTER 2

CASCADES SYSTEM AND WOOD PALLETS

In the Netherlands, the reported total use of woody biomass increased from 1,210,000 mt. in 2014 to 1,670,000 mt. in 2017. Table 1 shows the increase in that number in 2018.

The reported growth is mainly composed of wood chips, either domestically produced or imported from Germany or Norway. Domestically produced chips come from forest, parks, and agricultural land management, 24% of which corresponds to the agricultural, food, and wood processing industry [1].

Table 1: Woody biomass market breakdown in the Netherlands in 2018 [9].

Balance of Woody Biomass (mt) in 2018 – The Netherlands				
	Production	**Import**	**Export**	**Consumption**
Other woody biomass (not pellets)	1,500,000	550,000	350,000	1,700,000
Wood pellets	5,000	400,000	250,000	155,000

The segmentation of the Dutch biomass industrial market is structured as follows [1]:

- Large – scale use of pellets for co-firing with coal to produce power.
- Biomass plants operating only on biomass for the generation of power and/or heat.
- Biomass plants using only biomass for the generation of industrial heat or steam.

2.1 Wood as a renewable resource

In the European context, forest biomass plays a relevant role to achieve the proposed 20% share of renewables as established by the Renewable Energy Directive (RED). However, when comparing wood as an energy source with other types of renewables, two main factors pop up: efficiency and sustainability. From an efficiency perspective, biomass lies below other power generating alternatives with higher efficiency and lower economic costs, such as wind or PV technologies, or even fossil natural gas [2]. Nonetheless, from a social sustainability perspective, biomass systems contribute in a higher extend than other electricity generation systems, due to benefits like jobs creation [3] given its longer supply chain.

In 2010, the total area of forest in the EU27 was over 157 million hectares, equivalent to around 38% of the land area [4]. Moreover, the theoretical biomass potential from European forests in that same year accounted for 1,277 M m^3 per year, including stumps and bark. Out of this figure, the actual domestic use reaches up to 543.7 M m^3. The forest industry is segmented into the pulp and paper industry and the wood industry (sawn wood, panels, other). Wood from trees used in the wood industry accounts for 260.6 M m^3. Additionally, 208.8 M m^3 are incorporated in the energy sector [5].

These figures show that the amount of consumed wood nowadays is so large that the forest areas and their quality are deteriorating. It also shows the pressure the market exerts on forests, due to population growth and increasing wood consumption. In this regard, forests are being exploited without considering the biodiversity loss and forest area reduction consequences.

Monoculture has been put on the table as one of the sustainable biomass solutions, thus it does not contribute to the environmental services of natural ecosystems and native forests. Monoculture forests do not have the CO_2 processing capacity as natural ones, the natural equilibrium is interrupted and the carbon cycle is not carried on as in native forests. In other words, by cutting and burning older trees, the stored carbon uptake is released in a short period, breaking the carbon cycle, and therefore an increase in carbon emissions is attained [6].

2.2 Pallets' overview

Pallets are flat structures that serve as a stable support for goods while being transported, stored, or lifted by forklifts or pallet jacks. They constitute the backbone of global product transportation, making them abundant and ubiquitous. It is estimated that only in Europe there were around 4 billion pallets in circulation in 2016 [7], [8]. Although lately alternative materials and techniques are on the rise, around 90% of pallets are still manufactured from timber [9][10].

Pallets are included within the wooden packaging sector (crates, boxes, and industrial packaging), which includes manufacture and repair operations. The total amount of wood used for the industry is more than 1 million m3 of softwood, mainly sourced from Scandinavia and Central and Eastern Europe [10].

85% of the production volume comes from about 45 suppliers united in Wooden Packaging and Pallet industry Association, with about 70% of the total market volume being produced by four large suppliers, all members of the EPV [10]. According to the association website, all EPV members hold Certificates of Custody from PEFC or FSC.

The theoretical average lifespan of a conventional wooden pallet, like that shown in Figure 1, rounds 5 – 7 years [7], [11], although if properly maintained and repaired can last up to 10 years [10].

Figure 1: Image of a common wooden pallet

- **Dimensions**

In general, there are no universally accepted standards for pallet dimensions; companies utilize different pallet sizes based on their needs, proposed load and transportation method.

The International Organization for Standardization (ISO) consents six pallet dimensions detailed in ISO Standard 6780. In Europe the most common size is 800 x 1200mm that holds the EPAL brand. As the Netherlands is the focus of this thesis, the attention focuses to the European perspective of standards and current situation of wood pallets in Europe.

- **Manufacturing**

There is not a fixed type of wood for pallet manufacturing, yet there are several factors that determine the type of wood used, such as geographic location (country of origin), applied load, wood price and availability, competition with other higher-value wood applications. Durability or robustness are independent properties from the type of wood used in pallet manufacturing. Instead, they rely more on the overall design [12]. Moving onto the European standards, the terminology of the EPAL 1200 x 800mm looks as shown by Figure 2.

Shortly, the standard 1200 x 800 mm EPAL consists of 11 same height and different-sized boards distributed as covering, flooring and crossing boards, 9 wooden blocks (logs) with 2 different sizes and 78 nails (convex ring type) with 3 different lengths.

This terminology complicates the dismantling process for a further recycling or reuse of the pallet, due to the presence of the long steel nails distributed across the pallet.

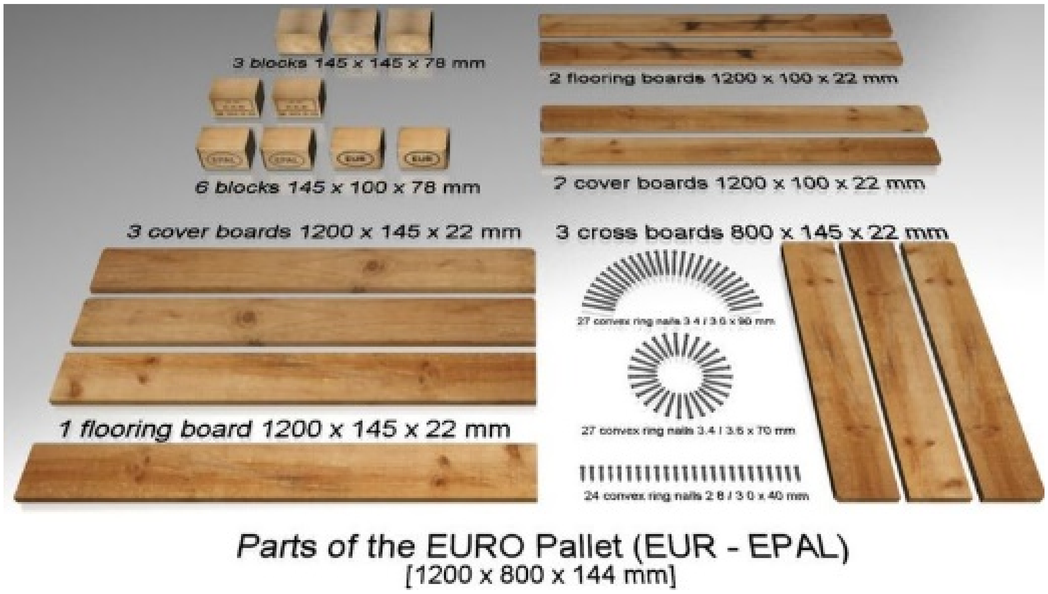

Figure 2: Features of a pallet under European standards [22]

- **Materials**

In general, 2 types of wood are used, hardwood and softwood. Softwood is cheaper, given that it comes from more abundant, accessible and faster-growing trees, like Pine and Spruce. Hardwood, like that of Oak, is more expensive, given its higher density and the possibility of cutting thinner boards to achieve the same level of strength as with softwood. Hardwood is used in pallets that require heavier loads capacity [12].

Pallet blocks are mainly produced from chipboard wood or wood particleboard, which are weaker than plywood but good enough to produce pallet blocks. The wood chipboards are originally made of forestry residues, the bark of trees and other low-quality biomass types not suitable for higher-value applications, while pallet boards are made from tree trunks in most cases [13].

- **Wood treatment**

Pallets are generally exposed to less sanitary environments than those where the goods have been packed and prepared. This makes pallets a sensitive medium for pest transferability [14].

To avoid biological contamination and invasions, the Food and Agriculture Organization (FAO) has established the International Standards for Phytosanitary Measures (ISPMs), among which is the ISPM 15. This standard specifies the "Regulation of wood-packaging material in international trade''. This standard states that the wood used in international transport of goods is only allowed to circulate if it has undergone prior phytosanitary treatment [14], [15]. The ISPM 15 technical regulations, force all EPAL licensed production, reuse and repair operations to comply with the standard since 2010[16].

The two types of treatment are: Fumigation with methyl bromide and heat treatment.

Fumigation with Methyl Bromide (MB)

Methyl – bromide is an odourless, colourless gas used to control a wide variety of pests in agriculture and shipping, like fungi, weeds, insects, nematodes and rodents. The substance quickly dissipates into the atmosphere and it is detrimental to the ozone layer, allowing increased UV radiation to reach the surface of the earth. When burned, it produces highly toxic and irritating fumes (bromides, carbon oxobromide, carbon dioxide and monoxide). Human exposure to high concentrations of methyl bromide can cause the central nervous system and respiratory system failure [17].

Environmental and health hazards caused MB banning since January 2005 in developed countries and the end of 2015 in developing nations, in alignment with the Montreal Protocol [15]. Nonetheless, although the chemical was phased out, the danger of contaminated pallets with MB is still alarming, due to the time gap banning between developing and developed countries [18].

Heat treatment

The heat treatment (HT) process is considered to be natural, environmentally friendly and implies inserting the pallets in a drying chamber for at least 30 minutes, making sure that the core temperature of the wood reaches at least 56 °C during that period [19]. Heat treatment is known as an effective method to control non-native pathogens that put foreign forests in a vulnerable position.

Figure 3 shows the stamp that is frequently found on pallets and the information it contains. In this case, the "HT" sign indicates that it is a thermally treated pallet.

In April 2013, the FAO approved wood treatments based on dielectric heating, where the temperature rise is done by submitting the wood to microwaves or radio frequencies produced in industrial ovens [15].

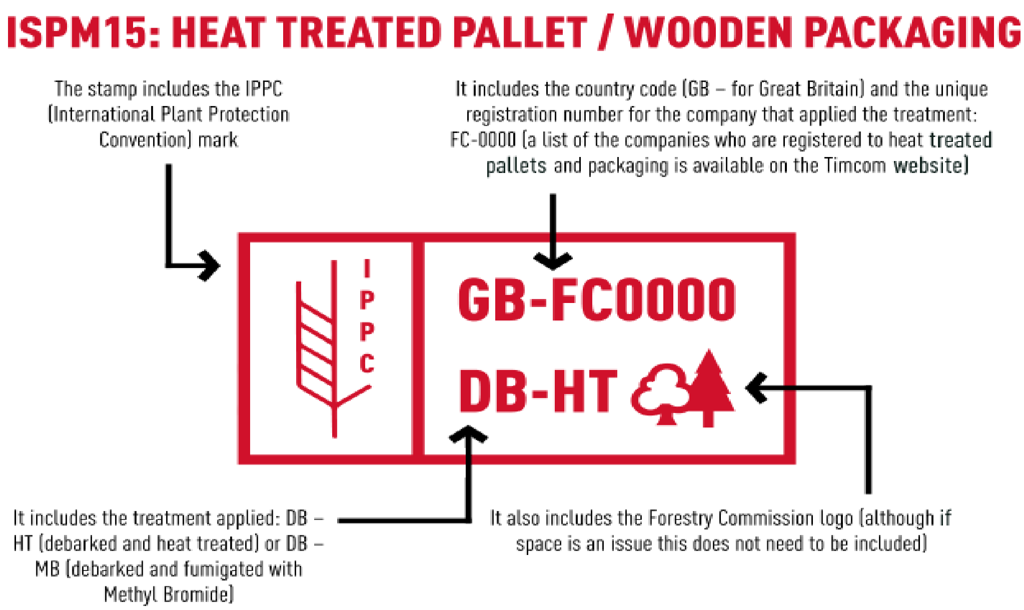

Figure 3: Relevant information included in the pallets stamp [30].

2.3 Pallets' lifecycle, management alternatives and current practices

In general, the lifecycle of a pallet considers the different phases of materials, manufacturing, transportation and use, refurbishing, and end–of–life disposal [20].

The real-life expectancy of the pallet determines the environmental impact of the operation since it regulates the type and number of refurbishing operations. The lifespan is a function of the pallet structural design, as well as the service environment conditions, among other factors [20].

The lifecycle of a pallet varies across companies and industries, is dependent on particularities of business practices along the entire supply chain and the transported product, as well as the overall pallet management strategy. The pallet lifecycle and current different end-of-life management strategies and loops shown in Figure 4.

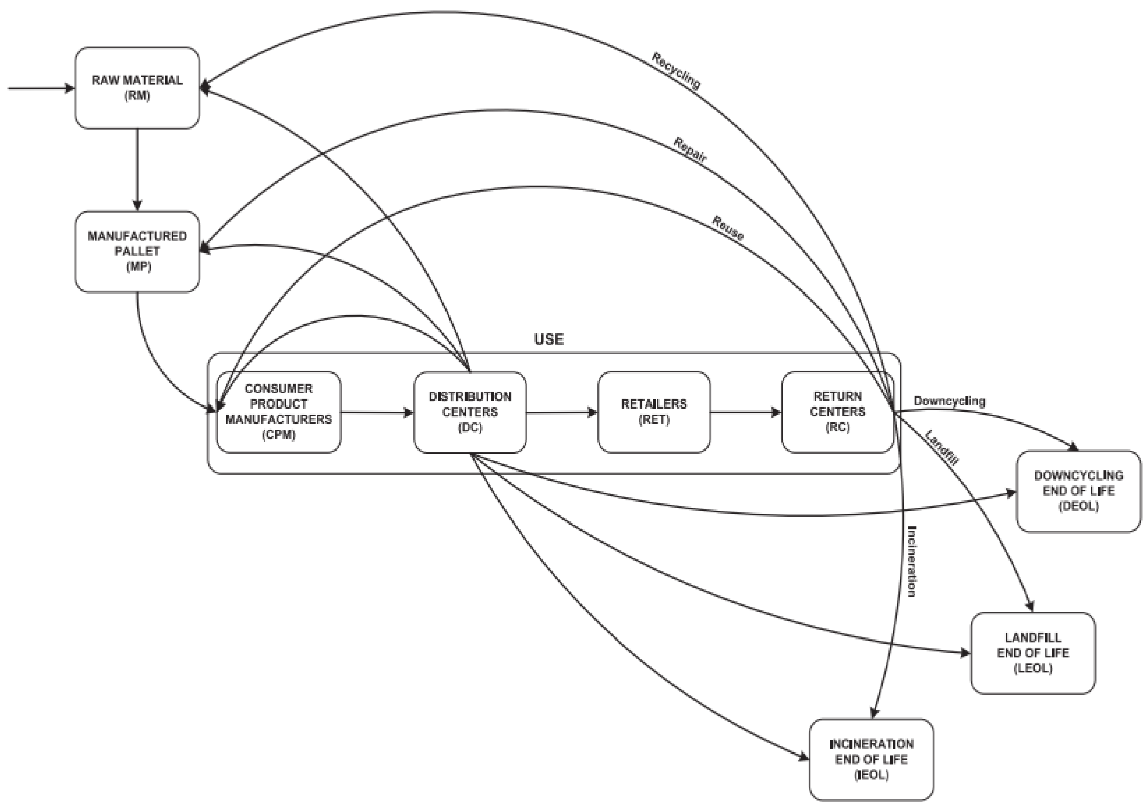

Figure 4: Lifecycle of pallets [2]

During the manufacture of wooden pallets, a certain number of residues are generated. Some companies simply use it as heat generating fuel, whereas other companies sell it to the panel board industry. At the end of their useful life as wooden pallets, materials are collected by waste collection companies that separate it into A-wood (clean waste wood) and B-wood (painted, lacquered and glued wood). Most of the wooden packaging waste classifies as A-wood [10].

The amount of recycled wood from the wooden packaging sector is self-monitored. Until 2005 this amount increased steadily to 39%, but it declined down to 30% in 2011. This decrease in wood recycling was due to a large portion of the same, around 50%, being destined for energy generation, pushed by the incentives directed towards its use for energy production [10].

- **Pallets wood waste down-cycling**

For pallets to be reused and recycled, it is critical to know from which type of wood they were produced, hard or softwood. However, pallet producers are not able to specify which type of wood was used to make the deck, since it is usually a mixture of hardwood and softwood species. In order to allocate pallets within the cascade's steps, it is crucial to know which type it is made of.

Currently, pallets mulching and combustion with energy recovery purposes represent a way to seize pallets' waste wood. However, considering the material's lifecycle, these alternatives are considered as down cycling, a practice that ultimately cuts off the value of the material.

The issue with down cycling practices is mostly related to the fact that many times the physical features of the waste materials allow them to still be used for different applications of higher benefit, such as furniture, flooring, wall covering, or novel wood composites. Economic analyses done in the furniture manufacturing industry point to the origin of raw materials as one of the most significant attributes to obtain a green product with lower emissions[109].

On the other hand, down cycling pallets involve further energy and resources investment to carry them related to transportation and post-processing facilities, i.e., where it will be finally incinerated for heating, drying or power generation purposes[4] [9].

2.4 Management strategies according to utilization

2.4.1 One-way pallets

One – way pallets strategy is an open loop that covers single-use expendable pallets. They are not expected to go back to the distributor or manufacturer, for which there are no established means for their recovery after use, and cover 50% of the total pallet production. They are less sturdy than those intended for pallet pools [10], and are widely applied in the white line appliances retail business, where the ownership of the pallet is transferred to the end-user with the product purchase. It is quite probable that the deck ends up in a landfill or given a brief use before being discarded [20], although they might also be repaired and reused [10].

These types of pallets have around 5 – 6 times higher overall weighted environmental impact compared with pooled pallets. This is due to factors like the amount of land required for timber production and steel manufacturing to cover a fixed number of trips by one option and the other. On the other hand, a key benefit of wooden pallet disposal in landfills is the long – term CO2 storage previously removed from the atmosphere by trees during growth [21].

Although one – way pallets show the highest environmental impact of all different pallet strategies, it is the least costly of all [22].

2.4.2 Pallet pool exchange

Many European industries smartly utilize what is known as the European Pallet Pool. This comprises an established agreement system between manufacturers and businesses that deal with the replacement, exchange, or repair of used pallets [23].

Pallet pool strategy includes the use of closed loops in two different systems: leasing or buy/sell programs. Leasing programs allow clients to access pallets through a contract with a pallet-pooling provider. This provider is also in charge of collecting pallets downstream for further repositioning at some point upstream in the supply chain. Pallet pooling relies on a return network of depots that collect, inspect, sort, repair and backhaul empty pallets [20].

- **Pallet Leasing**

Pallet pool leasing strategy involves three different parties: the transport company as intermediate consignee, the driver who transports the consignment and the recipient of the unloaded goods. The process consists of trucks with empty pallets going to a loading location and exchanging the empty pallets for those already loaded with the goods to be transported. Once the driver delivers the loaded pallets, the same number of empty pallets is received in return at that location [24].

The European Pallet Association (EPAL) runs the European Pallet pool. It currently manages around 450 million EPAL Euro pallets and 20 million box pallets in the open exchange pool. It holds more than 1,500 licensed production and repair operations in over 30 countries, with 14 EPAL National Committees and 3 EPAL representatives [25]. According to the association, every single EPAL Euro pallet reduces the planet's carbon budget by 30 kg, due to their practiced multi-uses global exchange system [25].

The euro pallet exchange system includes the following countries: Belgium, The Netherlands, Luxembourg, Germany, Austria and Switzerland. If by any case, pallets with the EPAL mark on their side leave this sector of the EU into a different country, there is no pallet return guarantee back into the area and it is automatically considered as lost [26].

In the Netherlands, the Faber Halbertsma Group is not only a pallet manufacturer, but they also repair and reinsert them into the cycle through a pooling loop for several industries, like high rotation goods, petrochemical and fresh foods companies [27].

In the last years, the pallet exchange agreement faced some issues given the crescent number of counterfeit pallets coming from Ukraine entering the system. According to EPAL, this number rises to 4 million units [28]. In this regard, the immersion of false EPAL pallets into the system makes it difficult to ensure their quality [28].

- **Buy/sell Strategy**

Buy/sell strategy is an approach that consists of selling pallets to customers in local depots or recycling facilities. There, pallets are also repaired, reused or destined for proper disposal [20]. This program mainly focuses on reusable higher-grade wood stringer pallets. These are sold, transported with products through the supply chain, and finish being purchased by a local pallet management facility to be repaired, reused or recycled [29].

Pool allocation

The allocation of pallets amongst the different circles of the loop in Figure 4 depends on their condition. Smaller repairable damages are fixed and the pallet can be used again. If the damage is severe making the pallet no longer usable, they are inserted into the recycle loop. Overall, the longer they remain in use, the more sustainable they become.

Pool limitations

The main obstacle to the wood pallet recovery is the incurred prices during the process. Those include the collection, transportation, wood examination, wood repair works and finally advertising and selling procedure prices. This leads to small and medium-sized businesses not turning to pallet pooling entities, due to the increased accessing cost. In this case, the least costly option of one – way pallets are preferred. Consequently, many pallets end – up in landfill or incineration facilities.

Issues like this contribute to pallet system loss. It has been reported that the annual loss rate of pallets circles 10%, pointing to the necessity of implementing advanced strategies like the use of radio – frequency identification technology for pallet tracking and management [30].

2.5 Pallets management in the Netherlands

In the NL, two of the recycling companies N.M. Heilig B.V. and Hein Heun, include a wood waste recycling line through which waste pallets are also managed. Heilig B. V's website, clearly states that their recycling units contribute to the reduction of wood waste by renewable energy production, pointing to waste wood down–cycling alternatives for electricity generation [31]. The same story is also read in the Hein Heun Groep website, which classifies the waste wood according to the Dutch legislation in three types and assigning a different destination according to the wood category. A – wood, which is used as a raw material in the chipboard industry, while B and C wood types are processed into secondary fuel for biomass plants [32].

Current actors on the Dutch pallet market are the manufacturers and wholesale traders, business clients and pallet pool organizations, and waste to energy-related actors.

2.6 The waste hierarchy or Lansink's ladder

The waste hierarchy, shown in Figure 5, is formed by six different categories of waste management. It aims to maximize the efficient use of natural resources by reducing and adequately managing waste streams. The ladder is composed of the following steps [33]:

1. **Reduce:** Quantitative and qualitative prevention and avoidance of waste by reducing and minimizing waste supported by replacing pollutant products with biodegradable alternatives.
2. **Reuse:** Reduce waste by reusing products and materials by implementing techniques such as up cycling.
3. **Recycling:** A long process where disposed items or waste materials are sorted collected and processed to manufacture a completely new product. It is the preferred option when waste cannot be reused.
4. **Energy:** This stage is known as waste-to-energy conversion. Materials are burned and lost forever in the energy-generating process.
5. **Incineration:** Another form of burning waste materials but without energy recovery. Its purpose is to dispose of waste and prevent it from being dumped on landfills.
6. **Landfill:** A site where waste is buried in the ground without generating energy, with heavy pollution consequences and precluding the reuse of materials.

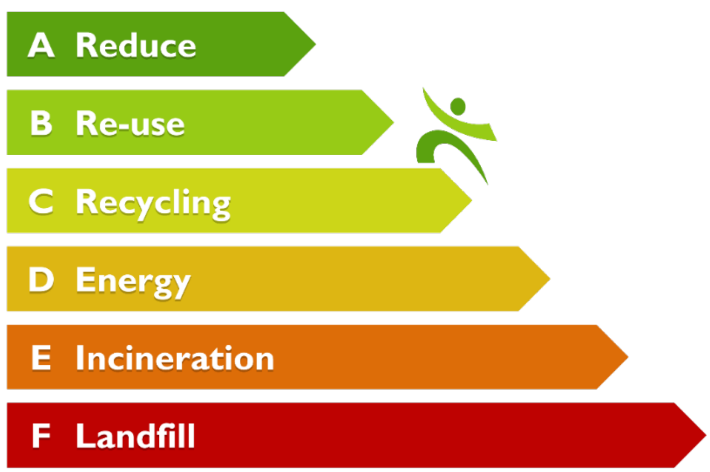

Figure 5: Waste hierarchy or Lansink's ladder [50]

2.7 Circular Economy and the wood industry

The world currently consumes over 100 billion tonnes a year of global resources, with a circularity negative trend of 8.6% for the year 2019, a value that previously reached 9.1% in 2018. From that global number of resources, biomass, composed of farming and forestry materials, takes about 24.6 Gt per year. Three key facts are related to the circularity negative growing trend: high rates of extraction, ongoing stock build-up and low levels of end-of-use processing and cycling [34].

The Circular Economy concept embodies a closed system comprised by processes that do not exchange flows with the outside environment, while also extending the added value of products for as long as possible. In turn, this leads to potential waste elimination by multiple use of the same material unit along the cycle to create further value [35].

The Ellen MacArthur Foundation extends the concept of Circular Economy to a restorative and regenerative system by intention and design. This implies re-designing products under the premise "made to be made again" and the use of renewable energy to power the system. An illustration of a system based on Circular Economy principles is illustrated in Figure 6.

The concept is built on three principles [36]:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

In Europe, the concept is promoted through the Circular Economy Package, part of the European Green Deal, which encourages the implementation of adequate waste management practices as central element. The process involves following the Lansink's ladder shown in Figure 5, established within the EU Waste Framework Directive (2008/98/EC). This waste hierarchy gives priority to waste reduction over preparation for reuse, recycling and energy recovery to disposal [35]. The energy recovery is stated as appropriate only in the case that waste cannot be prevented, reused or recycled with less GHG emissions [37].

The graph in Figure 6 shows the different flows upon which the Circular Economy is built. It is structured by two different cycles: the bio-cycle and the techno-cycle, fed by "Feedback loops" that ensure the continuity of the system's operation. This occurs by re-feeding the different cycles with valuable waste from the same process, or adequate waste streams from other processes [38]. These dynamics by-pass the need for fresh materials' extraction at current rates.

Wood is sorted in the bio-cycle, along with food and water. In this cycle, energy production from biomass breaks the material into minor components that are turned back to nature for soil restoration. This means that the system must be re-fed with fresh material at some point, whereas coming from nature or as adequate waste from other processes.

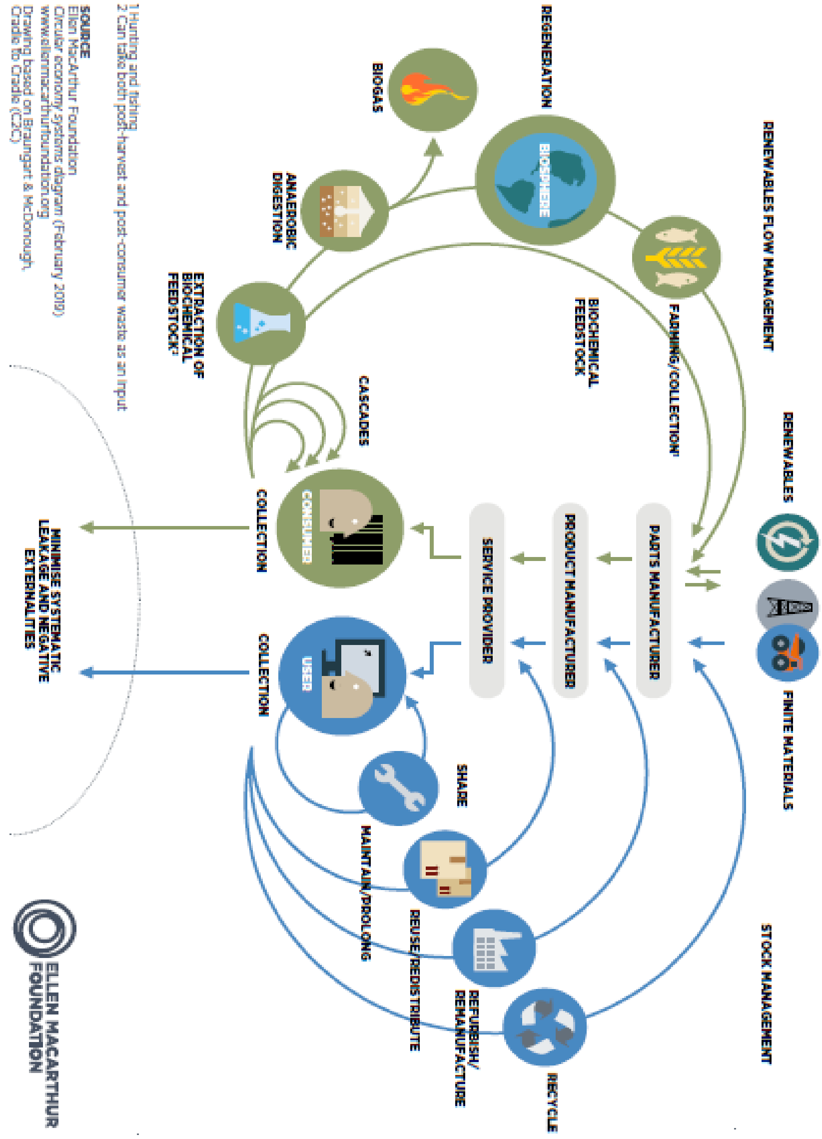

Figure 6: Circular Economy Diagram and system flows [47]

2.8 Cascades system definition and wood cascading

Many publications have shown different definitions of cascading. Sirkin and Ten Houten (1994) define it as "a method for optimizing resource utilization through a sequential re-use of the remaining resource quality from previously used commodities and substances" [17].

Fraanje (1997), Dornburg (2004) and Arnold (2009) described the usage of a resource in several phases during certain intervals of time, defining cascading as a complex interaction of material flows and their utilization in different streams, material cycles and incorporation into diverse cascade chains [11]. Morris (2015) described the cascading use of biomass as an "optimized co-production" to create the most optimal value of resources. On the other hand, Mantua (2012a) described wood cascading as the "multiple uses of the wood resources from trees" by availing the residues and recycling material. Hoglmeier et al. (2013) refers to cascading as the idea in which more productive use of resources is attained. For example, a piece of recovered timber can be used in products of higher quality with greater dimensions, rather than cracking it at the recovery stage.

The principle of cascading use of biomass comes from the forestry sector and it was proposed aiming to maximize resource efficiency and GHG emissions reduction [39]. The concept relates to the Circular Economy in the sense that it induces to the sequential re-use of the same unit of a resource for multiple high-grade material applications, followed by a final use for energy generation [40] as seen in Figure 7. Thus, the cascading principle applies the ideas of the circular economy, promoting the reuse and recycling of products for higher-value uses, and lastly for energy purposes when other options are not viable.

Vis et al. (2016) defined cascading as an effective resource utilization technique that can be achieved through recycling of materials of the total biomass availability present in the system. The study observed that the cascaded use of wood mainly consists of converting wood into a product, and using that product at least one more time for either energy purposes or material usage. According to Kammerhofer (2012), the word cascading is applied to biogenic resources such as wood that are used sequentially and possibly repeatedly: first for material usage and application, and ultimately for following energy applications. From an environmental perspective, the longer the sequential cascading process takes, the longer the wood products can store carbon within them.

Wood cascades shows an alternative in which wood's duality as a material can be covered with a sustainable use, by first covering its material use and lastly for energy purposes. Increased wood cascading, thus could reduce harvest pressures of forested ecosystems. It replaces fresh wood demand through post-consumer waste recovery, and creates a time extension for the same resource. Subsequently, forest biomass carbon stocks remain intact [39], [41], and [42].

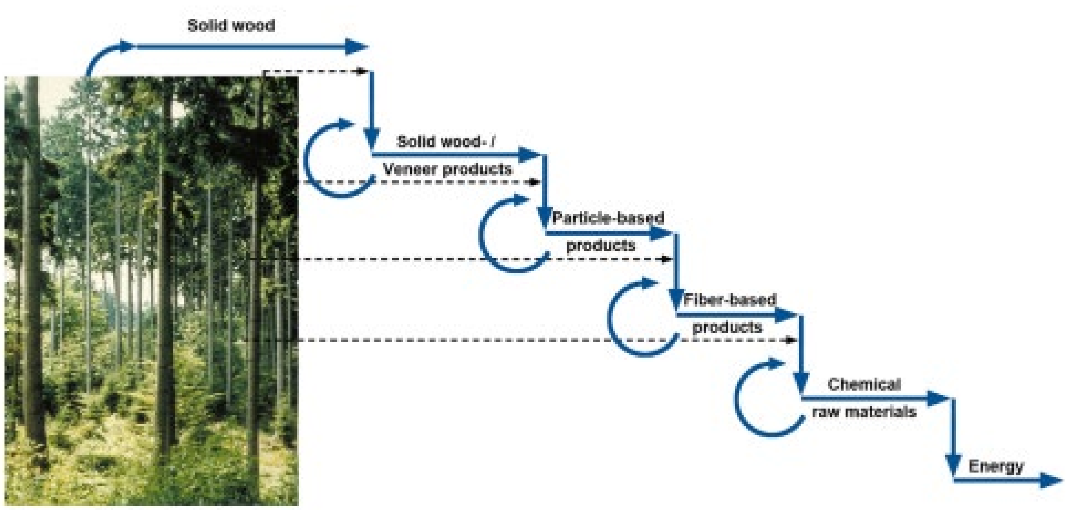

Figure 7: Cascading use of wood to improve resource efficiency [53]

2.9 Wood cascading in the EU

In Europe, about 17.3 Mm3 is used in the Wood Packaging Material (WPM) sector, representing 17% of the EU sawn timber production and embodied by around 3000 companies. Out of that WPM share, 75% accounts for wooden pallets.

In 2017 members of the European Panel Federation (EPF) signed the Venice Declaration along with the European Furniture Industries Confederation (EFIC). The EPF has members in 25 countries and represents the manufacturers of particleboard, MDF, OSB, hardboard, soft board and plywood. It counts for up to 5000 enterprises in Europe [43].

The agreement establishes the principles for the Circular Economy and sets the path for the continued collaboration and contribution of the wood-based panel industry in Europe. Amongst other things, it aims to balance the pressure on wood availability, create a level playing field by removing market distortions, enhance the role of wood in the circular economy and create a market pull for wood products. Within its market distortions removal, the Venice Declaration agreement considers banning the financial incentives for woody bioenergy. This principle aligns with Lansink's waste hierarchy, in which energy recovery purposes lies at the bottom of the possible processes for which wood is an asset. However, there is still a need for greater synergies, so the use of wood for products is highlighted as prime use instead of energy [39].

In terms of a wood cascading system, three different market levels are conventionally identified [40]:

- The market as a whole, encircling all the interrelations within, e.g., the wood market.
- The submarket level, which bases on product groups, e.g., wood panels.
- The manufacturing level, that separates semi-finished products, such as particleboard,
- from finished products or final use, like cabinets.

A graphical explanation of this cascading system shown in Figure 8:

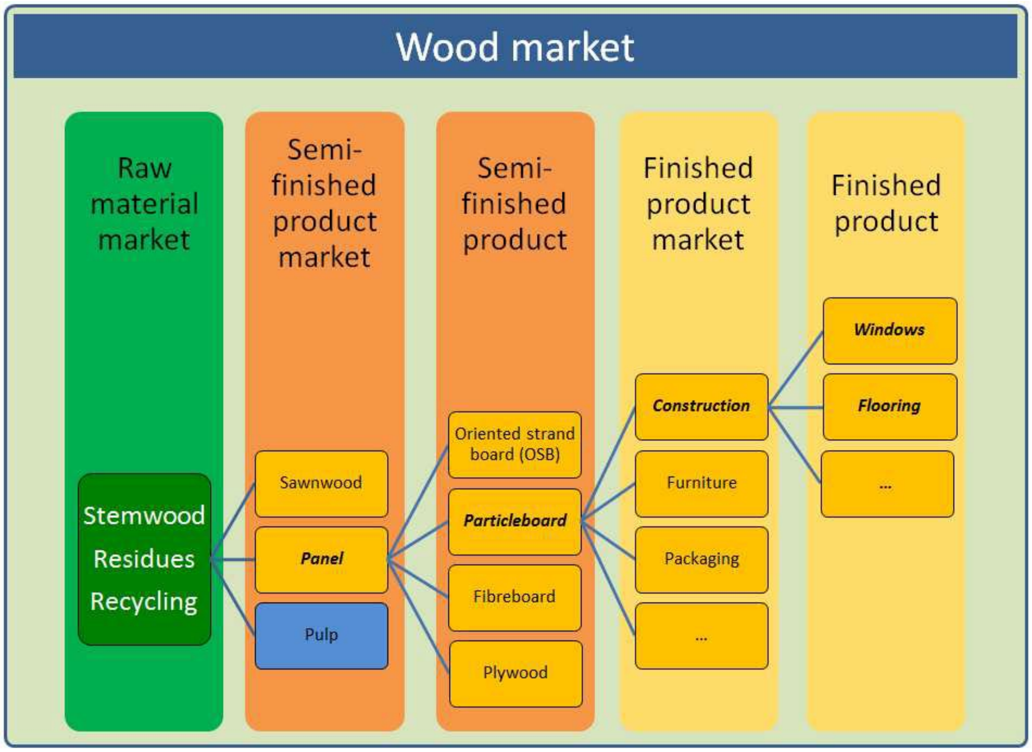

Figure 8: Wood market structure and cascades in EU28 [52].

Considering the categorization of the wood market shown in Figure 8, it recognizes the following situation in the European wood cascading potential [40]:

- Semi-finished products sector uses residues and recycled material, but only provides residues.
- The supply of recycled material takes place after consumption of the finished products sector.
- The sawn wood sector limits only to the use of round wood, yet provides a significant amount of residue material.
- The particleboard industry utilizes residues and recycled material but results in no residues. This is so far the current industry using post-consumer wood in considerable amounts, with a share rounding 30% out of the utilized resource.
- The pulp industry is both a consumer of recycling and residues and a provider of recycling material.

Being this the overall perspective for the wood cascading system, most of the wooden pallets circulating in the EU hold the potential to be cascaded.

It has also been recognized that the potential of different countries to transform their economy into one with high cascade rates depends on several factors, such as the availability of forest resources, the size and performance of the wood industry as the provider of residues, the population and economic strength of the country for the consumption of wooden products and paper, and the relation between material and energy uses [40].

Figure 9 shows the relation between the total volume of provided and used material for cascading (residues, recycled material of wooden products). Countries highly industrialized with small forest resources and strong wood industry, use residues and recycled materials and show high provision and utilization rates. The Netherlands stands as the country with the highest wood utilization rate. Given the high subsidies given to biomass-based energy, it is most likely that a big share of the provided wood is being used for energy purposes [40].

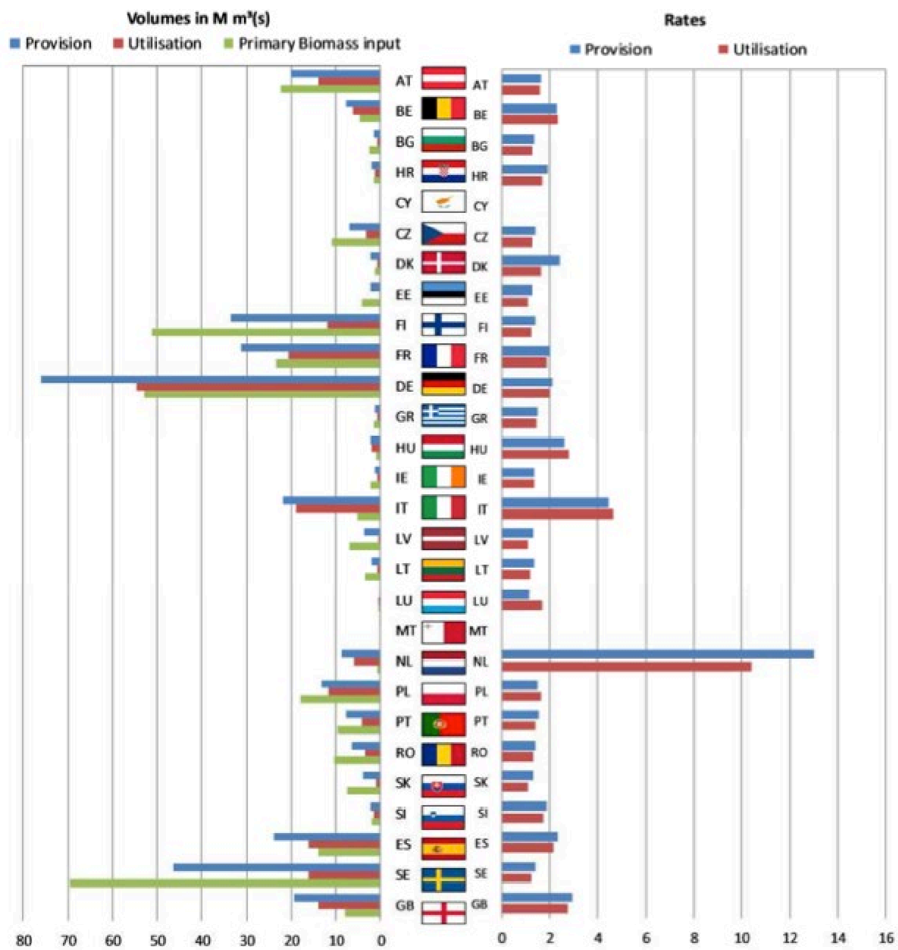

Figure 9: Provision and utilization volumes and rates of cascading materials in the EU [52]

2.10 Legislation on wood waste management

In the Netherlands, the wood demand is covered by imports. Although the country produces half of its consumed round wood, half of it is also exported. Wood pellets are the main source of solid biofuels consumed, most of which are imported [44].

In the Netherlands, the Dutch National legislation, following the European directive on packaging and packaging waste, endorses producers and importers of packaged products responsible for the prevention, collection and recycling of packaging waste. The legislation is extended to companies producing and trading packaging products in the first instance and to those responsible for removing the packaging on import [45].

Wood products are subject to the EU Timber Regulation since March 2013, except for waste. The latter applies to residual timber products that have completed its lifecycle and would otherwise have been discarded as waste. However, this exemption does not apply to by-products from manufacturing processes involving material that has not completed its lifecycle and would otherwise have been discarded as waste [37].

Dutch Legislation, through its National Waste Plan (LAP), classifies waste wood into three types:

- A – wood: unpainted or untreated wood;
- B – wood: not falling under category A or C, including painted, varnished and glued wood;
- C – Wood: impregnated wood, treated timber where sometimes certain substances are pressurized into the wood to extend the lifespan of the material [37].

The same LAP gives a minimum standard for processing all three categories and emphasizes on recovery when it comes to A- and B- wood. The recovery operation considers retrieval of material, products and main use of waste as a fuel or other means to generate energy. Also, important to remark that the Netherlands gives no preference between the options [37].

The new Dutch waste plan LAP3 promotes the use of reclaimed wood with the minimum standard of "useful application by material use". It is stated that in case the minimum standard for a waste material is not technically possible to meet, the restriction is displaced to "any useful application".

In this regard, the LAP3 introduces an important step by defining the concepts of by-product and end-of-waste themselves. By this new addition, it encourages the implementation of the Circular Economy and Cascading system to achieve the intended circular economy target for 2050 as part of the European Green Deal.

The previous LAP2 waste management plan weighted the use of waste wood for energy or up-cycling purposes as equal alternatives [10]. The Dutch wooden packaging sector took a relevant role by forcing the government to ban energy generation from wood packaging waste that could instead be up-cycled. However, the low demand from the particleboard industry (the main application for reclaimed wood), and increasing renewable energy subsidies are some reasons constraining the Dutch waste cascading system.

2.11 Concluding Remarks

A cascades system intends to extend the life of the same unit of material for as long as its features allow it to. This case is especially interesting for wood in the Dutch context, given its high dependence on wood imports for the furniture and bio based energy industry.

Pallets operation on its side, count on a circular management system known as pallet pools, in charge of reinserting damaged pallets into operations by execution of certain material recovery tasks, such as refurbish, repair and recycle of decks in bad-shape. However, despite this recovering cycle, a stream of wood residues that are not always seized is generated.

In the Netherlands, these streams are retrieved by recycling companies, yet only a few shares of the recovered material are upcycled and the rest is sent to energy-generating facilities. In this case, this operation is done without following any sustainable path, such as that established by the waste hierarchy, despite it being stated by waste management legislation instruments.

Transforming the Dutch economy to Circular, requires the application of sustainable practices such as wood cascades, in order to keep the materials within the productive cycle for as long as possible, thus diminishing the amount of fresh input necessary to keep the market going.

CHAPTER 3

GASIFICATION

Gasification is a thermochemical conversion process that consists of the degradation of carbonaceous feedstock at high temperatures, resulting in intermediates products like bio-oils or tars, and final products like syngas [46]. Apart from the liquid and gaseous products, solids are also generated in a lower extent as carbon, char and ashes [47]. Char is a mixture of unconverted organic fractions and ash [48]. These gasification products are especially useful in the energy and chemical industries, amongst other possible applications.

Overall, gasification consists of several overlapping sub-processes, such as drying, pyrolysis and partial oxidation, or incomplete combustion of organic materials [46]. This thermochemical transformation yields a producer gas or syngas mainly comprised of a mixture of CO, H_2, CH_4 and CO_2. Other components of the gas are light hydrocarbons like ethane and propane, and heavier hydrocarbons such as tar-oil [48], [49].

In brief, the overall gasification reaction represented by [46]:

$$\boldsymbol{Biomass \rightarrow CO_{(g)} + H_{2(g)} + CO_{2(g)} + CH_{4(g)} + Tar_{(l)} + H_2O_{(l)} + H_2S_{(l)} + NH_{3(g)} + trace\ species} \quad \textit{Eq. 1}$$

When historically compared to combustion, the process is relatively new, and its applicability is not restricted to biomass. Since its deployment in the fossil industry, it has been widely used for coal processing, management of petroleum residues, municipal solid wastes, and another carbonaceous feedstock [48], [50].

Figure 10 shows a flow diagram of a gasification process.

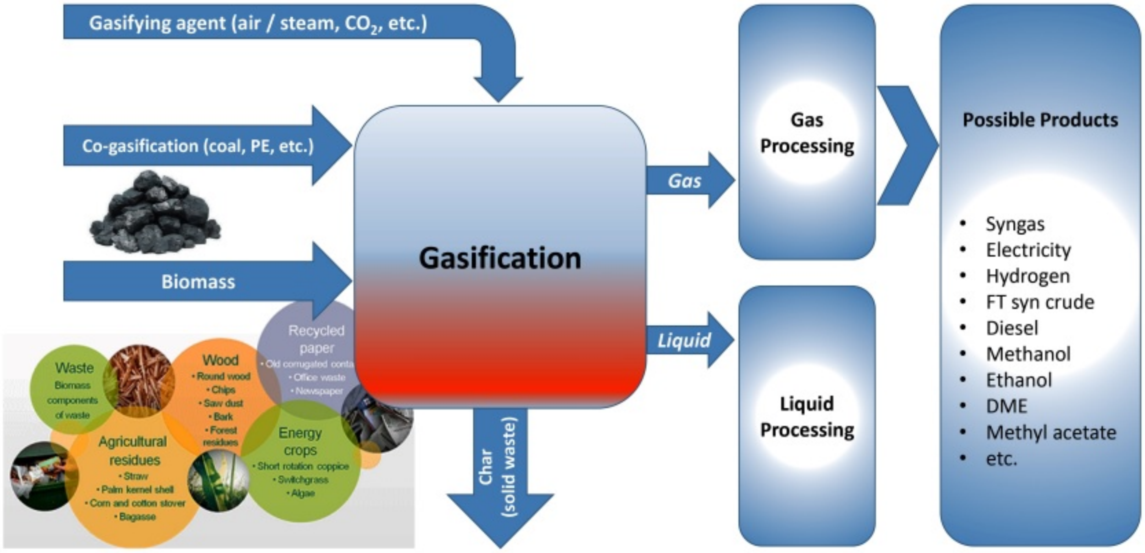

Figure 10: Typical gasification system for power generation or chemical production [61]

3.1 Technology Overview

Gasification holds the advantage of being a flexible technology with regards to the feed, as shown in Figure 10. Raw biomass of all types suits as gasification feed; wood, agricultural and herbaceous biomass, marine biomass, human and animal waste, contaminated and industrial waste biomass, and/or a combination of all these [46]. This flexibility gave gasification its extended use in the different industries for waste revalorization. Gasification can convert them all together into high-valued synthesis gas (Syngas) that can be used for various applications downstream [50]. The quality of the resulting syngas depends on several factors such as feedstock material, gasifying agent, design of the reactor and catalyst, as well as the operational conditions of the gasifier [48].

Gasification shows an inclusive alternative to process certain residues which transformation downstream is still a challenge, given the number of resources their transformation could carry. Lignin-rich streams, a common waste of bio refineries and other biomass handling processes, is a special case for which gasification shows an alternative to increasing its benefit. It embodies an economic and environmental sustainability key issue for these industries to deal with. Traditionally, lignin is burned for heat or electricity production on-site, lowering its benefit. On the other hand, the gasification of lignin-rich residues offers the potential to produce higher-added-value products, such as liquid fuels and chemicals [51].

The process occurs in the presence of a gasifying agent, which combined with heat decomposes the feedstock into the mentioned products. Traditional gasification agents used in this technology are air, oxygen, steam, carbon dioxide, supercritical water, among others. Overall, oxygen, steam carbon dioxide and supercritical water gasification result into syngas with higher heating values than with air as a gasifying agent. Nonetheless, air is the most commonly used agent, given the low-cost of air, the readiness of reaction and simplicity of the gasification reactor [52].

The gasification process takes place in a reactor called gasifier, and its design and operation can affect the reactions, processes and products. These reactors can be classified into three main groups according to their operation: Fixed bed gasifiers, fluidized bed gasifiers and entrained flow gasifiers [50]. Additionally, various gasification methods have emerged and been further developed, such as plasma gasification and gasification in supercritical water of wet biomass, aiming to convert different feedstock to gas products [48], the supercritical water gasification can handle materials with moisture up to 95% [53].

Currently, the most conventionally used types are fixed and fluidized beds, although the entrained bed is also gaining interest in applications. A review of 50 gasifiers manufacturers around Europe, the U.S. and Canada showed 77.5% of the designed equipment are fixed bed type, 20% are fluidized beds and 2.5% were entrained flow gasifiers [52]. Figure 11 shows a sketch of these equipment technologies.

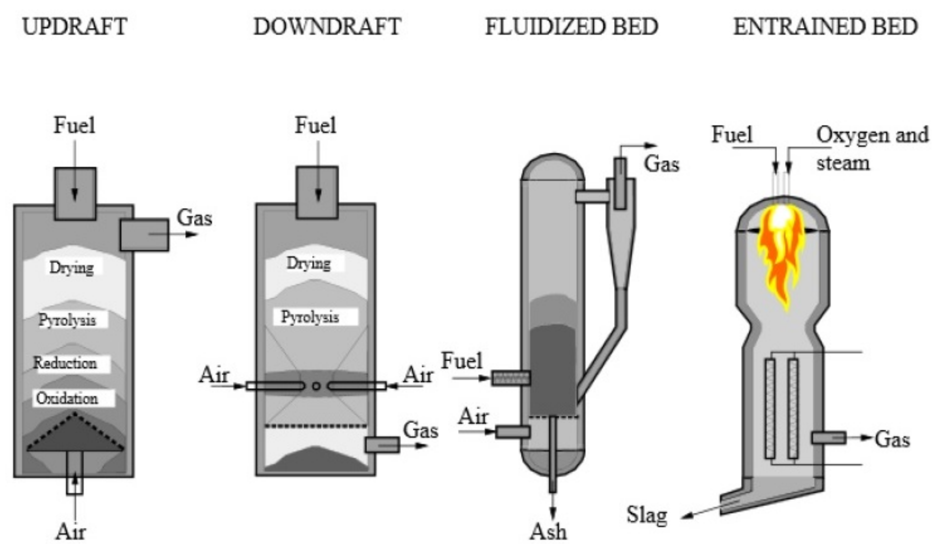

Figure 11: Conventional gasification technologies [61]

A graphic summary of the distinct features and variable operations of each gasifier shown in Table 2.

Table 2: Characteristics of different gasifiers [65]

Gasifier	Characteristics
Fixed bed	(a) Small capacities (0.01–10 MW)
	(b) Can handle large and coarse particles
	(c) Low product gas temperature (450–650°C)
	(d) High particulate content in gas product stream
	(e) High gasifying agent consumption
	(f) Ash is removed as slag or dry
	(g) May result in high tar content (0.01–150 g/Nm^3)
Fluidized bed	(a) Medium-size capacities (1–100 MW)
	(b) Uniform temperature distribution
	(c) Better gas–solid contact
	(d) High operating temperature (1000–1200°C)
	(e) Low particulate content in the gas stream
	(f) Suitable for feedstocks with low ash fusion temperature
	(g) Ash is removed as slag or dry
Entrained flow	(a) Large capacities (60–1000 MW)
	(b) Needs finely divided feed material (< 0.1–0.4 mm)
	(c) Very high operating temperatures (> 1200°C)
	(d) Not suitable for high ash content feedstocks
	(e) Very high oxygen demand
	(f) Short residence time
	(g) Ash is removed as slag
	(h) May result in low tar content (negligible)

Choosing one technology or the other depends on the biomass feedstock characteristics, such as moisture, particle size or density, inorganic content (ash) and toxicity, as well as the amount of biomass to be processed.

Gasification as a technology also shows certain limitations, mainly centred about technology. The technical barriers and needs shown in Table 3.

Table 3: Technical barriers and needs relating to the commercialisation of biomass gasification and syngas [78]

Technical barriers	Technical needs
The more established gasification systems require high quality, homogeneous feedstocks in order to operate reliably and efficiently. Entrained flow gasifiers have strict specifications relating to particle size and moisture. Fluidised bed gasifiers are susceptible to agglomeration of the inert bed material by molten ash (or slagging) which reduces performance and availability.	Robust gasifier performance with industrially relevant biomass feedstocks *i.e.* that meet an achievable specification. Alternatively, use of more flexible gasifier designs able to handle mixed feedstocks, such as plasma gasifiers.
Most downstream processes require a high-quality syngas, and therefore the raw syngas must be cleaned to remove dust, alkali metals, halogens, sulphur, tars and potentially CO_2. This process usually means the crude syngas must be cooled, cleaned in a variety of different steps (such as filtering, reforming, quenching, polishing), and then compressed and heated before final use. These changes in temperature and pressure can impact capital costs and increase energy demand.	Integrated processes optimised for energy efficiency, or the use of syngas clean-up technologies that operate at high temperatures in order to avoid large changes.
Technical challenges facing some systems	**Technical needs**
Some gasifier systems produce high tar levels, which can clog heat transfer equipment and pipes when they condense during cooling processes (fouling). This leads to increased corrosion and erosion, higher maintenance requirements to avoid pipe blockages or reduced performance.	Robust performance of the integrated gasifier and gas cleaning, and correct design to minimise fouling.
Fluidised bed gasifiers produce a relatively high fraction of hydrocarbons (methane, ethylene etc.) This reduces the process conversion yield for some processes and may increase the size of the downstream process units.	Efficient production of high-quality syngas by optimising the gasifier operating conditions.
Some gas cleaning processes (specifically low temperature processes such as water scrubbing) produce significant volumes of contaminated waste water.	Processes optimised to minimise the environmental and economic impacts of effluents, or installation of waste water treatment plants.

3.2 Gasification of Biomass

The thermochemical conversion of biomass via gasification offers an effective method to obtain combustible gases (CO, CH_4, and H_2) through partial oxidation using air/oxygen as a gasifying agent. But also, biomass can be thermally transformed using steam to produce a gas with a high H_2/CO ratio [54].

Thermochemical processing of biomass via gasification holds the benefits of being a cleaner transformation path and the most effective technology for the production of hydrogen, biofuels and high-value chemicals from syngas [55]. Research points to biomass gasification having the potential to twist how biomass is seized. In the case of this study, gasification provides wood waste the possibility of being enhanced as a cleaner energy source, while at the same time providing equal or superior benefits than combustion technology.

Around 80% of the commercial and operating biomass gasification facilities run on woody biomass (wood chips). In Europe, specifically, most of these operate for power or combined heat and power (CHP) production purposes. On the other hand, the production of biofuels from biomass gasification is mostly found around the U.S. and Canada, as shown in Figure 12: Commercial, demonstration and pilot-scale share and distribution of biomass gasification facilities [68]. These facilities centre their efforts to the production of ethanol from woody biomass and Municipal Solid Waste.

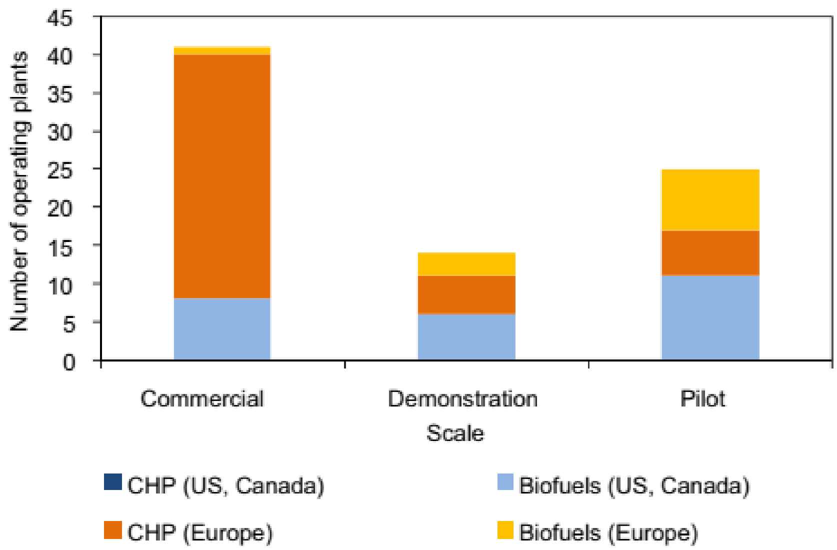

Figure 12: Commercial, demonstration and pilot-scale share and distribution of biomass gasification facilities [68]

3.2.1 Syngas processing for advanced biofuels production

The production of biofuels from syngas can be done by Fischer –Tropsch process or fermentation of syngas. The petroleum industry has relied on Fischer-Tropsch processes for the production of several fuels from coal, therefore, the technology is more mature than the biochemical pathway, add to that the higher efficiency it shows.

Fischer-Tropsch (FT) for liquid biofuels

This process is well known and applied by diverse countries in the world given its application in the coal industry. It allows converting the solid fuel into other types of energy carriers, mainly diesel fuel and jet fuel. However, the process is easily applicable to biomass-derived streams, and in essence, it bases on the potential for CO to exchange oxygen with hydrogen in the presence of a catalyst [56].

Product output distribution is affected by temperature, H_2/CO ratio in the feed gas, pressure, used catalyst type and composition [56]. Thus, depending on these operating conditions, product stream composition will vary from methane to higher molecular paraffin and olefins [50], as shown in Table 4. The unescapable generation of a wide range of hydrocarbons, like olefins, paraffin and oxygenated products make the FT process applicable for the production of a variety of products, like gasoline and diesel. FT diesel shows the advantage of being superior to conventionally refined diesel in terms of higher certain number and low Sulphur content. Following this thread, FT products apart from low Sulphur, are also free from nitrogen and metals [56].

Table 4: Range of fuels produced via the Fischer – Tropsch process [12]

Product	Carbon number
SNG (Synthetic Natural Gas)	C1-C2
LPG (Liquefied Petroleum Gas)	C3-C4
Light naphtha	C5-C7
Heavy naphtha	C8-C10
Middle distillate	C11-C20
Soft Wax	C21-C30
Hard Wax	C31-C60

Fermentation of Syngas

Syngas fermentation is a novel route to transform gaseous CO_2, H_2, and CO rich streams into fuels and chemicals. Lactogenic microorganisms that convert syngas to alcohols, organic acids and other chemicals in anaerobic conditions execute the process. Now, ethanol is the most important bio-product that is generated during syngas fermentation [57], [58].

Figure 13 shows the overall process for the integration of gasification and syngas fermentation for the production of alcohol and other chemicals.

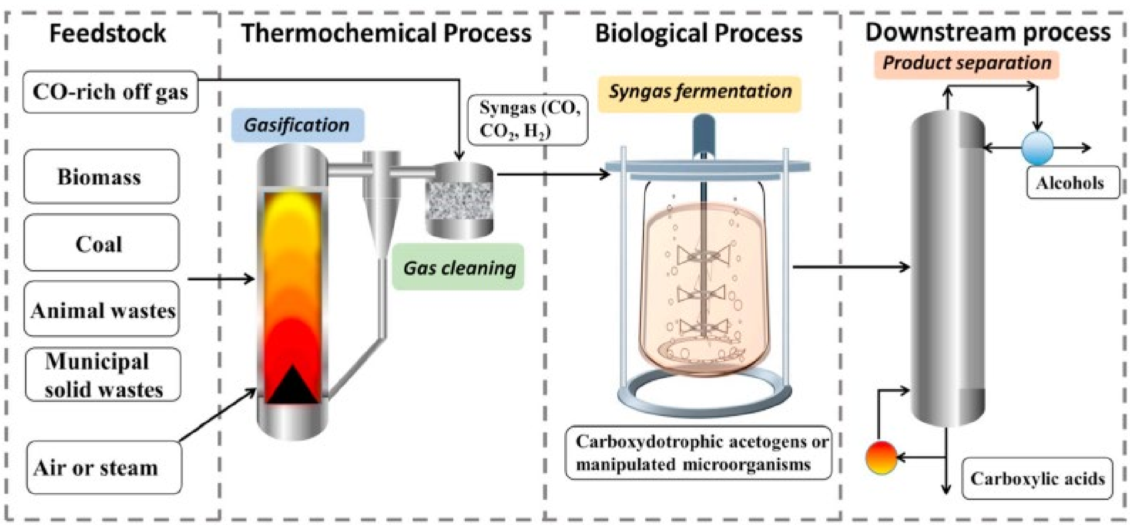

Figure 13: Schematic diagram for the integration of gasification and syngas fermentation processes for conversion of CO-rich gas into alcohols and carboxylic acids [68]

Syngas fermentation microorganisms are divided into monocultures or mixed cultures, according to their performance. These microorganisms lead to obtaining alcohol such as ethanol and butanol, as well as other substances of economic interest for the chemical industry such as acetic acid, butyric acid and hexanoic acid. Mixed cultures also show the potential to produce alcohol and other chemicals.

From an economic perspective, successful industrial-scale syngas fermentation operation requires flexible integration of various feedstock and robust processes that withstand variable syngas quality. LanzaTech, a collaboration of private investment and the U.S. Department of Energy-Pacific Northwest National Laboratory, produce aviation fuels via syngas fermentation combined with catalytic conversion of ethanol to jet fuel [57].

3.2.2 Biofuels from Syngas

As mentioned before, syngas is a flexible feedstock in which production can be customized according to the used feedstock and different operating conditions to be used as a building block for the production of different biofuels.

Bio-Synthetic Natural Gas (Bio-SNG)

Bio-SNG production from Syngas embodies an interesting way for biofuels production, given that the existing Natural Gas infrastructure, distribution means and sales are the same as that used for methane, and they are already present in many parts of the world [59].

Bio-SNG consists of gas with around 95% content of methane with similar properties to fossil natural gas. The production of Bio-SNG via catalytic gasification of biomass exhibits high feasibility given its low cost for methane production [60], and overall conversion efficiency from biomass up to 70% in energy basis [61].

Hydrogen

Hydrogen generation embodies the most important use of syngas nowadays. Despite crescent interest in its use as biofuel for mobility, it is mostly used for ammonia and methanol production, and it is mainly produced via steam methane reforming in the fossil industry. For this reason, although hydrogen is a clean burning energy carrier, its production is not always as clean as its use-phase because of the important amount of emitted CO_2 [62].

There are two main routes for hydrogen production from biomass, thermochemical and biological pathways. Of these two, thermochemical processes are found to achieve higher energy efficiency and hydrogen yield, posing biomass gasification as a financially viable hydrogen production option [63].

Although electrolysis has taken over as a clean way to produce hydrogen, gasification has been widely used for hydrogen production in large quantities. Hydrogen as a transportation fuel covers a range of diverse vehicles inland, maritime and aeronautic mobility, and it offers an alternative to electric vehicles and biofuels [64].

On the other hand, hydrogen can also be utilized as enhancing chemicals for the production of other synthetic fuels, such as green gasoline via methanol or bio-SNG [65].

Ethanol (EtOH)

Ethanol is one of the oldest and most given attention to biomass-derived fuels. It has received considered attention as a potential gasoline substitution or alternative, to the current point of being blended with gasoline in transport applications. This popular practice arose as investigations proved a reduction of GHG emissions when fossil gasoline is combined with this biofuel, but only in the case of such being of second generation [46].

Apart from the thermochemical pathway, fermentation of syngas also shows a viable way to produce ethanol. This technology combines the gasification step with a following syngas fermentation step in which acetogenic organisms convert the gaseous feedstock into ethanol.

Dimethyl Ether (DME)

DME is one of the most valuable derivatives of MeOH given its wide applications in paints, agricultural chemicals, cosmetics, etc., but in the area of the fuel, it can be used as a diesel substitute. DME is also an intermediate product for the production of high-octane gasoline.

DME can be produced via 2-stage synthesis using MeOH as intermediate or by direct synthesis from syngas. In terms of conversion, more DME is obtained via direct synthesis, reaching up to a 95% conversion of syngas to DME.

Methanol (MeOH)

It can be used as an H2 carrier, fuel or platform chemical for the production of other substances [55]. In the field of transportation, MeOH is seen as a potential substitute for automotive fuels, especially gasoline, given its previous use for this purpose before gasoline increases its popularity [46].

Methanol can be produced by natural gas reforming, which is the primary method, or as a by-product in Fischer-Tropsch synthesis.

3.3 Gasification in the Netherlands

The Energy Research Centre of the Netherlands (ECN) has been working on gasification technology and processes for some time now. The institution has developed the MILENA gasification technology, capable of converting biomass into synthetic natural gas with high efficiency, low N_2 content and no need for an O_2 separation plant. The technology consists of indirect gasification in a fast fluidized bed, and combustion of the remaining char with air in a separate bubbling fluidized bed [66]. A sketch of the technology shown in Figure 14.

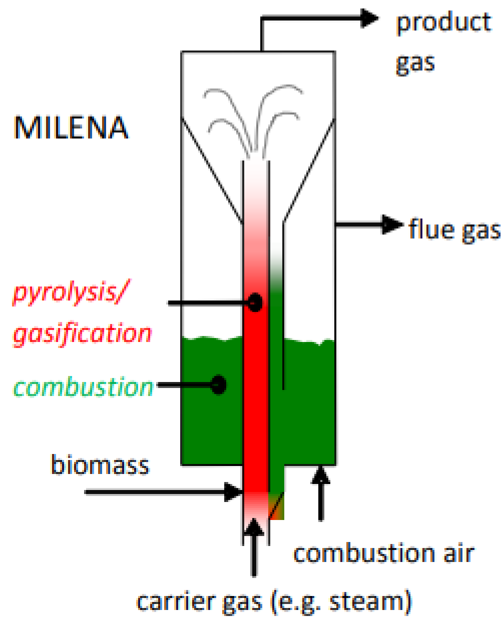

Figure 14: MILENA indirect gasifier with a gasification reactor surrounded by a combustion reactor [3].

ECN along with Royal Dahlman, Gasunie, local and regional government, as well as several other companies started the Alkmaar 4 MW bio-SNG demo project from woody biomass. The core of the plant is composed of MILENA gasification technology and OLGA tar removal technology, combined with ESME methanation technology, both also developed by ECN.

The project was also initially joined by HVC Alkmaar, a local waste incineration company, which later withdrawn from the project due to market developments. The project, which construction began in 2015, expects to produce 2.6 million m3 / year of SNG to be injected in the local natural gas grid [66].

After the development of the MILENA technology for bio-methane production, the technology has expanded its range of applications. The company Dahlman is offering a commercial size Bio-CHP plants based on the mentioned technology with capacities of 2 – 4 MWe.

Additionally, and regarding commercial applications of gasification technology beyond demonstration plants, the Canadian company Enerkem in alliance with the Port of Rotterdam, the Amsterdam-based chemical company AkzoNobel, and Air Liquid have embarked in the construction of a large gasification project for the production of methanol from Municipal Solid Waste (MSW). The project aims to the sustainable production of methanol with the best environmental profile in the market. The new project will gasify 300,000 tons of waste a year, producing more than 200,000 tons of methanol [67].

The AkzoNobel vision of the process shown in Figure 15.

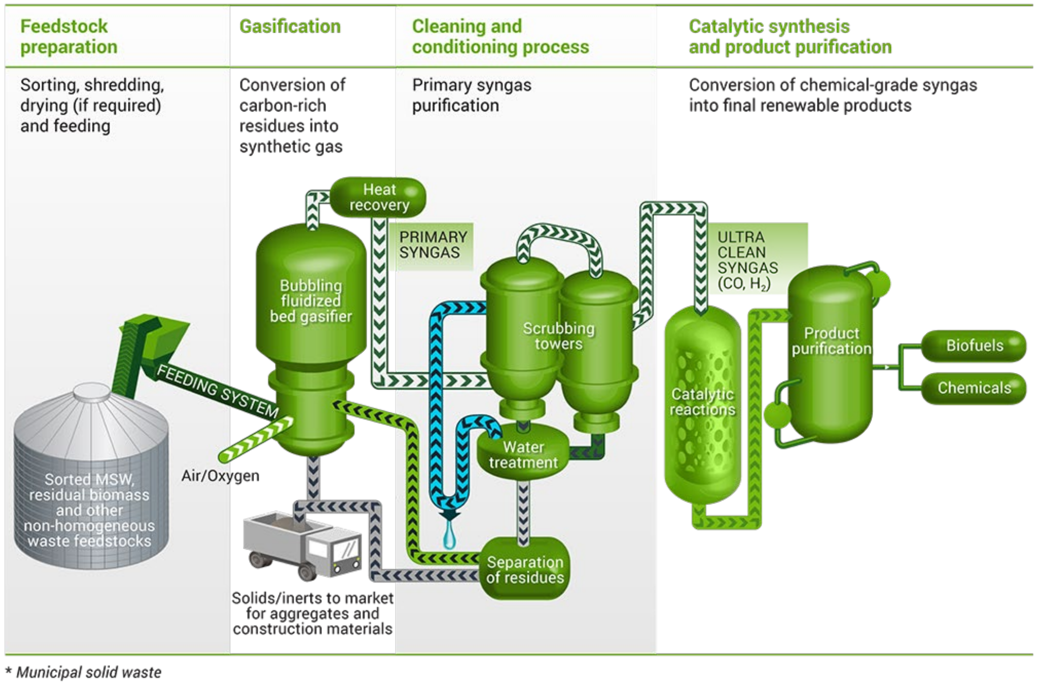

Figure 15: AkzoNobel gasification process of MSW in the Port of Rotterdam process flow [80]

The gasification industry in the Netherlands is not new, but still lacks some maturity to drive forward the number of active and large-scale projects, most of them are still on pilot scale, this reflects the numerous hinders in front of a wide implementation of the technology. The main obstruction represented by a structural misalignment between the institutional framework guiding technology development and the technical requirements of the technology [68].

A major outstanding feature of these projects is that they are innovative and show high efficiency and integration rates, especially when it comes to the development and integration of the MILENA technology with post processing and methanation stages, still deployed at pilot scale.

- **Main Take-outs**

Gasification is a thermochemical process that allows to play with different feedstock types to produce a gaseous stream called producer gas, a solid stream composed by ashes and bio-char, and a liquid stream comprised of tar-oils. The producer gas is cleaned and turned into “Syngas” which allows to produce a number of biofuels, such as Bio-SNG, hydrogen, methanol, ethanol, DME, among others. These are produced via Fischer-Tropsch or fermentation processes.

The technology is already being used in different parts of the world as method to process MSW and produce biofuels. In Europe, wood gasification is mostly used to operate CHP facilities, whereas in places like the U.S. and Canada, it is used to produce biofuels. Particularly, in the Netherlands the technology has been researched on and developed in ECN. Some companies offer it commercially for CHP applications, but it is taking an important leap in operations thanks to the construction of a large-scale MSW treatment facility being built in Rotterdam for the production of Methanol.

CHAPTER 4

ECONOMIC AND ENVIRONMENTAL PERSPECTIVES OF CASCADES AND ADVANCED BIOFUELS - LITERATURE REVIEW

4.1 Economic view of a wood cascades system

From an economic perspective, the circular economy permits the system to function in such a way that there is no need for fresh materials, since materials are fully recycled. Yet, for this scenario to become real, the way products are designed and produced would have to allow them to be completely recyclable at every level [34].

The economic implementation of wood cascading displays some influencing factors, which according to some studies resemble those affecting the implementation of a Circular Economy model [69]. From a pure economic perspective, economic competitiveness, market risks, and financial mechanisms appear to exert a large influence in the implementation of cascading and circular models [69] – [71]. In addition, existing waste wood and energy regulations, as well as resource policies play a role within the implementation of the new economy.

Jarre et al. (2020) sort the barriers and benefit of implementing a wood cascades system according to the following classification of indicators:

- **Policy:** Main issues on legislation and incentives are categorized under this sort. Factors such as national regulations on waste pollutants in wood, incentives for recycling, resource taxation, and incentives for renewable energy are some examples of indicators falling under this classification. The country's energy policies influence the final use of the waste wood stream, transforming this indirect factor into an important aspect of the business model feasibility and supply chain. From this perspective, policies also influence financial mechanisms and regulate the financial institutions offering economic support to emerging businesses. Financial mechanisms involve joint investment for new technologies development (waste sorting, wood treatment, design, among others), proof of concept and technologies' scaling up [71], and overall, the implementation of new and circular business models, as well as emerging relationships between the different actors.
- **Market:** Access to secondary wood resources, market risks and industrial competition are considered as market barriers. Influencing factors such as availability of recovered wood, export of cascaded products, economic costs, energy vs. material competition for wood use. Market risks compare the readiness of using wood for energy purposes, as opposed to

utilizing it for goods production. The former only requires collection, transportation to the incinerator and minor treatment. Whereas the wood cascading system involves a longer supply chain with additional sorting, cleaning, chemical or mechanical treatment, and extra administrative work [69]. Market prices for cascaded products are strongly dependent on the cost of side-streams from waste providing industries, and the available volume of material being fed to the system. The different stages of the cascade chain might increase production costs, given the different upcycling treatments the material is subject to along the chain to meet the specified quality [70]. However, market prices have been found to also be dependent on other infrastructure related aspects, such as the space for work and storage of second-hand products [72]. Economic competitiveness of wood resources involves the quantity of waste material being allocated as a feed stream for production of goods, or for energy purposes.

- **Technical implementation:** Divided into design practices, physical requirements (wood material properties), and processes related to waste management infrastructure. Some examples are incentives to design cascade chains and for companies that use small pieces of wood, new technologies, material recovery, logistics, wood tracking, existing facilities, quality of waste wood collection and sorting processes, among others.
- **Environmental effects:** Considers Forest management issues related to wood cascading as well as results and limitations of quantitative studies. Also comprises factors around carbon storage in wood products and the main methodological barriers that environmental assessments need to overcome. Some influencing factors under this category are related to impact allocation criteria, data availability and reliability, product type and durability, hypothesis on carbon neutrality, assessment costs, etc.
- **Stakeholder involvement:** Consists of both the role of producers and consumers, the acceptance of second-hand wood use and the degree of communication and information exchange along the supply chain. Some related factors are networking within the supply chain, public willingness to use, attention to the end-of-life of products, long-term responsibility, changing the role of actors, general knowledge, among others. An economic transition towards a circular model also increases awareness and better understanding in the consumer's side. The insertion of wood cascading activities as part of the economic system, leads to a mind-set switch regarding the use of fresh resources and raw materials, as well as less waste generation and change of production patterns [73]. Additionally, wood cascading is strongly dependent on the availability of upstream wood flows, which are quite subtle to changes in waste management up the supply chain [70]. Within a circular economy, business models point to the creation of new services for direct and reverse logistics, which adapted to the different wood market levels, translates into opportunities for innovative businesses, stronger customer relationships, more stable supply of materials, growing demand for certain

services, and employment creation. Financial mechanisms comprise all the institutions and entities in charge of the economic support and advance of novel business models. It involves joint investment for new technologies development (waste sorting, wood treatment, design, among others), proof of concept and technologies' scaling up. The entities usually assess the economic viability of circular business' models basing on the registered return on investment of successful linear economy model projects [71].

4.2 Environmental perspective of wood cascading

The cascading system lies its focus on the diversification of end-of-life utilization options guided by the waste hierarchy or Lansink's ladder. For this purpose, the Cascading system is proposed to function based on a four-dimensional model for a resource economy. The proposal is structured according to the following dimensions [35]:

- **Appropriate fit or resource quality**

It implies that a resource must be used again for an application with the highest possible demands or value creation. It is described as a function of the amount of embodied energy, the degree of structural organization and the chemical composition of a given resource, as well as a function of the effort required producing or reproducing the quality. The higher the quality, the greater it is potential to carry out more highly demanding tasks. In the case of wood, for example, a way to evaluate its resource quality can be by the physical size of the wood segment or particles as follows: tree, beam, plank, veneer, slices, large chips, wood-wool, small chips, fibres, pulp and fuel.

- **Augmentation or Utilization time**

Describes the whole lifespan over which a resource has been utilized. The Ellen MacArthur Foundation states that the number of consecutive cycles and time spent in each cycle must be extended as much as possible to maximize the product life [36]. In this regard, the utilization in time includes the reuse or recycling of the material [35].

- **Consecutive relinking or Resource "salvage ability"**

This aspect relates to the reclamation or recycling of resource quality from a lower level, to a higher level of a cascade chain, or another substance cycle. This dimension also considers the energy and labour requirements for achieving the necessary quality of a material. In practice, the total energy expenditure for achieving the necessary degree of separation is the determining factor in the decision of whether a product will be repaired or maintained.

- **Balancing resource metabolism or Consumption rate**

This dimension considers the volume or rate of resource flow. This dimension is important because it is the major determinant in diminishing resource reserves and in generating pollution. Sustainably speaking, appropriate resource exploitation takes into consideration the regeneration capacity of ecosystems to achieve resource quality for lost or dispersed assets [74].

These four dimensions ensure effective wood cascading, which demands good quality recovered material; clean, homogeneous and of usable dimensions. The better the condition of the wood, the upper it can be placed; thus, the more profit can be extracted from it.

Previous research has shown that the possible number of cascade steps has a direct effect on the ecological benefits of this system application for a material [41]. However, one of the main constraints affecting wood cascading environmental impact assessment is the lack of standardization regarding system boundaries [69], [75]. This is reflected in the opposite opinions found in literature, and how sensitive the system results to be in concern with the different system boundaries.

A particular case is the benefits or disadvantages deriving from the number of cascading steps. Högleimer et al (2013) [76] found that the environmental benefits of the cascading system decreased with additional system steps. On the contrary, Gärtner et al. (2013) [77], found that under most conditions, the higher the number of cascading stages, the higher the environmental benefits of the high-value material use before the energy recovery step.

This disagreement between scientific points of view affects further technology development and deployment, as well as restructuring policies and regulatory framework around the field.

Environmentally influencing factors of the wood industry and wood cascades

With regards to measuring specific impacts of wood goods and the adoption of a cascades system, the Life Cycle Assessment method is used as instrument. From LCA's it is also possible to identify the main stages of a supply chain embodying the most remarkable impacts. The study of Adhikari et al. (2018) [78] breaks down the different stages of timber production and assesses their higher or lower environmental impacts according to the most relevant categories of an LCA for the wood industry.

- **Energy use in cascading**

The energy used for material processing is an important environmental aspect of the wood supply chain related emissions [79]. The timber industry utilizes primary energy for processing and materials handling, drying of raw materials, and utilities and services like boiler and condensation steam, heating and lighting. It is a common practice in the wood industry to use wood process residues, such as low-quality logs with large defects, off-cuts, and other valuable pieces as energy source. Although a cleaner option, these practices contribute to environmental impacts through the depletion of timber resources [78], which in turn could be cascaded.

- **Land-use change**

Land use is an important category within the environmental assessment of materials and goods. A cascades system reducing the amount of required forestland area [80], potentially reducing up to 35% of fresh resources [42]. Nonetheless, research shows that land-use savings are dependent on the final application of the material and the processes to which the unit of material is submitted to downstream [81].

- **Carbon capture**

A cascades system also affects the carbon capture ability of forests, given that young trees store less carbon than older forests [82]. Short-rotation forests are deprived from offering the biodiversity and natural services offered by native forests. Which in turn can lead to ecologic regulation of water and nutrient cycles or soil maintenance [83]. Wood cascading counterbalances the negative environmental effects of short period wood harvesting by providing wood feed into systems without necessity of fresh wood. From a climate change mitigation perspective, it represents the possibility of larger carbon uptake by forests as consequence of a declination in stands felling.

- **Fossil-based materials substitution**

Adhesives, coatings and chemicals utilised during wood treatment also account as elements that could affect the environmental footprint of wood products. Although they extend the lifespan of a wooden product, they contain toxic elements that can contribute to ecosystems degradation [87].

On the other hand, the high-quality use of high-value wood assortments is associated with positive results in environmental assessments. This is particularly relevant when wood is used as substitute for non-wood materials in areas such as construction. In this case, the substitution is associated with positive environmental results [77].

- **Transportation**

Transportation of wooden products has also shown to hold a large environmental impact throughout the chain. Lindholm and Berg (2005) [85] determined the importance of considering different transport alternatives in the timber processing industry, given the considerable environmental impact it carries along the chain. Transportation of timber from forests to industrial sites consumes more fossil energy than any other block of the supply chain [78]. The use of railway transport and biofuels in the transportation process have the capability of replacing 96% of the fossil energy [85].

- **Product lifespan and carbon storage**

Part of the carbon taken by trees from the atmosphere remains sequestered during the service life of a wood product. The longer a particular wood fibre is used or reused as material, the longer the stored carbon will remain away from the atmosphere. Combustion of wood-based material ensures that 100% of the carbon stock is re-fed to the atmosphere as CO2. If the material is landfilled, carbon is stored in a semi-permanent way, with the remainder emitted as CO2 or Methane.

Adhikari et el. (2018) determined that the disposal of wood wastes can be minimised by feeding lower amount of fresh materials throughout the production process as well as by promoting recycle, as well as the insertion of waste by-products into the manufacturing process of timber goods [84].

- **Disposal**

When products are disposed instead of being reused, recycled and refurbished, they will generate pollution and GHG emissions due to transport from source to landfill, toxic chemicals release due to wood treatment, and the need for creation of new disposal sites. Likewise, if disposal is based on burning of used products, it produces smoke, contamination and emissions into the environment [78].

- **Technology**

Technology can be a determinant factor when it comes to wood cascading. Obsolete technology, inefficient procedures and production methods, management-based operational practices, and administrative and institutional issues can lead to a larger wastage of wood that could otherwise be harnessed and used [78].

- **Wood waste and by-products**

Wood waste prevention increases the efficiency of primary wood utilization while also reducing the environmental impacts associated to the industry and its processes. On the other hand, it also fulfils timber product demand without further damage to the world forest resources.

- **Policy support**

Policy support is vital to realize the environmental impacts related to the timber industry and its processes. This includes robust planning, promoting further collaboration with other stakeholders as well as suitable policy measure of impacts [78].

4.3 Environmental view of gasification biofuels

Several studies on lifecycle assessment of gasification of lignocellulose biomass for the production of syngas and different biofuels, namely methanol, natural gas, hydrogen and ethanol, from sugarcane bagasse and woody biomass via the gasification technology, generally lead to the conclusion that the overall environmental impact for the biofuels is negative. This conclusion is because biomass absorbs a large amount of carbon cultivation [86], yet this conclusion is not always objective given the sensitivity of this assertion.

The environmental impact assessment of biofuels takes into consideration five stages of product life-chain, shown in Figure 16, from which feedstock production embodies one of the most sensitive aspects of the process.

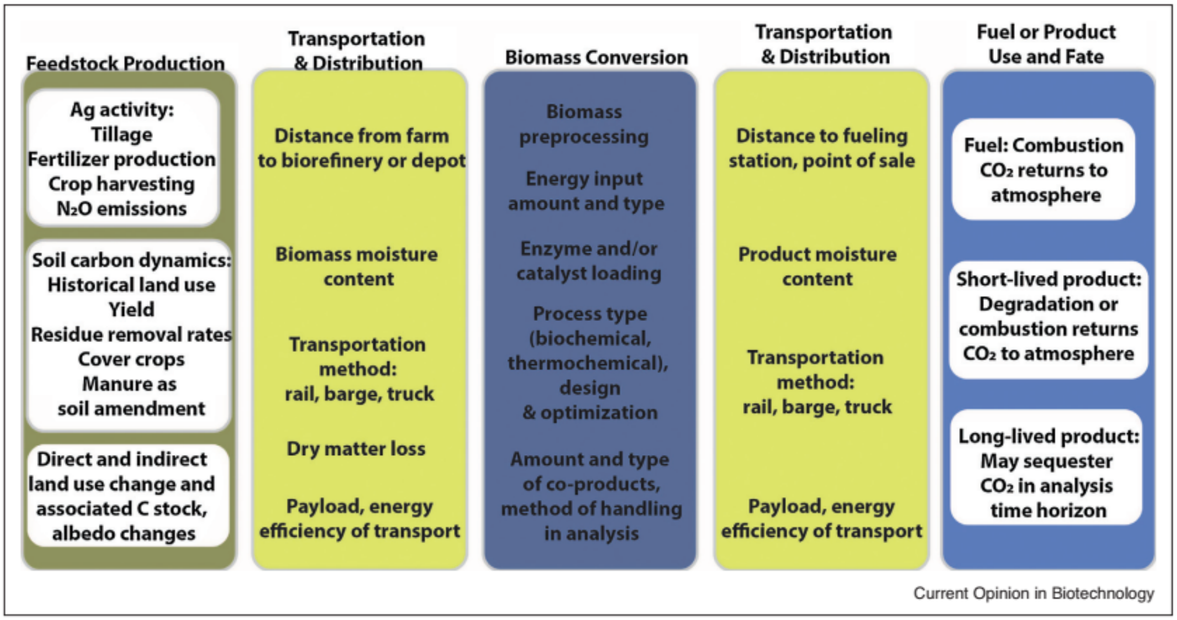

Figure 16: Influencing factors of LCA biofuels and bio products life cycle [99].

Lifecycle Assessments of biofuels are notably affected by management practices of feedstock production, as well as the type of feedstock, site conditions in which they are grown and the conversion process.

- **Feedstock**

Feedstock production entails a group of factors that largely affects a biofuel environmental impact assessment. Within the biofuel production chain, some of the elements with most remarkable influences are, land-use change (LUC) and land management change (LMC), as well as the soil organic carbon. The latter takes place when regulatory or market demand incentive farmers to switch to the production of energy crops, or introduce double cropping and/or agricultural land expansion at the expense of valued natural capital such as grasslands, wetlands, or forests [87]. Garlapati et al. [88] state that feedstock cultivation for biofuels generation can generate increased GHG emissions particularly when the origin is forests or native grassland.

Moreno et al. (2013) [89] determined the importance of feedstock origin with regards to the land use as far as biofuels production concerns. For hydrogen production, it was demonstrated that feedstock holds an important role on the LCA of the overall system. In this case, waste from forestry is considered as an appropriate raw material for hydrogen obtainment via gasification, given that such feed does not compete for land.

Jungbluth et al. [90] reported the counter productivity of some biomass-to-liquid fuels in reducing GHG emissions when compared to fossil fuels, particularly those coming from short rotation wood and straw. On the other hand, those biofuels derived from waste biomass have greater potential in reducing GHG emissions [88]. Short rotation forestry entails a large environmental impact coming on the categories of acidification, eutrophication and ozone depletion [91]. Haase et al (2009) [92] showed that from a water footprint perspective, short rotation forestry accounts for major impacts than forest wood. The former depends on additional irrigation, as opposed to forest wood, which mainly depends on rainwater. The same author reflects a larger share of land used by woody biofuels than those of fossil origin. As far as the environmental burdens carried by one and the other, the same author reveals that the emissions related to short rotation forestry products in specific, accounts for GHG emissions 3 to 4 times higher than for forest residues [92].

Moreover, systems utilizing revalorized feedstock hold the potential of providing the largest environmental services, due to the avoidance of the impact related to dedicated crop or wood production, which account for an important share of the environmental impact. Residual feedstock also bypasses the emissions related to waste management and completely skips the LUC implications entailed by the biofuel production [91].

Sunde et al. (2011) [91] evaluated the differences of energy input between the use of forest residues against dedicated forestry products. The results show that the Biomass-to-Liquid (BtL) biofuels deriving from forest residues are responsible for lower environmental impact than standing timber operations, since it carries almost the complete environmental impact from forestry operations. Fleming et al. [93] investigated the sustainability of lignocellulose Fischer-Tropsch biofuels for light-duty vehicles, and pinpointed at feedstock characteristics, land use changes and associated carbon sequestration, nitrous oxide emissions resulting from agricultural activities, co-product allocation, energy accounting practices, associated infrastructure and commercial-scale fuel production, as well as the vehicle propulsion system efficiency as the key issues affecting sustainability of BtL fuels.

From a feedstock processing perspective, Patel et al. (2016) [94] remarked the importance of moisture content and particle size of feedstock as far as the environmental impact goes. These two characteristics affect the biomass pre-treatment, an energy intensive step within the supply chain. The larger the particle size, the more energy will be necessary to invest in order to adapt the raw material to the requirements of the thermochemical step. The same story applies to moisture and ash content. Tan et al. (2013) [95] reported that during mixed alcohols (ethanol and higher) production, moisture and ash content reduction during pre-processing steps can decrease associated GHG emissions over 13% when moisture is reduced from 50 % to 30%, and 7% when ash content is lowered from 7% to 1%.

- **Technology**

The environmental impact associated to the operative phase of a gasifier relate to variables such as temperature, pressure, reactor type and specific heating rate of the technology [94]. These operating conditions, like in the case of any other thermochemical process, are related to the energy efficiency of the equipment as well as the type of energy used for the conversion, i.e., fossil or alternative.

Ahmed et al (2019) [96] studied the dependence of gasification emissions factors on the scale of the operation, and determined that small-scale biomass gasification emits less CO2, CO and soot than open burning. Nonetheless, the technology still requires further improvements before emissions from small-scale systems are competitive with emissions from large-scale biomass power generation.

Moreover, the generated residues also hold an environmental impact that must be accounted for, and the final disposition of the same entail major or minor environmental impact depending on the waste final management. Zaman (2013) [97], assessed the environmental burdens of a pyrolysis-gasification system of municipal solid waste (MSW), and concluded that the main environmental impact derives from the volume of emissions coming from the technology as well as the final residue disposal. The main LCA impacts were registered on the aquatic depletion, global warming potential and acidification categories.

Although woody biomass and MSW differ in feedstock composition, some of the environmentally harmful elements resulting from the thermal treatment of biomass will be different from that of MSW, yet depending on the origin and pre-treatment of the former, the environmental impact might hold larger or lower environmental challenges. In the case of wooden pallets, those chemically treated must be deviated from the thermochemical treatment, given that the presence of heavy metals and other components resulting from the wood pre-treatment would be released from the process as air emissions, and hold a remarkable environmental burden.

Additionally, there exists the potential emissions of producer gas and particulates. The producer gas contains CO, SO_x, NO_x and volatile organics resulting from the incomplete combustion and oxidation of trace elements in feedstock, reason why leakages must be avoided during the entire gasification process. Yet, an efficient producer gas clean-up system is also essential to remove pollution precursors such as nitrogen and chlorine [98], in order to by-pass operation related emissions.

The clean-up system is also responsible for removal of particulate matter (PM2.5) and insufficient combustion and gasification side-products. In this regard, the production of tars during gasification is an unavoidable challenge, which contribute, to important environmental problems if they are not disposed properly [99].

- **Process integration**

The integration of gasification facilities with other processes or sectors leads to a reduction of the overall system emissions as well as an increase in efficiency. This is beneficial from an energy and waste management perspective.

An integration between industries or sectors leads to lower environmental costs than with stand-alone systems, as reported by Holmgren et al. (2016) [101]. The study points to larger GHG emissions reduction by integrating gasification-based biofuels streams with other coming from existing industries. In particular, the integration of waste energy between systems targets lower environmental emissions and higher product profitability. As a result, lower energy intensity of the gasification process [101] it is achieved by lowering energy input requirements. This factor is vital especially because used energy derives from fossil resources in many cases.

Part of the process efficiency in the thermochemical transformation biomass is affected by the energy use throughout the process. The process efficiency is dependent on the amount of injected energy to produce a biofuel with a specific energy content. In this sense, the energy efficiency is independent of the energy source utilized, fossil or renewable, but the sustainability of the process is determined by the origin of the source. In this sense, research shows that the introduction of waste energy streams into thermochemical processes contributes to a higher process efficiency and so, to a lower carbon footprint. The use of lignin as an energy source has been shown to be one of the alternatives to decrease the introduction of external energy into the process.

On the other hand, technology has shown to play an important factor within the supply chain of biofuels from waste. Ardolino et al. (2019) [100] compared the environmental impact of gasification and anaerobic digestion for biomethane production from biowaste. The study concluded that the gasification alternative shows better environmental performance and a higher carbon seizing than biomethane produced via anaerobic digestion.

- **Other supply chain elements**

With regards to the next stages of the biofuels supply chain, transportation has shown not to have a rather irrelevant influence on the final environmental impact assessment of biofuels production, and this is especially remarkable for a country such as the Netherlands, where the distances are rather short. However, Adhikari (2018) [84] listed the environmental burdens related to this production stage can still be decreased by changing the utilized sources of energy. Part of the suggested strategy includes the use of biofuels, or other clean energy carriers in the transportation phase instead of fossil-based energy to reduce CO_2 emissions [46].

With respect to the environmental impact of the use phase of biofuels, it has been showed to be sensitive to the final application of the fuel, and that for which the fossil fuel alternative involves a larger environmental burden than the biobased fuel. For example, and in the case of bioSNG, it shows the best environmental performance when replacing oil-based heating and transportation systems, but it does not become as important when replacing natural gas systems [102].

✓ **Main Take-outs**

A Cascades system for pallets waste wood would strengthen the existent dependencies within the wood market structure and impulse the creation of new ones that would enforce the wood industry and the advance towards a cleaner sector. This would require a fresh approach in every aspect of the chain, from the workforce to the financial means and economic instruments that support entrepreneurial activities. The introduction of reverse logistics also carries the need for sound interactions between stakeholders in order to ensure the stable availability of wood flows, while at the same time avoiding market related risks. Injection of new technologies and scaling-up possibilities rely on financial aid from concerning entities, which must assess business feasibility by the particularities of circular models.

The environmental perspective of advanced biofuels produced from cascaded waste wood point to an overall reduction of the carbon footprint of the same. This is due to the avoidance or minimization of certain processes that embody the largest environmental impact of biofuels. Feedstock production phase accounts for an important environmental impact of the whole chain. With the feed of cascaded wood, important categories of the LCA of biofuels, especially those related to Land Use Change and Management, as well as fossil fuels use and their related consequences are expected to be diminished.

CHAPTER 5

METHODOLOGY

The present research study focuses on analysing the current waste wood pallet management systems in the Netherlands, and the viability of implementing a cascading system as feedstock source for gasification biofuels as energy recovery means. This approach is structured while keeping the main research question in mind: **What are the environmental and economic implications of implementing a waste wood cascading system in the Netherlands with gasification as energy recovery alternative for the production of biofuels**? In addition, the accompanying sub-questions mentioned earlier.

After desk research with archival data was conducted on how destining cascaded wood would influence the environmental perspective of biobased fuels production (chapter 2), a comparison of this empirical data with literature research (chapters 3 & 4) occurred in this chapter.

To develop the Outline for a cascaded system, participatory and collaborative approach, was used through face-to-face interviews to different actors already involved in the industry and education sector. The conducted interviews allowed obtaining insights about the situation of the transition towards a Circular Economy in the Netherlands, specifically in the wood sector. The interviewed actors are already somehow involved in the waste wood upcycling movement, or in the case of the company, have valuable knowledge about wood supply operations and logistics. The information and results of the desk research that was previously conducted, and the outlines of the cascaded system were presented to them, and their perceptions were taken into consideration when structuring the Outline for a cascaded system.

Table 5: Interviewed persons from the industrial and educational sectors.

Institute	Interviewee	Position	Date	Location
KIDV (Kennisinstituut Duurzaam Verpakken) https://kidv.nl/	Marcel Keuenhof	Packaging expert	1st:01/07/2019 2nd:06/04/2020	Den Haag
HMC (Hout en Meubilerings College) https://www.hmcollege.nl/	Claudia Blankespoor	Teacher and upcycling expert	1st:18/06/2019 2nd:09/04/2020	Rotterdam
Stunt Stichting https://www.stichtingstunt.nl/	Frank van Polanen	Manager and program counsellor	1st:04/07/2019 2nd:14/04/2020	Delft

No interviews were conducted to actors in the biofuels sector. The conclusions deriving from linking both activities are the result of desk research of the biofuels status in the Netherlands and how destining cascaded wood as advanced biofuels feedstock would influence the environmental perspective of bio-based fuels production.

This data was complemented by extensive literature research to analyse the current Dutch situation, especially when considering to be a Circular country by 2050, as well as to complement the information from the interviews with scientific bases available in literature.

This study is only an exploration to determine the most relevant aspects regarding the topic in concern. From both perspectives, economic and environmental, only barriers and limitations are determined, but the extent of their influence is only addressed as far as the qualitative information allows to reach.

In this case study, system boundaries are only descriptive of the different involved entities and interactions between them. Additionally, wood is not considered as a carbon neutral energy source when used as energy direct feed, i.e., without cascading. Yet, cascading is considered as a positive alternative to landfilling procedures by reducing the amount of valuable material being sent to these facilities.

The methodology is based on the studies of Singh et al (2019) [72] and Jarre et al. (2020) [103] for the economic view. A major difference between the present case study and those, upon which the structure is based, is the intention of reaching qualitative results. This implies that a deep study on the different variables affecting the identified aspects in both perspectives, were not studied based on statistical or quantitative analyses, The methodology of [72] includes group modelling, stakeholder analysis, CLD, and a workshop with stakeholders and experts, in addition to a much larger set of interviews. [103] identifies factors following categories , but it has a much more elaborate methodology to map and identify the factors in a systematic way in the literature set that has been systematically generated.

In the economic section, relationships between groups are established, instead of between items, as it is done in the cited studies. This is because the interviews were not enough as to make a statistical comparison about the influence exerted by some variables over specific limitations, and this objective lied apart from the main goal of this study.

The environmental section is addressed under a similar methodology as the economic view but relying on relevant concepts and studies related to wood cascading. Thus, the backbone of that section is constituted by the four different dimensions of a wood cascades system, as well as different supply chain elements with remarkable influence on the proposed system. Such influencing factors are derived from the different blocks composing the timber industry processing chain cited in the study of Adhikari et al (2018) [78].

5.1 Netherlands as case-study

The use of biomass for power and heat generation is endorsed by current policy and legislation across Europe. Electricity and heat-generating facilities are encouraged by receiving fees per unit of energy produced from non-fossil alternatives, which includes biomass. This credit accounts for displaced CO_2 emissions equivalent to the required fossil energy to produce the same energy from waste wood [20].

In the Netherlands, the recently opened Biomass Power Plant 'Bio Golden Raand' in Delfzijn, operated by Eneco, with a production capacity of 49.9 MW, bases its operation on recycled waste wood chips from domestic and industrial activities, as part of the switch to renewable energy sources. The plant claims to avoid the emission of 250,000 tons of CO_2 per year [104] and intends to serve as an inspiration for future plants abroad [105]. Yet, this is not the only facility basing its energy generating activities on biomass, it is only a representative case of the many others dedicated to this activity throughout the country.

On the other hand, the Dutch wooden packaging sector involves the production and repair of wooden pallets, crates, boxes and industrial packaging. Within this segment, wooden pallets take about 75% - 80% of the total production volume [10].

The Sankey Diagram in Figure 17 shows the different woody biomass flows in and out of the Netherlands, their distribution throughout the different economic sectors as well as the final consumption. An important gap between imports and internally produced resources is to note, given the limited space of the country. This translates into a high dependency on woody imports to cover the internal demand for wood as a material and energy source. According to Sheng Gog et al. (2016) [106], a considerable amount of woody biomass was incinerated to generate electricity and heat, as seen on the left side of the diagram. Likewise, it can be seen that waste wood of the different types (A, B, C) are directly sent to energy producing facilities without any indication of a cascading system to seize woody wastes.

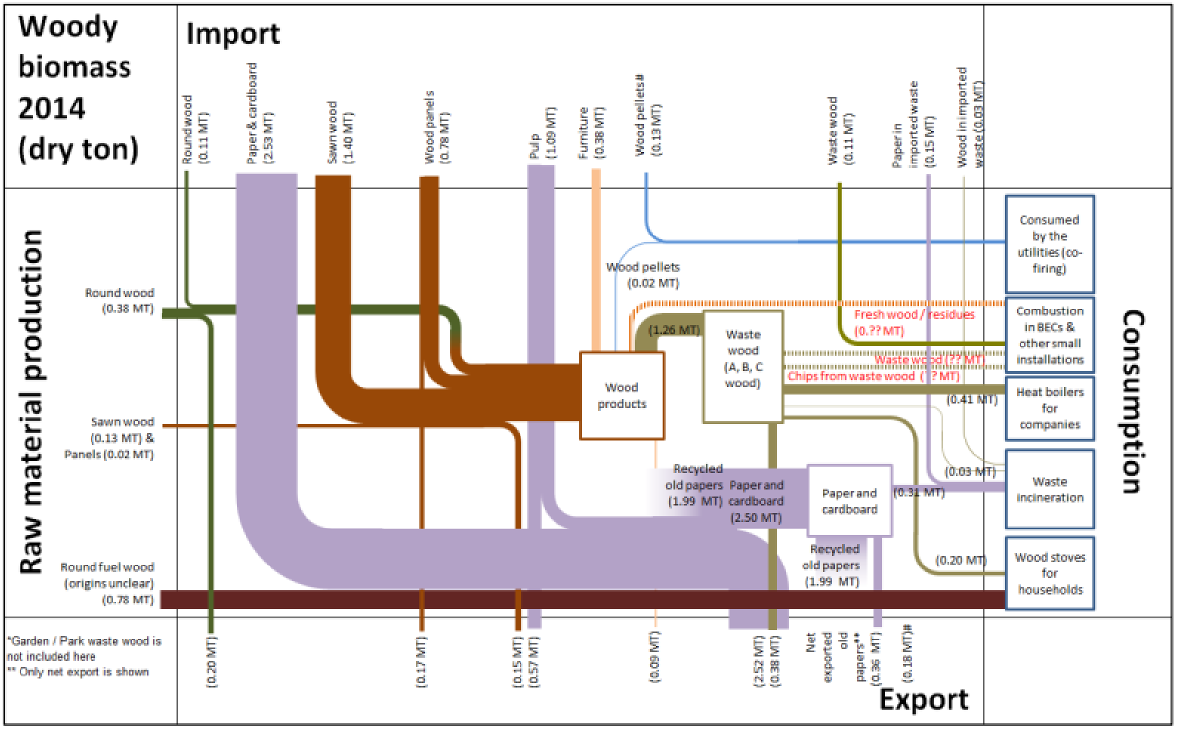

Figure 17: Sankey diagram for woody biomass flows in the Netherlands in 2014 [106]

On the other hand, the Netherlands is the third biofuels producer in Europe after Germany and France, reaching a production of 1.65 Mtoe of fuels, specifically bioethanol from starch (wheat, tapioca) and biodiesel from used cooking oil [107]. Most of the advanced biofuels' initiatives are steered to the utilisation of waste streams instead of fresh biomass for the production of fuels such as SNG.

The total biofuels consumption in the country was 23 PJ in 2018[107], and the distribution of renewable energy consumption from biomass sources, including liquid biofuels and waste incineration plants shown in Figure 18.

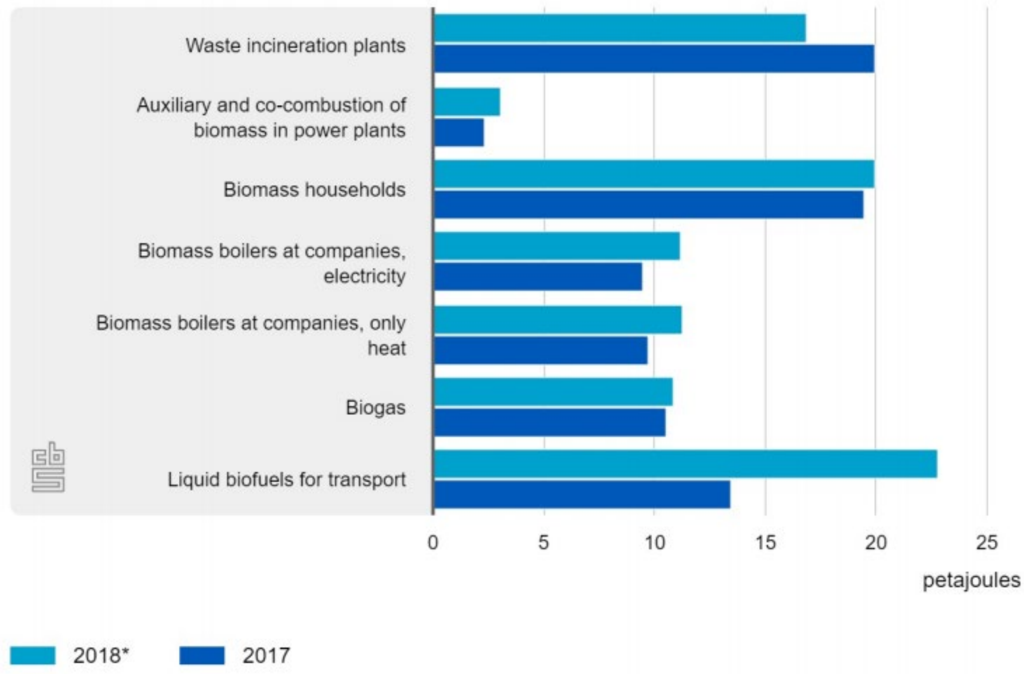

Figure 18: Renewable energy consumption from biomass sources in the Netherlands [4].

Despite that SNG, bioethanol and biodiesel are the main biofuels used in the Netherlands, this case study only considers bio-SNG and bioethanol as base cases when necessary. Biodiesel from syngas is not considered due to its very early research phase and lack of reliable information with regards to its production.

5.2 Interviews Information

Three different entities were interviewed. Each one of them performs activities related to upcycling in their own way. The content of the interviews shown in the Appendix 1.

- **KIDV – Netherlands Institute for Sustainable Packaging (The Hague)**

This entity was established in 2013 to contribute to a circular economy for packaging materials. They advise and inspire companies with practical advice to make their packaging more sustainable, offering factual knowledge and tools based on scientific literature.

The company is financed by the Packaging Waste Fund (Afvalfonds Verpakkingen) with two million euros per year for a period of ten years. The money comes from Packaging Waste Management Contribution [108].

- **Stitching Stunt Foundation (Delft)**

The Stunt Foundation is also taking part on the movement by making small products from recovered wood with no automated processes or new technologies. They receive economic support (grants) from the municipality of Delft, and focus on social and training goals rather than revenue increase. Their stakeholder portfolio includes volunteers, who are partially paid or not paid at all, Gemeente Delft, Doel, clients of wood products, Werkse for manpower, and rehabilitation centers. 25% of their feedstock is wood pallets used for a small- scale production of small products such as cutting boards, wine crates, tables, some furniture, small structures, as well as creative products. The material is supplied by companies dropping the wood at the Foundation's facility and it comes from the construction sector and retailers. In some cases, they also collect the material themselves. Wood pallets are used for beams, wood flooring and wine crates. Customers are local and regional companies, individuals and SMEs desiring to support their non-profit goals, and their client acquisition is directly done by own staff, word of mouth, few exhibitions. The organization does not count on marketing or sales department.

This is social enterprise with a strong approach towards sustainable, social return, and co-creation practices. They create unique pieces from residual materials (commercial origin). It is a small organization of about 20 employees in total and some volunteers.

Their activity is focused on the residents of Delft, and they believe in the force of integration of as a way to contribute economically and socially to the development of the city of Delft.

- **HMC School**

The HMC School is an existing low-profile actor of the wood cascading business. The school is specialized in teaching wood design in general, counts on state-of-the-art machinery, and it is also taking part in knowledge spreading through workshops. The school is already generating a small economic profit from upcycled wood products, and open to mass production with lower operational and capital costs. Their material supply comes from regular timber wholesalers (FSC logo) and residual MDF wood, as well as multiplex and solid wood (hard and soft). Wood pallets are rarely used, around only 1% share. Their customers approach them via students or non-profits on a project basis.

5.3 Outline for a cascaded system Methodology

The methodology follows a practical course in this project; thus, cascading is not considered as a part of a proposed full circular economy, due to the impracticality of achieving a circular economy in the short run either in pallets cascading or even in other wood-related sectors. The reason behind choosing a "reuse circular economy" is to tackle the constant necessity of fresh material input feed to the system and losses at the end of the cycle. So that, the suggested concept to be dealt with is a transition towards a "reuse economy" or a circular economy with feedback loops, reflected by the material cascading and biofuels production from waste pallets.

By relying on the Lansink's ladder framework and the circular economy concept, a new system has been appropriated, targeting the management of wood from waste pallets in a more effective manner. This system embodies a smooth transition from current waste pallets management procedures, consisting of recycling and combustion for energy purposes, to cascading and biofuels production.

The proposed framework in this study is addressed as an "outline for a cascaded system", which seizes potential economic and environmental gains from moving to new waste management procedures. This outline for a cascaded system includes policy measures for both, production and post-consumer ends, and practical steps at the industrial sector to stimulate the transition. This last step includes symbioses between actors to drive forward existing policies and stimulate the creation of new ones. Additionally, support of the Small and Medium Enterprises (SMEs) through a network of new establishments is addressed to ease the closed loop and retrieval of waste wood pallets. This newly created network is expected to break the stagnation between the existing pallet pools trading system and new cascading entities.

Economy-wise, a circular economy business model (CEBM) is nominated to form the base of the financial strategy for entities interested in this transition, the CEBM is chosen following an analysis of the business model dimensions, design options, actions to be taken and economic benefits related to each and every dimension.

Finally, the positive environmental impact is derived using influential factors and indicators of the related categories of the waste pallets, such as, policy, market and technical implementation categories.

- ✓ **Main Take-outs**

The methodology to answer the former three sub-questions relied upon the concepts found on scientific literature, especially regarding the operations of a cascades systems, its main variables, especially how its economic integration fits within the transition towards a Circular Economy, and the environmental consequences of such implementation.

The obtained information from the Interviews was used in concordance with the results of the desk research to clarify the important points to answer research sub-questions and to structure the outline for a cascaded system. The latter is also built upon previous case studies found in other countries of the EU, such as Italy.

CHAPTER 6

OUTLINE FOR A CASCADED SYSTEM

After identifying the current life cycle management of wood pallets in the Netherlands it becomes crucial to introduce a comprehensive production, consumption and finance policy-related outline for a cascaded system to guide the transition as far as bio-products and bio-energy concerns.

The outline for a cascaded system addresses certain background aspects, such as existing waste-to-energy incentives, pooling systems, existing facilities already in charge of waste handling and management, among others. This information is contrasted with current wood competition as material and energy source, and the latter is compared with other and more efficient sources of renewable power. This intends to remark certain aspects of bioenergy within the energy transition panorama, which passes by understanding its relevance within this movement but also pinpointing its drawbacks.

In order to structure a viable outline for a cascaded system, it is also necessary to evaluate the aforementioned material competition, and assess which use of waste wood induces to a larger economic and environmental benefit for the Netherlands. After a careful evaluation of such aspects, the cascaded upcycling alternative was found to add more value and bring along a larger package of profits by following the waste hierarchy and aligning the outline for a cascaded system with the road to a circular economy by year 2050.

By considering these aspects, the outline for a cascaded system involved conducting interviews to three different Dutch entities already taking part in the waste material upcycling movement (each on its own); Netherlands Institute for Sustainable Packaging (KIDV) in Den Haag, the Stitching Stunt Foundation in Delft and the HMC Wood and Furniture College in Rotterdam. The information obtained from these interviews was complemented with literature review available in scientific literature found in articles published in Elsevier, ResearchGate, Nature and other relevant journals with published cases and information related to the object of this study. However, the backbone of the present outline for a cascaded system is adapted from a previously structured case in Italy: The Rilegno Case. This case was carefully evaluated and adjusted to the Dutch scenario by considering the main differences as far as background, social, political, environmental and regulatory aspects of the case in question.

Table 6 CEBM pertinent design options to waste pallets and recommended actions for the transition to a circular model, shows an analysis of circular economy business model optimised for the purpose of transition and offers recommended actions to achieve benefits following circularity and reuse of waste wood, the strategy used here follows the four-dimensional model explained earlier in chapter 2. Meanwhile tables from 7 to 15 is dedicated to give an insight to the positive and/or negative environmental and economic impacts following the transition based on indicators and influencing factors. These factors cover the policy, market, stakeholders and technical implementation. The analysis of the environmental impact is based on the study of Matteo Jarre et. al. Add to that the sorted barriers and difficulties in front of paving the way to a smooth upcycling implementation.

At the end of the outline for a cascaded system the Italian case study of the “Rilegno consortium” is added to make a comparison between the enabling tools used in Italy and be reflected to the Dutch case. This makes lessons learnt clear to pave the way to a similar transition in the Netherlands through breaking or circumventing existing barriers.

6.1 Promoting the Circular Economy and waste wood cascading – Policy perspective

Considering the current situation regarding waste wooden pallets management in the Netherlands, as well as the existing regulatory framework governing waste management, and the available technology regarding gasification, an outline for a cascaded system is structured.

The structure was carried out by obtaining information from interviews to real life actors already involved in the wood packaging industry to observe the current situation around the managing of packaging materials and waste pallets upcycled, as well as to identify the needs and current limitations faced by the industry towards the implementation of a cascades system. Then, followed scientific literature review in order to build the bases of the outline for a cascaded system. The model was also complemented by considering past experiences from intended similarly operating supply chains which would supply an overall idea of how this morel could work in a European environment. Lastly, an overview and analysis of current European and Dutch regulations was executed, with the aim of constructing an outline for a cascaded system adjusted to the Dutch scenario.

This novel approach considers the possible economic gains and environmental benefits of implementing such a system in a way that is readily applicable within the European Green Deal. Part of this European package is destined to encourage the use of cleaner energy technologies and means that enhance material revalorization and waste minimization.

From linear to circular economy through feedback loops

The introduction of feedback loops, enables the “reuse economy”, applicable to waste pallets, ensuring a stable leap from a linear to a circular system, as well as the continuity of the new model in time without compromising the operation of the system nor ecosystems health. The transition from linear to a circular management system shown in Figure 19.

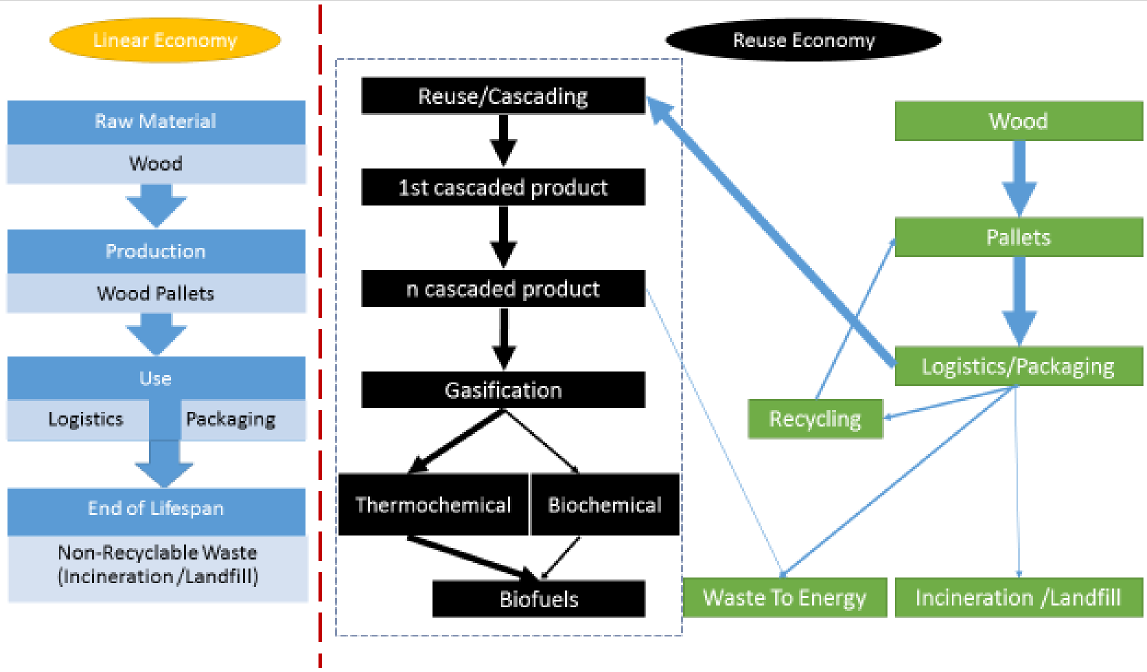

Figure 19: Comparison between linear and circular waste wood pallets management

Employing feedback loops in waste wood management depends on factors such the type of wood used, quality, quantity and the availability of matching these features with processing facilities, as well as market prices and end-users' preferences and demand. A graphic description of the feedback loops in a circular waste pallets management system represented in Figure 20.

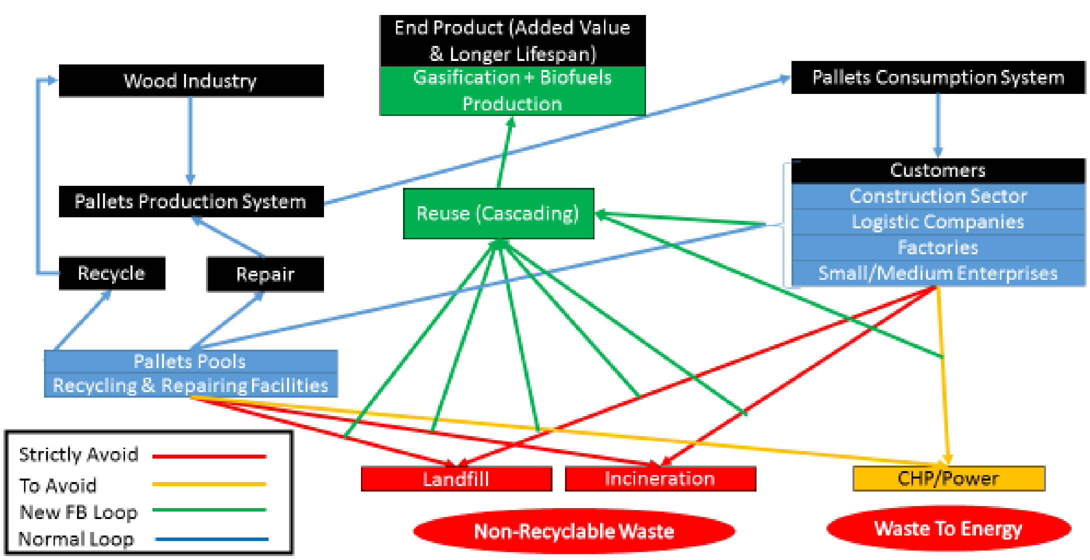

Figure 20: Feedback loops in a waste pallet's circular management system based on material cascading

Depending on the abovementioned factors, wood pallets would be cascaded to produce other higher value goods or sent directly to gasification facilities and biofuels production.

Cascading waste wood from pallets could follow routes such as:

Small quantities of hardwood can be allocated in bicycles production at small scale via single-stage cascading. This route was observed among many other observations during a visit to the HMC school in Rotterdam on 18/06/2019.

Using small pieces of hard wood in large quantities for massive production of cutting boards and kitchenware. Given the short lifespan of these products (1 to 2 years), the remains can be further compressed into blocks suitable for a second cascading stage in furniture production. This example was observed during a visit to the Stunt Foundation in Delft on 14/04/2020.

Using a mixture of soft and hardwood pallets to build different structures, such as pavilions, huts [110].

6.2 Policy instruments to support the circular model and waste hierarchy

Typically, translating the vision of linear operations into a circular economy implies a full set of policy instruments to be strictly followed at both the producer's and consumer's ends. These instruments are not limited to regulations alone, but extend to cover the technical, regulatory and financial foundations of the wood pallets economy [111]. In this case, the outline for a cascaded system focuses on moving upwards the Lansink's ladder approach towards material reuse.

6.2.1 Production-oriented policy instruments

- **Support for Eco-design of pallets:**

An Eco-design consists of integrating environmental protection criteria aiming to minimize negative environmental impacts during the life cycle of a product [112]. From this definition, the eco-design of wood pallets should produce eco-friendly pallets enabling their reparability, durability and recyclability. This action must be supported in the following ways:

✓ The Eco-design Directive should set minimum mandatory requirements on pallets design and manufacture, so it is easier and safer to dismantle and reuse while keeping environmental considerations in mind. Some elements to consider are:

- Working on novel designs to replace steel nails, and relying on biodegradable and eco-friendly glues and paints.
- Implementation of eco-friendly treatment methods to kill pests and insects.
- Design according to the nature of the supply chain, this creates a balance in the market between offered pallets and demand, thus avoiding the misuse of pallets and increases the usage efficiency.
- Incorporating modern software for pallets design should be intended.
- Pallet's design should be done in such a way that dismantling can be executed by machines instead of labour, which is time consuming.

- ✓ As for fresh wood resources harvesting reduction, pallets raw material diversion to other material streams, especially suitable waste coming from other processes, represents a viable way to not compromise pallets production without negatively affecting virgin sources.

- **Addressing planned obsolescence:**

In Europe there is no specific EU regulation mentions planned obsolescence. Planned obsolescence should be the foundation of further actions of wood pallets after giving the proper definitions of by-products and waste.

Looking at the waste wood classifications of the LAP it is observed that differences between the A, B and C wood types are still vague. Even with the introduction of LAP3, the given definitions of by-products and end to waste are not enough to decide the priorities of the future pallets' applications, so that it is mostly sent to the bottom of the Lansink's Ladder as a quicker and theoretically a cheaper action.

- **Extended Producer Responsibility (EPR):**

The EPR calls for an environmental policy approach in which the producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle. This environmental policy has a crucial positive implication on the transition towards a more wood pallet oriented circular economy.

As the name implies, the responsibility of the pallets producers (manufacturers) will be extended to include collecting or taking back obsolescent pallets to sort and treat them for a further cascading process or even to a gasification plant directly in case cascading is not feasible or available at some time point.

- **Fostering industrial symbiosis & Support for SMEs**

Industrial symbiosis describes the association between two or more companies or facilities in which the waste materials or by-products of one become the raw materials for the other. Achieving such symbiosis requires a sharp diversion in the conventional relation between industrial entities by creating a circular network rather than intermittent and distant relationships [113].

Until now there are lots of acting industrial symbioses in the EU such as The European Resource Efficiency Platform (EREP), EUR-ISA and inno4sd, which are networks aiming to bring key stakeholders together. These participants join common interests on innovation for sustainable development, creating a mechanism for reducing carbon emissions, preserving critical resources and securing business sustainability. Their activities are limited to advisory and guidance services, but do not reach a real decision-making level.

Their success is limited to lower stratus and fail in some cases due to lack of subsidies or financial support from governments to push crucial R&D activities forward. Such is the case of the UK NISP.

In the case of the Dutch waste pallets scenario, it is noticed the total absence of this symbiosis between pallets pools, manufacturers and end customers.

Small and Medium-sized Enterprises (SMEs) incubate 85% of the new job opportunities in the EU [114]. The same applies to the wood pallets industry, as there are numerous acting SMEs, yet their share in the pallets market is still low, given the absence of R&D tools at the SMEs.

6.2.2 Consumption-oriented policy instruments

- **Strengthening reuse and remanufacturing**

Reusing and remanufacturing wood pallets involves the participation of different consumers, from individuals to commercial and societal levels. At individual levels, action on throw-away mentality is to be modified towards a refuse-reuse-recycle system. Businesses are in charge of monitoring, control and promote cascading and circularity through pallet pools and other waste management alternatives. should be achieved by all consumption slices, personal, commercial and societal. Societally, the outlines of quality and obsolescence borders must be drawn clearly to eliminate vague spots at the total societal level which is by nature influential on both individual and commercial aspects.

- **Green Public Procurement**

The Green Public Procurement (GPP) or green purchasing is the process of transforming the public authorities to major consumers using their purchasing power. Thus, they can choose environmentally friendly goods and contribute in the sustainable circular economy [115].

The boost of deploying the GPP is mainly represented by a more active local intrusion of the Dutch municipalities in the pallets sector, and of course in the wood industry. This implies municipalities and provinces taking responsibility of buying and selling big quantities of wood pallets to local schools, companies, foundations, and companies. For a more effective and efficient selling method, the contract must imbed an obligatory clause dedicated to future collection. Such clause should facilitate the retrieval and collection of pallets and must give financial gains to both ends.

The proposed GPP deployment and target differ from those of the current private pallet pools.

Another option or addition to this structure besides municipalities is the creation of a proxy or intermediate governmental authority where activities are dedicated to mass trade of sustainable products.

- **Financing & regulating feedback loops of the circular economy for pallets wood waste**

Besides production and consumption-oriented policy instruments, it is inevitable to talk about the financial aspects of the circular economy. This includes the creation of a business model in charge of handling the continuity of the feedback loops and the feed of the raw material to the system.

Before looking into the details of the business model dimensions, a proper pattern has to be clearly identified. The wood pallets matching pattern is the cascading and repurposing one, which is –in some aspects- similar to the recycling pattern but finally forms a total independent form, paving the adequate means and grounds to build upon.

The features of cascading and repurposing pattern are multiple cash flows/revenues, co-product generation from waste wood pallets.

The Circular Economy Business Model (CEBM) to be chosen from for the case of the wood pallets should be flexible enough to cover the CEBM dimensions. These dimensions are:

- ✓ Value proposition: represents the first step by defining the benefits offered to customers based on products, services system. The value of reusing and upgrading the waste wood pallets can be classified as products and/or services.
- ✓ Value delivery: is how the values proposed of wood pallets are delivered to customers by engaging customers and value delivery processes.
- ✓ Value creation: is how the value is created, that encompasses the actors and activities involved in value-creating processes, including production.
- ✓ Value capture: represents the way companies and authorities earn financial and environmental benefits.

Table 6 shows the CEBM design options applicable to the waste pallets and actions for the model transition.

Table 6: CEBM pertinent design options to waste pallets and recommended actions for the transition to a circular model

BM dimensions		CEBM design options	Action	Benefit (circular product economy dimensions) Source: self-concluded in conform with 4-dimensional model
Value proposition	Product	Long-lasting products	Pallets eco-design to guarantee durability, reliability, easy dismantling and eco-friendly treatment Source: Literature + KIDV	Appropriate fit Increased quality Utilization time New industries (eco-friendly)
		Used pallets as production inputs (cascading and biofuels production raw material)	Waste pallets collected from consumers (B2C mainly) and sent to cascading entities or to biofuels plants (new products with added value)	Utilization time Resource salvage ability Balancing resource metabolism New jobs (entrepreneurial)

			Source: Literature, KIDV, Stunt, HMC	
	Service	Recyclable production inputs	Take waste pallets back /retrieve from SMEs, municipal waste and pooling using service/lease contracts Source: Literature, KIDV, Stunt	Utilization time Appropriate fit Balancing resource metabolism New business opportunities (consortiums)
		Reusable production inputs	Take waste pallets back /retrieve majorly from B2B consumers, (in limited cases from regular B2C) using service/lease contracts Source: Literature, KIDV	Utilization time Consecutive relinking New business opportunities (network of collaboration)
Value delivery	Target customers	Green customers/ B2B customers	Focus on customers push a green economy, those are mainly business ones Source: Literature, KIDV, Stunt, HMC	Consumption rate Balancing resource metabolism Appropriate fit Increased support to interested active stakeholders
	Value delivery Processes	Connecting suppliers and Customers	Achieved directly by extending producer responsibility and applying green public procurement Source: Literature, KIDV, Stunt, HMC	Balancing resource metabolism Resource salvage ability Create a network of data exchange, R&D and collaboration
		Providing used pallets	Provision is voluntary done by SMEs which are not member of pallet associations Source: Literature, KIDV, Stunt	Resource salvage ability Consecutive relinking Increased retrieval and more circularity
		Taking back used pallets	From pools and members of pallets associations. Achieved by the help of the associations, municipalities Source: Literature, KIDV	Resource salvage ability Appropriate fit Increased retrieval and more circularity from pooling

Value creation	Partners and Stakeholders	Collectors of waste pallets	An independent authority responsible for collecting pallets from consumers (similar to debt collectors of money) Source: Literature	Resource salvage ability Balancing resource metabolism EPR, data centre, GPP
		Public institutions	Municipalities by activating the green public procurement Source: Literature	Resource salvage ability Balancing resource metabolism EPR, data centre, GPP
		Retailers	SMEs and individuals contributing in creating feed to the cycle via a form of symbiosis Source: Literature, KIDV, Stunt	Resource salvage ability Consumption rate Direct Economic benefits, entrepreneurial, innovation
		Manufacturers	Extended Producer Responsibility and defining the planned obsolescence of pallets through R&D, cooperation with authorities and legal contracts with consumers. Establish extensive forward and reverse supply chains Source: Literature	Appropriate fit Augmentation New cascading department, expand sales, new products
	Value creation processes	Taking back waste pallets	Inevitable step to gather the raw material of the new cycles through reverse smart logistics system within a network of collaborators Source: Literature	Resource salvage ability Consumption rate Direct Economic benefits, entrepreneurial, innovation
		Upcycling of Pallets components (boards and blocks)	Entering a cycle of woody products cascading Source: Literature, KIDV, Stunt	Appropriate fit Balancing resource metabolism Specialized and higher value of man power
		Upgrading	Gasification: From biomass (pallet) to syngas FT: From syngas to biofuels Source: Literature, KIDV	Appropriate fit Balancing resource metabolism Expand syngas industry and cascading, new machinery and equipment

Value capture	Revenues	Additional product revenues: 1. Preserve wood as raw material 2. Deforestation mitigation 3. CO_2 emissions reduction 4. Global warming mitigation 5. Product added value by emergence of new cascaded products 6. New entrepreneurial concepts 7. New jobs (specialists) 8. New industries within the existing ones (cascading besides recycling and repair of pallets)	Promote sales of cascaded products, diverse collection meets high demand sectors and relatively sold for high prices compared to recycled or repaired pallet (almost free and require collection, transportation and labour work) Source: Literature, KIDV, Stunt, HMC	Resource salvage ability Consecutive relinking Augmentation Appropriate fit Extra sales and interest in new woody products, higher social and environmental reputation
	Costs	1. Raw material costs drop due to usage of waste as feed to system 2. Capital is needed (design & pallet handling processes) 3. Transportation (logistics) 4. Labour 5. Manufacturing requires radical transformation in existing companies by adding new departments for cascading or initiation of totally new companies to practice cascading processing of pallets	Industrial symbioses, governmental & NGOs intrusion, new protective policies for the emerging technology, define the planned obsolescence Source: Literature, KIDV, Stunt	Balancing resource metabolism Resource salvage ability Appropriate fit Decreased capitals and running costs on the long term due to expanded industry

Based on the lessons learnt from the recycling process in the NL, the practical steps to be taken are the following:

- Government involvement to issue protective policies to the emerging cascading technology and businesses, as well as stimulating policies to rule the transition to upcycling rather than recycling, and even down-cycling processes. This is done by incentivizing material cascading and biofuels production from biomass waste, and wood pallets in particular. Another aspect of this governmental participation is the implementation of green public procurement by allowing local entities, such as municipalities, to behave as a purchaser. Green public procurement remains limited, but includes the combined task of extending producer's responsibility. The producer in this case is either the pallets' manufacturer, or even the municipalities, in charge of retrieving sold pallets. Another aspect demands clearly defining the concept of the planned obsolescence, which makes the separation, transportation and treatment of waste pallets easier, cheaper and fulfils the appropriate fit requirement.

- A legal frame should encompass the sales/retrieval activities of pallets, especially in the case of B2B with regular and relatively high mass transactions. This can be simply done by adding legal clauses to the contracts between sellers and buyers, demanding pallets' return or transportation to sorting locations, so the process is structured and easier to monitor and manage. A number of different actors within the Dutch context have been previously mentioned within this study, and their interactions shown in the Appendix.
- Looking at the recycling experience in the Netherlands, many glass and plastic retrieval techniques can be applied to pallets and biomasses. An effective technique is to apply a deposit to sold pallets, which incentivizes the return process from retail to manufacturers or involved authorities (3rd party), and facilitates further sorting step and upcycling. This can be applied to both B2B and B2C. Another technique is sorting of waste, which is widely applied in municipalities where consumers separate their waste before being sent to the proper destination. This step depends on the material quality, consumption rate, market demand and most importantly, the ability of "cascaders" and biofuels plants to absorb and treat the available feed's quality and quantity. This technique is mostly applicable to the construction sector and small retailers, which form a large portion of the consumers' pie.
- Establishing a logistics network, including pools, waste and skip centres, as well as sorting points. This is achieved by using the existing logistics network between these parties, but with effective and high-quality management, so that pallets end up in the right destination rather than current down-cycling destinations.
- Stimulating existing wood trading companies to incorporate extra activities related to cascading besides the current lease, buy/sell, recycling and repair businesses. This addition to business can't be attained without incentives or subsidies to the private sector to accommodate to the new industry and to be able to bear the capital costs. Industrial symbioses and creating new institutions behaving as intermediates or coordinators are inevitable.

  SMEs role can be escalated to act efficiently by monitoring the existing entrepreneurial opportunities emerging in the market. Small companies dealing with wood have the chance to diversify their business and capture extra value from waste by adding cascading departments or tasks as an intermediate to manufacture woody products from waste. Again, industrial symbioses are a must in the case of SMEs.
- Expanding the capacity of the existing gasification and Fischer-Tropsch plants in the Netherlands by incentivizing capacity upscaling of the existing (MILENA, Alkmaar 4 MW) and to-create facilities. This way, the economic viability of such projects is driven forward by establishing lobbies that demand government subsidies and incentives to cover high capital and R&D expenses.

The different interactions within the new waste pallets management system shown in Figure 21: Policy instruments and interaction paths between actors within the novel business model.

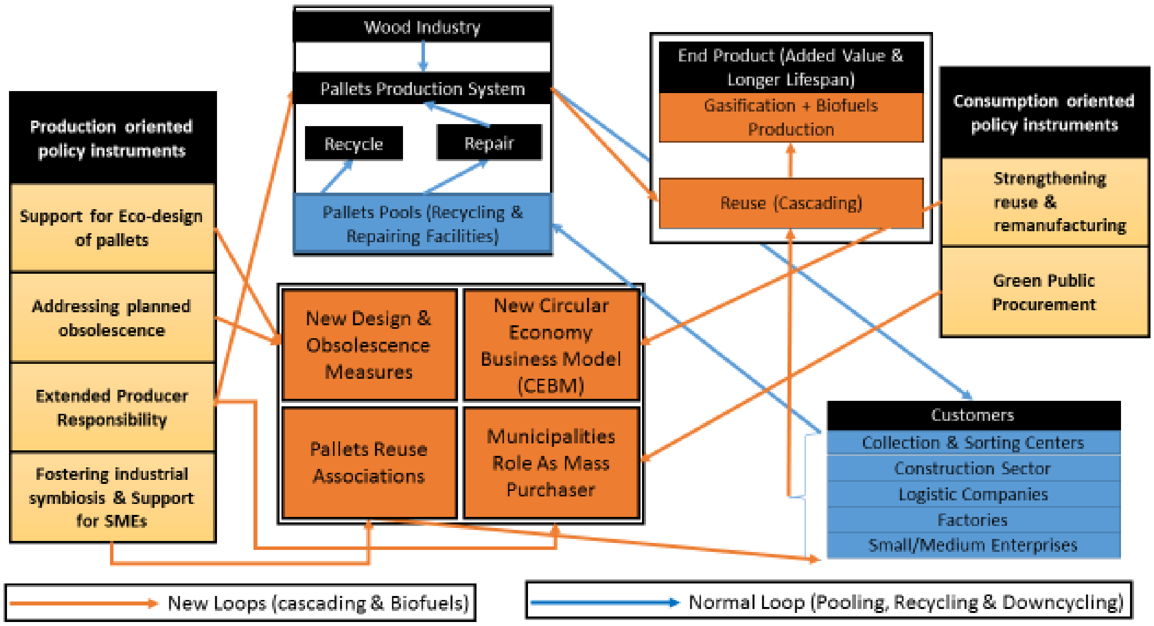

Figure 21: Policy instruments and interaction paths between actors within the novel business model.

✓ **Main Take-outs**

Transition towards more wood material cascading requires radical policy changes working in parallel with other measures to promote feedback loops. For this aim, certain actions are necessary:

- Active participation of local government to achieve more circularity aligned with waste hierarchy principles. The role of the municipalities is mostly policy-wise and extend from production to finance passing by the consumption of the waste wood. One of the major tasks required by the governmental and NGO's is to achieve a green public procurement.
- Network creation and support for entrepreneurial activities in charge of innovation and SMES. Such network encircles these stakeholders and their interactions with pallet pools and recycling entities. The actions of this network remain feeble unless a radical change occurs in the Dutch energy sector and their waste management regulations. In this regard supporting waste-to-energy practices without a correct enforcement of cascading systems and practices following the Lansink's ladder principle.
- Change in vision and problem awareness by society, supported by spreading the word through efficient channels. This change of individuals towards reused products is vital towards advancing to a more sustainable management of waste.

CEBMs are expected to act as enabling tool for revalorizing of material flow and/or supporting local industrial network. This helps with achieving the four-dimensional model of improving the appropriate fit or resource quality, utilization time, resource salvageability and balancing resource metabolism or consumption rate.

Environmentally, the impact of the transition is derived based on relevant factors supported by existing indicators in the current management process. These indicators are related to (sub)categories showing a positive and –at the same time- a negative impact. Transforming the negative impact to a positive one requires -but it is not limited to- the following:

- Collaboration between stakeholders
- Policies encouraging up scaling of reuse and confronting the waste to energy incentives
- New intelligent reverse logistics system
- Support of new design of pallets by working with R&D centres
- Increased accommodation of upcycling facilities to handle feedstock with different properties
- Optimal use of existing infrastructure for fossil fuels and natural gas, etc…

In general, this CEBM should financially provide incentivised return, asset management and collaborative consumption, while environmentally should mitigate the environmental effect by increasing the lifespan of wood and protect the natural biodiversity.

The results from more reuse can be reflection on extra sequestration of GHGs, lowering feedstock input to the system (hence less raw material consumption and less deforestation rates), more biodiversity and soil protection from erosion, add to that less fossil fuel and related emissions to its use.

CHAPTER 7

BARRIERS AND BENEFITS FOR A CASCADED WOOD PALLET SYSTEM

Sub-questions answered in this chapter: What are the economic benefits and limitations of implementing a cascading system for waste wood pallets in the Netherlands? What are the environmental benefits and disadvantages of implementing waste wood pallets as input material for syngas production in the Netherlands?; How does the end of life and extension of use of wood pallets compare for different approaches of upcycling reusing and gasification?.

7.1 Economic benefits and limitations of a cascades system for waste pallets in the Netherlands

In order to find out the barriers and limitations of the proposed system, three face to face interviews were carried out in order to get an idea about the status of waste management and upcycling in the Netherlands.

The identified barriers and benefits were categorized based on the study executed by Jarre et at. (2020) [103] in the first place and complemented with information from other relevant sources found in scientific literature. The classification is done with the objective of analysing the different limitations by categories and to identify the relationships between them from a wider context.

7.1.1 Identified barriers for wood cascades implementation in the Netherlands

The limitations shown in Table 7. These are the result of the interviews conducted to the actors involved in the upcycling industry in the Netherlands.

Table 7: Identified barriers and limitations to waste wood cascading according to interviewed institutions

Institution	**Identified barriers / limitations**					
KIDV	Waste-to-energy incentives	Lack of existing network connecting stakeholders	Marketing and sales tools	Public awareness and social acceptance of upcycled products	Chemical treatment of Wood	-

Stunt Foundation	Specialized workforce	Availability and price of raw materials	Financial ability to secure a space for the new work	Sector Dedicated marketing	Lack of material cycle awareness	-
HMC School	Lack of reverse logistics	Material availability (25% only coming from waste pallets)	Lack of appropriate technology / specialized workforce	Lack of marketing	Limited market expansion	Poor government support

- **Barriers' sorting**

The barriers shown in Table 7 were categorized into 5 different sorts following the criteria stated in the study of Jarre et al (2020). Each one of the limitations listed in Table 8, even if they are repeated across the interviews. Just as in the cited study, a common limitation between interviewed entities is a reflection of the importance that particular barrier within the bigger picture. In this case the repetition of the same factor between entities is an indicator of it being an important aspect to address in the transition within the Dutch context from a current actor's perspective.

Table 8: Sorting of the identified barriers for cascading implementation in the Netherlands following the criteria stated in Jarre et al. (2020)

Identified limitation	**Category**				
	Stakeholder involvement	***Technical implementation***	***Market***	***Environmental effect***	***Policy***
Waste-to-energy incentives	✓	✓	✓	✓	✓
Lack of existing network	✓	✓	✓	✓	✓
Marketing and sales tools	✓	✓	✓	✓	✓
Public awareness/social acceptance	✓	✓	✓	✓	✓

Chemical treatment	✓	✓	✓	✓	✓
Specialized workforce	✓	✓	✓	✓	✓
Availability/price of materials	✓	✓	✓	✓	✓
Financial support	✓	✓	✓	✓	✓
Sector dedicated marketing	✓	✓	✓	✓	✓
Lack of reverse logistics	✓	✓	✓	✓	✓
Lack of appropriate technology	✓	✓	✓	✓	✓
Limited market expansion	✓		✓		
Poor government support	✓	✓	✓	✓	✓

7.1.2 Identified economic benefits of wood cascading implementation in the Netherlands

Similarly, to the identified barriers, each interviewee gave his/her perspective of the possible benefits deriving from wood cascading implementation. A summary of the benefits shown in Table 9.

Table 9: Identified benefits deriving from wood cascading implementation in the Netherlands according to the interviewed actors

Institution	**Benefits**					
KIDV	Job creation	Awareness increases with regards to upcycling	New market products	New services	Technological innovation	Assets increase in the industry

Stunt Foundation	Upcycling process awareness	Sustainability awareness	-	-	-	-
HMC School	Creation of new products	Material reuse awareness	New working mind-set	New skills development	-	-

- **Benefits' sorting**

Just as in the case of the barriers, identified benefits are also grouped according to the same classification criteria as before. The data seen in Table 10. The benefits were categorized by relying on the classification found in Jarre et al. (2020), as well the theoretical bases stated in CHAPTER 4. Thus, the benefits were categorized according to the contribution to or influence over the limitations listed on Table 8 and the set to which they belong according to the used criteria. The benefits might also not be directly related to the rest of the categories, but they can indirectly influence the mentioned aspects following the different paths shown in Figure 22.

Table 10: Sorting of the identified benefits of a cascading system implementation in the Netherlands following the criteria stated in Jarre et al. (2020)

Identified benefit	**Category**				
	Stakeholder involvement	***Technical implementation***	***Market***	***Environmental effect***	***Policy***
Job creation	✓	✓	✓		✓
Upcycling awareness increase	✓			✓	
New market products	✓	✓	✓	✓	
New services	✓	✓			
Technological innovation	✓	✓	✓	✓	

Assets value increase in the industry	✓		✓		
Sustainability awareness increase	✓		✓		
Creation of new products	✓		✓		
Material reuse awareness	✓	✓	✓	✓	
New working mindset	✓	✓			✓
New skills development	✓	✓		✓	

- **Identifying connections among sorts**

Considering the classification done in Table 8 and Table 10, interactions between the different categories could be obtained by following the patterns from the study of Jarre et al (2020). These interactions shown in Figure 22. This way, it was possible to assess which limitations were connected to the economic perspective of the cascades system implementation and whether that influence could be catalogued as direct or indirect. A direct dependence is assumed to occur when two blocks are straightforwardly connected one to the other, whereas an indirect case is that in which a sort is connected to another one that directly affects the set under question.

For example, the Forest Management and Carbon Storage block does not exert direct influence on Infrastructure, but it shows an indirect influence through Energy and Resource Policy. This differentiation was done to get a clearer idea of how the different involved aspects can interact with each other in the studied context.

Although relying beside the scope of this study, the graphic in Figure 22 can also set connecting lines between the environmental and economic aspects of this case study.

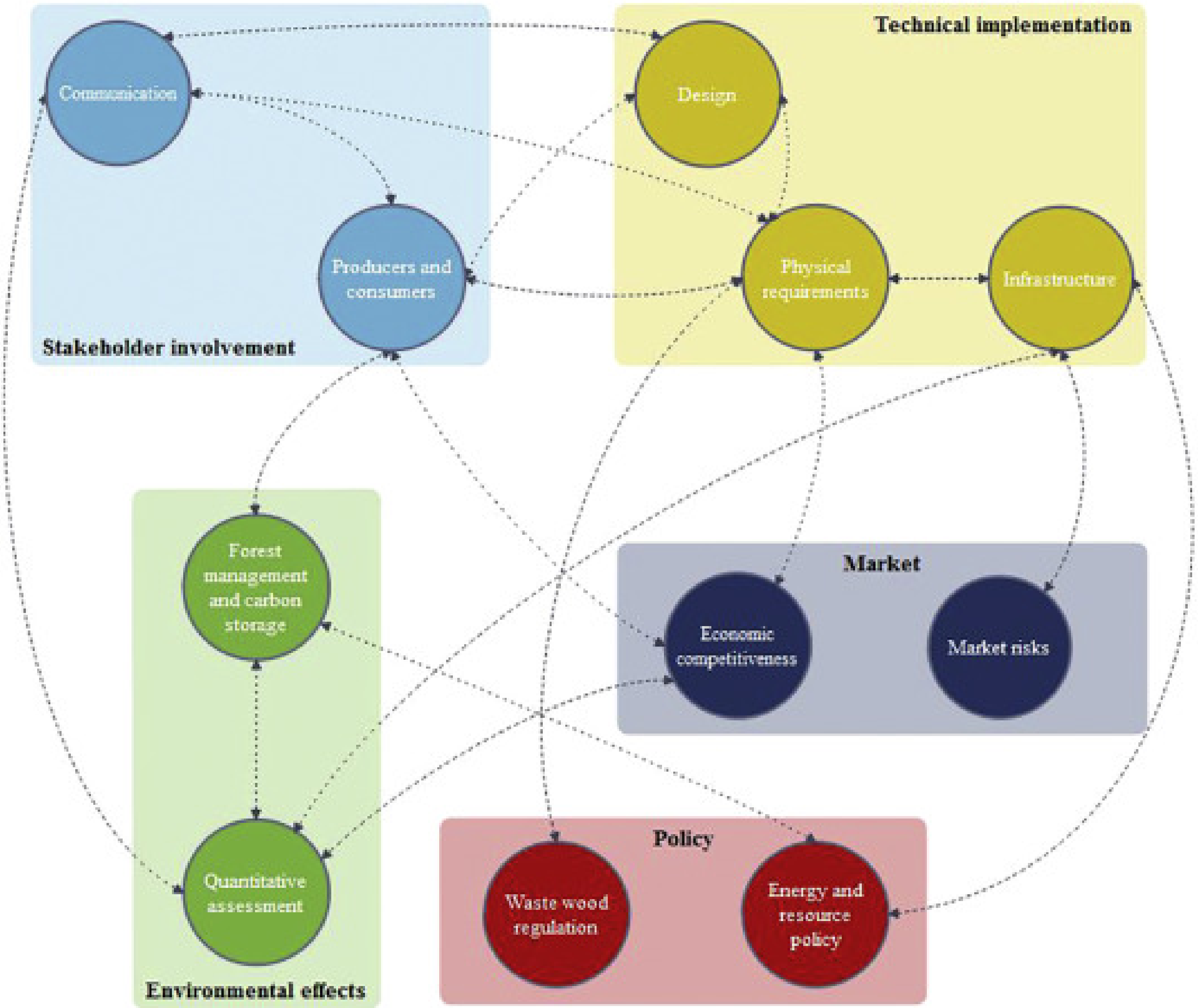

Figure 22: Categories and interdependencies among categories in the analysed context for wood waste cascades. Source: Jarre et al (2020)

7.2 Environmental benefits and disadvantages of wood cascading as feedstock for advanced biofuels

In this study, an environmental evaluation of the wood cascades system is performed with the aim of pinpointing the advantages and disadvantages of coupling it to biofuels production. The cascades would serve as feedstock supplier for gasification biofuels in the Netherlands.

In order to identify the main hotspots for benefits and disadvantages of coupling wood cascades with biofuels production, this methodology relies on the four dimensions of wood cascades cited in Section 4.2 as the main sorting categories. Additionally, the main environmentally influencing factors of the timber industry and wood cascades, also listed in Section 4.2 are being related to the main dimensions of wood cascading. This way it is possible to relate these hotspots with those of the biofuels supply chain and the entailed environmental impacts.

7.2.1 Identified barriers for wood cascades implementation in the Netherlands

Table 11 shows the insights obtained from the representative of each institution and their perspective from an operational point of view.

Table 11: Identified environmental difficulties of wood cascading according to interviewed institutions

Institution	*KIDV Sustainable Packaging Company*	*HMC School*	*Stitching Stunt Foundation*
Perspective	• Sensitive to government decisions • Chemically treated wood	• FSC or PEFC are difficult to implement. • Responsible and active forest management is much needed • Customer mind-set • Students mind-set	• Lack of proper machinery

- **Barriers' sorting**

The difficulties are grouped according to by the four dimensions of wood cascading listed in Section *4.2 Environmental perspective of wood cascading*. These dimensions are considered as the main four categories.

This way is possible to establish a relationship between the cascades and advanced biofuels supply chain, and identify which elements would be counterproductive to the biofuels production process as consequence of feeding it with waste wood from cascades.

Table 12: Sorting of the cascades system's implementation barriers according to the four dimensions of cascading.

Identified difficulty	**Category or dimension**			
	Appropriate fit / resource quality	***Augmentation / Utilization time***	***Consecutive relinking / Resource "salvage ability"***	***Balancing resource metabolism / Consumption rate***
Waste-to-energy incentives	✓	✓	✓	✓

Chemical wood treatment	✓	✓	✓	
FSC or PEFC are difficult to implement.				✓
Lack of responsible forest management				✓
Lack of customer and public awareness to wood reuse	✓	✓		
Lack of proper machinery	✓	✓	✓	

7.2.2 Identified environmental benefits of wood cascades system implementation in the Netherlands

Table 13 shows the identified advantages of implementing a wood cascades system for waste wood in the Netherlands according to the interviewed actors.

Table 13: Identified environmental benefits of wood cascades according to interviewed institutions

Institution	**KIDV Sustainable Packaging Company**	**HMC School**	**Stitching Stunt Foundation**
Perspective	• Prevention of forest felling • Less transportation and energy consumption • Less fossil fuels • Less CO_2 emissions • Fresh material input reduction • Prevention of waste	• Preventing careless down cycling • Replacement of some materials	• Less forests felling. • Less transportation • Better balance of the nature.

- **Advantages sorting**

To evaluate the environmental benefits of wood cascading, the insights obtained from the interviewed entities were categorized according to the cascades system dimensions cited in section in section *4.2 Environmental perspective of wood cascading*. The sorting shown Table 14.

Table 14: Sorting of the cascades system's implementation benefits according to the four dimensions of cascading.

Identified advantage	**Category or dimension**			
	Appropriate fit / resource quality	***Augmentation / Utilization time***	***Consecutive relinking / Resource "salvage ability"***	***Balancing resource metabolism / Consumption rate***
Prevention of forest felling			✓	✓
Less transportation and energy consumption	✓	✓	✓	✓
Less fossil fuels				✓
Less CO_2 emissions				✓
Fresh material input reduction	✓	✓		✓
Prevention of waste	✓			

- **Allocating factors of remarkable influence of cascading among the four dimensions**

By sorting out the different influencing factors of wood cascading between the different dimensions of wood cascading, it will be possible to establish a relationship between the advantages and limitations of the proposed system. This way it would also permit to overlap such factors with the advanced biofuels supply chain.

Table 15: Sorting of the environmentally influencing factors of the timber industry and cascades chain

Influencing factor	**Category or dimension**			
	Appropriate fit / resource quality	***Augmentation / Utilization time***	***Consecutive relinking / Resource "salvage ability"***	***Balancing resource metabolism / Consumption rate***
Energy use	✓			✓
Land-use change		✓		✓
Carbon Capture				✓
Fossil-based materials substitution	✓		✓	
Transportation	✓	✓	✓	
Product lifespan / Carbon storage	✓	✓	✓	✓
Technology	✓		✓	✓
Wood waste and by-products	✓	✓	✓	✓
Policy support		✓	✓	✓

CHAPTER 8

DISCUSSION

In order to discern How does the end of life and extension of use of wood pallets compare for different approaches of upcycling, reusing and gasification, no scenarios were proposed, but instead, the information was extracted from the data obtained from the literature review executed throughout the present study.

8.1 Economic benefits and limitations of wood cascading system implementation in the Netherlands

A wood cascading system intends to seize the value of waste materials by employing it as feed for consequent processes, allowing the production of goods of higher value in different stages. This way, the same unit is reutilized consecutively for different material applications according to its quality and quantity. As a final step, the material is sent to energy recovery facilities with the purpose of extracting its energetic value, as stated by the Lansink's waste hierarchy.

The followed methodology allowed to pinpoint the different influencing factors concerning this system's implementation in the Netherlands from the actors' perspective, and to study the different interconnections between them according to relevant scientific literature.

The reviewed literature states that a wood cascades system in countries with good economies and scarce natural resources holds the potential of bridging the existing supply-and-demand gaps for the wood industry. At the same time, this system contributes to a sustainable economic growth led by an efficient management of existing resources entailing environmental benefits for the wood industry [116].

In the first instance, it can be stated that there are some stakeholders in the Netherlands already taking action towards the transition to a circular management of waste wood flows. Some operative pallet pools are in charge of retrieving damaged decks and executing recovering activities that permit their reinsertion into the system. On the other hand, there are some local and small actors already working in wood waste upcycling activities on their own. This is an indicator of an early stage of upcycling and cascading activities taking action on the path towards a Circular Economy.

However, certain limitations are limiting the expansion and spreading of the activities, and from an actors' level this is indicated by the lack of a network that allows stakeholder interactions.

- **Policy Support**

Policy and institutional support are elements of vital relevance to incentive the transition towards a more material reused for goods production. Robust production planning, adequate policy measure of impacts, and promotion of collaboration with other stakeholders are vital to lead forward the implementation of more sustainable practices in the wood sector [84].

In the case of the Netherlands, the existing waste-to-energy policies and the priority given to clean energy generation over woods production, is interconnected with the upcycled wood market risks. The connection is derived from the use duality of wood, which causes a material competitiveness between both sectors. In this regard, the existing financial mechanisms supporting the transition are available, yet they do not seem to represent a constraint or limitation to the transition given that the financial support is already available in different European and Dutch financial institutions. Instead, it is a matter of the relevance given to energy over material use of wood waste flows.

This said, in the specific cases of the Netherlands, policy support is not a common limitation addressed by the different interviewed actors, yet it is a factor that evidently undermines the transition towards a more sustainable waste wood management. With this situation in mind, unless novel business models independent from policy support are not considered as an alternative, it does represent a remarkable influencing factor to consider in the transition. In other words, an update of national regulations in which emerging upcycling businesses are supported is vital to drive the transition forward.

However, steps are being slowly taking on this direction by the Dutch government. Biomass is cited as one of the priorities within the transition towards a circular economy in the optimization of SDE+ regulations, which passes by removing regulatory obstacles that hamper the material use of waste wood and its substitution in the energy sector by other wood processing residues like lignin. The initiative also pursues the avoidance of clean waste wood being used for energy purposes and substituting it for less clean "B-type" wood [122].

In this regard, a strategic goal is the optimization of the efficiency in the use of biomass by cascading, and multiple valorisations achieved by an increased use of loops along the supply chain. This goal is supported by a request to amend biomass policy in such a way that it allows to divert waste streams towards material use besides energy purposes. This represents a way to encourage the cascaded use of biomass and foster the circular economy without compromising energy targets [122].

This revision thus asserts the intention of a clear transition towards a cleaner economy based on a better suited and adjusted legal framework to the reality of the non-neutral carbon nature of wood. However, a legal framework must be accompanied by sound actions based on that new approach in order to start moving towards the Circular Economy target in year 2050. The lack of accelerated actions from the government, poses certain limitations on the promotion and activation of a wood cascades systems. Such limitations are related to feedstock supply, network creation, technology advances adoption, consumer awareness, market issues, financial support and stakeholder involvement.

- **Market**

Table 8 shows the market share as a relevant aspect to consider within the transition.

The interviews show the struggle of upcycling businesses to secure a sound and predictable flow of materials and products of similar or consistent quality in order to ensure a continuous production of their goods [72], [117], [118]. Similarly, the price of upcycled goods is not only dependent on the availability of material flows, but also on other several factors such as consumer acceptance. This barrier added to the lack of proper marketing channels pose an important obstacle for upcycling businesses to find effective selling channels or marketplaces, despite the growth of online platforms and offline outlets. Currently, a reduced number of consumers are interested in upcycled products, contrarily to the majority which seems more interested is mass-produced goods [72]. Thereby the importance of increased consumer awareness to motivate market growth.

From a policy perspective, the existence of waste-to-energy incentives and poor government support is also responsible for hindering the transition towards fostering upcycling practices within the economy. The economic competitiveness of wood given these mentioned factors contribute to increased market risks of upcycling businesses given the uncertainty surrounding material availability for the use of wood as source of energy. Simpler supply chains and lower quality requirements for energy purposes place a steep road ahead for upcycling entrepreneurships.

Likewise, the interviews [119] and the scientific literature reflect the importance of wood treatment with regards to material availability for upcycling processes. Chemically treated wood limits its posterior allocation inside the cascades due to the remaining of toxic chemicals. Therefore, that type of wood is directly sent to incinerating facilities to prevent it from reaching human-health threating applications during its second life.

An important aspect to note in the case of the Netherlands is the relationship between the Market risks, of which material availability is an influencing factor, and its relationship with the country's policies. This aspect has been discussed in the Policy category section of this chapter.

Wood material supply, as reflected by the literature, is crucial to keep market stability of upcycled goods. The absence of a logistics chain to allocate raw material among the different levels provokes important sensitivity to wood supply and prices. This fact is endorsed by the interview done to the Stunt Foundation, in which the absence of an official supply chain is addressed as cause of unstable supply and volatile prices.

Wood cascading is heavily dependent on a proper waste flows management throughout the whole chain; thus, it is also sensitive to management decisions taken upstream. Current energy incentives, lack of proper waste management framework and vague bases of current regulations contribute to market instability of wood flows. Prioritization of energy generation from waste streams by national policies cause greater profitability than reinserting the material into the cascading chain for waste wood collectors [69]. As a result, the cascaded wood market experiences an irregular supply of raw material as consequence of this material competition.

- **Technical Implementation**

Efficient cascading implementation heavily relies on design, so the reuse, recycle or remanufacture of a product is easier [69]. In the case of wooden pallets, a proper design adequate for a cascading process downstream, enables parts of the deck or the piece as a whole to be easily deconstructed into its components. By preserving the material's quality, the material is readily available to be cascaded or up-cycled, contributing to material availability.

Physical requirements of the wood are one of the key elements for wood cascading implementation, especially when it comes to waste wood treatment [69]. Chemical treatment techniques to which the wood is subjected have shown to have negative health and environmental effects, reason why these chemically treated pallets are directly sent to incineration. By adopting the use of less toxic wood additives, as mentioned during the KIDV interview, a larger quantity of pallets would also be available for different applications, also contributing to sounder wood waste flows.

Infrastructure also plays an interesting role in fostering or retaining the advance of wood cascading and Circular Economy. The prevalence of energy conversion facilities over waste wood sorting facilities is a crucial factor limiting the new cascaded system, which has been influenced given the sound support given to waste-to-energy facilities. The lower density of wood cascading facilities implies longer distances to transport the material, echoing into higher products costs [69], [70]. Also, by inserting new working mind-sets and skills in the wood sector, as stated by sector actors [118], new pallets design and decks configurations would ease the retrieving and material seizing process, which would impulse the creation of new and valuable products.

Coupled to infrastructure, the absence of adequate logistics has repercussions on the general costs, especially when concerning waste wood collecting activities and transportation to post-use treatment facilities. Research shows that transportation accounts for 89% of total logistics costs [69]. On the other hand, upcycling businesses constantly struggle with securing a predictable flow of materials and products of similar or consistent quality.

Implementing a circular wood cascading system would bring about the emergence of new profitable markets at the different levels shown in Figure 8: Wood market structure and cascades in EU28 [52]., which among other factors requires specialized and high-value workforce in charge of the development, production and maintenance of the new circular products. In the case of wood pallets, the addressed limitations regarding material recovery, repair and recycle would also come in handy for the existing pallet pools, which also present the same logistic related limitations. This way, an integration of experience and lessons learnt from existing pallet pools could be easily extrapolated into the circular cascades systems to foster material upcycle.

From an economic perspective, the KIDV representative expressed that an important economic leap from a cascades model is expected once innovation penetrates the market. In this regard, innovation involves from a financial point of view the technical and engineering spectrum of the term. The HMC school envisions mass production leading to less operational costs, high quality eco-design using technologies, like 3-D printing, laser cutting, ERP, CNC. The Stitching Stunt Foundation equally points towards the use of automated processes and new technologies that would lead to less expenses and higher work efficiency.

- **Stakeholder involvement**

For the cascading principle to operate efficiently, a strong connection between stakeholders must exist, supported by efficient communication to share information among involved entities. As a result, a strong network that acts according to the principles of circularity is created. This is shown by the quantity of identified barriers related to this category in Table 7.

Social awareness regarding wood cascading is necessary [69], since this influencing factor enhances the public acceptance and preferment of cascaded wood products. At the same time, it encourages manufacturers to opt for this circularly managed material to produce their goods. Additionally, R&D and new skills development in the cited field closes the gap between involved stakeholders namely science, industry, designers and governments, to push the model forward.

Given the long wood material's lifespan, tracking the new products throughout their life is difficult, thus holding producers accountable alone for the end-of-life management of their products is not an easy task. A tracking and certification system, as well as information about end-of-life management of products is included as a way to promote post-consumer responsibility over wood materials. Additionally, a tracking system would also permit to monitor the quantities, quality and direction of the wood flows, thus ensuring a continuous and steady supply to the involved parties.

Tables 9 and 10 also reflect the importance of building strong stakeholder relationships with regards to the benefits this action brings. As the system expands, so does the number of benefits linked to this category, and this also would bring a positive change in the rest of the categories.

The creation of new partnerships, in which parties set up new collaborations beyond the boundaries of their organization or existing partners is an important factor of the advance towards a circular economy. The government's role, in this case, is to stimulate and facilitate stakeholder involvement by developing new connection paths between parties, as well as creating novel ways in which these can connect and collaborate[123].

The emergent network gives place to new trading and economic paths between the different levels and sub-levels of the existing wood market structure shown in Figure 8: Wood market structure and cascades in EU28 [52]. As consequence of new trading paths creation, economic opportunities for different business would arise in form of new partnerships based on service providing business models, increasing demand for advanced logistic services and a growing demand for specialized worked force within every category of the wood market structure supported by a stable wood material supply.

Additionally, as a launching partner, the Dutch government can also offer support and strengthen mutual communication and cooperation with emerging businesses, giving place to a strong cooperative network. As a result, the acceleration of initiatives like that of the Stunt Foundation and HMC School is attained, while also contributing to solve certain social issues. Indeed, the Stunt Foundation representative clearly expressed that government and SMEs support is inevitable for start-up stimulation.

8.2 Environmental perspective of biofuels production from cascaded wood

After identifying the different dimensions that give shape to the environmental perspective of a wood cascades system and the relationships between the studied factors of the chain, some benefits and disadvantages were identified.

With no doubt, the balancing resource metabolism and consumption rate is the dimension with the most benefits by the proposed system implementation, followed by Appropriate fit/resource quality. These two categories can interconnect as a result of the proper allocation of resources along the chain according to their physical and chemical characteristics. This means that by using resources according to their present quality and following a proper allocation framework, a positive result can be seen in natural spaces and biodiversity. In turn, this leads to lowering the need for fresh resources input, and providing natural ecosystems the space to exercise their inherent metabolic activities as part of the climate change mitigation strategy.

From a biofuel’s perspective, this is a positive characteristic. The production of biofuels from wood would not exert as much of an environmental burden as it is nowadays. Thus, the ecosystem balancing effects deriving from the benefits of the cascades can also be extended as an environmental benefit for the energy recovery step.

One of the main barriers for coupling both systems is the dependence of biofuels production upon the material flows deriving from the cascades. The biofuels sector is highly demanding in the quantity of raw materials, thus coupling it with a cascades system, that intends to reuse a unit of material for as long as possible, involves a high level of complexity.

In the first place, it is necessary to address the policy adjustments in order to ensure an economically and environmentally viable transition towards the production of sustainable biofuels from cascaded waste wood.

Waste-to-energy incentives is an influencing factor linking both supply chains. From an environmental perspective, promoting the down cycling of wood waste straight to energy extracting facilities, does increase material availability for biofuels production, but it sharpens the consequences of the system as a whole on the environment. This is true unless a strictly regulated cascades system monitoring is established, which ensures that the features of the materials are only suitable for energy harvesting.

For this reason, a wood cascades system passes by a modernization of concepts and legislation to ensure that the transition is sustained by adequate policy support and indeed contributes to a reduction in GHG emissions, while also guaranteeing economic growth. Policy support is vital to make all four dimensions of wood cascading work.

Policy-wise, there is acknowledgement that the Dutch government can do better on promoting the transition to a circular economy, in fact, within the different documents addressing a transition towards this model, there is recognition for the need to reframe the way current policies address waste and its management. The "From Waste to Resource Programme" addresses specific objectives that supports the transition acceleration. Among these objectives, identifying and eliminating unnecessary obstacles in legislation by creating scope for innovation in legislation and in standards is cited. On the other hand, adopting an approach to specific material chains and waste streams is addressed, which includes stimulating high-quality recycling in each material chain as well as using residual biotic streams in a high-quality way[121].

A benefit of coupling the wood cascades with biofuels production comes with a reduction of the energy input throughout the whole system. Less energy use within the chain is proportional to the required resources to cover the energy demand of the system. Given that an important share of the energy used in the chain comes from fossil resources, a lower energy input would also imply GHG emissions reduction.

In the same manner, the interviews reflect a diminished use of fossil fuels as consequence of the implementation of the cascades along the wood industry processes, yet this reduced use of fossil fuels could be even lowered when feeding the system with cascades derived biofuels.

Yet, the subject of GHG emissions reduction as consequence of the energy use is extremely sensitive to the system boundaries and the methodology utilised to evaluate the environmental impacts.

Additionally, the most optimally the wood is fitted within the cascades according to its quality, the lesser energy it will need to adjust it to the requirements of the stage in which it is allocated.

Similarly, coupling both systems would also show a positive effect on land use change and the carbon capture ability of natural systems. The lower quantity of fresh resources required to feed the system; the less amount of land is needed to adjust the feedstock to the industry material demands. With less forest felling taking place natural ecosystems are granted the opportunity of self-restoring, thus succeeding in their natural balancing processes, thus representing an environmental advantage for the total system. Both, the wood and the advanced biofuels production industry would see a decrease of their consequences of this factor in the related LCA categories to this aspect.

On the other hand, despite the cascades and circular management lead to a drastic reduction of fresh material input, some incoming flow would still be necessary. In this regard, information from the interviews reflects the need for a controlled and sustainable management of the forests being exploited [118] to cover the material demand. This in turn represents a shared environmental benefit for both systems being coupled.

Another factor influencing the environmental perspective of the proposed system is transportation. Although this element does not represent a relevant burden for the biofuels supply chain, it does for the cascades system. Transportation is responsible for an important impact within the timber industry, and for a material it is also representative of the embodied energy.

In order to decrease the amount of transportation, a proper design of the cascades chain is necessary as far as logistics and infrastructure distribution go. Less transportation would decrease the amount of embodied energy related to this block. In this regard, both the biofuels production and the wood cascades system would see benefits deriving from this advantage. If less transportation is necessary within the whole system, then it could be possible to cover the fuel demand of the chain with the biofuels being produced.

Similar to transportation the product lifespan is also determinant in the way it stores invested energy and resources throughout its transformation processes. Thus, the longer the product lifespan, the longer it is able to store carbon for. This is especially important when dealing with bio-based energy applications. Nature is able to release carbon at controlled rates and this enables it to keep its natural balance. By mimicking this behaviour less anthropogenic alterations of the carbon cycle are expected when using forest-based resources.

Technology is vital for an efficient management of resources, and it is also important within the cascades chain. The more efficient a technology is, the more it leads to resource salvage ability and correct allocation of wood pieces along the material chain.

Lack of proper machinery leads to larger wood material wastage, which in a well-structured wood cascades system is not a disadvantage, since what's not suitable for one stage could be an appropriate fit for another. In this case, this represent a heavier material flow being injected to the biofuels producing process. Thus, old-fashioned machinery embodies a down-side for upcycling processes but an advantage for the energy harnessing step.

Reusing wood waste flows and by-products of different processes, targets energy and resources savings. Also, reusing the same unit multiple times leads to augmenting the utilization time of wooden material, thus harnessing woods potential to capture carbon for a longer time.

In general, it can be said that certain cascades system constraints do represent an advantage for biofuels production. However, this can mislead to thinking that if both electricity production and biofuels are both considered energy purposes, why would producing biofuels be more advantageous than instead producing electrical power. In this regard, the clear difference is that biofuels can be reinserted as transportation fuels to cover the energy demand for this cascades system to function in a more carbon neutral way. This represents a viable opportunity to substitute fossil fuels sourcing the system and their associated effects not only in emissions deriving from these activities, but also the repercussions they hold in the other considered aspects such as LUC and carbon capture and storage.

With this background being considered, it remains to evaluate the feasibility of this proposal from a quantitative perspective to study the extent of the environmental benefits or disadvantages deriving from the use of cascaded wood wastes as substitution for forest practices as source of biomass feed for biofuels production.

CHAPTER 9

CONCLUSION AND RECOMMENDATION

Given the fact of the existence of operative pallet pools, spread private initiatives benefiting from the cascading system, coalitions and declarations (EPF, EFIC, Venice declaration), abundant waste material as process input, defined market levels, as well as the necessary technology for the production of biofuels via gasification are already existent and within the country's economy and energy transition portfolio. This shows a paved way at different aspects to commence a heavier upcycling process in the country.

In summary, the implementation of a cascades system for waste wood pallets in the Netherlands, is already an incipient movement with several already operative actors working each by their side. In this concern, the Netherlands has this advantage of different existing businesses, making it one of the most prepared countries for the intended transition to a Circular Economy.

Nonetheless, it still presents some challenges ahead. The main one represented by the large economic support given from a political level to biomass- based facilities as part of the Dutch renewable energy package. In this sense, it is necessary to restructure the backbone of bio-based incentives to promote a more expanded application of upcycling practices over energy generation from biomass. This said, there is no such thing as complete absence of economic support in the Dutch scenario for emerging circular businesses, but instead an absence of structural framework that brings all the elements operating in an isolated way, together into one system that operates synergistically. Other limitations deriving from this issue are lack of public awareness, lack of proper technology and proper pallets design, and an active network that supports the operation and keeps the internal flows at a stable rate.

Economic advantages of switching to this new system are mainly represented by the emergence of new and sustainable businesses in the lower and mid-market levels, that would contribute to a circular economic growth, material efficiency and jobs creation, while lowering the dependence on imports of fresh natural resources.

Regarding the effects of coupling biofuels production with a waste wood cascades system, the results that the qualitative research points to are environmental benefits for both biofuels production and the cascades system. Large share of environmental footprint of biofuels, just like with wooden goods, derives from Land Use Change effects and biodiversity loss during crop phase, due to the constant need for fresh input. By introducing the cascades systems as provider of feedstock for advanced biofuels, environmental repercussions can be minimized. Additionally, the need for fresh input is reduced by profiting from the residue of the upcycling stages. Additionally, wood cascades promote the adoption of sustainable energy practices and management in the industrial sector, by integrating mass and energy flows to cut on the need for more fresh resources. Nonetheless, these benefits are limited by the complexity of coupling such a feedstock demanding sector, like biofuels, with the cascades. Unless this transition is done with deep understanding of the several challenges that might arise, it could otherwise result into an increase of the need for more fresh resources.

It remains to study to what extent does this interconnection benefits the biofuels production from an environmental and economic perspective.

9.1 Waste wood lifespan comparison

When implementing a waste wood cascades system, the result is a prolonged life of the same unit of material. Pallet pools currently align with reusing practices of worn pallets; however, their activity only reaches as far as their own treatments for repair are enough as to keep the same unit of material in the cycle. This means that there will always be a waste wood flow outside their system.

By introducing pallet pools as the core of a larger system, an extension of the existing lifespan of waste wood pallets is attained. A cascaded system operating in parallel, or as an "outer shell" of pallet pools would seize worn material and introduce it into a different productive cycle according to its present conditions.

The cycles following the pallet pools, would recover the material and cascade it along the chain, extracting its added value down to the energy recovery step, in which an advanced thermochemical process, such as gasification, would break down the remaining of the material for energy purposes. In this case for advanced biofuels production that can be inserted into the cascades cycle or used for general mobility purposes.

Upcycling, reuse and gasification of wood all present advantages from a material, economic and environmental perspective. The first two prevent the value of the material to be scaled down in one single step for energy production. Instead, they prolong the inherent worth by turning it into a second-hand item with different benefit. However, once the good produced from the recovered wood has reached the end of its useful lifetime, and without a proper chain that recovers its remaining value, would equally end-up in combustion facilities or landfills. Its lifespan was indeed extended by being used for a second time, yet it still contains valuable matter that can be used for a different purpose than energy generation.

Gasification, likewise, is itself a cleaner alternative than combustion given its lower associated air emissions (energy, and process). It also exhibits a higher flexibility with regards to feedstock and final product.

Thus, when pallet pool circular cycle operation is coupled to a larger system that resembles its operation in other levels of the productive chain, the value of the wood unit is extended and revalorized as long as its quality and features allow to. When this unit of material is subsequently also included as feed for an advanced biofuels chain, a reduction in the overall footprint of the system can be expected.

In this regard, the extension of the lifespan of the material also implies the extension of its inherent value, which would instead be available to be harnessed several times along its lifecycle. This means that with a correct business model, and the collaboration of diverse political and economic institutions, the unit could keep an economic value that lasts for a few cycle levels, increasing the material's productivity along its lifetime.

Going further on the environmental perspective, by executing the cycles of reuse and upcycling repeatedly, the carbon storing capacity of the material is being maximized, thus stored carbon is kept away from the atmosphere for a longer period of time.

9.2 Outline for a cascaded system

The proposed outline for a cascaded system interlinks the fundamental operations within the cascading and circular system elements, such as production, consumption, financial and policy instruments. Each element plays a significant role in closing the cycle, enabling the transformation from current linear practices to an economy based on cascading operations that include environmental, economic, and even social gains.

The production element acts as an enabler to new pallets eco-design, this way, disassembling waste decks becomes easier and faster, allowing to recover the valuable 11 boards and sometimes the 9 blocks of the pallet. On the other hand, a novel design approach would also generate pallets that are ultimately safer and lighter, with a more hygienic structure, making up-cycling processes more efficient.

The aforementioned benefits achieved by a novel pallets design faces certain limitations, such as increased costs associated to the novel eco-designs' patterns and prototypes. Another difficulty lies in incentivizing manufacturers to implement innovative pallets designs, given the increased production costs at the early phase. Furthermore, the misalignment between the interests of manufacturers, users and recyclers and the absence of incentives for such improved design is also a limitation for this new approach.

Planned obsolesce is another limitation encountered by this new production alternative. The absence of obligatory policies related to this issue holds back the transition towards a more efficient allocation of resources. By addressing this factor, diverse benefits can be generated by giving a proper pallets obsolescence definition. A solution walks through the introduction of incentives for producers to switch to the mentioned eco-designed pallets, as well as opting for more straightforward means of retrieval, in which both consumers and producers can be part of. These resolutions should be implemented at a national level following a system that puts municipalities at the core of the operation. In the Netherlands, such framework is possible to achieve given that Dutch municipalities hold active financial independence, and count as effective authoritarian entities, connected through the Association of Netherlands Municipalities (VNG).

Increased cascading quantity tops the benefits list, followed by augmented quality-oriented pallets being sent to the right following stage, thus avoiding any improper or useless applications. This action should be coordinated with the waste pallets receiving facilities, guaranteeing good quality material feedstock for the facility. Moisture, size of particles, type of wood among other factors to be considered.

Extended Producer Responsibility (EPR) is the third product side action. EPR is a relevant factor within the Circular Economy, yet there are certain difficulties that make the EPR harder to implement. Specifically, EPR mainly targets massive pallet sales to specific stakeholders, such as wholesalers and big factories with a continuous mass demand of pallets. Collection and cooperation with post-consumers are complicated issues, due to the associated difficulty of retrieving small amounts of waste pallets, such as those sent to individuals., which otherwise end-up as dump in landfills. This is why empowering every involved stakeholder, from producers to consumers, embodies an efficient solution for pallets retrieval. The fourth activity is fostering industrial symbiosis & Support for SMEs. This imbeds the creation of a new independent association targeting the reinsertion of waste pallets from different sources as feed for the wood cascading system. For such association to succeed, it must act aligned with framework and policy makers, professional associations, pallets pools, NGOs and manufacturers.

R&D tools would allow SMEs to explore available opportunities in the dynamic market, as well as getting support from the multi-European fund programmes in the field of circular economy, such as COSME (the EU programme for the Competitiveness of Small and Medium-sized Enterprises), LIFE Programme and Horizon 2020[130], among others.

Moreover, the abandonment of SMEs from joining symbioses creates extra hitches. Associations' membership is almost exclusive to larger businesses with major influence on political decisions. The same also count on the potential to turn knowledge into opportunities for entrepreneurship, by using their strong structure and internal diversity.

Policy instruments concerning consumption embrace strengthening reuse and remanufacturing of the wood pallets, aligned with the conceptual basics and dynamics of this case-study. Waste hierarchy and the circular economy principles create preferences to efficient waste management options. A stronger support for individual initiatives includes spreading post-user material awareness, so to switch from the throw-away mind-set to a recover and reuse mentality. This fresh mentality results in a larger wood quantity available for cascading purposes, extra pristine wood felling savings, as well as direct and indirect environmental gains.

New jobs creation tops the list of the social advantages, accompanied by indirect financial profits at the individual level, due to less taxations or extra incentives.

Economic growth is easier to monitor, control and promote via the existing wood pallets cluster network of pools, repair and recycle companies. This network of pallets collection plays a significant role in sorting the entered pallets to the system, especially because it already counts on existing infrastructure and tools for this objective. Traditionally, waste pallets are subject to long and rather costly processes to enhance the element's features in order to be reinserted into the system.

On the other hand, strengthening reuse and remanufacturing measures, would allow pallets to be sorted for additional uses, that being cascading or gasification. Moving to this new approach on waste pallets management is not possible without reengineered infrastructure and trained personnel in charge of sorting used decks. The process runs through a collection criterion, such as the wood type (hard or soft), particle size, quantity, quality and the demand from potential buyers.

Green Public Procurement (GPP) is another element addressed within this outline for a cascaded system. However, the issue with GPP is that it is a voluntary act rather than an enforced activity, reason why it lies at the bottom of the list as an effective instrument. GPP aids to create the feedback loops on which the circular economy model is based. In the case of wood pallets, this voluntary action should follow a structured organization that leads to create frequent and massive pallets demand, thus turning this element into a game-changer instrument.

The financial side represented by adjusting Circular Economy Business Models (CEBM) for waste pallets. This process is founded on defining the dimensions of the CEBM and its relevant design options. Proper actions related to waste pallets have to be identified, followed by showing the gains and benefits reflected on the four circular product economy dimensions. Using this approach, a narrower vision can emerge to define a final and suitable CEBM.

Overall, this outline for a cascaded system faced the lack of sound statistics regarding circulating wood pallets in the Netherlands. Figures oscillate according to the consulted resource, and the absence of a pallet bank turns monitoring and tracking pallets locally and across nations a difficult task.

On the other hand, cascaded woody products is dominated by Small and Medium Enterprises, embodied by small and non-profit organizations, which encounter advance limitations when it comes to technology up scaling. Zero incentives and no direct interferences from larger businesses create barriers from official entities to apply EPR and GPP.

RECOMMENDATIONS

Overall, it is important to conduct a numeric assessment of the overall biofuel lifecycle considering cascaded wood as feed material, and compare it against the use of fresh biomass, agricultural crops, and forest residues, which classify as a lower-impact biomass, but whose environmental benefit is still subject to discussion.

It is suggested to analyse the necessary financial and regulatory instruments that could support the biomass-based facilities in order to harness their potential throughout the transition, from legislation, infrastructure and assistive technologies, benefiting from the experiences of European and international bodies that have made important strides towards the implementation of the circular economy system.

For subsequent studies, to present ideas supporting the proposed outline for a cascaded system and fill the gaps to reach an integrated plan that is flexible and capable of analysis, implementation and monitoring.

Additionally, it would be interesting to evaluate the possible scenarios that would result from the deeper integration of the government within the transition as procurer, launcher and partner, instead of the entity that only provides grants, subsidies and credits for emerging circular businesses.

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APPENDIX

RILEGNO CASE STUDY (ITALY)

The outline for a cascaded system that has been set for Dutch case can follow to some extent the roadmap of the Rilegno case study to avoid any expected failures, extra efforts or expenses and overcome existing barriers.

Rilegno is a national consortium in Italy that coordinates and promotes the collection, recovery, reuse and recycling of wooden packaging waste. The consortium has created a cooperative scheme that links private and public entities, where responsibilities are shared between the municipality, its inhabitants and companies (consortium).

Rilegno has already contributed to wood waste recovery, accounting for 6 % of the total weight of civic separated waste in Italy, with approximately 2M tons of wood recovered and recycled in 2019. [131]

At the first instance, Rilegno looks like a normal recycling entity that has cooperation with municipalities and industries in a specific region, but the consortium of Rilegno showed a unique form by having a full set of enabling tools to achieve an outstanding success. Those tools are:

- Specializing only in the treatment of the waste of wood packaging materials (pallets, coils, crates, food packaging boxes, etc...). Pallets and used pallets form around 67% of the total system feed, followed by the industrial packaging by 23%. [132]
- The registered companies in the consortium exceed 2000, these companies are from all types of wood packaging panorama companies (manufacturers of wooden pallets (41%), suppliers of wood packaging materials (13%), wood fruit and vegetable packaging manufacturers (12%), industrial wood packaging manufacturers (31%), importers (2.5%) and recyclers (0.5%), these percentages ensure the diversity of stakeholders, enhance the expansion of the network and encompass the marginal SMEs as well. [133]
- Active incorporation of the majority of the municipalities across the country.
- Employing 421 platforms distributed in an organized network to facilitate the processes of the consortium, this helps also sorting the raw materials in the collection locations, as pallets are dominant in the industrial areas, while small woody waste are found heavily in urbans.
- Employing 15 recycling points established in a small geographic area close to Milano city add to those 69 pallets repairing points.
- The recycling of wood is essentially oriented towards the production of chipboard panels and to less extent blocks for pallets and cellulose paste. This shows clear and direct production lines which have a tremendous influence on reducing the operational costs, at the same time,

it adds value to the waste by reusing and upcycling rather than downcycling in a form of waste-to-energy or incineration.

- The strategy of Rilegno is built on following the priorities of Lansink´s waste hierarchy (reduce, reuse, recycle, etc…).
- Technical implementations of the consortium act smartly to reduce logistics costs, the first volumetric reduction of wood waste takes place at the platforms, by pressing, crushing, shredding or chipping.
- The consortium contains wood packaging and logistics research center called CRIL, this research center's activities are based on the analysis and evaluation of the quality of wooden packaging using a technological and chemical laboratory. The aim of CRIL is to evaluate the quality and the dangerousness of the material, in view of subsequent reuse. CRIL organizes training courses and study of packaging and pallets. [134]

The lessons learnt from the Rilegno experience can form the corner stone to establish a similar environment for the reuse of wood packaging materials.

As a matter of fact, changes have to take place during deployment in the Netherlands taking into account the local governmental policies and targets.

These changes involve a direct cooperation with an in-house research centre, extend the responsibility of local entities towards a handy management process including sorting and logistic activities and above all an appropriate fit for the end-of-life process towards coming up with new products with added value. The Netherlands incubates lots of high-profile scientific centres such as TNO, those focus on circularity and sustainability from the environmental perspectives, thus, it is inevitable to form a network of collaborators or at least a consortium centred around waste wood reuse activities to achieve changes related to the red-taped policy, protect the innovation to be able to penetrate the meso-level.

The chipboard industry in the Netherlands occupies a very small share of the wood market so that it is recommended to orient the waste wood to product furniture or kitchen wares.

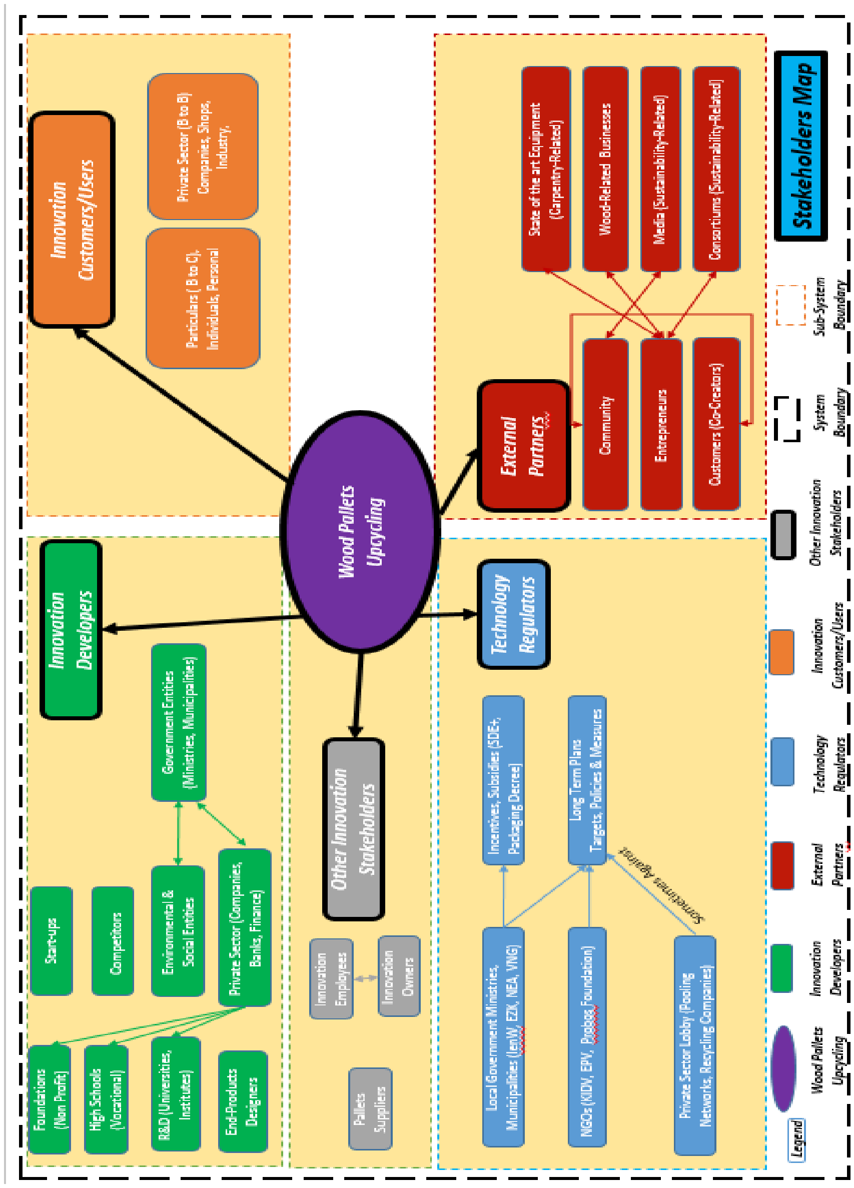

Figure 23: Stakeholder map and interactions within the circular economy model