Biomass pre-treatment for bioenergy

Case study 1: Biomass torrefaction

Torrefied wood pellets

IEA Bioenergy

InterTask project on Fuel pretreatment of biomass residues in the supply chain for thermal conversion

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Abstract

The trade of solid biomass across countries, especially long distance like across oceans, is limited by the characteristics of biomass energy carriers. The high water content of fresh biomass, between 50-60%, bulk density as low as 200 kg/m^3 for dried biomass (20% m.c.), and energy content below 3 GJ/m^3 pose several problems along the supply chain of producing and transporting solid biomass (Food and Agriculture Organization of the United Nations, 2015). Pre-treatment to reduce the water content and increase the energy density of solid biomass is required to reduce long distance transport cost.

This report, which is one out of six separate case study reports that illustrate the added value of pretreatment technologies in specific fuel supply chains, analyses the effects of pretreatment on supply chain efficiency by comparing the energy consumption along the supply chain of White Wood Pellets (WWP) supply with Torrefied Wood Pellet (TWP) supply.

While WWP have become a global standard energy commodity in the recent decade, TWP are just at the beginning of the industrial implementation phase. TWP are made using the same raw material as WWP, implementing an almost similar machinery set up with the additional roasting of biomass to increase the energy density (22,2 GJ/mt instead of 17,56 GJ/mt taken as industry average values) and improve the handling, storage and grinding properties.

Whether energy can be saved across the supply chain by producing torrefied wood pellets instead of white wood pellets depends on the balance between increased processing energy consumption and decreased transport energy consumption. For the supply chain analysed in this study, from Indonesia to Japan, overall energy savings of 6.7% at minimum can be reached by shifting from WWP to TWP, resulting from a 16% increase in bioenergy, used for drying and torrefaction, a reduction in the consumption of liquid fossil fuels of 20.9% (Diesel, MDO and IFO) and a 2.3% reduction of electricity consumption on MJ/GJ supplied basis. The energy reduction across the chain results in a 10.3% GHG emission reduction for TWP compared to WWP.

The additional torrefaction processing step of roasting the biomass, requires additional heat. This heat is partially supplied by the combustion of syngas which is released during the torrefaction process, reducing the required fuel wood input proportionally, resulting in a very similar overall thermal efficiency to WWP processing. The pelleting of torrefied wood does consume slightly more electricity than the pelleting of WWP per tonne pelletised but is slightly more efficient if compared on energy basis. (IBTC M&E study 2018).

A sensitivity analyses concerning the influence of shipping distance shows an increased advantage of TWP with increased shipping distances. The raw material moisture content also impacts the savings on otherwise similar supply hains, with increased moisture content reducing the relative advantage of TWP. This since the thermal efficiency in the TWP is lower, resulting in fewer savings when the drying energy becomes more dominant in the overall supply chain energy balance. As improved grinding characteristics is another benefit of torrefaction, this would allow for the use of briquettes instead of pellets in traditional power plants as coal mills coiuld grnd both pellets and briquettes. The production of briquettes requires less electricity, resulting in a 10.3% energy saving and 33% GHG saving across the chain.

Table of contents

1 Introduction

Using biomass as a renewable source of carbon will be pivotal for reaching renewable energy and climate goals in several world regions. The difference between national targets and production capacity, coupled with regional differences in production cost, has resulted in the international trade of biomass. Between 2000 and 2010, the trade of solid biomass has grown from 56.5 PJ to 300 PJ, mainly driven by demand from the European Union (Lamers, Junginger, Hamelinck, & Faaij, 2012). Until 2035, international trade of biofuels, both solid biomass for power generation as well as transport biofuels, is expected to increase six-fold compared to 2012, driven by demand from the European Union, Japan and India (International Energy Agency, 2012).

Between 2012 and 2015, the industrial demand for wood pellets in the EU stalled, increasing much slower than the years before, as a result of policy changes in main consuming countries (Biomass Magazine, 2016a; Canadian Biomass, 2017a). After 2020, little additional demand is expected from the EU, by that time however major demand growth is expected from Southeast Asia, notably from Korea and Japan, and potentially China (Biomass Magazine, 2016b; Canadian Biomass, 2017b). By 2025, a total industrial demand for wood pellets from Europe, the UK, Korea, Japan and Canada is expected to be about 42 million metric tonnes per year (700 PJ), the heating market in Europe, the UK, the US and Canada is expected to increase steadily to about 25 million metric tonnes per year (400 PJ) (Canadian Biomass, 2017b).

The trade of solid biomass across countries, especially across oceans, is limited by the characteristics of biomass energy carriers. The high water content of fresh biomass, between 50-60%, bulk density as low as 200 kg/m^3 for dried biomass (20% m.c., bulk m^3), and energy content below 3 GJ/m^3 pose several problems along the supply chain of producing and transporting solid biomass (Food and Agriculture Organization of the United Nations, 2015). Pre-treatment to reduce the water content and increase the density of solid biomass is required to reduce long distance transport cost.

Pretreatment can be defined as all the intermediate process steps through which the physical or chemical characteristics of biomass resources are modified on purpose, before usage for final conversion into a useful energy carrier (heat, electricity, gaseous or liquid biofuel). This report is one out of six separate case study reports that illustrate the added value of pretreatment technologies in specific fuel supply chains.

Aside from economic benefits in increasing the density of solid biomass, pre-treatment of transported biomass, through application of heat, is necessary to reduce biological activity and phytosanitary risks (Kopinga, Moraal, Verwer, & Clerkx, 2010). Processing biomass into standardized size, quality and technical specifications also enables continuous consumption of traded biomass by industry and utilities (Verhoest & Ryckmans, 2012).

Lower grade biomass sources, such as residues, may have relatively high nitrogen or ash fractions, low ash melting temperatures, excessive particle size or may contain other unwanted components such as heavy metals or impurities in form of foreign object or simply soil. These aspects could pose operational problems in feeding or converting the biomass to final energy carriers. Pre-treatment of biomass may provide an attractive approach for enabling the use of such lower grade fuel sources.

The dominant process implemented for the pretreatment of woody biomass, meeting the above criteria, is currently pelletization of roundwood or residues. This process is comprised of debarking, grinding/chipping, drying, milling and pelletization, and results in a product of water content below 8%, bulk density over 650 kg/m^3, and calorific value over 16,5 MJ/kg well standardized in ISO 17225-2 and 6 (International Organization for Standardization, 2014a, 2014b).

Despite the success of wood pellets, further upgrading to improve the energy content, bulk density, reactivity in combustion, brittleness and water resistance is desirable to better compete with fossil alternatives. Torrefaction, in other words the roasting of feedstock, is a technology seemingly able to improve all of these characteristics. In recent years torrefaction has developed from prototype to full industrial scale processes, and seems to become an important upgrading technology for the next decade (Wild et al., n.d.).

This study is raising and examining the question whether there is an advantage of pre-processing through torrefaction compared to standard wood pelletization when comparing supply chain energy efficiency on a cradle to gate basis. All supply chain steps, from harvesting to delivery to customer fuel-yards will be examined and compared through the comparison of two alternative supply chains of (torrefied) pellets, produced from sustainable feedstock in Indonesia (Kalimantan) and consumed in Japan. In a sensitivity analyses results gained are analyses for other potential supply chains. Demand for imported pellets in Japan is expected to increase over the coming years (Argus, 2016). In this emerging biomass market, opportunities exist to invest in new pre-treatment technologies. Indonesia on the other hand offers a largely untapped bioenergy production potential and is geographically close to Japan (NL Agency, 2012).

The original intent of this study was to compare two existing supply chains. However, for the sake of easier comparability, replicability and application of results for future project evaluation, a hypothetical supply chain with either white wood pellet (WWP) or torrefied wood pellet (TWP) production as core element were analyzed, based on data gathered from existing supply chains. The main focus of the analyses is a comparison of energy efficiency of the processes across the supply chain, while also looking into GHG footprints based on BioGrace data (BioGrace, n.d.).

2 Reference value chain

2.1 REFERENCE SUPPLY CHAIN – STRUCTURAL LAYOUT

The wood pellet production supply chain consists of several operational steps, and depends amongst others on the type of feedstock and the geographical locations of feedstock, production units and demand. A simplified representation of the pellet value chain consists of three essential steps, the collection of raw material, the pre-treatment of raw material through pelletization and the conversion of pellets into useful final energy.

However, as a result of the spatial and temporal misalignment of biomass availability and bioenergy demand, supply chains contain several pre-processing, storage and transportation operational steps. The reference value chain in this analysis is considered to consist of five distinctive locations, as can be seen in Figure 1: field side (1), pellet plant (2), export harbour (3), import harbour (4) and end consumer (5). Storage is required at all locations, as well as transport between the different locations. Feedstock is processed at the field side, the pellet plant and the end consumer.

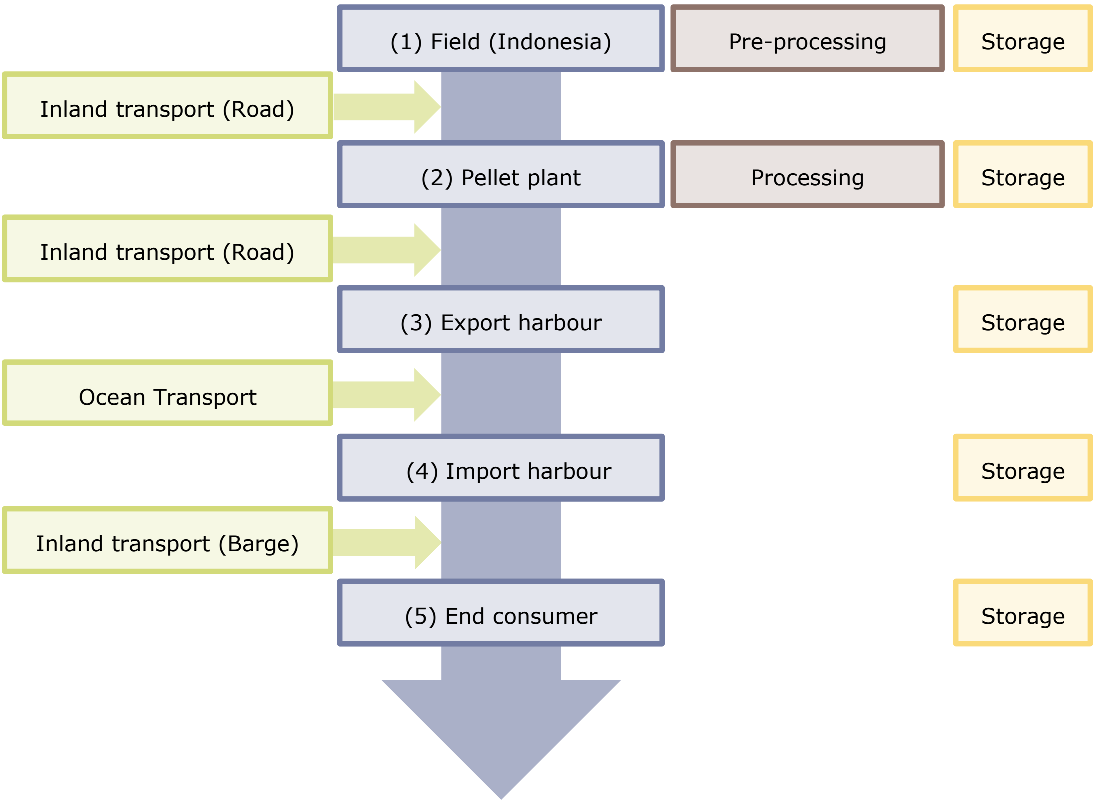

Figure 1 – Representation of the wood pellet supply chain components included in the scope of this research

The exact processing steps in a pellet plant depend on the type of raw material used, as can be seen in Figure 2. When log wood is used, for instance roundwood or thinnings, chipping of the raw material is required before further processing. Raw material delivered in the form of wood chips, must be course ground before drying. This first size reduction step reduces the energy demand for drying in the next supply chain step. Furthermore, whereas grinding of wet feedstock requires more energy than dry feedstock, the risk of fires and explosions is lowered when grinding wet material (Obernberger & Thek, 2010). Residues from the wood, pulp and paper processing industries, in the form of wood shavings, sawdust and wood dust, are frequently used to produce pellets. These residues consist of fine particles and do not require course grinding. Sawdust usually requires drying to lower the moisture content, whereas wood shavings and wood dust generally do not need drying and are therefore fed into a fine grinder as the first processing step (Obernberger & Thek, 2010). After the raw material is sufficiently reduced in size and moisture content, the material is ready for pelletization. Just before this processing step, additives are added to the dried material in order to aid the binding process. These additives can consist of solely steam or water, which forms a liquid layer on the surface and adjusts the moisture content to the desired level, or can be in the form of biological additives like starch (Obernberger & Thek, 2010). The pelletization of the prepared material produces pellets with relative homogenous particle size distribution, shape and moisture content (Obernberger & Thek, 2010). The pellets produced in this process are hereafter referred to as white wood pellets (WWP).

After pelletization, the pellets need to be cooled, increasing the stability and durability of the pellets, in order to be safely stored (Obernberger & Thek, 2010). Pellets remain biologically active to a certain extent, and self-heating during storage is an ever remaining issue. Sufficient cooling after the production of pellets, as well as additional cooling before transport of pellets to an export ports lowers the risk of accidental fires as a result of self-heating.

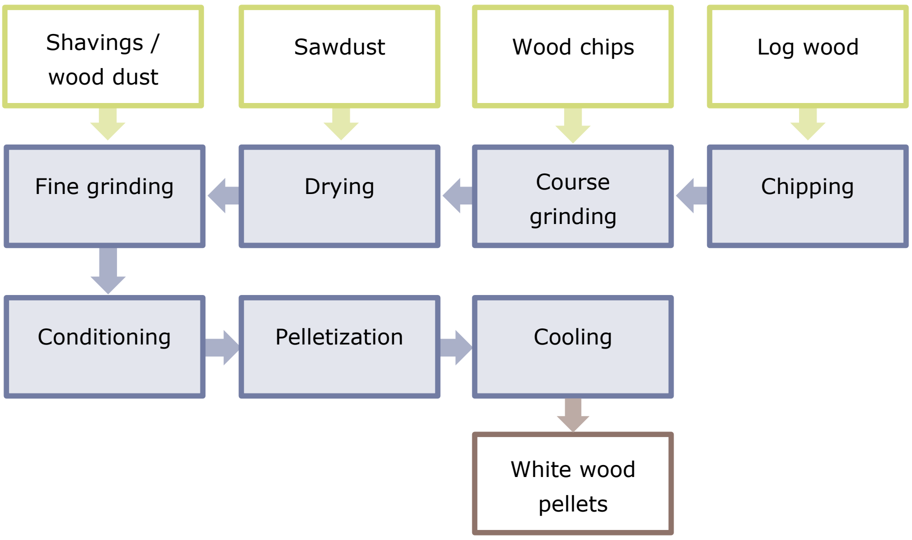

Figure 2 – White pellets processing steps

Raw material and pellets need to be stored at different moments throughout the pelletization process. Raw material is generally stored in a wood yard or warehouse to account for fluctuations in raw material inflow. During the pellet production steps, storage is required to store dried material before the pelletization step to ensure continuous production and uncouple the drying and pellet production steps. Produced pellets need to be stored to await transport to export ports.

In order to calculate the energy consumption across a specific supply chain, the following assumptions were made:

Biomass in the form of forest residues and thinnings (50% m.c.) is assumed to be harvested or result from harvesting processes of value timber in Kalimantan, Indonesia, and transported by truck to a pellet plant. Raw material is chipped in a diesel driven chipper, dried, ground and densified to ISO 17225-2 I2 requirements, to create white wood pellets containing 8% moisture, with a bulk density of 650 kg/m3 and a NCV of 17.56 MJ/kg. Pellets are transported by truck over 15 km one-way to the Pontianak port in Kalimantan. Rail access is not available in the particular location investigated in this case study and is assumed to be rarely available for producers in South East

Asia and many other resource rich locations, therefore truck transport is considered the most suitable transportation mode. In-port logistics consist of the unloading and conveying of pellets into storage and later on conveying from storage onto vessels. Air travel of supervisors and quality surveyors to export ports is included in this stage of the supply chain. Pellets are transported across 5315 km (2875 nautical miles) to the Tokyo Bay ports in Japan on Handysize ships, at a speed of 13 knots/h.

At the import port, pellets are unloaded and conveyed to storage and later transferred onto trucks, to be transported for 50 km one-way to the end consumer. In this final supply chain stage only the energy of unloading and conveying pellets to the consumer stockpile is included. Energy consumption for the different supply chain components is taken from the (IBTC M&E study 2018). All energy consumed for transport and milling within the consumers plant is outside the scope of this research.

2.2 REFERENCE SUPPLY CHAIN – ENERGY ACROSS CHAIN

The processing of the raw biomass requires the bulk of the total energy across the chain. As shown in Figure 3a, drying of biomass feedstock is the most dominant energy consumer across the chain, with a calculated energy consumption of 48%. When excluding the drying stage, to more clearly show the other steps, it shows that the other large contributors are (Figure 3b): the operational steps to harvest and transport raw biomass (17%), processing electricity consumption (15%) and ocean transport (16%). All of the other supply chain steps contribute the remaining 4%. This includes several operations, such as the chipping of biomass, truck transport of pellets, supervisor & surveyor travel and loading, unloading and conveying in the import and export ports and at the end consumer.

The bulk of the fuel used in the supply chain is supplied in the form of bioenergy (48%), since this is the assumed fuel used to supply the drying energy at the pellet plant. Drying heat is generated by burning process residues such as bark, hog wood or by burning residues from the paper, pulp and wood industry. As long as the biomass used to fuel the drying process is sustainably sourced, this part of the energy consumption can be considered renewable and sustainable. Liquid fuels, diesel, marine diesel oil (MDO) and intermediate fuel oil (IFO), represent 37% of the total energy consumption across the chain. These fuels are mainly used in the transportation steps, as well as in some loading and unloading chain components. The remaining 15% consists of electricity consumption, mainly consumed in the pellet plant and some during loading and unloading.

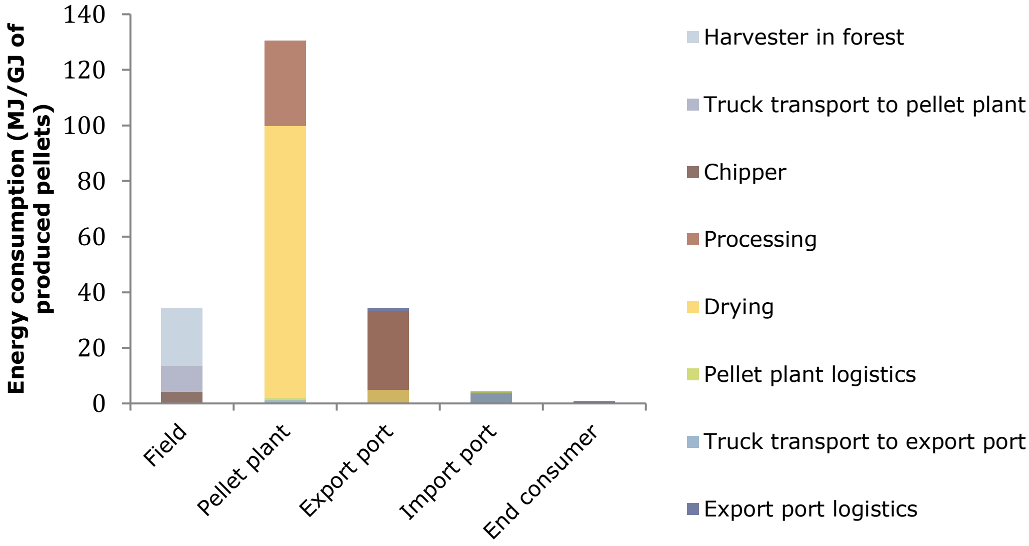

Figure 3a - Energy consumption in the reference value chain of supplied WWP to consumer stockyard

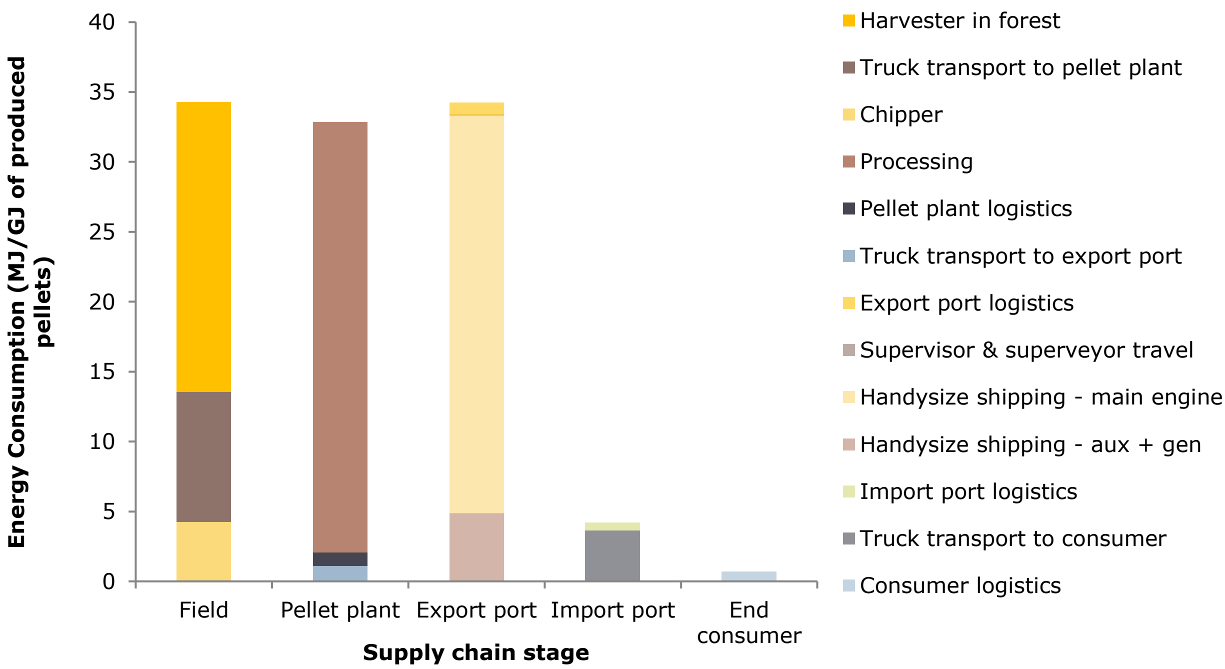

Figure 3b – Energy consumption in the reference value chain of supplied WWP to consumer stockyard – excluding drying energy requirements.

3 Opportunities in the reference supply chain

Pelletization results in a relatively homogenous solid biofuel, with a larger energy density than raw biomass, which can be stored for a period of time without self-heating. WWP are often used as carbon neutral fuel to replace coal in electricity plants, but do have also certain disadvantages to coal. The energy content of white wood pellets is considerably lower than coal, 17.6 compared to about 22-27 MJ/kg, as well is the bulk density, 650 kg/m^3 compared to up to 850 kg/m^3 (Bergman, 2005). As a result, a ship carrying WWP transports roughly half the energy as it would with coal, 11.4 GJ/m^3 compared to 20.4 GJ/m^3. Per unit of delivered energy, white wood pellets are therefore almost twice as expensive and energy intensive to transport compared to coal.

Another disadvantage of WWP is the ease with which white wood pellets disintegrate upon contact with water. As a result of the hydrophilic nature of WWP, storage must be absolutely waterproof and all handling steps must be completely sheltered from rain or must be halted during rainfall. This does not result in significantly increased energy consumption, other than idling engine fuel consumption if ships interrupt loading due to bad weather b ut has cost effects. On the other hand, if the average loading and unloading time of vessels is increased freight will be lowered proportionally to the days saved in port. This does entail that investments in port infrastructure are recovered eventually faster as more tonnage can be loaded within a year.

There are serious safety issues when working with WWP. Pellet offgassing, the release of carbon monoxide in storage or transport facilities, as well as self-heating of pellets, are hazards (International Maritime Organisation, 2009). Hence storage rooms as well as vessel holds have to remain under permanent control and have to be ventilated before safe entry is guaranteed.

White wood pellets also have their disadvantages for power plant end consumers compared to coal. Since WWP are less brittle and more difficult to grind than coal, grinding performance is decreased in existing power plants is increased when consuming white wood pellets (Perry & Rosillo-Calle, 2006). This could also limit the share of WWP used in existing power plants, since grinders are scaled based on the use of coal as fuel. The disadvantageous grinding particulars and the lower particulate energy content compared to coal furthermore reduces the rated capacity of existing power plants, and increases the capital expenditure per unit of delivered energy.

Some of these disadvantages can be reduced by adding a torrefaction step to the pellet process. Torrefaction can be either combined with pelletization (or briquetting), in which the torrefaction step is included before the compacting of raw material, or can be done after pelletization (Ghiasi et al., 2014a).

As can be seen in Figure 4, the combined torrefied pellets production process is similar to the standard wood pelletization process, with the addition of a roasting step between the drying and pelletization steps. This roasting step does not only drive out water content remaining after drying, but also a certain percentage of the volatile matter each biomass is comprised of, resulting in a product with different characteristics to white wood pellets. Torrefied pellets, when processed to minimum requirements of ISO TS 17225-8 (International Organization for Standardization, 2016), contain 90% of the biomass' initial energy and only 70% of the initial weight (Bergman, 2005). Accordingly, the NCV of torrefied pellets is considerably higher than that of white wood pellets, 22.20 MJ/kg compared to 17.56 MJ/kg (Bergman, 2005). The bulk density is increased from 650 to up to 850kg/m3. In this research, calculations are based on a proven bulk density for torrefied pellets of 720 kg/m^3. By driving out more of the volatiles (i.e. torrefaction at higher temperatures or longer residence times) the NCV to weight ratio can be further improved, however, process efficiencies might deteriorate unless syngas is used as drying fuel or in co-generation.
Torrefied pellets are considerably water resistant and are therefore much less vulnerable to rain or

other sources of moisture. While torrefied pellets are not entirely waterproof, and the hydrophobic quality is determined by the specific compaction process and eventual addition of binding agents, the TP can, in the majority of cases, withstand moisture without disintegrating (Stelte, 2015).

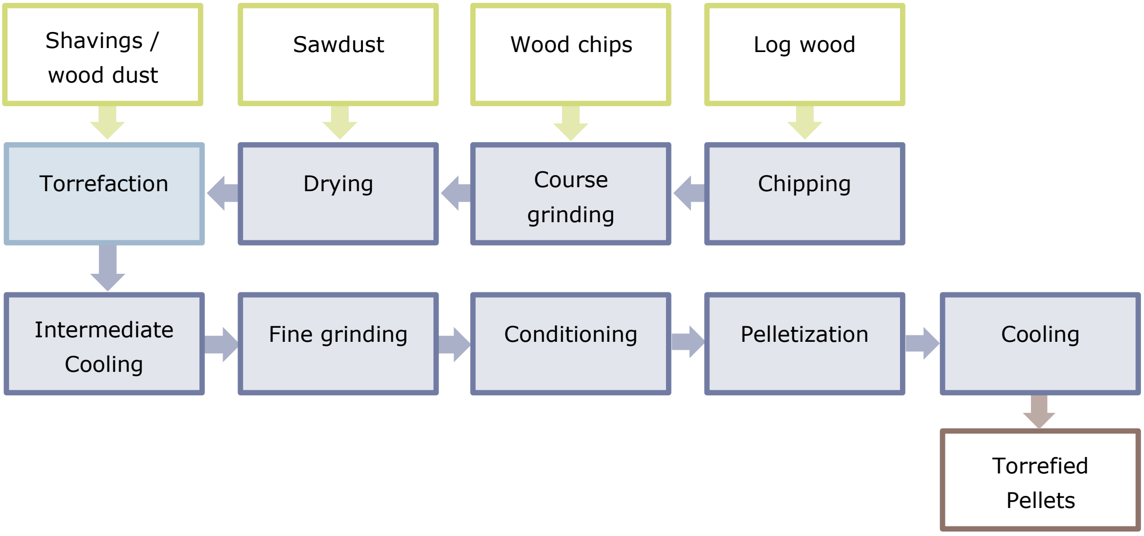

Figure 4 - Torrefied pellets processing steps

The main improved characteristics of interest to the energy industry are the higher calorific value, higher brittleness, improved water resistance, higher bulk density and higher reactivity in combustion (Wild et al., n.d.). Most torrefaction processes also reduce the chlorine content of input feedstock significantly, thereby enabling the production of pellets from higher chlorine containing biomass feedstocks, such as grasses or agro by-products (Keipi, Tolvanen, Kokko, & Raiko, 2014).

When analyzing entire pellet supply chains, it becomes obvious that it is preferable to establish additional pre-treatment and densification as early in the chain as possible. The improved handling characteristics and increased energy density of torrefied pellets result in lowered energy consumption during transport from processing plant to customer. By including torrefaction at the pellet plant, the subsequent handling, truck transport and shipping of pellets becomes more energy and cost efficient and the characteristics of the produced biofuel are more suitable for handling within existing coal chain premises and installations in the import and export port and at the end consumer.

4 Supply chain comparison white wood vs torrefied pellets

4.1 ENERGY COMPARISON ACROSS THE CHAIN

Producing torrefied wood pellets adds a torrefaction processing step to the WWP production process which requires additional heat to roast the biomass. However, torrefaction also releases syngas during the process which can be combusted or co-combusted, reducing proportionally the fuel wood input into drying. In reference to final products the overall thermal efficiency of WWP processing and Torrefied Pellets processing is almost identical. The pelleting of torrefied wood does consume slightly more electricity than pelleting of wood only(IBTC M&E study 2018). Whether torrefied pellets save energy across the supply chain depends on the balance between marginally increased processing energy consumption and decreased transport energy consumption. Figure 5 shows that for this particular supply chain, from Indonesia to Japan, overall energy savings of 6.7% can be reached by shifting from WWP to TWP.

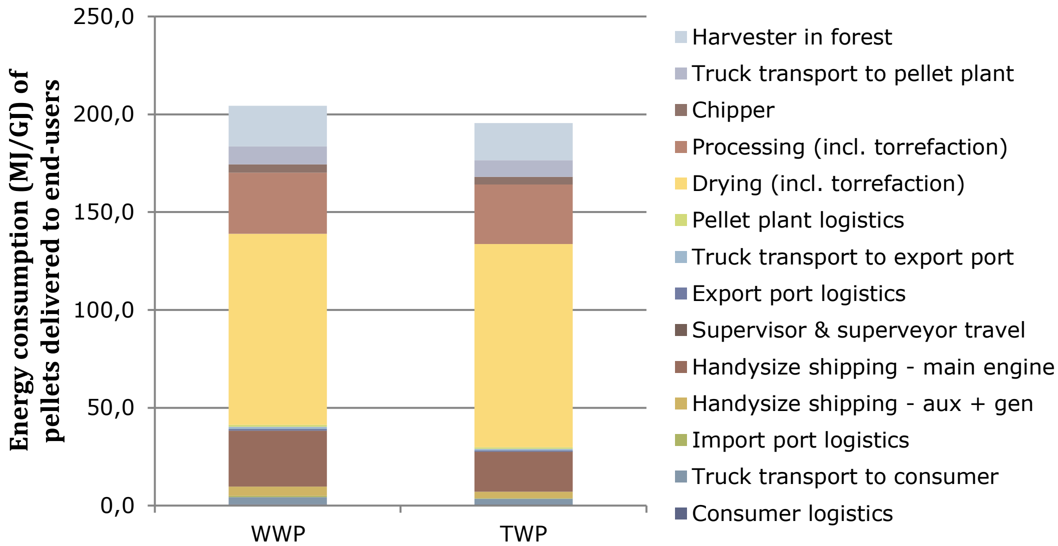

Figure 5 – Comparison the energy consumption of white wood pellets (WWP) and torrefied wood pellets (TWP) supplied to the end consumer

On final product energy basis, upstream harvesting and transport is 8.2% less energy intensive for TWP than for WWP. The torrefaction process is fueled partly by the combustion of the energy containing gasses released during the torrefaction process, thereby reducing the need for additional input of fuel wood and reducing the need for harvesting and transport of raw material. The production of TWP requires the same amount of process heat as WWP. Differences are within up to +0,5% for TWP compared to WWP. Processing of torrefied wood pellets requires more electricity per tonne, 188 kWh/mt compared to 152 kWh/mt for white wood (IBTC M&E study 2018). This is, however, largely offset by the larger energy density of TWP, resulting in only slightly higher electricity consumption per unit of delivered energy, 8,5 kWh/GJ for TWP versus 8,8kWh/GJ for WWP.

Table 1. Full chain calculation comparison results in MJ per GJ delivered energy

Pellets from Wood, pelletised or torrefied and pelletised				
	Device/Machine/Installation	Normalised WWP	Normalised TP	Energy consumed TP/WWP
		MJ/GJ	MJ/GJ	%
NCV of product		17,56	22,20	
Raw material				
	Harvesting smaller machines			
	Harvester in forest	20,73	19,02	91,77%
	Loader to truck			
	Truck to plant	9,30	8,53	91,77%
	Chipper	4,25	3,90	91,77%
Processing (pretreatment)	black box data from processors	31,16	30,49	104,18%
	thermal and electric energy incl drying	97,69	103,75	
	Source IBTC study			
Downstream				
to port	Wheel loader 300kW	0,49	0,38	79,10%
	Truck	1,09	0,86	79,10%
	Train			
	(Un)Loader or crane 300kW	0,49	0,38	79,10%
in port	Conveyor	0,05	0,04	79,10%
	Loader	0,49	0,38	79,10%
	Conveyor	0,05	0,04	79,10%
	Crane 400kW Diesel	0,31	0,25	79,10%
	Auxiliary			
	Vessel berth engin			
	Surveyor&Superviser travel	0,06	0,05	79,10%
pellets shipping				
main engine	Handysize	49,55	35,39	71,41%
	Handymax	38,85	27,74	71,41%
	Panmax	32,02	22,87	71,41%
aux+gen	Handysize	6,66	4,76	71,41%
	Handymax	5,18	3,70	71,41%
	Panmax	4,38	3,13	71,41%
unloading	cranes	0,05	0,04	79,10%
	elevators			
	conveyors	0,01	0,01	79,10%
tertiary transport	shifters			
	loaders to truck/train/barge	0,49	0,38	79,10%
	train			
	truck	3,64	2,88	79,10%
	barge			
	loaders from truck/train/barge	0,49	0,38	79,10%
Consumers stockpile	Loaders	0,17	0,14	79,10%
	4 Conveyors	0,05	0,04	79,10%
	full chain of pellets			
	Handysize	227,27	212,10	93,33%
	Handymax	215,07	203,40	94,57%
	Panmax	207,44	197,95	95,42%
	downstream logistics only			
	Handysize	68,38	50,31	73,57%
	Handymax	56,19	41,60	74,03%
	Panmax	48,56	36,15	74,45%
	full chain on WWP and torrefied briquettes			
	Handysize	227,27	203,86	89,70%
	Handymax	215,07	195,16	90,74%
	Panmax	207,44	189,71	91,45%

The energy consumption reduction across the TWP supply chain mainly stems from a reduction in downstream logistics, 26,4% if based on transport in a Handysize vessel. The longer the distance the supply chain is bridging, the larger the energy savings as a result of the transport energy consumption having a larger share across the supply chain (i.e. from Brazil to China, see 4.2). The downstream energy reduction across the chain is the largest for transport in Handysize ships (26.4 %) and slightly lower for transport in Handymax (26.0%) or Panamax ships (25.6%). The energy reduction is larger for the shipping component than for the other logistics stages, which is why the Handysize chain, in which the share of shipping is relatively larger, results in a larger energy saving. The reduction in downstream energy requirements confirms the advantage to establish additional pre-treatment as early in the chain as possible.

In terms of energy carriers consumed and again referenced to MJ energy supplied to customer, a 16% increase in bioenergy, used for drying and torrefaction, is needed in the processing of torrefied wood pellets. The consumption of fossil fuels is however reduced, with an 20.9% reduction of liquid fuels consumption (Diesel, MDO and IFO) and a 2.3% reduction of electricity consumption. The picture of a very relevant overall energy reduction across the supply chain of 6.7% is completed by an even more considerable reduction in fossil fuels.

4.2 SENSITIVITY

4.2.1 Shipping distance

The impact of logistics on supply chain energy consumption and GHG emissions is large. With shipping in this case study accounting for 31% of the non-renewable energy consumption across the supply chain. Therefore the comparative sensitivity of the overall GHG balance to shipping distance variations for the two supply chains is worth analyzing.

Since a considerable energy consumption and GHG emissions reduction can be realized for downstream logistics for torrefied pellets compared to white wood pellets, the longer the shipping distance, the larger the expected savings are. Figure 6 shows the respective energy consumption for different shipping distances.

For intra-continental transport distances, for instance from Russia to the UK, the supply chain savings are 1.8%. For the supply chain analyzed in this paper, from Indonesia to Japan, the energy savings have increased to 5.3%. In the current situation, a significant share of the worldwide pellet trade is between the southeast of the United States (SE US) and the UK / ARA (Amsterdam-Rotterdam-Antwerp), for this supply chain, potential energy savings increase to 7.1%. Longer transport distances are possible, for instance from southwest (SW) Canada to the Netherlands (10.6% savings), SE US to Japan (11.0% savings) and Brazil to Japan (11.7% savings).

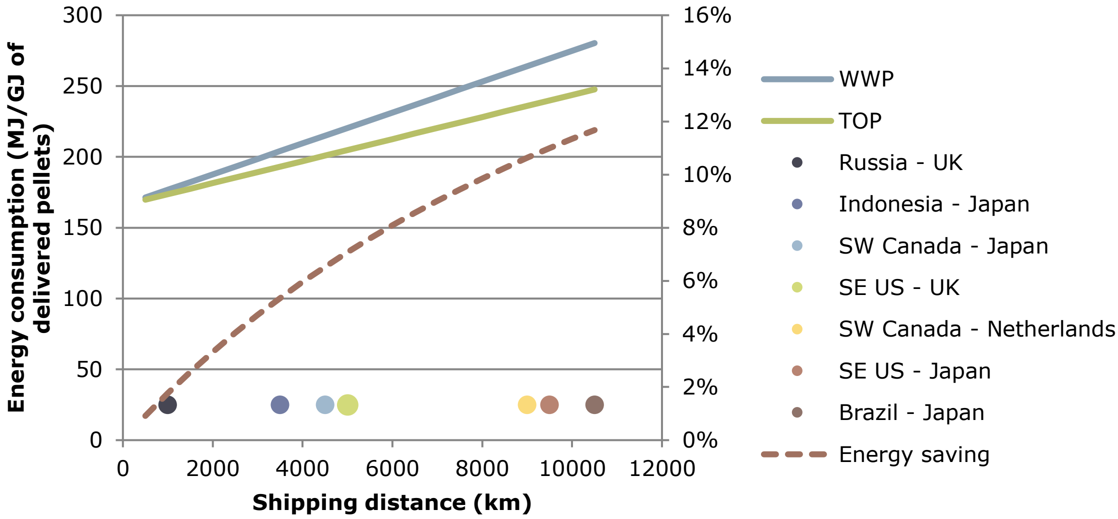

Figure 6 – Impact of shipping distance on supply chain energy consumption for Torrefied Pellets (TWP) and White Wood Pellets (WWP)

4.2.2 Moisture content

Drying the feedstock, so evaporating and removing the water content from the feedstock, represents the dominant energy consumer in the overall chain. The thermal efficiency of production torrefied pellets, including the energy required for torrefaction, is marginally lower for TWP than for WWP, as a result of which, the potential energy savings are slightly reduced for increased feedstock moisture content. If pre-dried feedstock is supplied, at 10% moisture, TWP result in an energy saving of 5.2% compared to WWP. For moisture content of 50%, this is reduced to 4.2%, as can be seen in Figure 7.

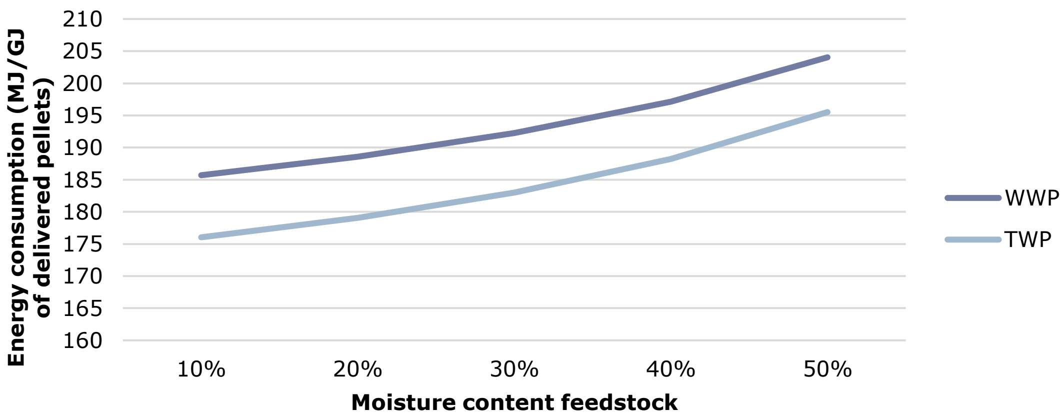

Figure 7 - Impact of moisture content on supply chain energy consumption for Torrefied Pellets (TWP) and White Wood Pellets (WWP)

4.3 GHG COMPARISON ACROSS THE CHAIN

Biomass used to provide the thermal energy in the pellet production process is considered carbon neutral under EU legislation, based on the assumption that CO_2 emissions during combustion will be re-absorbed during the subsequent tree growth[1]. In order to compare the GHG emissions across the chain, the GHG emissions resulting from biomass combustion are not included in the overall calculation.

The GHG calculation along the chain, using BioGrace emission factors, results in an increased advantage of the torrefied wood pellets (Figure 8). Importing torrefied wood pellets instead of white wood pellets can reduce 11% of the CO_2 emissions across the analysed chain (BioGrace, n.d.). This reduction is larger than the relative energy reduction since GHG emissions from bioenergy consumption covering the thermal needs were assumed to be carbn neutral.

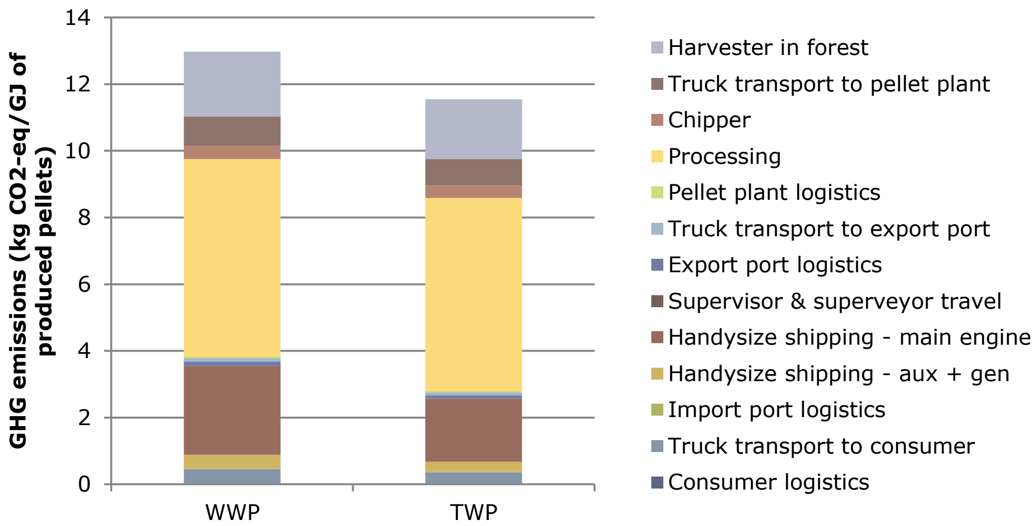

Figure 8 – Comparison of the GHG emissions of white wood pellets (WWP) and torrefied wood pellets (TWP) supplied to the end consumer

4.4 GHG COMPARISON WITH FOSSIL FUEL

The advantages of torrefied pellets over white wood pellets make this fuel especially interesting for the replacement of coal in power plants. In order to assess whether the co-firing of torrefied pellets results in greenhouse gas reductions, the emissions must be compared to fossil fuel alternatives, in this case (hard) coal.

This comparison is relevant for regulatory purposes since policies in different world regions incorporate GHG emission saving thresholds for replacement of fossil fuels with bioenergy. The European Commission has one of the most advanced and detailed thresholds, dictated in The Revised Renewable Energy Directive (RED II) (2016/0382 (COD)) (European Commission, 2016). If this new proposal is accepted, biomass used to produce electricity and heating/cooling in

[1] This assumption ignores some potential sources of CO_2 emissions, such as (indirect) land use change, and ignores the time lag between the moment of harvest and the re-absorption of carbon. Taking these aspects into account is beyond the scope of this research.

installations starting operation after 1 January 2021 will have to meet a reduction target of 70%. This is increased to 80% for installations starting operation after 1 January 2026 (status European Parliament Plenary vote 17.01.2018). This directive has also set rules for calculating the greenhouse impacts of biofuels and fossil fuel comparators (Giuntoli, Agostini, Edwards, & Marelli, 2015a). Those numbers are as of today not agreed yet, but an increase against todays thresholds is certai as is the resulting need to increase the overall supply chain efficiency.

According to the methodology guidelines of the European Commission, the emission factor of energy production from conventional hard coal is 260.8 gCO_{2eq}/MJ (final energy). This is based on the consumption of conventional hard coal in a power plant with 43.5% efficiency (electrical). The emissions associated with provision of hard coal are largely the result of combustion of coal, 96.1 gCO_{2eq}/MJ (221 gCO_{2eq}/MJ final). The emissions for the supply of coal, including activities such as mining and transportation, account for 16.2 gCO_{2eq}/MJ (37 gCO_{2eq}/MJ final)(Giuntoli et al., 2015a). Emissions vary per region, reflecting differences in power plant efficiency, mining practices, transport distances etc.

In line with the proposed methodology to calculate GHG savings, the emissions of torrefied pellets should however be compared with the default GHG emissions of electricity or heat production instead of the reference coal emission factor. The Fossil Fuel Comparator for electricity production is 186 gCO_{2eq}/MJ_{el} (as defined in the COM(2010) 11 and SWD(2014) 259) (Giuntoli, Agostini, Edwards, & Marelli, 2015b).

Using the assumption of a power plant with 43.5% efficiency the emissions along the Indonesia – Japan supply chain translate to 29.6 gCO_{2eq}/MJ_{el} for WWP and 26.3. gCO_{2eq}/MJ_{el} for TWP. Comparing this to the Fossil Fuel Comparator set by the European Commission, gives a GHG reduction of respectively 84.1% and 85.8% for white wood pellets and torrefied pellets. When translating the results from this case study to a supply chain between the southeast of the US and Europe (UK/ARA region), total emissions increase to 15.1 gCO_{2eq}/MJ for white wood pellets (34.7 gCO_{2eq}/MJ_{el}) and 13.0 gCO_{2eq}/MJ for torrefied wood pellets (29.9 gCO_{2eq}/MJ_{e}) as a result of the larger shipping distance (as presented in Figure 6). This would result in a GHG reduction of respectively 81.3% and 83.9% for white wood pellets and torrefied pellets.

Future emission reduction targets could clearly become a barrier for internationally transported wood pellets. If the 85% reduction target were to be adopted, this could reduce the potential to only short-distance supply chains. The potential benefit of torrefied pellets in this is also clearly shown. For those supply chains in which the GHG threshold is approached, whether it be the post 2026 threshold, or the 80% reduction proposed for post 2021 installations, the additional savings of torrefied pellets could become relevant. This is especially interesting for supply chains associated with higher emissions, for example as a result of longer transport distances.

4.5 ADDITIONAL ENERGY REDUCTION POTENTIAL

The analyses so far compare products of same form factor. However, the brittle characteristic of the densified torrefied biomass would allow densification into larger pieces such as briquettes or cubes, as this would still be acceptable feed material for coal mills. 50mm max in each dimension seems currently to be the maximum size acceptable by standard coal plants. Recent tests at coal power plants like the one at PGE plant in Bordman, Oregon are carried out with both pellets and briquettes/cubes of torrefied biomass (Personal communication with AIREX and HEETWAY). Briquetting reduces electricity consumption in densification by almost 50% in respect to pelleting (Personal Communication, Wolfgang Stelte). In this case, the energy consumption advantage of the torrefaction chain versus the WWP chain almost doubles to 10,3%. The GHG advantage increases accordingly, to a 33% reduction of torrefied wood briquettes (TWB) compared to WWP, as can be seen in Figure 9.

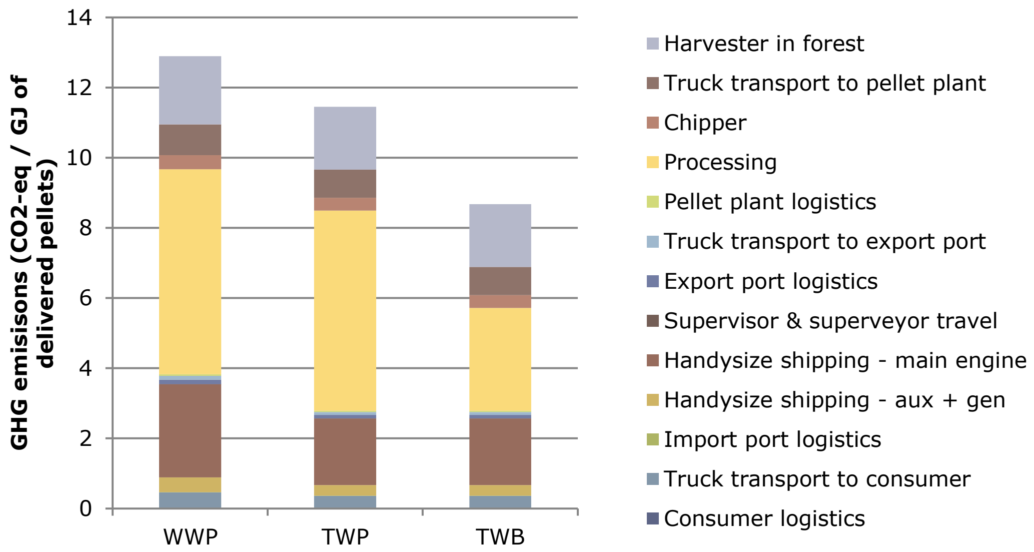

Figure 9 – Comparison of the GHG emissions of white wood pellets (WWP), torrefied wood pellets (TWP) and Torrefied wood briquettes (TWB) supplied to the end consumer

If biomass is torrefied to a higher degree as contemplated and practiced by some of producers, the specific energy uptake in densification is also reduced, especially as for such material some binders will be added reducing the friction in the compression channel.

The above energy savings do not yet include the potential savings in the stages of pre-conditioning for combustion and combustion itself as a result of the increased brittleness of torrefied biomass. Torrefaction prior to densification can highly reduce the energy needed for grinding. Ghiasi et al. (2014b) have shown that the energy required to grind torrefied chips was reduced from 292 kJ/kg for untreated wood chips to 39 kJ/kg for torrefied wood chips. Similar reductions were also found by Phanphanich & Mani (2011), whose research found a factor 10 energy reduction for pine chips and a factor 6 reduction for logging residues. Repellin et al. (2010) have also found grinding energy reductions up to 90% for material torrefied at 280 °C. These results are based on lab-scale tests, but are considered indicative for potential reductions on industrial scale.

5 Recommendations

Producing and supplying TWP instead of WWP made from forestry residues and thinnings, the conventional/fossil energy consumption across the supply chain can be reduced significantly. For the analysed chain from Indonesia to Japan by 6,7%. If the form of the torrefied product is changed to <50mm briquettes this advantage increases to 10,3%. Perhaps more importantly, torrefied wood pellets supplied to the end consumer account for 14% fewer GHG emissions compared to white wood pellets (33% in case of briquettes). The driving force behind the use of wood pellets, whether white or torrefied, is the aim to reduce fossil energy consumption and to reduce GHG reductions. Therefore, analyzing, and investing in, technologies that could achieve larger reductions is of paramount importance.

GHG reductions especially are relevant for pellets produced and transported to countries with specific GHG reduction targets. At this moment, this holds especially for the European Union. Meeting future GHG reduction tresholds will form a potential barrier for new wood pellet projects, especially if future GHG emission reduction tresholds for the supply chain are increased to levels of 80-85%. This will potentially determine the supply chains of future wood pellet trade. Although these specific targets are not yet in place in Japan, towards the future, investing in pellet chains with the lowest possible GHG emission will result in more sustainable and secure business cases.

The potential for TWP is especially large in emerging markets, such as Japan, where investments in power plant facilities to adapt to the use of pellets still need to be made. The advantage of torrefied wood pellets over white wood pellets is largest if the entire chain is designed for TWP, specifically if an existing coal chain can be utilized at least partially. This way, the benefits in easier storage and handling and more efficient transport and grinding apply to every supply chain stage, including end consumers.

Although this analysis is focusing its research on energy consumption along the chain only, concluding with advantages of torrefied product, and does not deal with costs it can be assumed that savings in energy consumption by the TWP chain do result in cost reductions which are at least proportional.

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