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UNIVERSITY OF VAASA

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CO₂ emission reduction in coating drying

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Foreword

I am grateful of support I had during this Thesis Project. I am most grateful for the support and advice from my Valmet supervisor Lari Heinonen who I need to thank also for this interesting research topic. I am also grateful for the advice from the University's Evaluator of this Thesis Carolin Nuortila and University's Supervisor of this Thesis Seppo Niemi. There were several Valmeteers who I had an opportunity to cooperate. Thank you all for the useful and interesting information that I needed in this topic. I am also grateful for customers I had opportunity to discuss during this project.

Also, I need to thank those Valmeteers in the office and remotely supporting me even through the most troubled times I faced this year. In the end, this was a great journey. I learned a lot and developed myself in the topic, which was not so familiar at first, but still – it is interesting. There are so many issues I am eager to learn more about after this Thesis.

Finally, I need to thank my friends, family and spouse for supporting me during the studies and this project.

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Aino Jalo

Abbreviations

Basis weight	Paper or board mass per square meter
BAU	Business As Usual
CEPI	Confederation of European Pulp and Paper industries
C1S	Coated one side
C2S	Coated two sides
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CH ₄	Methane
C ₃ H ₈	Propane
C ₄ H ₁₀	Butane
CRB	Corrugated Recycled Board
CSRD	Corporate Sustainability Reporting Directive
CWTL	Coated White Top Linerboard
DNSH	“Do No Significant Harm principle” in EU Taxonomy regulation
EED	Energy efficiency directive
EIB	European Investment Bank
ESR	Effort Sharing Regulation
ETD	Energy Taxation Directive
ETS	European Emissions Trading System
EU	European Union
EUA	European Emission Allowance
EUGBS	European Green Bond Standard

FBB	Folding Box Board
“Fit for 55”	Proposed climate package by the EU Commission to reach the target The European Climate law sets to reduce CO ₂ emissions of 55 % from 1990’s levels by 2030.
FMT	Finished metric tons. Tons of board or paper produced in machine.
GC1	So called “White Back” in FBB grade. On reverse side or back layer of chemical pulp is thicker or white pigment coated as appearance of both sides are white.
GC2	So called “Cream Back” in FBB grade. Mechanical pulp in middle ply or bleached mechanical pulp in middle ply.
GHG	Green House Gas
IEA	International Energy Agency
IED	Industrial emissions directive
IR	Infrared radiation
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NFRD	Non-Financial Reporting Directive
NG	Natural Gas
N ₂ O	Nitrous Oxide
OCC	Old Corrugated Container
PFCs	Perfluorocarbons
RED	Renewable energy directive
SBB	Solid Bleached Board
SBS	Solid Bleached Sulphate Board
SUB	Solid Unbleached Board
SUK	Solid Unbeached Kraft

web

Paper drainage

WLC

White Lined Chipboard

Symbols

B	Dry coating color basis weight [kg/m ²]
D	Coating color dry solids [%]
E	Energy [kJ]
$E_{air\ drying}$	Air drying energy efficiency [%]
F	CO ₂ emission factor [tCO ₂ /MWh]
K	Coating drying energy consumption per year [MWh/a]
m_{CO_2}	Carbon dioxide mass equivalent to energy in reaction [kg/kJ]
m_{ev}	Evaporated water mass [kgH ₂ O]
m_{gas}	Gas mass of exothermal reaction [kg/mol]
P	Production of board or paper machine per year [t/a]
q	Specific Energy of water [kJ/kg·H ₂ O]
W	Total basis weight [t/m ²]
Q	Heat amount [kJ/kg]
ΔH	Enthalpy change [kJ/mol]
$\Delta H_{C_3H_8}$	Enthalpy change of Propane [kJ/mol]
$\Delta H_{C_4H_{10}}$	Enthalpy change of Butane [kJ/mol]
ΔH_{CH_4}	Enthalpy change of Methane [kJ/mol]
ΔH_{CO_2}	Enthalpy change of carbon dioxide [kJ/mol]
ΔH_{H_2O}	Enthalpy change of water [kJ/mol]
ΔH_{O_2}	Enthalpy change of oxygen [kJ/mol]
$\sum H_1$	The sum of the heat formation (Enthalpy of formation) in combustion reaction of source material [kJ]
$\sum H_2$	The sum of the heat of formation (Enthalpy of formation) in combustion reaction of products [kJ]

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ABSTRACT:

The production of coated board and papers will increase with the increasing market share of “take away” products and internet shopping. Increasing the production of board and paper grades used in packaging increases the coating drying phase greenhouse gas (GHG) emissions if there will not be any actions to mitigate these emissions. Coating drying is needed for different board and paper grades used in packaging material use. Especially food and liquid packaging have special needs for coating as well as coating drying in the manufacturing process.

The purpose of this thesis was to calculate carbon dioxide (CO₂) emissions in the coating drying section of board and paper machines in 2020. In addition, the purpose was to determine methods to decarbonize this coating drying section. This topic was researched from global and European Union area points of views. There are different climate programmes to support the transition to renewable energy and supporting energy efficiency increase. The European Union has a leading role in emissions mitigation and adaptation and also has a significant influence on global emission regulations. As a primary energy resource, natural gas (NG) is mainly used in coating drying, especially in non-integrated mills or in mills which are using recycled fiber as raw material. Other energy resources in the use of coating drying are liquefied natural gas (LNG), liquefied petroleum gas (LPG), medium or low-pressure steam and electricity. From the global point of view, the primary energy used in heating of coating drying is mainly from fossil fuels.

Based on the calculations made in this thesis, the CO₂ emissions by energy consumption in coating drying heating in year 2020 were on average 882 ktCO₂ globally, and 187 ktCO₂ in the EU area. The proportion of average CO₂ emissions by gas (NG, LNG, LPG) in heating energy consumption by the coating drying process were 722 ktCO₂ globally, and 141 ktCO₂ in the EU area.

Methods to decrease the CO₂ emissions in the coating drying section can be divided into two parts: to improve energy efficiency in coating drying or changing the fossil fuel based heat resource to alternative fossil free heat resource. According to Valmet's estimations, improvement of energy efficiency can save approximately 20 % of energy used in coating drying as heating energy. This means that CO₂ emissions of coating drying in 2025 will be approximately 26 % less than if improvements are not made to increase energy efficiency in coating drying by 2025. Board and paper producers' thoughts on CO₂ reduction were considered, and as a case example a Finnish forest industry company's board machine's coating drying section was studied. EU regulations, fundings and targets of CO₂ reduction were considered from the point of view of decarbonizing coating drying.

KEYWORDS: board machine, paper machine, coating drying, primary energy, natural gas, GHG, carbon dioxide, energy efficiency

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TIIVISTELMÄ:

Päällystetyn kartongin ja paperin tuotanto kasvaa "take away" -tuotteiden ja verkkokaupan markkinaosuuden kasvaessa. Pakkauksissa käytettävien kartonki- ja paperilaatujen tuotannon kasvu lisää päällystyskuivauksen kasvihuonekaasupäästöjä, mikäli päästöjen vähentämiseksi ei tehdä toimenpiteitä. Päällystyskuivausta tarvitaan eri pakkausmateriaaleihin käytettäviin kartonki- ja paperilaatuihin. Erityisesti elintarvike- ja nestepakkauksilla on valmistusprosessissa erityistarpeita päällystykseen ja päällysteen kuivaukselle.

Tämän diplomityön tarkoituksena oli laskea hiilidioksidipäästöt kartonki- ja paperikoneiden päällystyskuivauksessa vuodelta 2020. Lisäksi määritettiin menetelmät päällystyskuivauksen hiilidioksidipäästöjen vähentämiseksi. Aihetta tutkittiin globaalisti ja lisäksi Euroopan Unionin alueen näkökulmasta. Uusiutuvaan energiaan siirtymistä ja energiatehokkuuden lisäämistä tukevia ilmasto-ohjelmia on erilaisia. Euroopan Unionilla on johtava rooli päästöjen vähentämisessä, ja sillä on myös merkittävä vaikutus maailmanlaajuisiin päästömääräyksiin. Maakaasu (NG) käytetään pääasiassa päällystyskuivauksen lämpöenergianlähteenä, erityisesti integroimattomissa tehtaissa, tai tehtaissa, jotka käyttävät kierrätyskuitua raaka-aineena. Muita päällystyskuivaukseen käytettäviä energialähteitä ovat nesteytetty maakaasu (LNG), nestekaasu (LPG), keski- tai matalapaineinen höyry ja sähkö. Maailmanlaajuisesti päällysteen kuivauksen lämmitykseen käytetty primäärienergia on pääosin peräisin fossiilisista polttoaineista.

Perustuen tässä tutkimuksessa laskettuihin arvoihin, vuonna 2020 päällystyskuivauksen tuottamat CO₂-päästöt olivat keskimäärin päällystyskuivauksen lämpöenergiankulutukselle globaalisti 882 ktCO₂ ja EU:n alueella 187 ktCO₂. Kaasun (NG, LNG, LPG) osuus CO₂ päästöistä päällystyskuivauksen lämpöenergiankulutukselle oli globaalisti 722 ktCO₂ ja EU:n alueella 141 ktCO₂.

CO₂-päästöjen vähennysmenetelmät voidaan jakaa kahteen tapaan: energiatehokkuuden parantamiseen tai fossiilisiin polttoaineisiin perustuvan lämmönlähteen vaihtaminen fossiilittoamaan lämmönlähteeseen päällystyskuivauksessa. Valmetin arvioiden mukaan energiatehokkuuden parantaminen voi säästää noin 20 % päällysteen kuivauksen kuluvaan energiasta. Päällystyskuivauksen hiilidioksidipäästöt olisivat vuonna 2025 noin 26 % pienemmät verrattuna tilanteeseen, missä päällysteen kuivauksen energiatehokkuuteen ei tehdä parannuksia vuoteen 2025 mennessä. Kartonkin ja paperin tuottajien ajatuksia hiilidioksidipäästöjen vähentämisestä haastateltiin, ja esimerkkinä käytettiin erään suomalaisen metsäteollisuusyhtiön kartonkikoneen päällystyskuivausta. EU-lainsäädäntöä, rahoituksia ja tavoitteita CO₂-päästöjen vähentämiseksi tutkittiin päällystyskuivauksen näkökulmasta.

AVAINSANAT: kartonkikone, paperikone, päällystyskuivaus, primäärienergia, maakaasu, GHG, hiilidioksidi, energiatehokkuus

1. Introduction

Coated board and paper grades are mainly used in packaging industry for different purposes and have different criterias depending on end purposes for packaging. The amount of coating color and dry solids content of coating color can vary depending on grades which means that CO₂ emissions of different coated grades can vary. Coating drying is one section of the coated board and paper manufacturing process. The purpose of coating drying is to dry the pigment coating color added in coating stations on the web (base paper). Coating dryer's primary energy can vary between gas, electricity or steam. There are different dryers for different coating drying purposes in use. (Valmet internal, 2021)

Board and paper industry is an energy intensive industry. (Lipiäinen & Vakkilainen, 2021) It consumes energy from power and fuels. (Bajpai, 2016). There are settled targets and regulations for energy intensive industries to Greenhouse Gas (GHG) reduction. As a background of this work are global emission targets and European Union's (EU) emission targets and regulations. There are assessed global targets to reach the goals of CO₂ emission reduction in different sectors of industry. (European Union, 2021b) Pulp and paper industry is a forerunner going towards the EU low-carbon bioeconomy. There are opportunities to lower consumption in bioeconomy and resource efficiency. (European Union, 2021e).

The European Climate Law's targets are to reduce net GHG emissions by 55 % until 2030 from the level of 1990 and GHG emissions to be negative by 2050. This Climate law was proposed on 14th July, 2021 by The European Commission. The proposal of the new climate law included so called "Fit for 55" package which aim is to reach the goals the European Climate Law sets. The law was proposed to include industry, energy, transport and housing to decrease CO₂ emissions. (Reuters, 2021a; Valmet internal, 2021)

The board and paper industry is the fourth largest industrial energy consumer in Europe. Mainly CO₂ emissions in the board and paper industry comes from combustion of energy resources. European board and paper industry is the net purchaser of 45 TWh of

electricity. In the future electricity has a larger role in energy use. Board and paper companies' energy decisions will depend on local, regional and national circumstances. Without breakthrough technologies gaseous fuels cannot be reduced to zero. (Confederation of pulp and paper industries CEPI, 2021b)

Today the increasing price of energy is a consequence of energy supply shortage in the markets. Gas fired power plants define the price for electricity because gas can be launched if there is a need for power when electricity production is not able to cover consumption. The increasing prices of gases has an impact to business investment decisions. The president of European Commission, Ursula von der Leyen said in her speech on 5th of October, 2021 *"If electricity prices are high, it is because of the high gas prices, and we have to look at the possibility to decouple within the market because we have much cheaper energy like renewables"*. (Euractiv, 2021b)

International Energy Agency (IEA) lists a few issues for the pulp and paper sector which should be achieved to reach sustainable development scenario. To achieve lower GHG emissions there should be accelerated energy efficiency and an increase the use of alternative fuels instead of fossil fuels. Policy makers have a significant role in GHG emissions mitigation and adaptation. The sustainable development scenario is shown in Figure 1. (International Energy Agency, 2021)

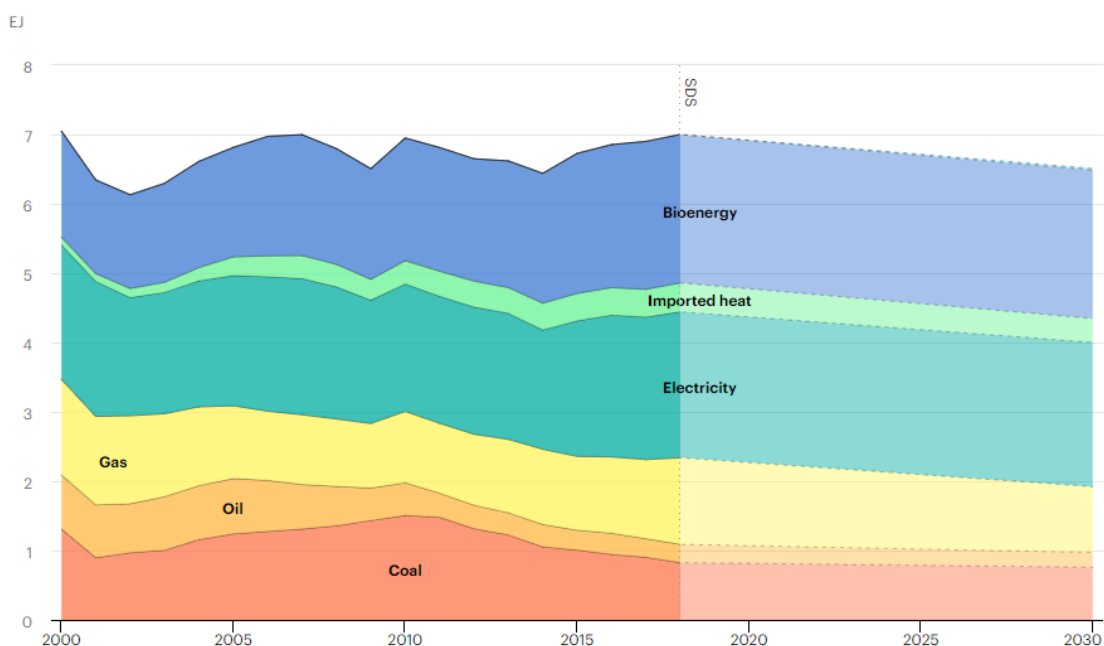


Figure 1. Pulp and paper sector final energy demand [EJ] in sustainable development scenario to 2030. (IEA, 2021)

Some Board and Paper Mills have own targets to reduce CO₂ emissions. One Finnish forest industry company has published targets to reduce fossil fuels to get the target of fossil-free mills in year 2030. One of the mentioned ways to have the target of fossil free mills by 2030 is to replace fossil fuel in coating drying to a fossil free option.

Energy use of paper drying is important to study because of the increasing energy costs and high consumption of energy. Fossil fuel changed to a renewable resource can be an option to achieve lower energy costs. (Stenström, 2020). Another option to reduce CO₂ emissions is improvement of energy efficiency in coating drying (Valmet internal, 2021).

The future trends of the board and paper industry show that the packaging industry will increase. Packaging increase will increase the need for coated boards and coated label products. In this study, the focus is on the coated boards and coated packaging papers. Coated boards and papers are used as packaging material of products. (Finnish Forest Industries, 2021; Valmet internal, 2021). “Take away” culture and the growth of internet

shopping have increased the demand of coated packaging products recently. Especially food products have special needs for board quality and coating so as coating drying properties. (Valmet internal, 2021) Customer brands are setting the quality and environmental requirements for products. One trend tends to be to decrease the plastic used in packaging as well as decrease CO₂ emissions of products. (Finnish Forest Industries, 2021; Valmet's Customer interview, 2021-03-22)

Gullichsen et al. (2000a) have mentioned that coated paper markets will increase in the future and need continuous improvement work of different coated grades for different customer needs. There are several mentioned main elements in the development of coated boards and papers:

- More specific paper products
- Development of coating technology
- Globalization of paper companies
- Progress in printing technology
- Environmental issues
- Development of coating color raw materials.

(Gullichsen et al., 2000a)

Figure 2 of board and paper production presents that in the future the containerboards will have the largest proportion of produced board grades. Containerboards consist of different kraft liners and recycled liners and includes coated and uncoated grades. Minor part of containerboards are coated. Cartonboards and other paperboards for packaging include several coated grades as well as other board and paper grades. (Valmet internal, 2021). Proportion of different grade's production is shown in Figure 2.

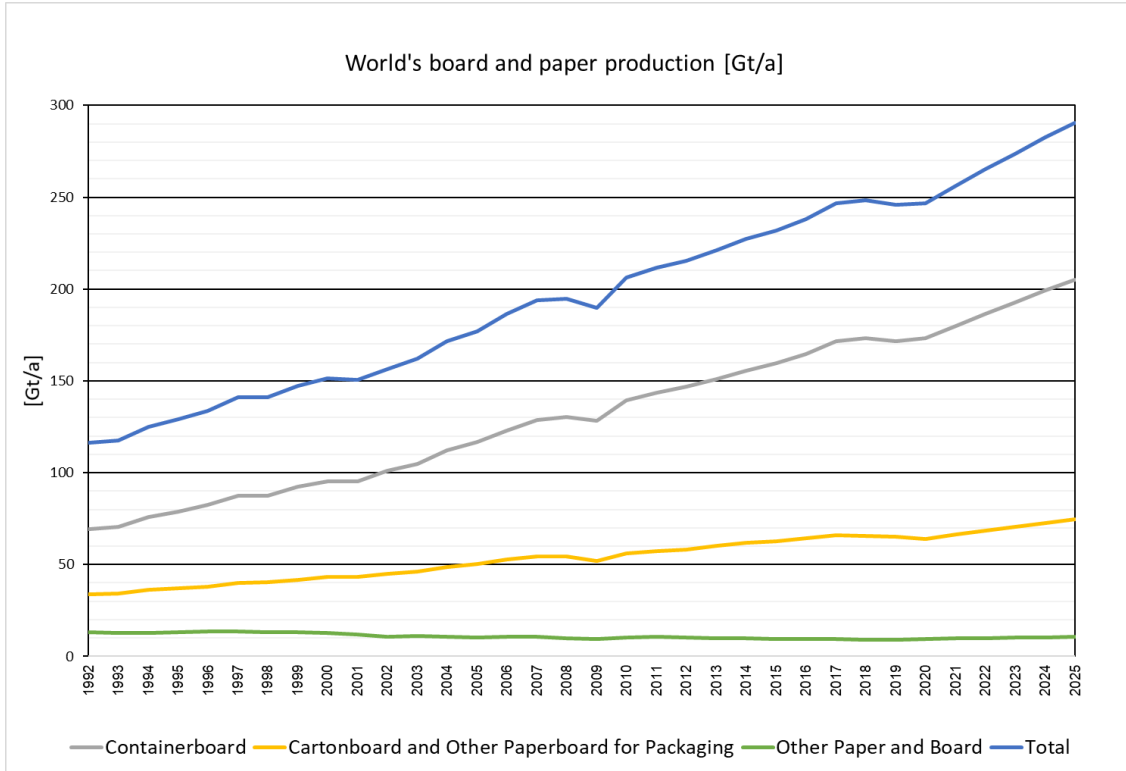


Figure 2. World's board and paper production. (Fastmarkets RISI, 2021)

In 2020 the total amount of produced board and paper in European area was 85.2 million tons. The largest amount of production consists of packaging board and papers. Total amount of packaging board and paper production was 49.6 million tons in 2020 in Europe. Figure 3 presents the share of different board and paper grades in Europe of total board and paper production in 2020. (Confederation of European Paper Industries CEPI, 2021a)

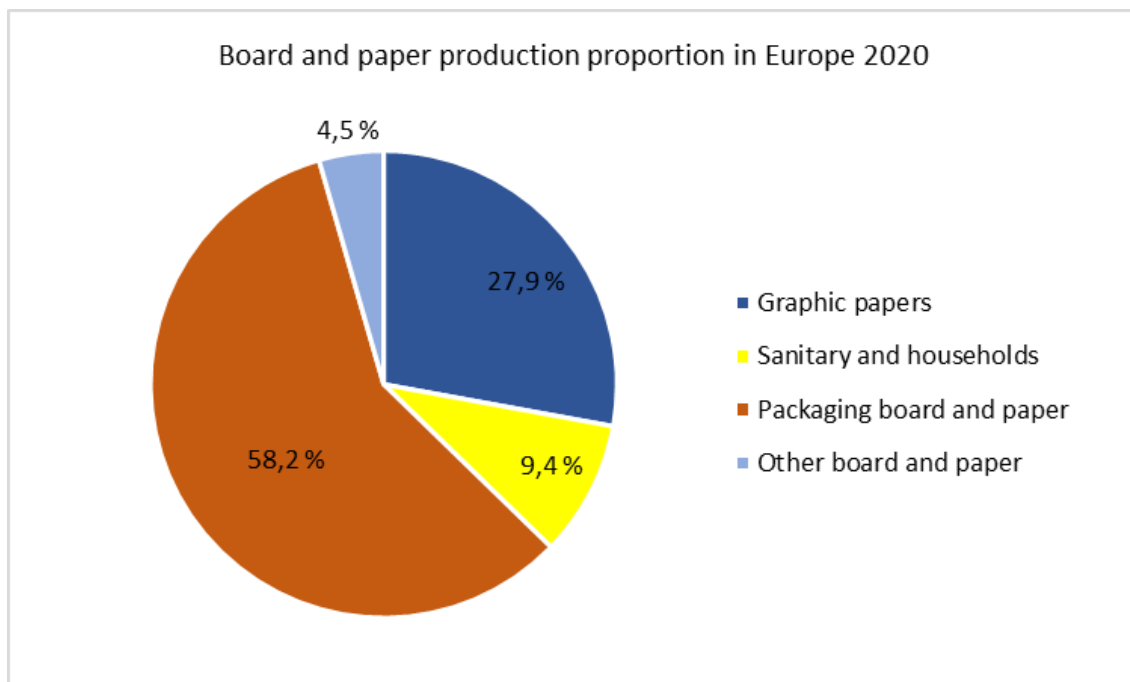


Figure 3. The proportion of board and paper production in 2020 in Europe. (Elaborated from CEPI, 2021a)

In this Thesis the research focus was on carbon dioxide (CO₂) emissions in coating drying section in board and paper machines. This work was executed as an assignment of Valmet Technologies Oy. There were calculated the amount of CO₂ emissions in coating drying process based on 2020 year's coating drying gas consumption data and additional calculations of coating drying heating energy consumption. Calculations were executed in global area and in European Union area. The future scenarios of CO₂ emissions in coating drying were also researched.

In addition, the purpose of this Thesis was to show the methods to decrease the coating drying CO₂ emissions. There were determined applicable EU regulations and fundings for CO₂ reduction in coating drying. There were arranged interviews related to board and paper producers' thoughts of CO₂ reduction. One of the Finnish forest industry company's board machine's coating drying CO₂ emissions by actual energy consumption in 2020 were shown as a case example.

2. Coated board and paper manufacturing process

Coated boards and papers demand is increasing. Coated board and papers are mainly used in packaging use for several end uses, for example food packaging or web market packages. Especially food or liquid packaging has special needs for coating. (Valmet internal 2021) Main principle of package is to protect the product inside the package. Boards are used as packaging because its properties are essential: strength, impervious and tight. Board is defined as its basis weight is higher than $150 \frac{\text{g}}{\text{m}^2}$. Board grades are divided to cartonboards, containerboards and special boards. (Gullichsen & Paulapuro, 2000: 55; Häggblom-Ahner & Komulainen, 2001: 72.) Figure 4 is showing board grade definitions which includes coated and uncoated grades.

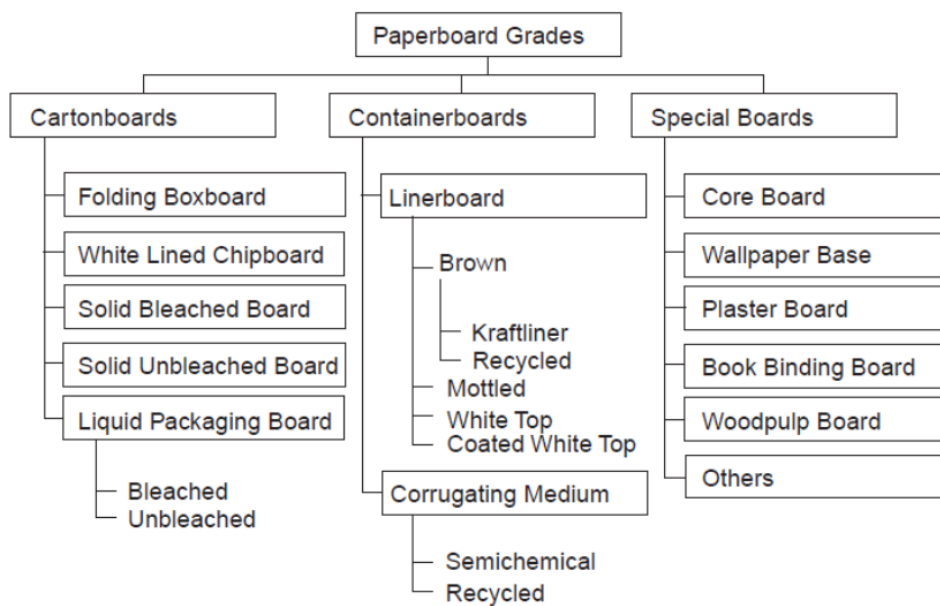


Figure 4. Board and paper grades. (Gullichsen & Paulapuro, 2000: 55).

Cartonboards can be divided to sub grades. Cartonboard can be folding boxboard (FBB), white lined chipboard (WLC), solid bleached board (SBB), solid unbleached board (SUB), bleached liquid packaging board or unbleached liquid packaging board. Folding box board (FBB) and White Lined chipboard (WLC) can be used in several types of packaging. Top ply is made of bleached chemical pulp. (Gullichsen & Paulapuro, 2000: 55.)

Containerboards can be divided as liner boards or corrugating medium boards. Linerboards can be brown kraftliner, brown recycled, mottled linerboard, white top linerboard or coated white top linerboard (CWTL). Corrugating Medium can be semichemical or recycled. Containerboards are for packaging purposes. (Gullichsen & Paulapuro, 2000: 55.)

Special boards can be core board, wallpaper base, plaster board, book binding board, woodpulp board or other grades. Specialty boards and specialty papers can be a part of packaging grades. Life cycle of paper grades usually starts as special papers and in the end is used as recycled material for other grades. (Gullichsen & Paulapuro, 2000: 55.)

2.1 Coated board and paper grades

This Thesis has only studied coated board and paper grades which are divided to Cartonboards, Containerboards, Specialty- and Packaging papers. There are different coating color amounts and coating color pigments used for different purposes. Coated board is usually coated on-machine with 2–3 layers of coating color on the top of the board. Total coat weight is usually 20–25 $\frac{\text{g}}{\text{m}^2}$. The first coating layer is called pre-coating which improves opacity and fill small pores of uncoated fibre surface. Top coatings give final smoothness, absorption, properties and gloss. (Paltakari, 2009: 32) Figure 5 is shown four different types of coating grades which has different coating color amounts.

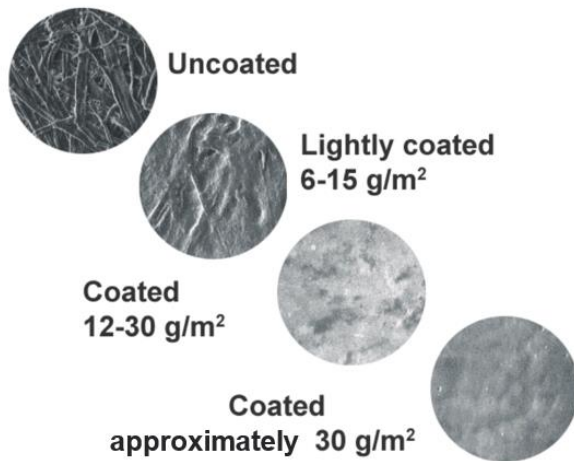


Figure 5. Coating grades. (Elaborated from Knowpap, 2021)

Folding box board (FBB) is used for several packaging applications. Total basis weight of folding box board varies $160\text{--}450 \frac{\text{g}}{\text{m}^2}$. Folding box board can be coated with different manners. Folding boxboard can be surface sized, uncoated, single coated on the top side, double coated on the top side, or double coated on the top side and single coated on the back side. (Gullichsen & Paulapuro, 2000: 58–59.) FBB may include only mechanical pulp or both – mechanical and chemical pulp. FBB where mechanical pulp in middle ply or bleached mechanical pulp in middle ply is GC2, so called “Cream Back”. If on reverse side or back layer of chemical pulp is thicker or white pigment coated as appearance of both sides are white, the FBB is described as a GC1 “White Back”. End use is typical for packaging, depending on grade it can be used for food packages as well. (Holmen Iggesund, 2021; ProCarton, 2021)

Corrugated Recycled board (CRB) includes recycled board in the middle layers. Can be used for several packaging end use e.g. food or other specified packaging use. (WestRock Company, 2021). Solid Unbleached Kraft (SUK) is also known as Solid Unbleached Board (SUB) which is defined as having less than half recycled content and less than 5 percent mechanical content and is unbleached. Board can be folding carton or chipboard. (FisherSolve Next, 2021). Solid Bleached Sulphateboard (SBS) consists only of bleached hardwood and coniferous wood pulp. SBS can be manufactured as multi-ply board or single ply board. (Gullichsen & Paulapuro, 2000: 60–61). SBS can be coated one side (C1S) or

coated two sides (C2S) (Holmen Iggesund 2021b). End use of SBS are liquid packages, cups, and plates or C2S end use can be as luxury packages which need graphical design e.g. luxury or cosmetics (Hägglom-Ahner & Komulainen, 2001: 72–73; Stora Enso, 2021)

Coated White Top Liners (CWTL) are different coated liners for packaging which includes bleached or unbleached chemical pulp in middle layers. End use is for packaging. It can be used to food packages, beverages, electronics or other packaging use. (Metsä Board, 2021f)

Specialty papers (specialties) are minor quantity products which can be manufactured in small board or paper machines. Grade variety is wide with specialties. A specialty paper is usually paper with specific feature. Specialty paper can be also only a part of the total product. Packaging papers can be corrugated board and the purpose is to protect the product during transportation (Gullichsen & Paulapuro, 2000: 101–102, 121.) Table 1 describes the summary of different coated grades of boards and papers.

Table 1. Coated grades of boards and papers. (Elaborated from Gullichsen & Paulapuro, 2000; Holmen Iggesund, 2021; Mayr-Melnhof, 2021; MetsäBoard, 2021f; ProCarton, 2021; See Appendix 1.)

Major Grade	Grade	Name	Description
Cartonboard	FBB	Folding Box Board	Can be GC1 “White Back” or GC2 “Cream Back”.
	CRB	Corrugated Recycled Board	Includes recycled board in the middle layers.
	SUK	Solid Unbleached Kraft	Also known as solid unbleached board (SUB). 2–3 coating layers in the top and unbleached mechanical pulp in middle layers.
	SBS	Solid Bleached Sulphate board	Coated one side (C1S) or coated on two sides (C2S).
Containerboard	CWTL	Coated White Top Liner	Includes bleached or unbleached chemical pulp in middle layers.
Specialties	N/A	N/A	Core board, wallpaper base, plaster board, book binding board, wood pulp board or part of the packaging product.
Packaging papers	N/A	N/A	Some coated papers used in packaging.

2.2 Coating application

Runnability (coating quality) requirements are coating color dry solids content, rheology, and water retention. Coating steps are:

- Application of the coating color to the base paper
- Metering coating color weight before, during or after application
- Drying of coating

- Finishing of coating layers by calendering where paper is compressed between two or more rolls (nips) to have the transformation in mechanical forces, heat and moisture. Calendering give the coated papers the final finish by increasing gloss and smoothness and decrease bulk and stiffness. The greater number of nips ensures the greater calendering result.

(ForestBioFacts, 2021; Paltakari, 2009: 19, 24, 20; Valmet internal, 2021.)

There are two methods of preparing coating color – the batch method and the continuous method. In batch method the coating color components are added one by one into a mixing tank and color is mixed in the tank before application. In continuous method the coating color components are added continuously to a mixing device. Coating color may include pigments, binders, additives and water. Pigment is the most important component in coating color. Pigments consist of many minerals or they can be synthetic. Another important component of coating color is binder. There can be many different binders including kaolin clay or calcium carbonite. Pigments are small particles by size as less than 10 μm . Thickener is added to the coating color to modify rheology and water retention of coating color. (Paltakari, 2009: 14–17; Gullichsen, Lehtinen & Paulapuro, 2000: 14.)

Coating color is applied on the web (base paper) in the coating stations when solids content of paper is between 50 % to 70 %. On-machine coating stations or off-machine coating stations are used. (Gullichsen et al., 2000: 416.) Coating is divided as two technologies: application of coating color and metering the coating color to designed coat weight. For the board grades, the coating is on-line mainly. The web temperature is approximately 80 °C when reaching the coater. (Paltakari, 2009: 415–416.)

Figure 6 presents the coating color circulation system principle where coating color is cooked in coating kitchen and is added to machine tank and in the end to the coating stations. The extra coating color is returned to the machine tank. (Paltakari, 2009: 22)

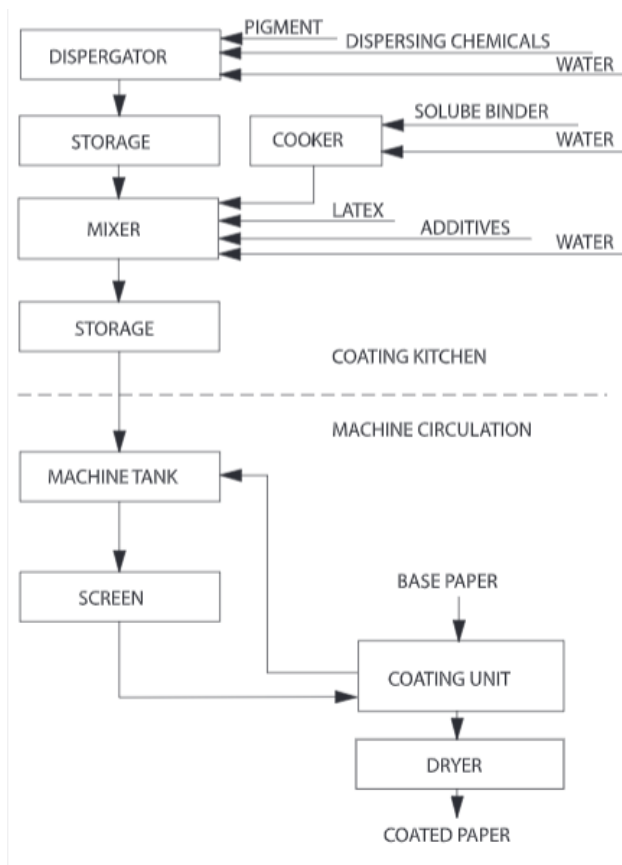


Figure 6. Coating color circulation system (Paltakari, 2009: 22.)

Coating methods include blade coating, film coating or curtain coating as coating method. Blade coating can be implemented by applicator roll coating stations, short dwell coating stations or jet applicator coating stations. Film coating can be implemented by curtain coating stations. Curtain coating is mainly used on specialty papers. (ForestBioFacts, 2021) Figure 7 presents the different coating layers on base paper by different coating methods.

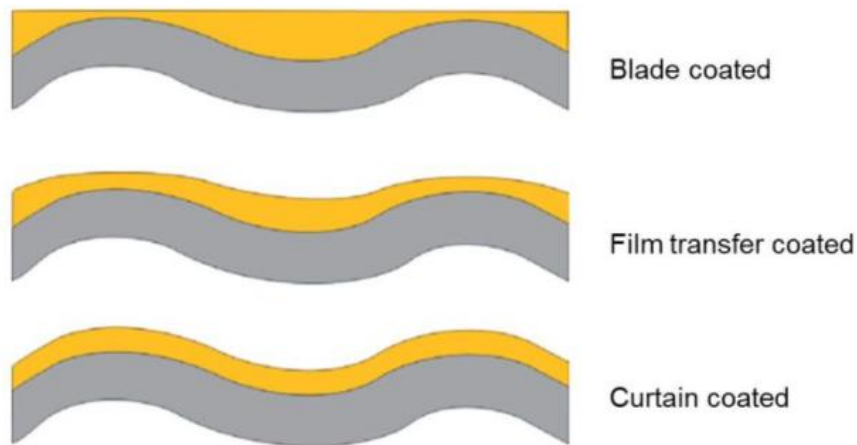


Figure 7. Coating layers by different coating application methods. (ForestBioFacts, 2021)

Coating can be on-machine or off-machine. Off-machine coating is used if there is variation of grades which the machine is producing. (ForestBioFacts, 2021) The color can be applied on one or many sides of the board or paper surface. Film coated surface is rougher and has less gloss than blade coated surface even if calendering is used after film coating. (Paltakari, 2009: 56, 520.)

2.3 Coating drying process

Coating drying process occurs after the pigment is added on the base board or paper. Dry solids content of coating color is 30–70 %. Coating drying purpose is to remove excess water and set the binders after coating color application. There are three types of coating dryers in use: Infrared radiation drying (IR drying), air flotation drying and cylinder drying. There are also combinations of IR and cylinder drying or an IR and air drying. Typically, dryers are placed in order as following: IR dryers, air flotation dryers and cylinder dryers. (Gullichsen et al., 2000: 14; Paltakari, 2009: 14–17, 415, 543.)

Heat transfer occurs by conduction, convection, or radiation (Incropera, Dewitt, Bergman & Lavine, 2007) Coating dryer's operational principles can be divided by heat transfer manners presented in Figure 8. Heat transfer to web occurs by convection and

conduction in cylinder drying, by radiation in Infrared drying and by convection in air drying. (Ahlholm, 2010; Knowpap, 2021)

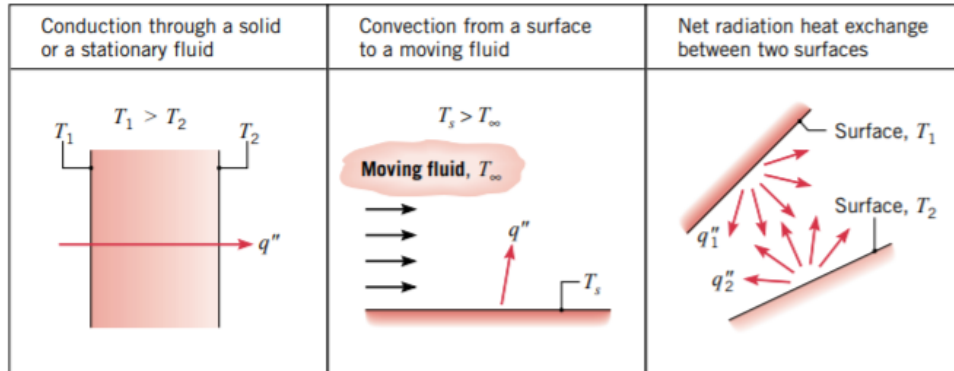


Figure 8. Heat transfer mechanisms. (Incropera et al., 2007)

Principle of infrared drying is that energy from thermal radiation is absorbed inside the web. Radiative material is heated by electricity or gas. Electricity based infrared drying is called electrical IR. Gas flame based heated infrared drying is called Gas IR. (Paltakari, 2009: 543–544.)

IR dryers increase the temperature of the web for quick dewatering effect to coating color caused by infrared heaters. IR drying is commonly used as first phase of coating drying to avoid sticking of rolls running the web to next coating drying phase. Quick evaporation is also beneficial from the end-product quality point of view. (Paltakari, 2009: 561.)

In gas IR dryers there are used natural gas consisting mainly of methane or mixture of liquid propane and butane as a fuel of Gas IR. Gas IR dryer is the commonly used drying type of coating since 1950s. In the 1980s electrical IR dryers came to markets. Electrical IR dryer has usually halogen lamp with tungsten filament heated to maximum 2 260 °C. (Paltakari, 2009: 547, 562.)

Air dryers can be divided as air flotation dryers and single-sided air impingement dryers. Single sided impingement dryers are used when uncoated side drying is not needed. Two-sided air flotation dryer consists of two opposite dryer boxes where air is distributed between two dryers. Mechanical contact from web to dryer is not allowed before coating color is non-immobilized. The non-contact air dryers are particularly used in first steps of coating drying when the solids-content of coating color is high. Impingement nozzles for air dryers have been developed to maintain web stability and heat transfer. (Paltakari, 2009: 548, 566.) In Figure 9, there can be seen two two-sided air flotation dryers.

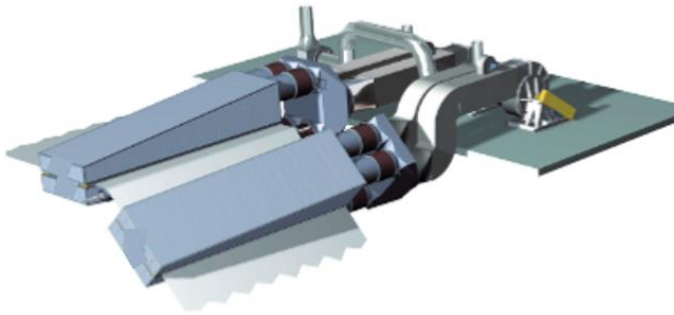


Figure 9. Two two-sided air float dryers. (Elaborated from Paltakari, 2009: 565)

Figure 10 presents the air flotation dryer where are two opposite dryers to dry the web in front and back side of sheet. The web is in the middle of dryers. Air flow is distributed to impingement nozzles by distribution channels. Thermal expansion occurs and the air flow is distributed to the web. Two-sided air flotation dryer ensures uniform impingement temperature and velocity in cross direction and machine direction. Figure 11 presents one sided air flotation dryer which can be used when drying is not needed on both sides of web. (Paltakari, 2009: 567)

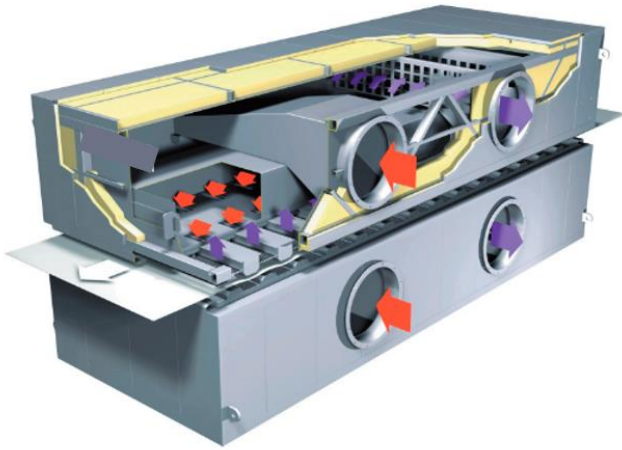


Figure 10. Two-sided air flotation dryer. (Elaborated from Paltakari, 2009: 567)



Figure 11. One sided air flotation dryer. (Valmet internal source, 2021)

Air dryers are commonly heated by gas burners or steam coils but sometimes heating is implemented by thermal oil coils or electricity. If air dryer is steam heated, important parameter is steam pressure to be achieved the needed impingement temperature. For air dryers, impingement temperatures are 170 °C – 185 °C operating by 10–15 bar steam pressures typically. Temperature needed for drying is achieved efficiently by gas, when achieved impingement temperatures are 300°C – 400 °C. Designed impingement velocities are typically 40–60 m/s or higher. (Paltakari, 2009: 566–567.)

Cylinder drying is typically the last part of coating drying. Cylinder drying can be used when the coating layer is dry enough to be in mechanical contact. Typically a cylinder drying section includes 2–6 cylinders. The last cylinders are sometimes used for web cooling if temperature is needed to decrease before next coating stations or before reel which is the next phase of the manufacturing line after coating drying phase. Cooling is typically needed in board machines. Cooling cylinders are cooled by cold water. Specific evaporation rate is usually 3–6 kgH₂O/m²h. Usually exhaust steam is used for heating exhaust air flow. (Paltakari, 2009: 574–576) Figure 12 presents a drying cylinder and heat transfer in drying cylinder. Heat transfer occurs by conduction from inside cylinder surface to paper sheet after convection from saturated steam to inside cylinder surface. (Valmet, 2012b)

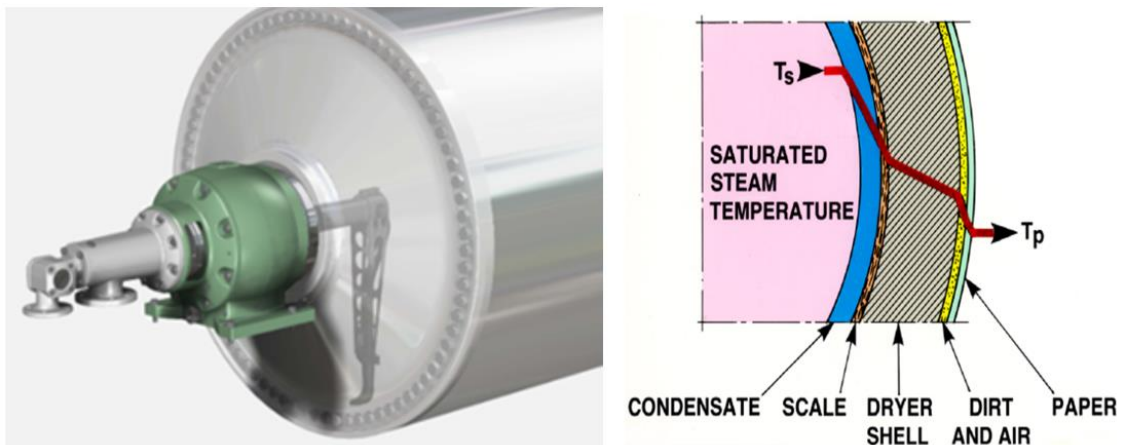


Figure 12. Drying cylinder heat transfer to web. (Elaborated from Valmet internal source, 2021; Valmet, 2012b)

Other components in addition of coating dryers using gas as a primary energy resource in board and paper machines are yankee cylinder and drying after sizing (Valmet internal, 2021). For board grades, the yankee cylinder is used in Europe in older cartonboard machines to improve FBB surface properties. Yankee cylinder can be heated also by steam. (ForestBiofacts 2021) Drying after sizers exists in new FBB machine lines which has come to the market in recent years (Valmet internal, 2021).

Table 2. Dryer types primary energies and heat transfer mechanism in coating drying. (Elaborated from Ahlholm, 2010; Knowpap, 2021; Valmet internal, 2021; Valmet, 2011)

Dryer type	Input energy options	Heat transfer mechanism for coating color drying
Air	Gas, high pressure steam, electricity, oil coils	Convection
IR	Gas, electricity	Radiation
Cylinder	Medium or low-pressure steam	Convection and conduction

Figure 13 presents the coating drying section where there are 4 coating stations after sizing. Sizing is process before coating phase which is used for improving the strength of board or paper (ForestBioFacts, 2021). In Figure 13 from right to left can be seen:

1. The 1st coating drying phase that consists of gas infrared dryer, air dryer heated by steam and drying cylinders heated by steam.
2. The 2nd coating drying phase consists of gas infrared dryer, steam heated air dryer and steam heated drying cylinders.
3. The 3rd coating drying phase consists of gas infrared dryer, two floating air dryers heated by steam and drying cylinders heated by steam.
4. The 4th coating drying consists of gas infrared dryer and air dryer heated by steam and cylinder group heated by steam.

(Valmet internal, 2021)

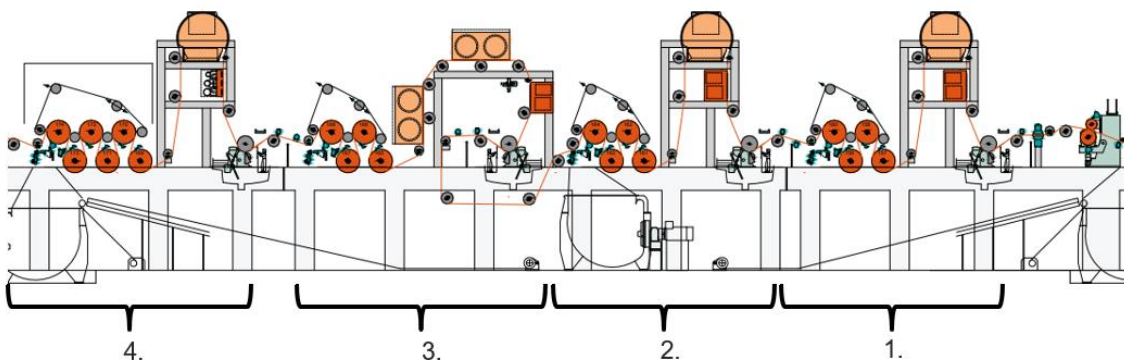


Figure 13. Coating drying section including coating drying phases 1. –4. (Elaborated from Valmet internal source, 2021)

Steps of the coating drying process after coating application is shown in Figure 14 where X_{av} [%] is the average dry basis moisture content of coated sheet. X_b [%] is the base sheet dry basis moisture content. X_c [%] is the coating color dry basis moisture content of coating color. T_p is temperature of the sheet [$^{\circ}\text{C}$]. $\frac{m_d}{A}$ is the water drainage rate from coating color to the base sheet [$\frac{\text{kg}}{\text{m}^2\text{h}}$]. $\frac{m_e}{A}$ is evaporation rate from the sheet [$\frac{\text{kg}}{\text{m}^2\text{h}}$].

- (a) Web's free drawn from coating application to dryer
- (b) Evaporation on front side of coating layer
- (c) Evaporation of deeper coating layer
- (d) Evaporation of base stock
- (e) Drawn after drying.

(Paltakari, 2009: 560.)

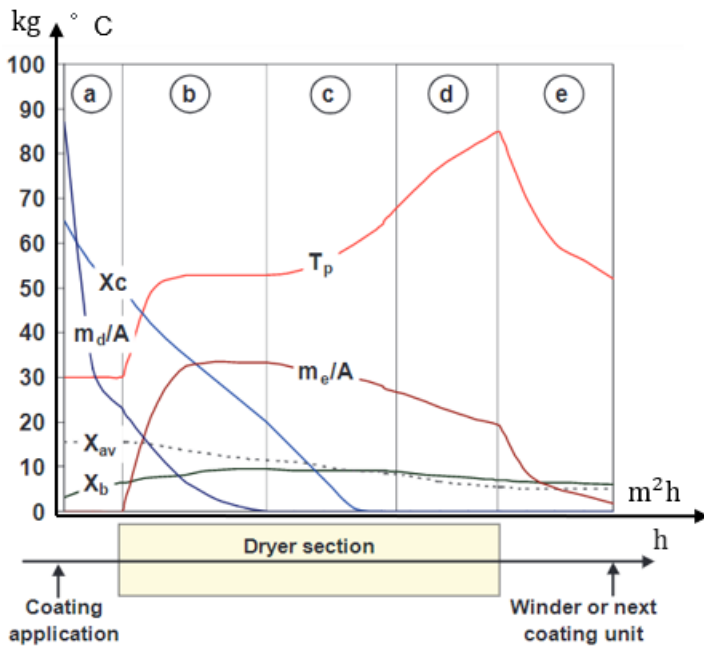


Figure 14. Coating drying phases in coating drying section. (Elaborated from Paltakari, 2009: 560.)

2.4 Heat resources in coating drying

Mainly the gases used in coating drying are natural gas (NG), liquefied natural gas (LNG) and liquefied petroleum gas (LPG). In addition to gas there are used electricity and steam

as an energy source of coating drying. (Valmet, 2012a). In EU area natural gas consumption is 95 % of gaseous fuels total consumption. (European Union, 2021q). Chemical content and combustion of NG, LNG and LPG are shown in Table 3. Emission factors of gases are presented in Table 4.

Enthalpy change ΔH can be shown by Hess law which is presented below.

$$\Delta H = \sum H_2 - \sum H_1 \quad (1)$$

Where,

$\sum H_1$ is the sum of the heat formation (Enthalpy of formation) in combustion reaction of source material

$\sum H_2$ is the sum of the heat of formation (Enthalpy of formation) in combustion reaction of products.

Enthalpy of formation changes are shown below for each chemical content of coating drying gases. (Seppänen et al., 2005)

$$\Delta H_{\text{CH}_4} = -74.9 \quad [\text{kJ/mol}]$$

$$\Delta H_{\text{O}_2} = 0 \quad [\text{kJ/mol}]$$

$$\Delta H_{\text{H}_2\text{O}} = -285.8 \quad [\text{kJ/mol}]$$

$$\Delta H_{\text{CO}_2} = -393 \quad [\text{kJ/mol}]$$

$$\Delta H_{\text{C}_3\text{H}_8} = -103.8 \quad [\text{kJ/mol}]$$

$$\Delta H_{\text{C}_4\text{H}_{10}} = -126.15 \quad [\text{kJ/mol}]$$

Heat amount of gas Q [kJ/kg] can be calculated by dividing enthalpy change ΔH [kJ/mol] of reaction by gas mass m_{gas} [kg/mol].

$$Q = \frac{\Delta H}{m_{\text{gas}}} \quad (2)$$

Table 3. Gases in coating drying. (Elaborated from Finnish Gas Association, 2014)

Gas	Content	Chemical formula	Combustion	Calculated heat amount [kJ/kg]*
NG	Methane	CH ₄	CH ₄ + 2O ₂ → CO ₂ + 2H ₂ O	55.4
LNG	Methane	CH ₄	CH ₄ + 2O ₂ → CO ₂ + 2H ₂ O	55.4
LPG	Propane	C ₃ H ₈	C ₃ H ₈ + 5O ₂ → 3CO ₂ + 4H ₂ O	59.5
	Butane	C ₄ H ₁₀	C ₄ H ₁₀ + 6,5O ₂ → 4O ₂ + 5H ₂ O	49.5

*Heat amounts are calculated by exothermal reaction released heat by calculating the heat amount of enthalpies.

CO₂ emission factor can be calculated by formula as follows to be shown equivalent amount of gas burned in reaction to get the equivalent amount of energy E [kJ].

$$\text{kgCO}_2/\text{kJ} = \frac{m_{\text{CO}_2}}{Q} \quad (3)$$

Where,

m_{CO_2} = Carbon dioxide mass by exothermal

reaction of gas combustion equivalent of energy [kg/kJ]

Q = Heat amount of gas [kJ/kg]

Emission factors of gases in use of coating drying are presented in Table 4.

Table 4. CO₂ emission factors of NG, LNG, and LPG. Comparison of values from Statistics Finland with values calculated in present work.

Gas	CO ₂ emission factor [kgCO ₂ e/MWh]*	CO ₂ emission factor [kgCO ₂ e/MWh]**
NG	199.4	178.4
LNG	200.9	178.4
LPG	233.6	214.2–220.6

*Statistics Finland 2021, See Appendix 4.

**Calculated by formation enthalpy changes based heat amounts. Calculated in present work.

Natural gas is the most common gas in coating drying in European area. Natural gas pipes are located near mills. Gases used in coating drying can include methane, propane, butane, or propane-butane mixture. (Valmet internal source, 2021)

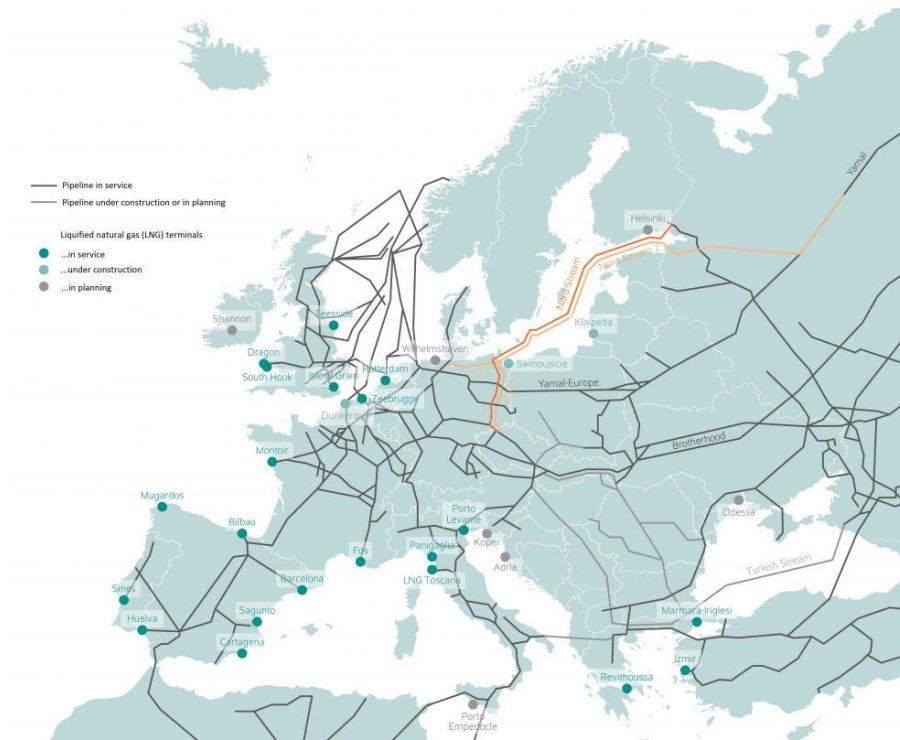


Figure 15. NG piping and LNG terminals in Europe. (Clean Energy Wire, 2021).

As seen in Figure 15, the NG piping is available or under construction for many areas inside Europe. Global natural gas consumption is presented in Figure 16 where the amount of consumption is described as GJ/capita.

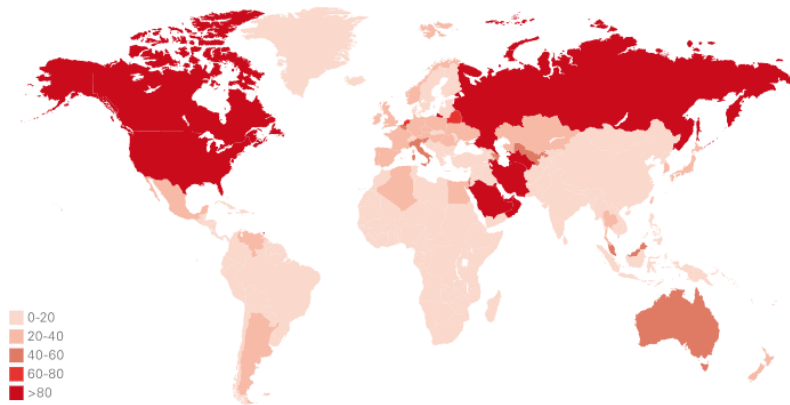


Figure 16. Natural gas consumption [GJ/capita] in year 2020. (Pb, 2021)

The largest NG consumption areas are Asia, North America and Middle East as seen in Figure 16. Figure 17 describes the price of electricity and natural gas for industries in 2020.

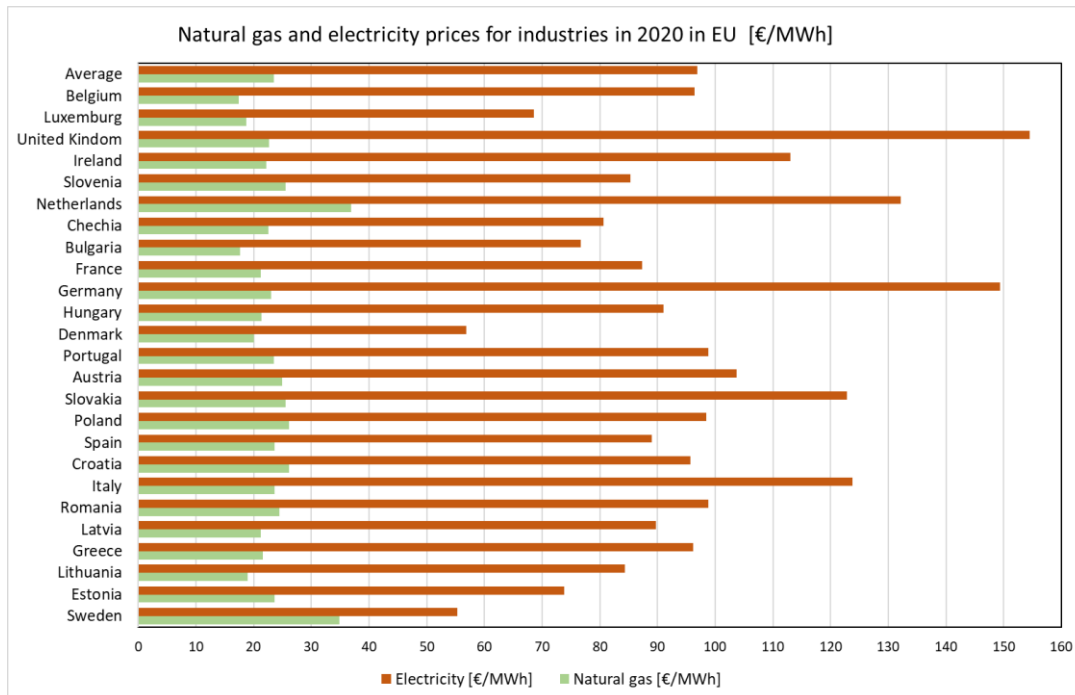


Figure 17. Natural gas and electricity prices for industries in 2020. (Elaborated from Statista, 2021a; Statista, 2021b)

In 2020 Natural gas price was cheaper than electricity for industries in EU area. Difference of price between natural gas and electricity for industries in 2020 was 73,4 €/MWh in average. (Elaborated from Statista, 2021a & Statista, 2021b). Natural gas is used in coating drying because of its availability and inexpensive price (Valmet internal source, 2020).

The board or paper mill can be integrated or non-integrated. Integrated board or paper mill includes the pulp production which is used as raw material to the board or paper machine.

There are benefits for energy efficiency especially in integrated mills which are using virgin fibres as raw material, so as cost-effectiveness. Thinking of steam generation in board or paper mill, the virgin-integrated mills usually produce steam from biomass which can be produced from wood barks or other suitable raw material which is available. (BillerudKorsnäs, 2020). The pulp production in virgin fiber based integrated mills can be surplus which reduce overall energy usage in integrated mill. Steam generated from fiber can be used for energy resource for board or paper machine processes (Koreneff, Huotari & Suojanen, 2019).

Especially in Northern Countries like in Finland and Sweden there are large integrated mills because of good availability of raw materials (Valmet's Customer Interview 2021-06-04). Economy of scale benefit is utilized in new integrated mills. New machines can produce even 500 000 tons of board per year. (Valmet's Customer Interview 2021-03-19). Some integrated mills have already highly invested in green energy and self-sufficient energy, some advanced integrated mills are already total self-sufficient but in some integrated mills part of energy is needed to purchase from the grid (CEPI, 2021b; Valmet's customer interview, 2021-03-16; See Appendix 8.). Figure 18 presents the integrated paper mill.

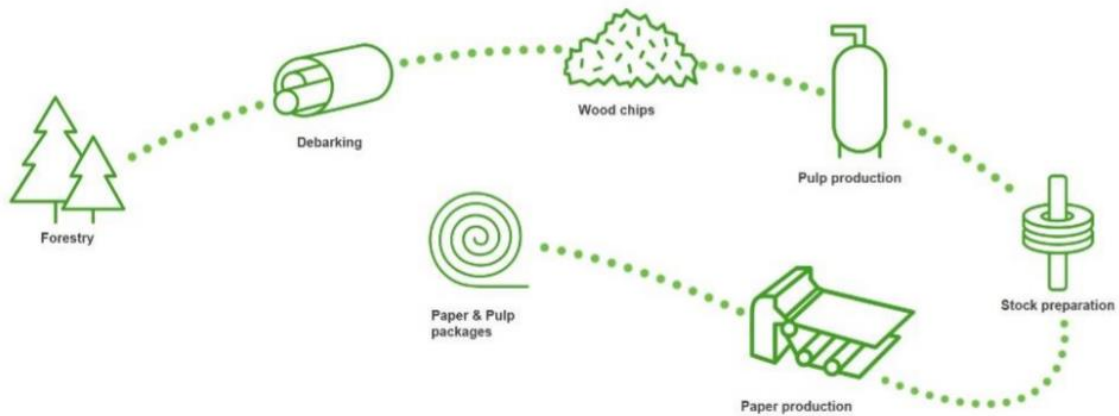


Figure 18. Integrated paper mill. (BillerudKorsnäs, 2020)

If the board or paper mill is non-integrated the dried pulp is usually purchased from integrated board or paper mills or non-integrated pulp mills and is converted to end-product. Non-integrated mills and mills which are integrated but are using recycled fiber as raw material has not the same benefits of raw materials to use as energy resource as virgin integrated mill has. (BillerudKorsnäs, 2020; See Appendix 8.)

The energy systems are different in Integrated and Non-Integrated mills. Integrated mills in Northern countries are usually energy producers. Mills which don't have the benefit of raw material surplus are energy consumers e.g Old Corrugated Container (OCC) Mills in Central Europe. (Valmet internal, 2021). Natural gas is a competitive energy resource for mills which use recycled fibres as raw material and do not have the benefit of surplus of raw materials (CEPI, 2021b). There is a certain difference between Nordic countries mills and central Europe mills related to input energy (Valmet's customer interview, 2021-03-16).



Figure 19. Non-Integrated paper mill. (BillerudKorsnäs, 2020)

Steam and electricity are used as primary energy for some coating drying phases. In coating drying the steam is used mainly for cylinder drying in the last part of the drying process when needed temperature can be lower as with gas burner based drying in the first phases of coating drying process. Electricity is used mainly for infrared dryers. (Valmet internal, 2021) Table 5 presents the emission factors of electricity and steam used in coating drying.

Table 5. Electricity and steam CO₂ emission factors. (Valmet internal, 2021)

Energy resource	CO ₂ emission factor [kgCO ₂ e/MWh]
Electricity*	126
Electricity (renewable resource) **	0
Steam*	167

*Average from European paper industries.

**Elaborated from Appendix 5.

Parameters affecting the selection of primary energy source in coating drying are:

- Required temperature of drying process
- Energy price.

(Paltakari, 2009: 566)

In Figure 20, heating power of air dryer is implemented by gas.

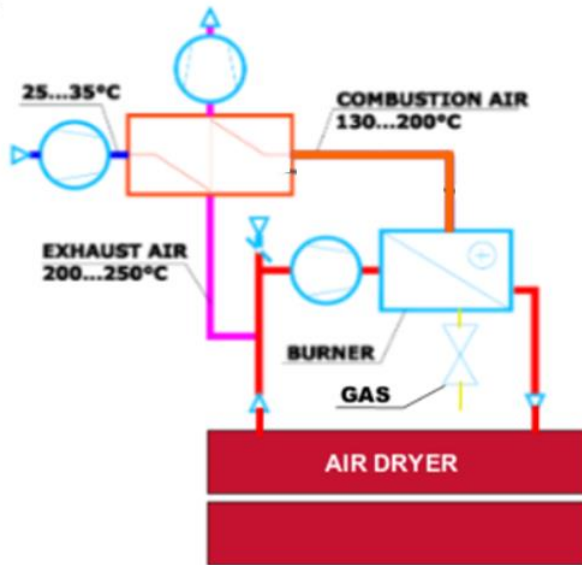


Figure 20. Air dryer which is heated by gas. (Valmet internal source, 2021)

2.5 Energy efficiency in air dryers

Air drying energy efficiency is defined as energy from air dryer divided by heating energy.

Formula is presented below as Equation 4. (Valmet internal source, 2021)

$$E_{air\ drying} = \frac{E_{airdryer\ to\ web}}{E_{heating}} \cdot 100\ \% \quad (4)$$

Input energy of air dryers consists of thermal energy $E_{thermal}$ and electrical energy $E_{electric}$. Thermal energy $E_{thermal}$ can be gas, steam or electricity delivered to heater unit. Electrical energy is fan's consumed energy. Electrical energy is 5–10 % of total energy input. (Paltakari, 2009: 573; Valmet internal, 2021) The specific energy consumption q [kJ/kgH₂O] can be calculated by Equation 5.

$$q = \frac{E_{thermal} + E_{electric}}{m_{ev}} \quad (5)$$

Where,

m_{ev} = evaporated water mass [kgH₂O]

Based on Valmet's several research projects and measurements, the specific energy q can be calculated in practice by measurement of gas consumption, or by other heat resource's consumption in coating drying divided by water amount to be evaporated. Specific energy can be improved by improving coating drying energy efficiency. (Valmet internal, 2021)

3. Calculations of coating drying CO₂ emissions

The CO₂ emissions are examined as gas consumption calculations in coating drying and coating drying heating energy consumption calculations. The gas consumption calculations are based only the Fisher Solve Next model where the gas consumption of board or paper machine is assumed to be the consumption of gas consumed in coating drying. The gas consumption data from FisherSolve Next is changed to CO₂ emissions by gas emission factor which is Valmet's estimate value of gas proportion including NG, LNG and LPG used worldwide for coating drying. (FisherSolve Next, 2021; Valmet internal, 2021)

Coating drying heating energy consumption calculations are based to the Fisher Solve Next related production data with additional calculations as shown below. Coating drying heating energy consumption consists of gas (NG, LNG or LPG), steam and electricity consumption in coating drying. Gas has the largest amount of coating drying heating energy consumption. Coating drying heating energy consumption is multiplied by CO₂ emission factor to have the results of CO₂ emissions in coating drying. The CO₂ emissions are proportionate to production of coated board and papers included in this study. (FisherSolve Next, 2021; See Table 1; Valmet internal, 2021)

Variables which are affecting to results of CO₂ emissions of coating drying are:

- Coated board and paper production [t/a]
- Coating color basis weight [g/m²]
- Coating color dry-solids content in the application station [%]
- Specific energy consumption in coating drying [kJ/kgH₂O]
- Coating drying heat resource CO₂ emission factor [tCO₂/MWh]

(Valmet internal, 2021)

Specific energy consumption is estimated as average range between 4 500 kJ/kgH₂O – 6 500 kJ/kgH₂O. Specific energy can be different in different dryers. (Valmet internal, 2021) Emission factor used for coating drying heating energy consumption calculations

is an estimated emission factor based on Valmet internal calculations. Emission factors used in calculations are presented in Table 6.

Four major coated board and paper grades are studied. As major board grades Carton boards, Containerboards and Specialty boards and papers and Packaging papers. Major boards and paper grades are divided as sub grades of boards and papers. For sub grades, there have been studied the production per year of each grade based on Fisher Solve Next modelled value from year 2020. Every grade has different amount of coating color and dry solids content of coating color which are affecting the energy needed to dry the coating layers. Data for calculations of different grade's coating color dry solid contents and coating color amounts is shown in Appendix 2. (Valmet internal, 2021)

Coating drying energy consumption per year K [MWh/a] can be calculated by Equation 6.

$$K = q \left(\left(\frac{P}{W} \right)^B - \left(\frac{P}{W} \right) B \right) \quad (6)$$

Where,

q = Specific energy (See Appendix 3.)	[MWh/kgH ₂ O]
P = Production of machine per year (FisherSolve Next, 2021)	[t/a]
W = Total basis weight (FisherSolve Next, 2021; See Appendix 3.)	[t/m ²]
B = Dry coating color basis weight (See Appendix 2.)	[kg/m ²]
D = Coating color dry solids (See Appendix 2.)	[%]

CO₂ emissions per year can be calculated by multiplying the coating drying heating energy consumption with emission factor F .

$$CO_2 \text{ emissions per year} = FK \quad (7)$$

Where,

K = Coating drying energy consumption [MWh/a]

F = Coating drying energy emission factor [tCO₂/MWh]

Emission factors of calculations of gas and coating drying heating energy consumption CO₂ emissions are presented in Table 6.

Table 6. CO₂ emission factors used in calculations in EU area and global area based on Valmet internal information.

Primary energy in combustion	Content	CO ₂ emission factor [tCO ₂ /MWh]*
Gas	NG, LNG, LPG	0.2
Energy**	Electricity, steam, NG, LNG, LPG	0.16

*Emission factor is based on estimates of different proportion of used primary energy for different coating drying phases.

**For coating drying energy consumption calculations, grade packaging papers and specialties are not involved.

Production of coated board and packaging is shown in the Figure 21. Total production in Global area of coated grades was 61 million tons. EU area proportion of global production of coated grades was 13 million tons in year 2020. (FisherSolve Next, 2021)

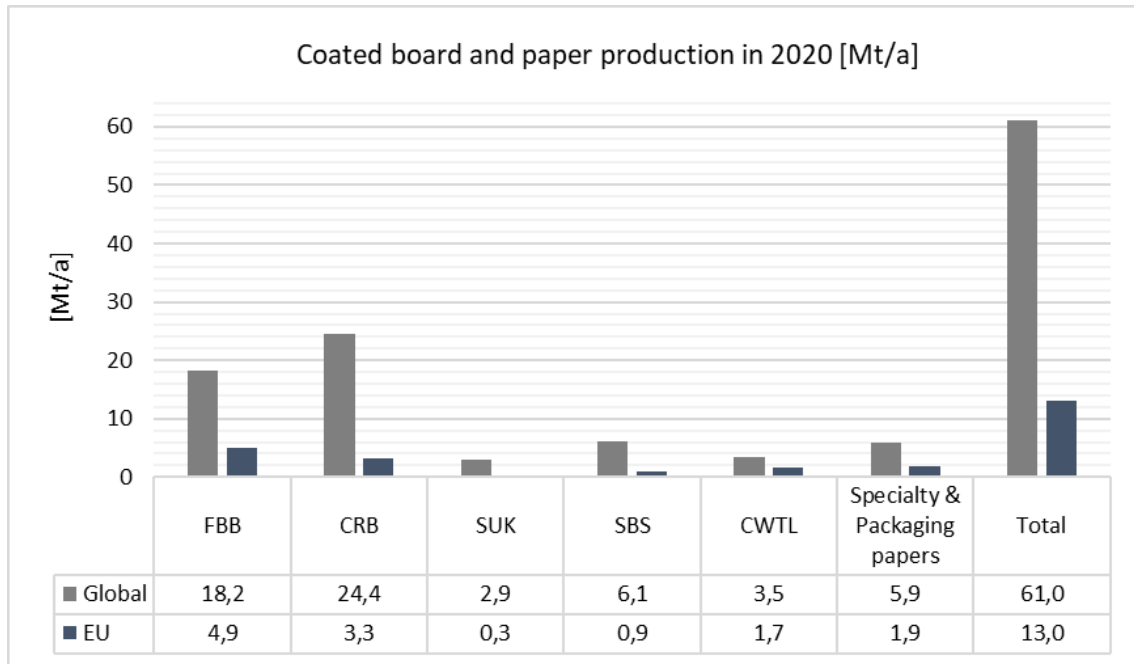


Figure 21. Coated board and paper production in year 2020. (FisherSolve Next, 2021)

Varying parameters are specific energy consumption and coating color dry solids content in the application point. All options are shown in Table 7. Actual probability is that the specific energy can vary between 4 500 – 6500 kJ/kgH₂O and dry solids content of coating color can vary from minimum to maximum dry solids content.

Table 7. Options to varying parameters to all different grades for calculations.

Specific energy [kJ/kgH ₂ O]	Dry-Solids content of coating color [%]
Specific energy min 4 500	average dry solids content
	min dry solids content
	max dry solids content
Specific energy max 6 500	average dry solids content
	min dry solids content
	max dry solids content
Specific energy average 5 500	average dry solids content
	min dry solids content
	max dry solids content

3.1 CO₂ emissions in Global area

Specific energy is assumed as an average 5 500 kJ/kgH₂O. Coating color amounts per grades, coating color dry solids per grades and board or paper total basis weights are assumed as cumulative of production for each sub grade in calculations. In total, the coating drying gas consumption was 3.6 TWh and coating drying heating energy consumption was 5.5 TWh in year 2020. Figure 22 presents the proportion of gas and energy consumption in coating drying by grades. For coating drying heating energy consumption calculations, the specialty & packaging grades are not studied.

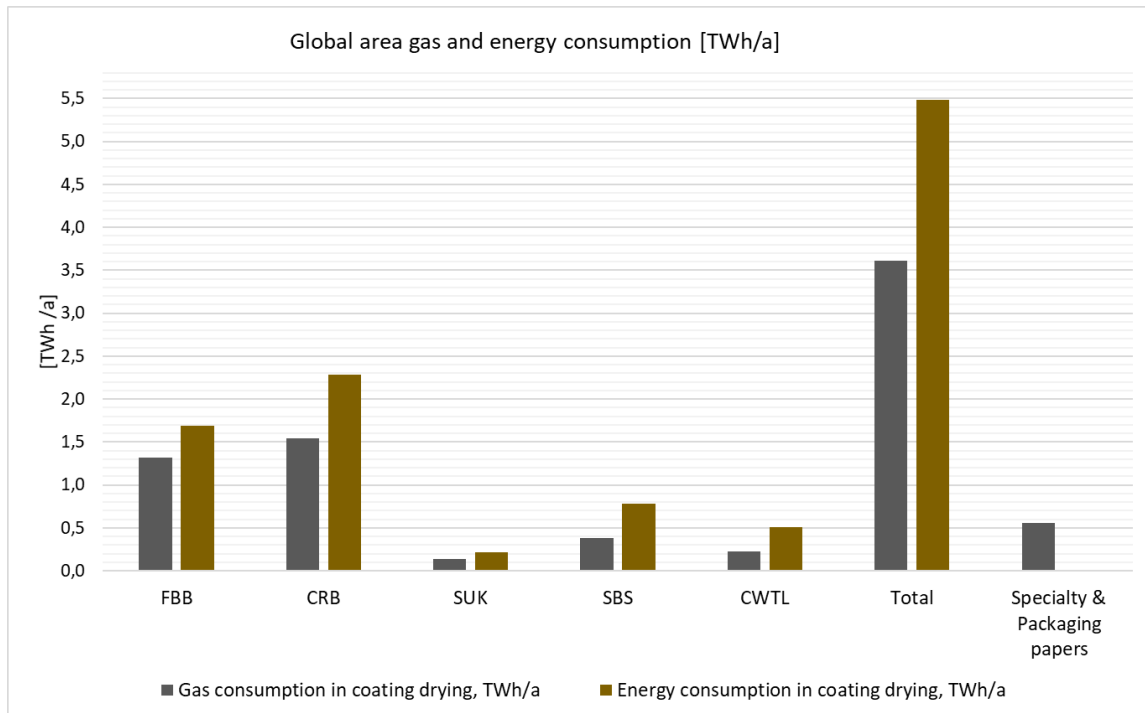


Figure 22. Global area coating drying energy and coating drying gas consumption in 2020.

The CO₂ emissions in coating drying in global area were 722 ktCO₂/a by coating drying gas consumption and 882 tCO₂/a by coating drying heating energy consumption. Figure 23 presents the amount of CO₂ emissions of coating drying gas and coating drying heating energy consumption globally in 2020.

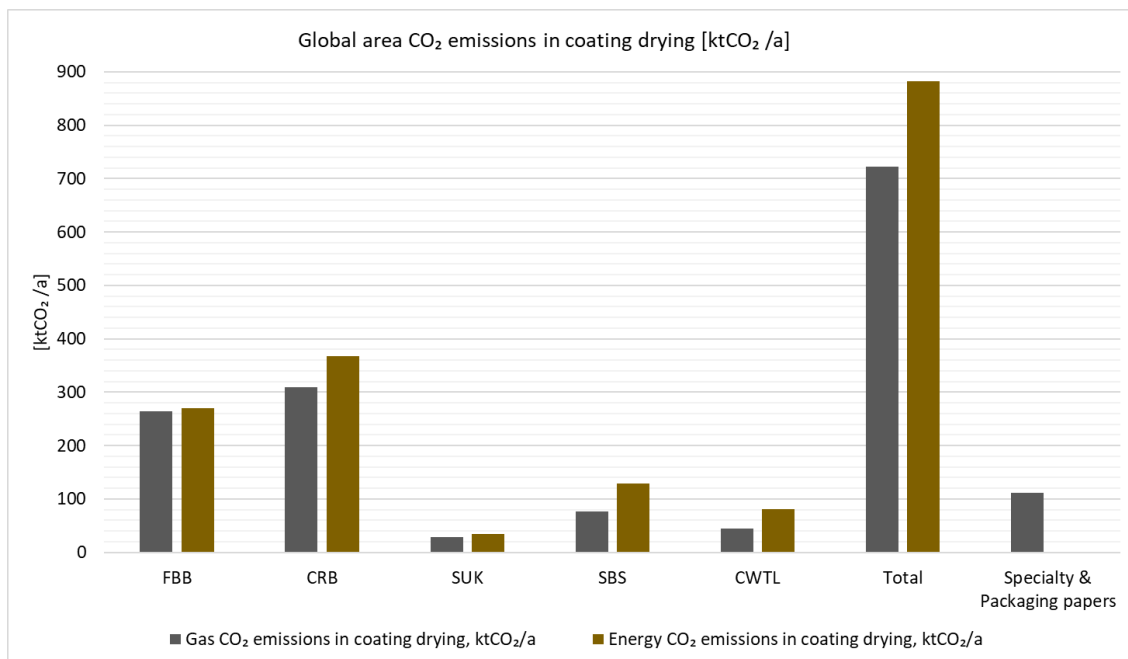


Figure 23. CO₂ emissions of coating drying gas consumption and coating drying energy consumption in global area in 2020.

3.2 CO₂ emissions in EU area

Same assumptions are made to EU area calculations as calculations of global area. For coating drying gas and coating drying heating energy consumption, the coating drying gas consumption was 707 GWh in total and coating drying heating energy consumption was 1.2 TWh in total in year 2020 in European Union. Figure 24 presents the proportion of coating drying gas and coating drying energy consumption by grades in EU area.

Coating drying heating energy consumption based CO₂ emissions in EU area were 187 ktCO₂/a. The proportion of coating drying heating energy consumption's CO₂ emissions by gas were in EU area 141 ktCO₂/a. The results are shown in Figure 25.

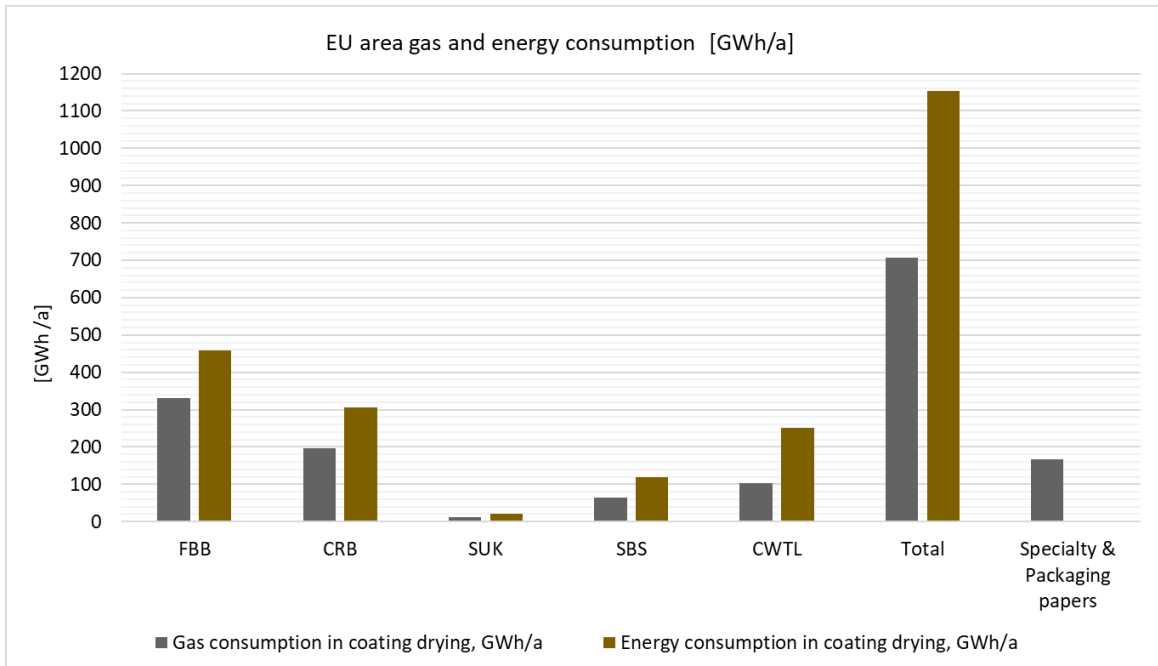


Figure 24. EU area coating drying gas and coating drying energy consumption in 2020.

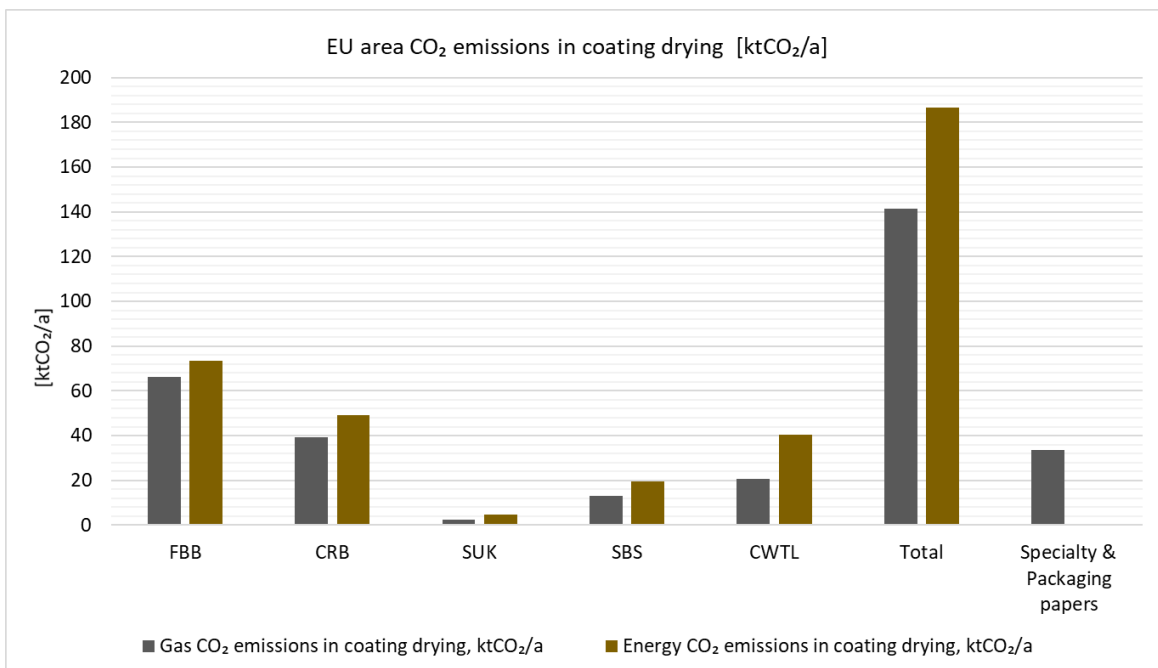


Figure 25. CO₂ emissions of coating drying gas consumption and coating drying energy consumption in EU area in 2020.

3.3 Future scenarios of CO₂ emissions in coating drying

Figure 26 presents the coated boards and papers production increase until year 2025. The production of coated boards and papers will increase which is increasing the CO₂ emissions of coating drying.

There are studied two scenarios of coating drying CO₂ emissions:

- Scenario 1: Business as usual (BAU)
- Scenario 2: Energy efficiency increase of 20 %.

In scenario 1, there is assumed that proportion of CO₂ emissions per produced ton of board or paper grade is in the same level as in 2020. In scenario 2 it is assumed that energy efficiency is increased 20 % by year 2025.

Figure 26 shows the production of different paper and board grades which are coated. 2020 year is assumed as baseline for future scenarios. In 2020 total amount of produced coated grades globally were 60 megatons. Major grades are containerboard, cartonboard and other paperboard for packaging and other paper and board. Major grades are assumed to include same grades than 2020 year's data based calculations.

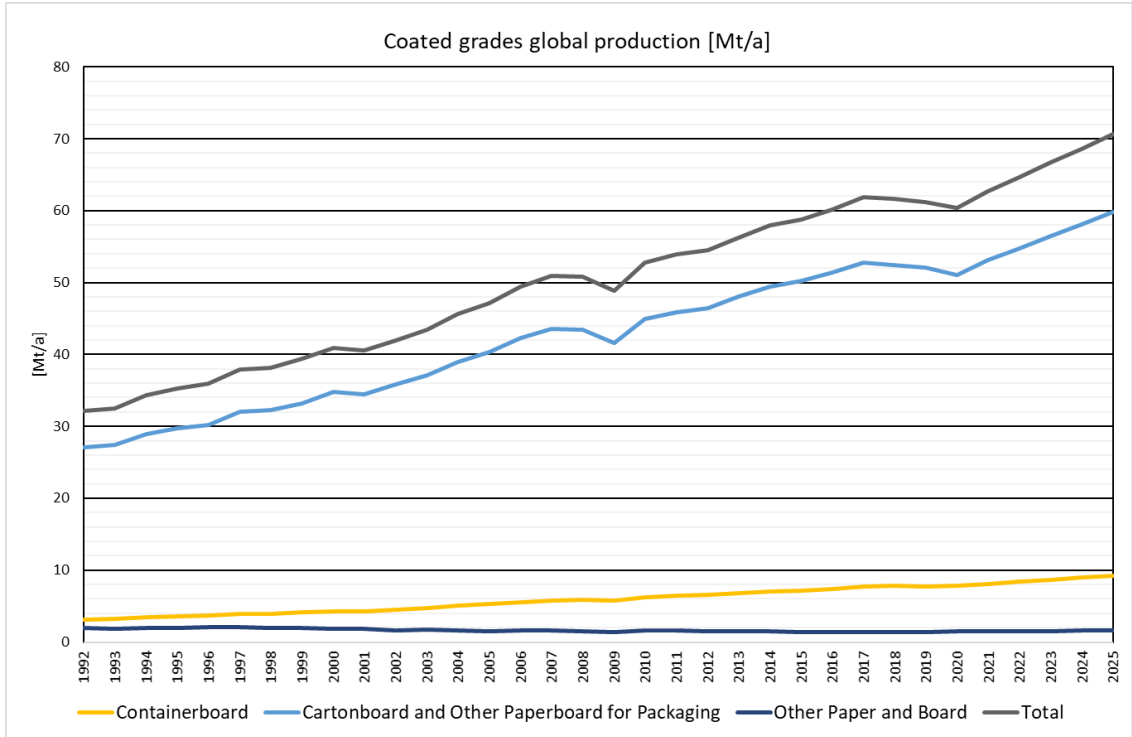


Figure 26. Coated grades global production. (Valmet internal analysis, 2021)

The CO₂ emissions are proportionate to production per year of coating drying. The factor of production amount per CO₂ emissions per year can be calculated by multiplying the production with CO₂ tons per year. Figure 27 presents the estimation of global coated grades production from baseline year 2020 to year 2025. The estimated increase of coated grades production from year 2020 is 11 million tons in total until year 2025.

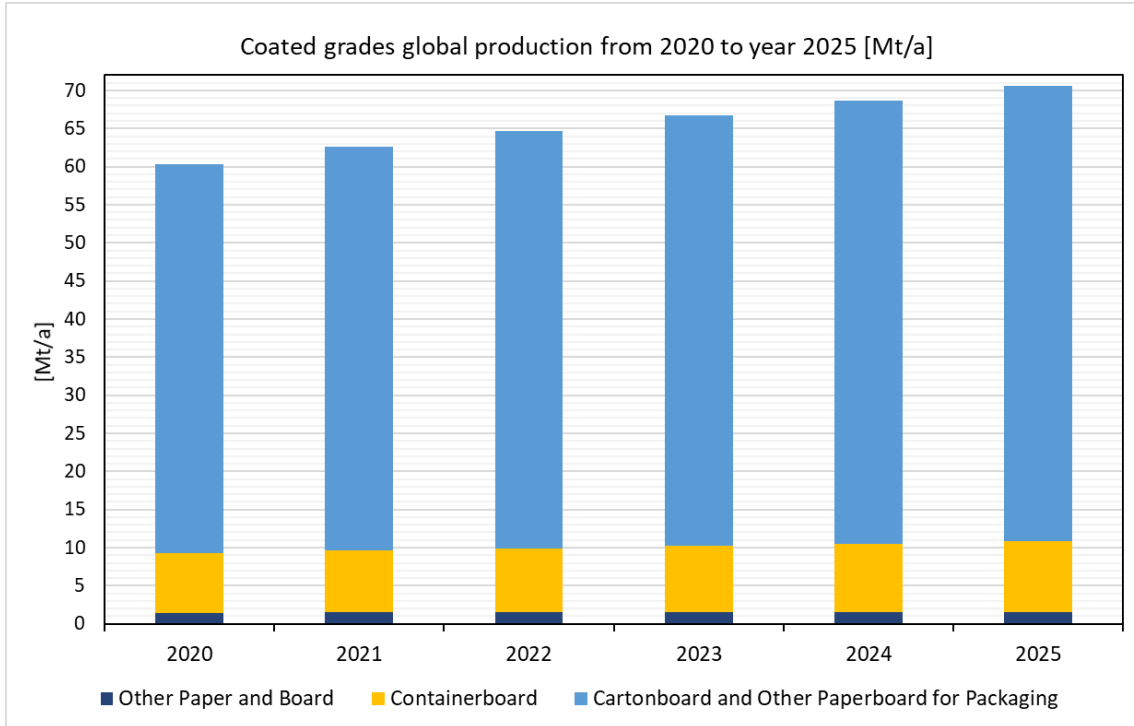


Figure 27. Coated grades estimated production from 2020 to 2025. (Valmet Internal analysis, 2021)

Table 8 presents the baseline year total CO₂ amount for coating drying heating energy consumption and target year 2025 estimated value based on linear reduction from 2020 to year 2025 of 20 % of CO₂ emissions.

Table 8. Gas and energy consumption kgCO₂/FMT factors.

Global	Baseline 2020 [kgCO ₂ /FMT]*	Estimated value in 2025 [kgCO ₂ /FMT]**
Gas	13.7	10.9
Energy	16.0	12.8

*Baseline is cumulative of production for different subgrades.

**Estimation is based on baseline and is assumed as 20 % linear CO₂ reduction from baseline 2020 to target year 2025 in scenario 2 calculations.

Scenario 1: BAU

In Business As Usual (BAU) scenario it is assumed that CO₂ emissions are proportionate to production which is assumed the same as on the baseline 2020 which is for gas consumption based emissions 13.7 kgCO₂/FMT and for coating drying heating energy

consumption 16.0 kgCO₂/FMT. Figure 28 presents global gas and heating energy consumption based coating drying CO₂ emissions. In total the gas consumption based emissions may increase by 2025 to the value of 965 kt/a and coating drying heating energy consumption based emissions to the value of 1.2 Mt/a. The total increasing amount of CO₂ emissions by coating drying heating energy consumption from 2020 to 2025 is 163 ktCO₂ which means 17 % increase of CO₂ emissions in coating drying heating energy consumption.

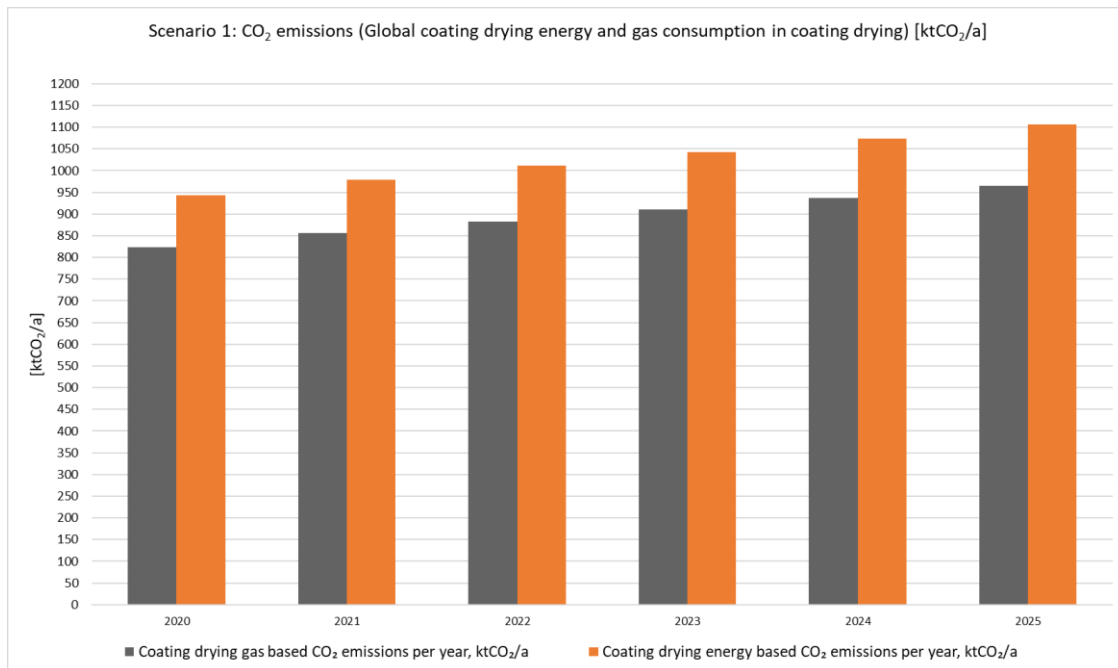


Figure 28. CO₂ emissions in coating drying by gas and coating drying energy consumption.

Scenario 2: 20 % improvement of energy efficiency

In scenario 2: 20% improvement of energy efficiency it is assumed that CO₂ emission reduction is 20 % until year 2025. CO₂ emissions can be reduced as 20 % by actions mentioned in chapter 4.1. Figure 29 describes the coating drying gas and coating drying heating energy consumption based CO₂ emission reduction in global area. Figure 29 describes the scenario 2.

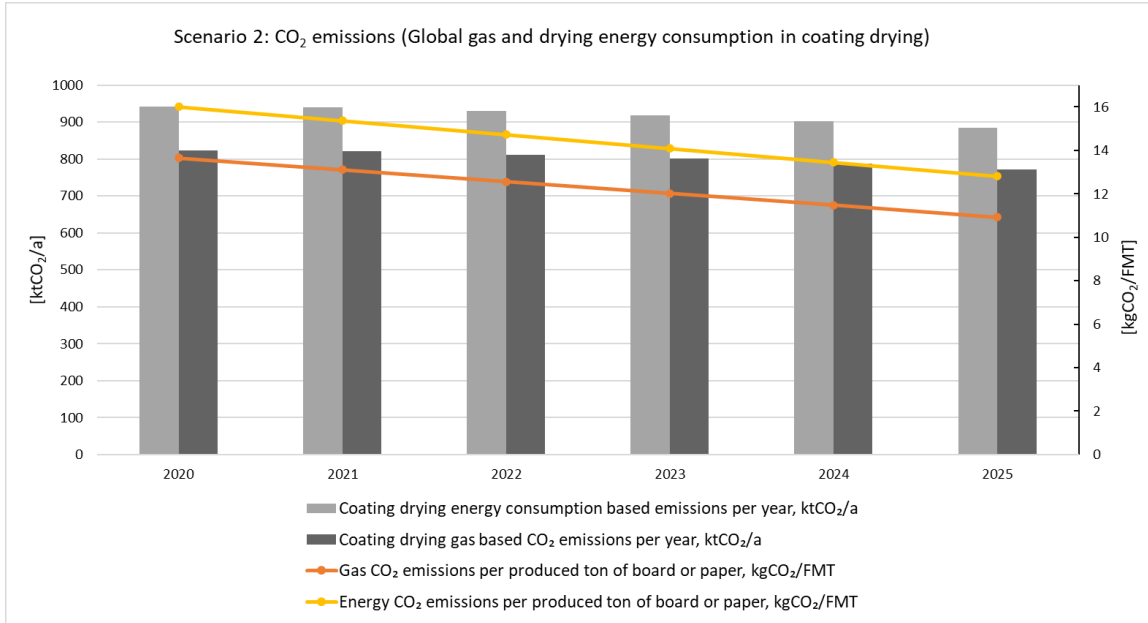


Figure 29. CO₂ emissions of gas and drying energy consumption in coating drying.

For gas consumption in coating drying based emissions, the reduction could be 13.7 kgCO₂/FMT to 10.9 kgCO₂/FMT and for coating drying energy consumption based emissions, the reduction could be 16 kgCO₂/FMT to 12.8 kgCO₂/FMT by 20% energy efficiency improvement until 2025.

3.4 Analysis

Average coating drying gas consumption and coating drying energy consumption based calculations results are shown in Table 9.

Table 9. CO₂ emissions in coating drying in 2020.

Area	Calculation	CO ₂ emissions in coating drying in 2020 [kgCO ₂ /FMT]	CO ₂ emissions in coating drying in 2020 [ktCO ₂ /a]
EU	Gas	13.4	141.3
	Energy*	16.8	186.7
Global	Gas	13.7	721.9
	Energy*	16.0	882.0

*Coating drying energy consumption calculations do not include the grade specialties & packaging papers.

Calculations of coating drying gas consumption and coating drying heating energy consumption were shown that CO₂ emissions in 2020 year were as cumulative to production as an average in global area by coating drying heating energy consumption: 882 ktCO₂/a, and in EU area 187 ktCO₂/a. The proportion of coating drying heating energy consumption CO₂ emissions by gas were 722 ktCO₂/a in globally, and in EU area 141 ktCO₂/a. If considering the values of CO₂ emissions by grades, by the coating drying gas consumption in EU area, CO₂ emissions were produced 13.4 kgCO₂/FMT, and by the coating drying energy consumption 16.8 kgCO₂/FMT. Globally by coating drying gas consumption, the CO₂ emissions were produced 13.7 kgCO₂/FMT and by coating drying heating energy consumption 16 kgCO₂/FMT.

There is a difference between EU and global area CO₂ emissions in coating drying per produced ton of board or paper. Coating drying energy consumption based emissions are as expected, higher than gas consumption based emissions because coating drying energy consumption include components which consumes gas (NG, LNG or LPG), steam or electricity. The coating drying gas consumption module is taking into account only the gas consumption in coating drying. Coating drying heating energy consumption calculations are considering the average specific energy, average coating color amount and average dry solids content per subgrades of board and papers as cumulative of production of each sub grade.

The results of coating drying heating energy consumption based CO₂ emission calculations can be compared to the emissions of other industries e.g. to the traffic emissions. In European area an average new car's CO₂ emissions are 122 gCO₂/km. Average car mileage per year in EU is 12 000 km/a. EU's target in 2021 is to set new cars limit as under 95 g CO₂/km (Odyssee-Mure 2021; Statista 2020). Total coating drying heating energy consumption CO₂ emissions in EU area (186,7 ktCO₂/a) can be shown as 127 527 pieces of new cars' annual CO₂ emissions:

$$\frac{\text{Total CO}_2 \text{ emissions in coating drying in EU area } \frac{t\text{CO}_2}{a}}{\text{average CO}_2 \text{ emissions of cars in EU} \cdot 10^{-6} \frac{t\text{CO}_2}{\text{km}} \cdot \text{average mileage of cars in EU} \frac{\text{km}}{a}}$$

$$\frac{186\,700 \frac{t\text{CO}_2}{a}}{122 \cdot 10^{-6} \frac{t\text{CO}_2}{\text{km}} \cdot 12\,000 \frac{\text{km}}{a}} = 127\,527 \text{ pieces of average EU cars annual CO}_2 \text{ emissions.}$$

If calculating the amount by new limit by 95 gCO₂/km of new EU car, the amount is 163 771 pieces of EU cars annual CO₂ emissions.

If considering the varying variables for CO₂ emissions, it can be demonstrated as the best technology calculation and worst technology calculation from year 2020. The best technology describes a limit value where is assumed that technology is the most energy efficient – Specific energy in coating drying is in minimum limit value as 4 500 kJ/kgH₂O and coating color dry solids content is in maximum limit value. In the worst technology calculation – the specific energy is in maximum limit value as 6500 kJ/kgH₂O and coating color dry solids content is in minimum limit value. Actual values in coating drying are not in limit values of specific energy or coating color dry solids. (Valmet internal, 2021)

EU area calculations by limit values and average, the energy consumption in coating drying by average is not in the middle of the best and worst calculation. For grade FBB, the average is near the worst technology calculation. Figure 3 presents the average and limit values results of coating drying energy consumption.

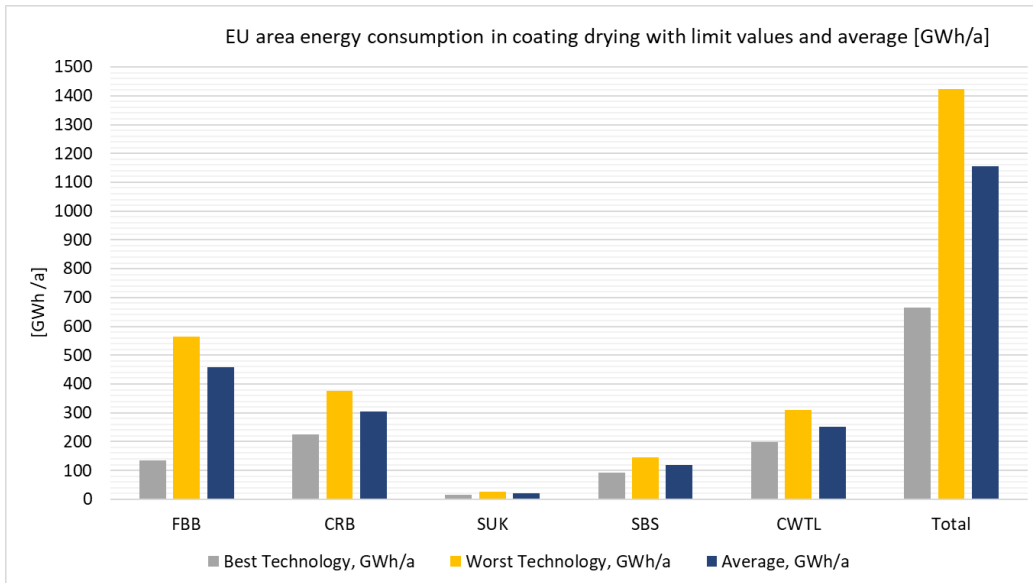


Figure 30. EU area drying energy consumption in coating drying with limit values and average.

The average values calculation result of CO₂ emissions in coating drying in EU area are somehow in the middle of the Best and Worst Technology, and for grade FBB the CO₂ emissions are as an average in the middle. The results of CO₂ emissions by limit values and averages are shown in Figure 31.

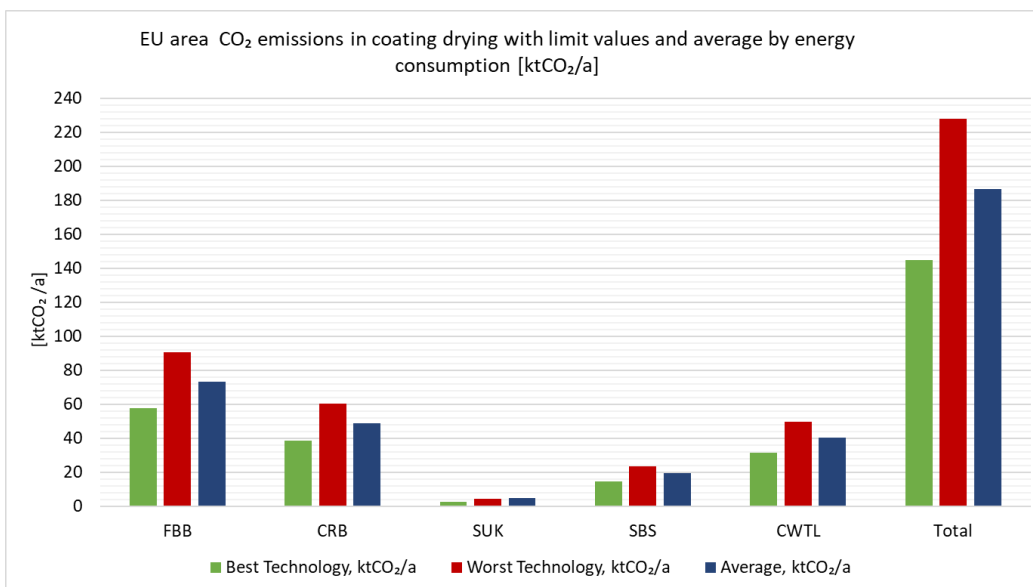


Figure 31. EU area CO₂ emissions in coating drying with limit values and average.

Global area calculations by limit values and average, the energy consumption in coating drying by average in the middle of the best and worst calculation. For grade FBB, the average is also in the middle of the best and worst technology calculation. Figure 32 presents the average and limit values results of energy consumption in coating drying in global area. The CO₂ emissions by average are in the middle of the best and worst technology which is presented in Figure 33. Comparing the EU values to global values, the grade FBB has larger proportion of energy based CO₂ emissions in EU than the proportion in global area emissions of maximum value of CO₂ emissions.

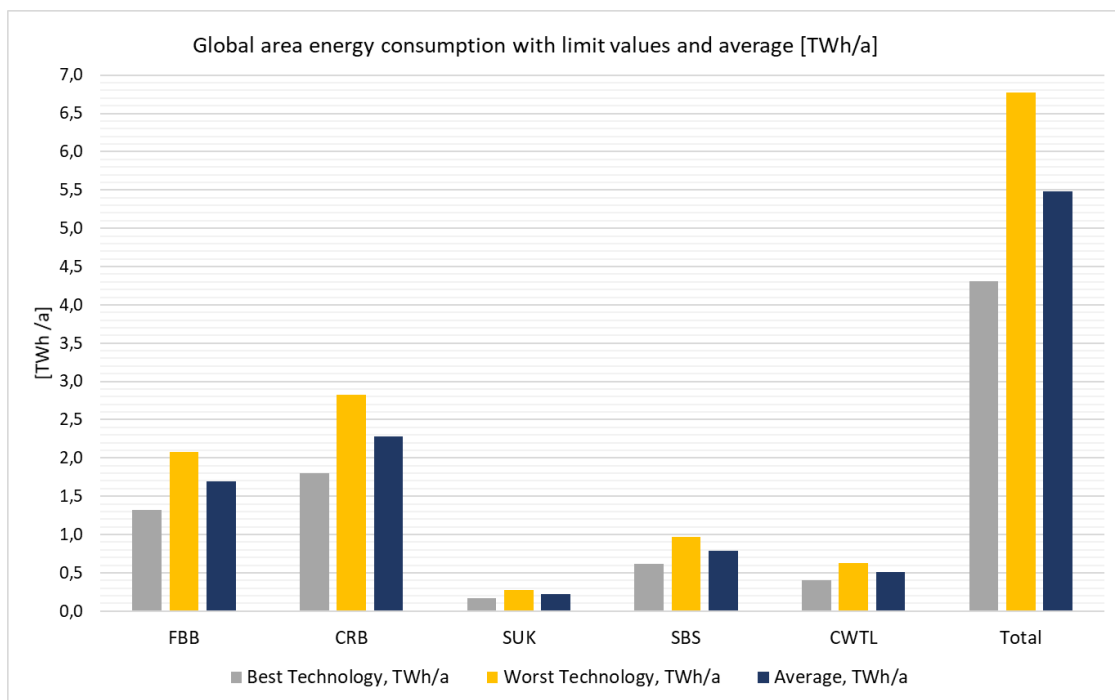


Figure 32. Global area coating drying energy consumption with limit values and average.

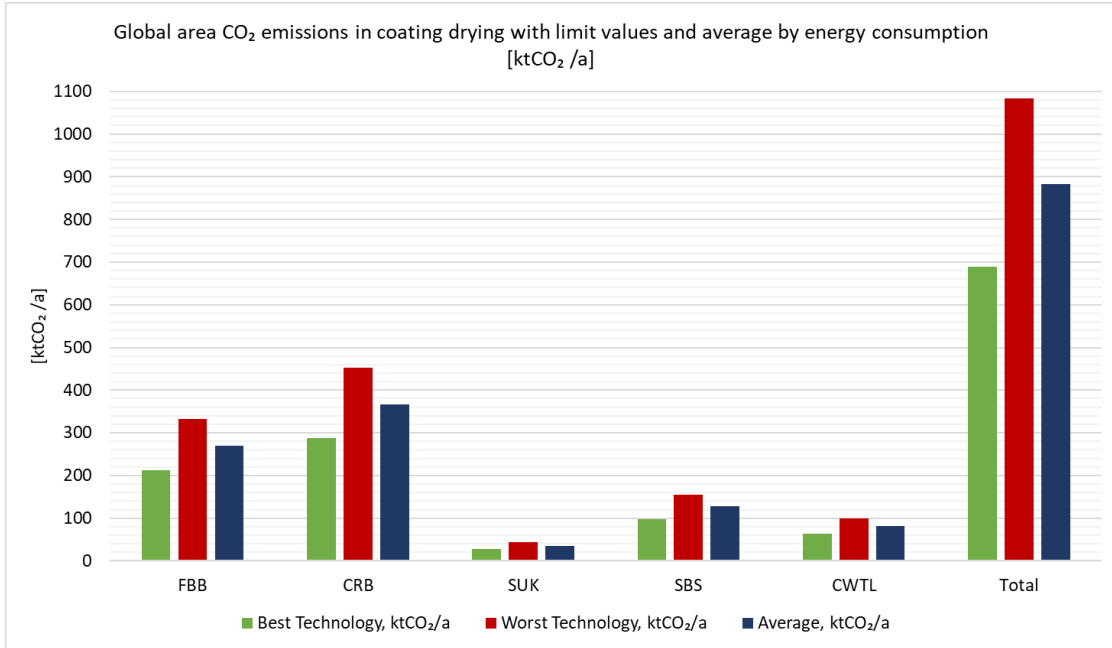


Figure 33. Global area coating drying energy based CO₂ emissions with limit values and averages.

The future scenarios of global CO₂ emissions in coating drying by total coating drying heating energy consumption in scenario 1: BAU shows that if the energy efficiency in coating drying is not increased, then the emissions will increase to value of 1.2 Mt/a which means 163 ktCO₂ increasing amount from baseline year 2020. This is 17 % increase compared to 2020 value of CO₂ emissions. In scenario 2: 20 % energy efficiency improvement by 2025 the CO₂ emissions of global coating drying by total coating drying energy consumption decreases to value of 885 ktCO₂/a. The energy efficiency increase of 20 % by 2025 year decreases the CO₂ emissions by 20 % which decreases one produced ton of cumulative of production by grades by coating drying heating energy consumption 3.2 kgCO₂/FMT until 2025 from value 16 kgCO₂/FMT to value 12.8 kgCO₂/FMT. Which means that CO₂ emissions of coating drying in 2025 will be approximately 26 % less than if improvements are not made to energy efficiency in coating drying by 2025.

4. Solutions to reduce CO₂ emissions in coating drying

Different solutions to reduce CO₂ emissions are to increase energy efficiency or to use fossil free heat resource for coating drying. Increasing energy efficiency will decrease energy usage and has a role in emission mitigation so as cost-effectiveness of board or paper mills (Kähkönen, Vakkilainen & Laukkanen, 2019; Valmet internal, 2021). Information and communications technology (ICT) may increase energy efficiency by optimization of processes. (CEPI, 2021b). Related to research and experimental cases by Valmet the coating drying energy efficiency can be improved by 20 percent by efficiency improvements of dryers. (Valmet internal, 2021)

4.1 Efficiency improvements

Energy consumption in coating drying can be decreased by different improvement solutions of air drying efficiency. (Valmet internal, 2021) One of the options to increase efficiency is to upgrade the IR dryer to an air dryer. Air dryers have better energy efficiency than IR dryers. IR dryer's typical energy efficiency is 25–35 %. Air dryer energy efficiency is 60–80 %. By comparing the Air drying to IR drying the energy efficiency can be increased by 50 % if changing the IR dryer to Air dryer. (Valmet internal, 2021) in Figure 34 there is demonstrated gas IR dryer energy consumption where 25–30 % of energy is transferred to heating the coating color and web.

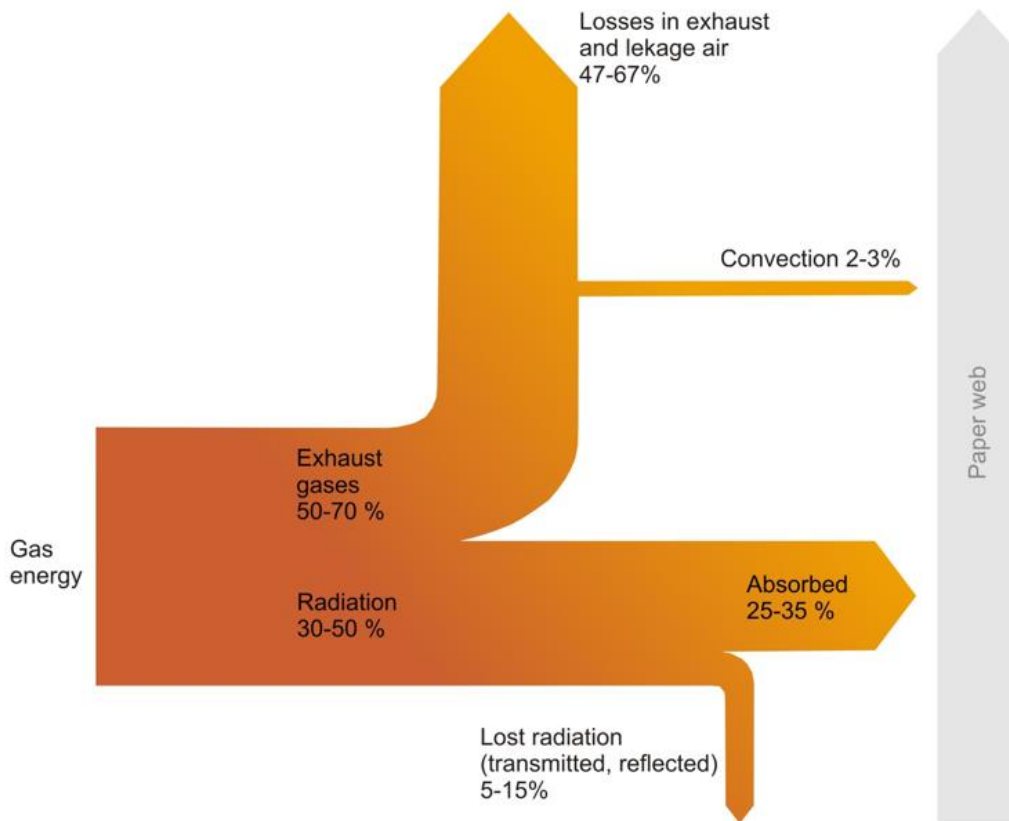


Figure 34. Gas IR dryer energy consumption. (Valmet internal source, 2021)

In addition of IR dryer change to air dryer there are a few parameters affecting to energy efficiency and drying capacity of air dryers:

- Impingement nozzles
- Nozzle to web distance
- Exhaust/Circulation ratio
- Exfiltrating air amount
- Adjustment of air system dampers
- Preheated supply air use

(Valmet internal, 2021; Paltakari, 2009: 574.)

Air dryer energy efficiency is described in figure 36. Air dryer's energy economy benefit is that 80–90 % of impingement air can be circulated back to dryer, 10–20% of air to exhaust. (Paltakari, 2009: 567.) Figure 35 describes the air dryer which is equipped by

nozzle type b, which has the most effective heat transfer coefficient which can be seen in figure 37.

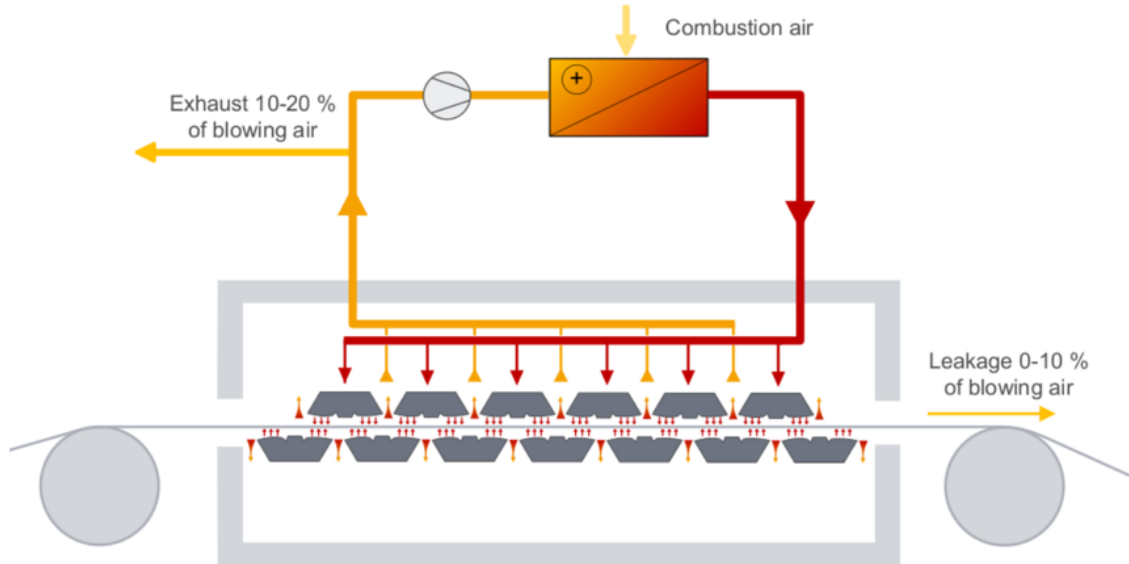


Figure 35. Air dryer energy efficiency. (Valmet internal source, 2021)

The first nozzle in 1960's in use was single-slot airfoil nozzle (c in the figure 36). The air is flowing direct to the channel between nozzle and web. Next development of nozzle was nozzle with two impingement slots on the sides of nozzle frame. After the single-slot airfoil nozzle came the overpressure nozzle (a in the figure 36). (b in the figure 36) has 25–30 % higher heat transfer than previous nozzle type with two impingement slots (a in the figure 36). (Paltakari, 2009: 570–571.)

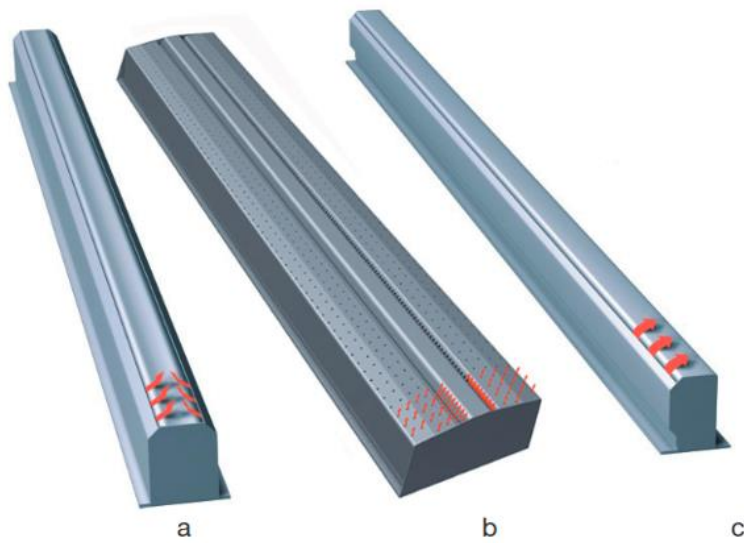


Figure 36. Impingement nozzles. (Elaborated from Paltakari, 2009: 570.)

Parameters affecting the heat transfer coefficient [$\text{W}/\text{m}^2\text{°C}$] of air dryers are:

- nozzle type
- nozzle spacing
- impingement slot width
- nozzle-to-web distance
- impingement velocity
- impingement temperature.

(Paltakari, 2009: 572.)

The Figure 37 presents the nozzles relative heat transfer coefficient by nozzle-to-web distance function. (Valmet, 2012)

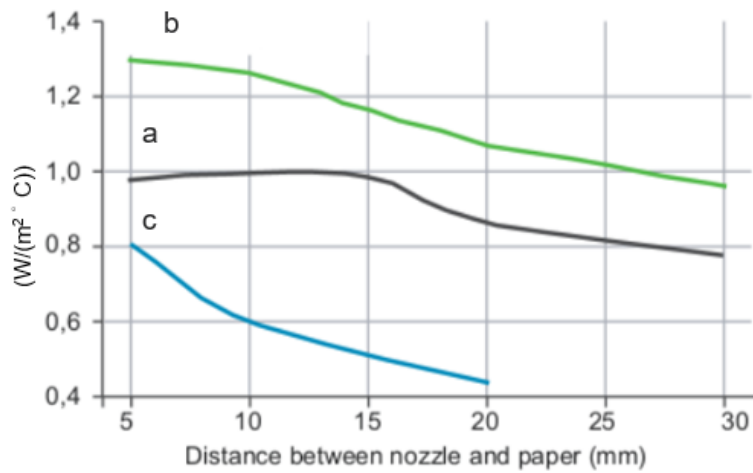


Figure 37. Relative heat transfer coefficient [$\text{W}/(\text{C})$] in air dryers by nozzle types a, b and c as a function of distance to web [mm]. (Elaborated from Valmet, 2012)

Upgrading nozzle type c to nozzle type b, the drying capacity can be increased by 50 %. Upgrading nozzle type a to nozzle type b, there can be increased 20 % of drying capacity. (Valmet 2021c). The difference between nozzle b compared to nozzle a heat transfer surface is shown in figure 38.

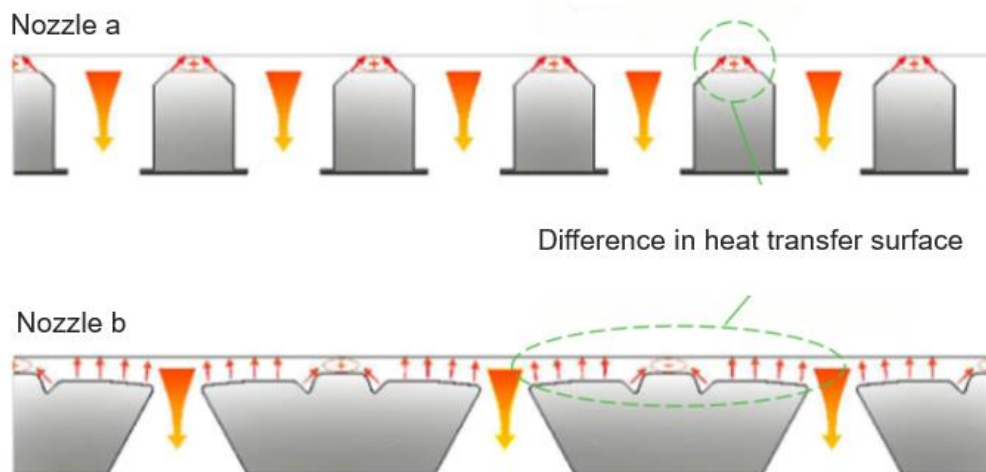


Figure 38. Differences between nozzle a and nozzle b heat transfer surfaces (Elaborated from Valmet internal source, 2021)

Exhaust/circulation ratio describes the exhaust impingement air to circulation to be used for heat recovery. (Paltakari 2009: 574.) Figure 39 presents the specific energy q [kJ/kgH₂O] as a function of exhaust/circulation ratio [%] and the impingement temperature [°C] as a function of exhaust/circulation ratio [%]. Specific energy q can be improved by efficiency improvements by Valmet. (Valmet internal, 2021)

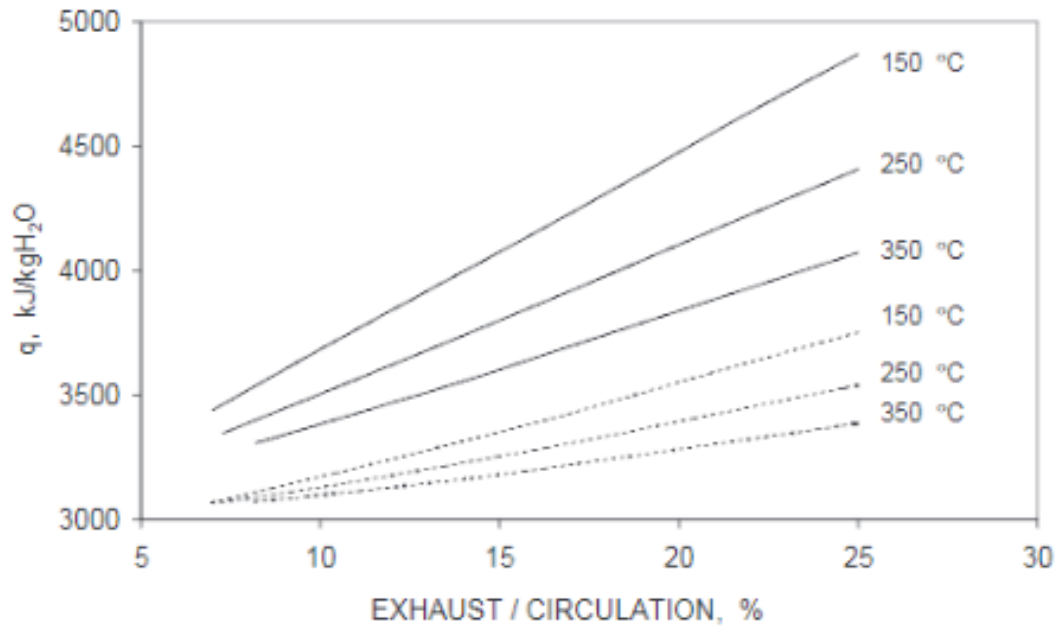


Figure 39. Specific energy consumption q [kJ/kgH₂O] in the function of Exhaust/Circulation ratio and impingement temperature [°C] in the function of Exhaust/circulation ratio [%]. (Paltakari, 2009: 574.)

Heat recovery system is shown in figure 40 where incoming cold air is pre-heated by heat taken from exhaust air of air dryer. Combustion air is led through the heat recovery system where it takes heat from hot exhaust air flow. (Valmet internal, 2021)

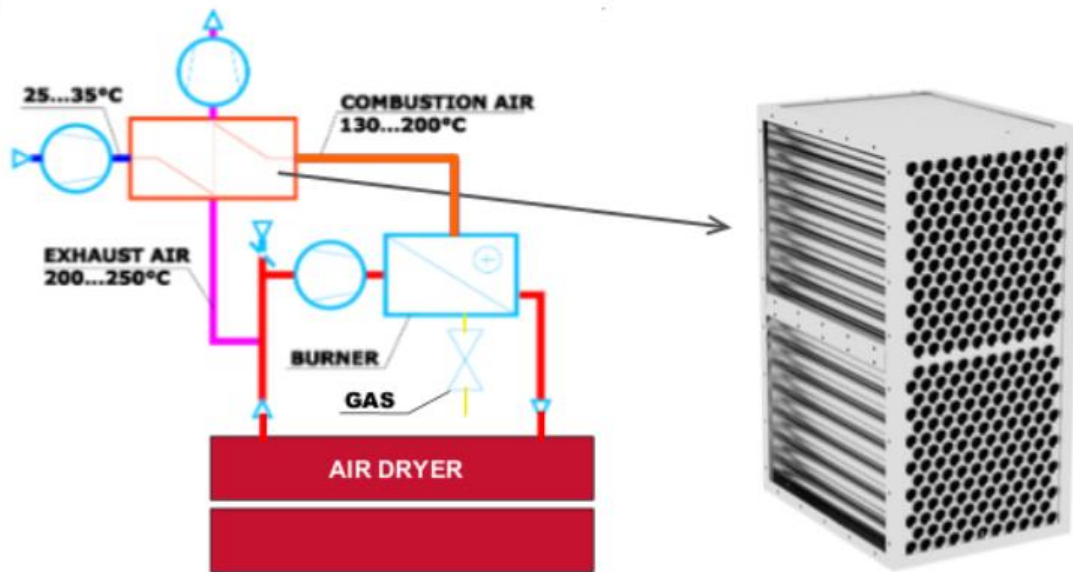


Figure 40. Heat recovery system for air dryers by heat exchanger. (Valmet internal, 2021)

Drying optimization optimizes energy consumption of dryers and quality of end product. Drying optimization describes drying strategy change or optimization of capacities of dryers. The product quality requirements have a significant role in drying strategy. Drying strategy can be e.g. High-High-Low per one layer coating color drying. High-High-Low strategy describes the coating drying strategy which is chosen as two high and quick evaporation level dryers at the first phases of drying and in the last phase of coating drying there are less evaporation dryers. High-High-Low strategy is shown in Figure 41. The IR dryers can be changed as air dryers. Drying strategy is chosen by considering of product quality and energy consumption. (Paltakari, 2009: 596.) Figure 41 presents the evaporation rate $\left[\frac{\text{kg}}{\text{m}^2\text{h}}\right]$ of coating dryers in the function of web velocity.

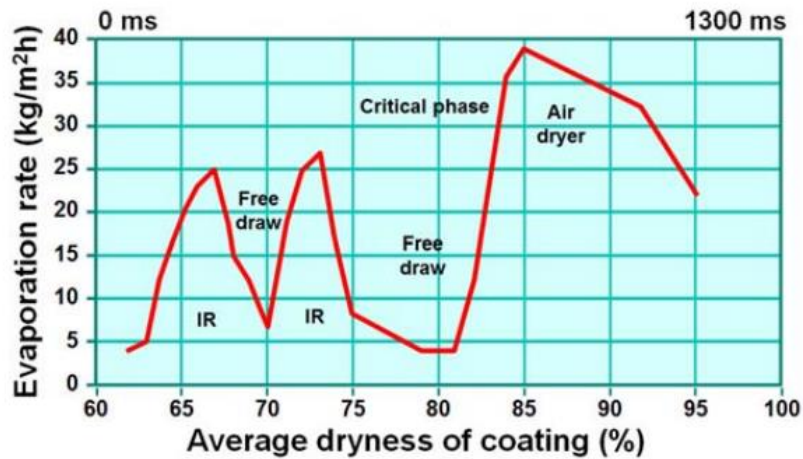


Figure 41. High-High-low strategy. (Valmet, 2012a)

4.2 Alternative heat resources

If considering the option to change the fossil fuel to less CO₂ emissions producing fuel based heating there are some options already. Electrification has a significant role in the future in emissions mitigation and adaptation. (Cepi, 2021b) The increasing electrification will affect the board and paper mills electricity systems. (Lipiäinen & Vakkilainen, 2021) The heat resource as gas can be replaced also by steam or electricity (Valmet internal, 2021).

CEPI lists a few technologies to replace natural gas in pulp and paper industry:

- Renewable and low carbon gases
- Hydrogen blends
- Biogas
- Biomethane
- Electricity.

(CEPI, 2021)

Electrification and increasing amount of renewable electricity generation could reduce CO₂ emissions in coating drying. The electricity which is produced totally by renewable resource has an emission factor which is 0 kgCO₂e/MWh. (Appendix 5).

Electrical duct heater is one option to achieve needed properties for coating drying. Heaters can be used e.g. drying air or drying make-up air. Duct heater can be used in industry properties. Installed heating power can be over 1 MW and temperatures needed to heat the air can be high. Parameters to consider for duct heater dimensioning are temperature needed for heating, air pressure, volume, velocity of air flow and installed power. (Mayer-Vastus, 2021; Tempco, 2021; Wattco, 2021) Impingement temperature needed in gas heated dryers are 300–400 °C. The velocity of impingement in air dryer is typically 40–60 m/s. (Paltakari, 2009: 567).



Figure 42. Duct heaters. (Mayer-Vastus, 2021)

Electric boilers by renewable energy resources could be one option to generate steam for cylinders instead of fossil fuel based boiler combustion and achieve CO₂ reduction. (Rahnama, Santos Silva & Kienberger, 2021)

4.3 Future solutions

There are already technological solutions to replace fossil fuels e.g. NG by renewable gases in use. Hydrogen and biogas have potential for replacing natural gas in EU area in

the future. (Euractiv, 2021b) Biomass is not available in non-integrated mills and in mills which are using recycled fiber as a raw material. NG seems to be popular in mentioned mills. Options to decarbonization are producing heat by heat pumps, solar thermal energy or biogas. Temperature requirements for coating drying can be too high for best available heat pump technology but heat pumps can be used as a part of wider circulation to heat lower temperature processes by exhaust air from coating dryers. Alternative fuels in paper and board industry needs setting and targets for alternative fuel use. (IEA 2021) Hydrogen has been mentioned as a possible solution to replace natural gas and reduce CO₂ emissions in paper industry. (Rahnama et al., 2021)

Solar cell technology has been studied to dry different products. One mentioned application to use solar radiation is for paper drying without transferring the solar energy to electricity but only use the heat of solar radiation to drying. As seen on figure 43 the solar cells are collecting the heat radiation where heat is collected to thermal storage tank and heat exchanger and in the end used to drying. In the study of solar cell radiation, there has been showed that the temperature of drying by solar radiation can be 30–200 °C. (Lingayat, Balijepalli & Chandramohan, 2021)

The disadvantage of solar drying is that the process might be too slow. The time when the paper dried was 10 minutes. The velocity of web in board or paper machine is typically over 1000 m/min (Knowpap, 2021). By using solar cells as a part of hybrid system there could achieved more efficient process of drying. (Lingayat et al., 2021)

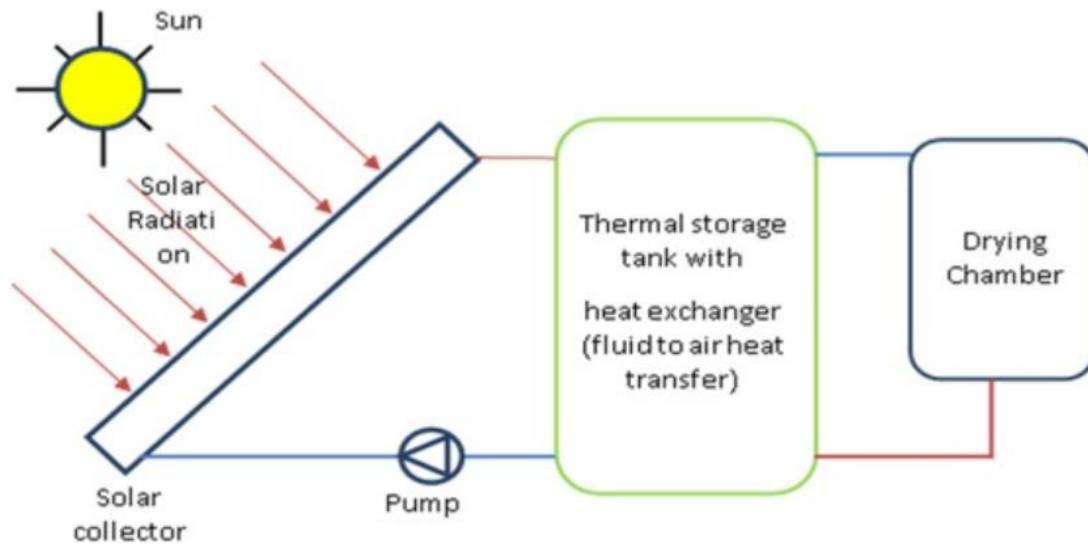


Figure 43. Solar drying principle (Lingayat et al., 2021)

Natural gas Co-Firing with biomass has been studied. Co-Firing has an effect to reduce CO₂ emissions if there is burned natural gas with other gas which has lower CO₂ emission factor. There has been made five experimental test runs with prototype burner where increased the proportion of wood dust to natural gas. Wood dust and saw dust are waste-products in forest industry. Experimental runs show that burning only natural gas, the CO₂ generation is 0.198 tCO₂/h. When there is added more biomass to the mixture, the CO₂ generation is getting lower linearly. Last experimental run is burned with 100% biomass which has CO₂ generation of 0 tCO₂/h because the biomass is considered as renewable resource. Maximum installed power of prototype burner is 20 MW. The advantage of co-firing is that existing boilers could be retrofitted to be applicable for biomass burners. (Klose, Vigants & Vigants, 2020)

Blending hydrogen with natural gas could be an option in the future technologies for combustion. Blending hydrogen in natural gas network is technology which is not familiar, and there is no research what the effects on devices and materials in long term are. (Energy Post, 2020) In 2018 year's research by Ogden, Myers, Scheitrum, McDonald & Miller there has been mentioned it is more feasible that biogas will be used than hydrogen is used for industry use e.g power to gas. For the transportation sector, hydrogen

could be an option in the short term but for industries it is unlikely even in long-term. (Ogden, Myers, Scheitrum, McDonald & Miller, 2018.) Considering the virgin-integrated board or paper mill, the biogas can't be produced from wood and other lignin rich materials. Cellulose is applicable for digestion of biogas. Biomethane can be produced from wood by thermal gasification. (Finnish Biocycle and Biogas Association, 2021)

5. EU Climate strategies and regulations for CO₂ reduction

The EU has settled different regulations and targets for climate change mitigation and adaptation. 2030 target is to cut GHG emissions by 55% by comparing emissions to 1990-year level until year 2030. (European Union, 2021a) 2050 target is to have zero net GHG emissions. (European Union, 2021b) The law which included the targets of 2030 and 2050 GHG reduction is called European Climate law. European climate law's background is from the European Green deal which introduced in 2019. The European green deal target is to make Europe the first climate-neutral region in the world by 2050. (European Commission, 2019). Figure 44 presents the elements of the European Green Deal.

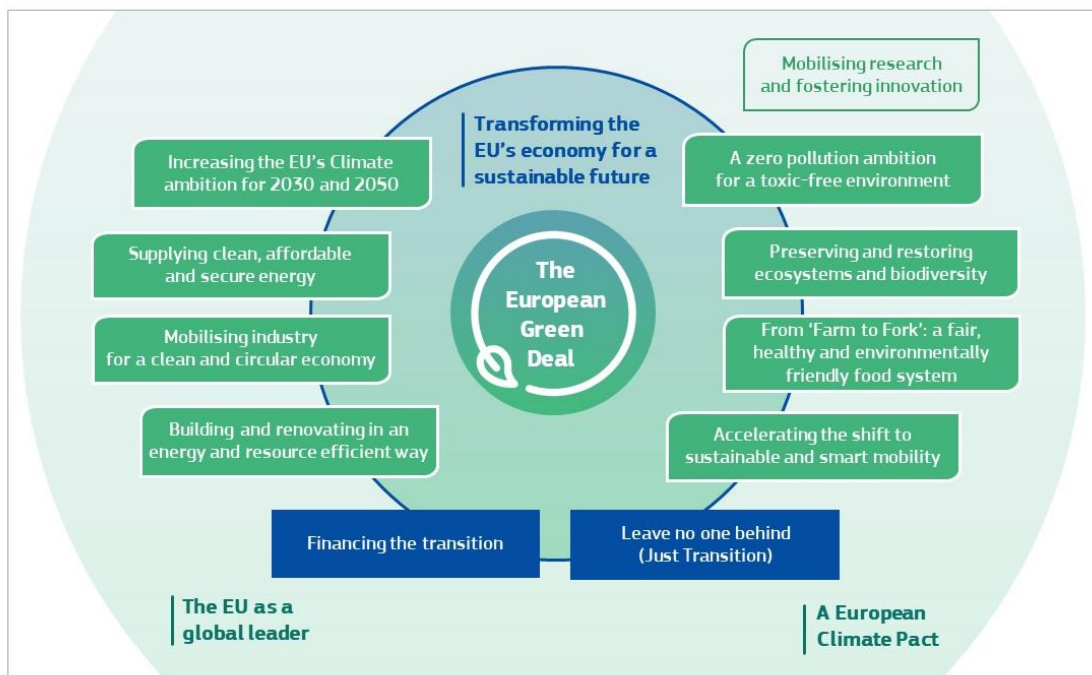


Figure 44. The European Green deal. (European Commission, 2019)

5.1 Targets

In July 2021 The European Commission published a package of new proposals related to GHG reduction. The package is called “Fit for 55”. The proposal includes upgrades of all primary objectives of EU climate regulations such as EU Emissions Trading System (ETS), renewable energy directive (RED 3), energy efficiency directive (EED) and as a new mechanism there is introduced carbon border adjustment mechanism (CBAM). (European Union, 2021c; Finnish Government, 2021). Industrial emissions directive (IED) is not included to “fit for 55” package. (Valmet internal, 2021)

Paris Agreement is the first climate agreement which was committed in December 2015. In 2015 the aim was to settle climate temperature to increase less than 2 °C. (European Union, 2021f) The history of the new climate package “Fit for 55” is from year 2019 when the Commission introduced the European Green Deal. In 2020 there was introduced the targets of 2030 to meet the Paris Agreement law’s goals. (European Union, 2021c) Paris Agreement law’s aim is to limit the global warming to increase 1,5 °C and to keep a long-term global average temperature increasing below 2 °C. The EU has had a leading role internationally related to GHG emission reduction strategies. (European Union, 2021f) Paris agreement law has 191 parties. (United Nations Framework Convention on Climate Change, 2021) The Paris Agreement is reviewed every five years. The next review of Paris agreement will be performed in year 2023. (Ministry of the Environment, 2021)

Greenhouse gas protocol standard splits CO₂ emissions as three scopes. Scope 1 emissions are direct emissions where CO₂ emissions only comes from the activities of organization or under their control e.g. fuel combustion. (Compare your footprint, 2018) Scope 2 emissions are from electricity purchased and used by the organization. Emissions are created during the production of the energy or used by the organization. Scope 2 emissions can be called as location-based emissions. Scope 3 indirect emissions can be called as market-based emissions. GHG protocol is the most used accounting tool for calculating GHG emissions. (European Commission, 2021a; European Court of Auditors, 2014: 9.)

Coating drying energy consumption based GHG emissions can be calculated by scope 1 and scope 2 emissions. It is assumed that the GHG emissions are coming only from energy consumption of primary energy used for coating drying purpose from burning process of gases, from steam generation and for purchased electricity. Burning of gases and steam generation are scope 1 emissions. Purchased electricity is calculated as scope 2 emissions. (See Appendix 9.)

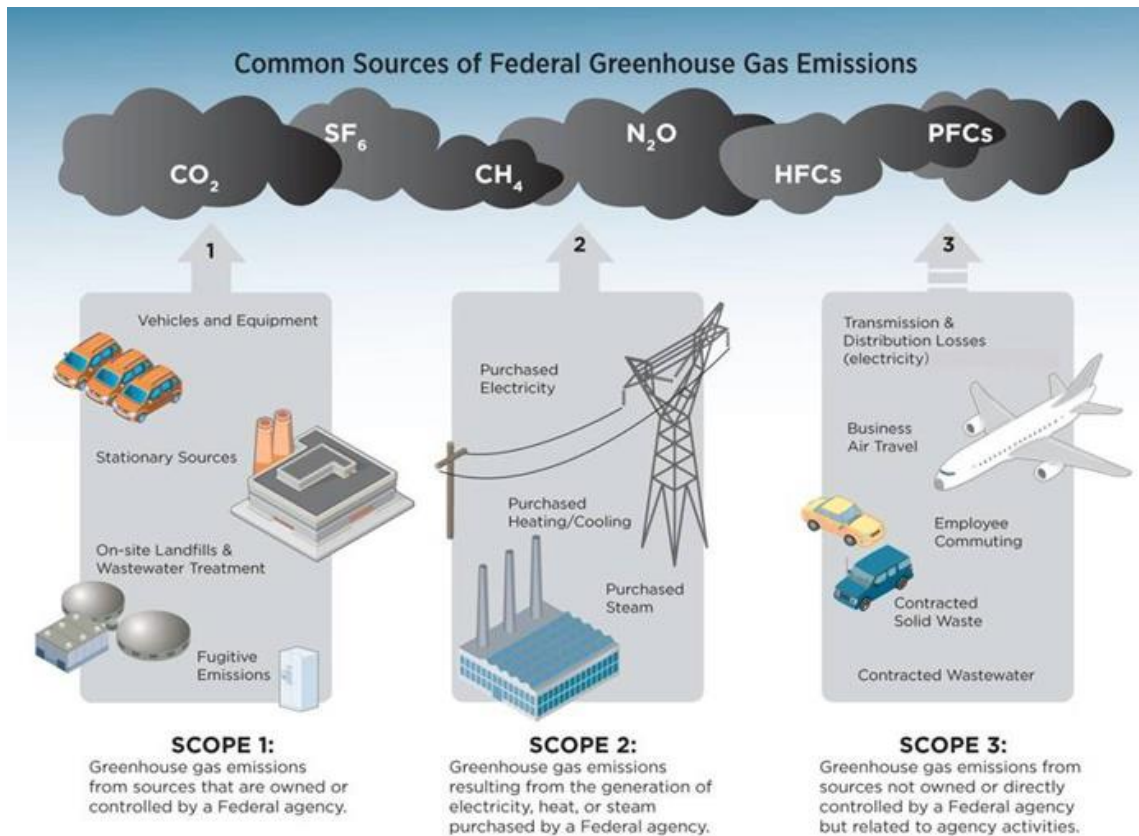


Figure 45. Three scopes of emissions by GHG protocol. (United States Environmental Protection Agency, 2021)

5.2 Finance

Some of the actions listed under The European Green Deal are the new technologies and innovations in EU. Horizon of Europe will finance research and innovations for 95.5 billion euros in 2021–2027. (Business Finland, 2021a). Horizon of Europe is a part of the European Green Deal programme. (European Commission, 2019) Criteria for Horizon of

Europe finance evaluating were in 2020: excellence (scientific and quality of innovation), impressiveness and project implementation (Business Finland, 2021b). There are different budgets for different types of projects. For research and innovation actions of new technology or information has the largest amount of budget. There is also mentioned finance called “innovation actions” for new or better services or products. (Business Finland, 2021c) Horizon of Europe program is divided to four pillars: Excellent science, Global Challenges and European Industrial Competitiveness, Innovative Europe, Widening participation & strengthening The European research area. 35% of Horizon of Europe will be allocated to climate objectives. 70% of the fund is allocated to small or medium enterprises. The Pillar called Global challenges and European Industrial Competitiveness include seven components where for climate, energy and mobility will be shared 15.1 billion euros. (European Union, 2021r) The budget share of Horizon Europe is presented in Figure 46.





HORIZON EUROPE BUDGET		Total
Horizon Europe programme structure		<i>in € million</i>
	EXCELLENT SCIENCE <i>of which</i>	25 011
	The European Research Council (ERC)	16 004
	Marie Skłodowska-Curie Actions (MSCA)	6 602
	Research infrastructures	2 406
	GLOBAL CHALLENGES AND EUROPEAN INDUSTRIAL COMPETITIVENESS <i>of which</i>	53 516
	Health	8 246
	Culture, creativity and inclusive society	2 280
	Civil Security for Society	1 596
	Digital, Industry and Space	15 349
	Climate, Energy and Mobility	15 123
	Food, Bioeconomy, Natural Resources, Agriculture and Environment	8 952
Non-nuclear direct actions of the Joint Research Centre (JRC)	1 970	
	INNOVATIVE EUROPE <i>of which</i>	13 597
	European Innovation Council (EIC)	10 105
	European innovation ecosystems	527
	European Institute of Innovation and Technology (EIT)	2 965
	WIDENING PARTICIPATION & STRENGTHENING THE EUROPEAN RESEARCH AREA <i>of which</i>	3 393
	Widening participation and spreading excellence	2 955
	Reforming and enhancing the European R&I System	438
TOTAL HORIZON EUROPE		95 517

Figure 46. Horizon of Europe budget share. (European Union, 2021r)

As a part of the EU ETS phase 4 revision there is mentioned funding to low-carbon innovation and energy sector modernization to help energy-intensive industrial sectors and power sector to support the future of low-carbon economy (European Union, 2021i). Board and paper industry is an energy-intensive industry (Bajpaj, 2016). The fund as a part of the EU ETS phase 4 is divided into innovation fund and modernisation fund (European Union, 2021i). The Innovation fund is a part of the NER300 programme which is supporting 20 billion euros in 2020–2030 for innovations in low-carbon technologies in energy intensive industries within the EU commercial area. (European Union, 2021j). The Innovation fund supports low-carbon technologies in energy intensive industries, carbon capture and utilization (CCU), Carbon Capture and Storage (CCS), innovative renewable energy generation and energy storage. Figure 47 demonstrates the innovation fund principle. (European Union, 2021k)

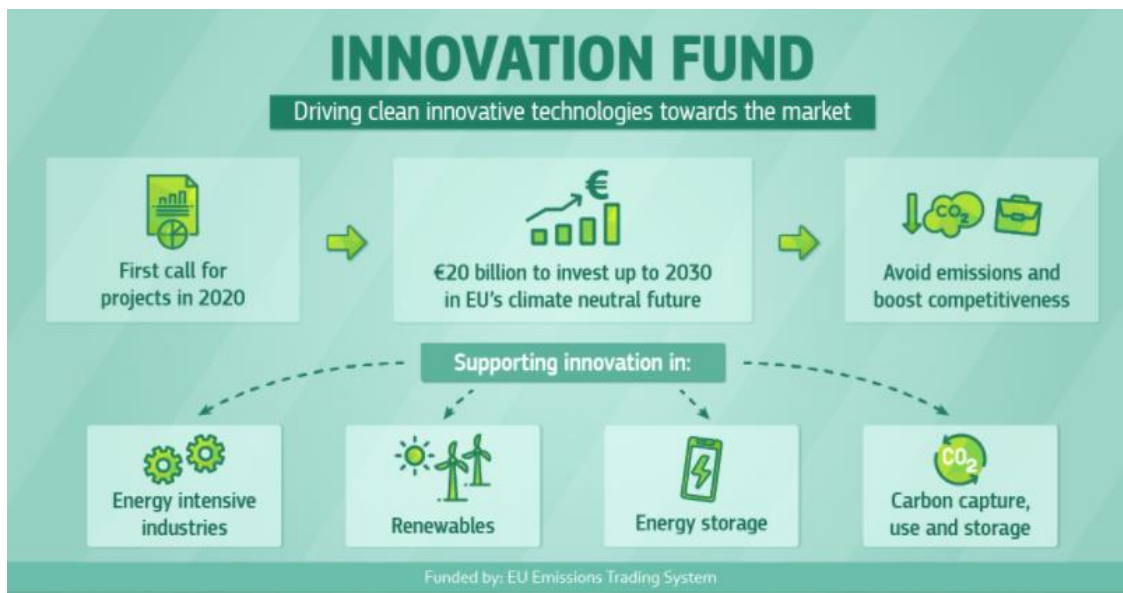


Figure 47. Innovation fund (European Union, 2021k)

The Modernisation fund is targeted to support 10 lower-income member states for transition to climate neutrality by improving the energy efficiency and modernize energy systems. (European Commission, 2021g) The member states included in the modernisation fund are listed in Figure 48.

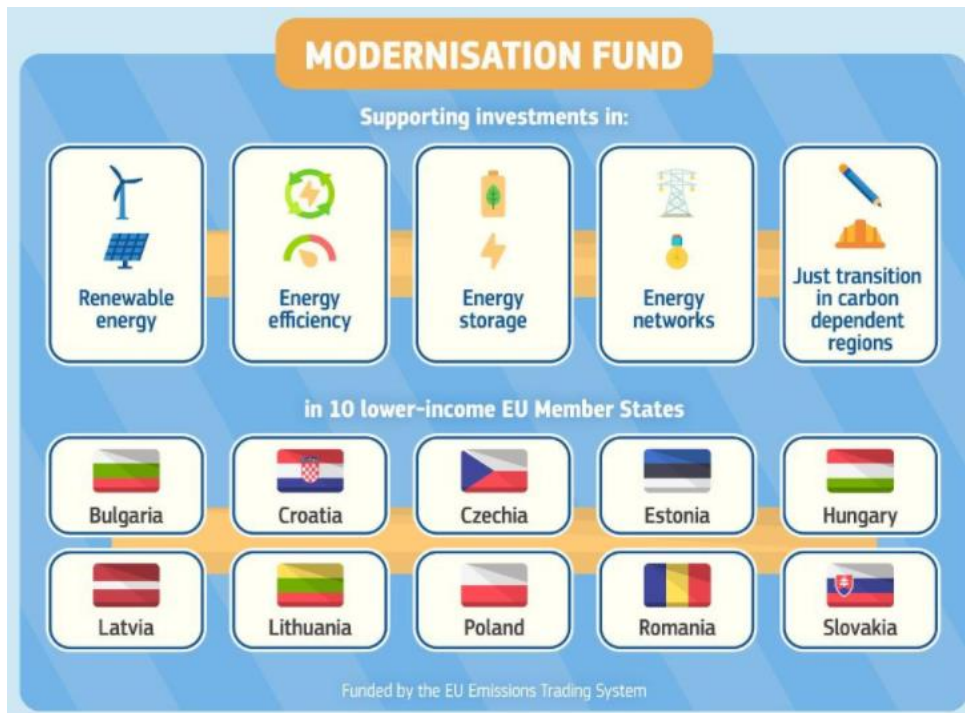


Figure 48. Modernisation fund. (European Commission, 2021g)

LIFE Funding is targeted usually to new technologies, practices, pilots and demonstrations (EU Funding Advisory, 2021). LIFE Funding will share 5.4 billion euros in 2021–2027 for investments in:

- Nature and biodiversity
- Circular economy and quality of life
- Climate change mitigation and adaptation
- Clean energy transition.

(European Commission, 2021h)

One of the EU funds is called InvestEU which is targeted to small and medium sized companies to support sustainable infrastructure, research, innovation and digitalization and social investment and skills. InvestEU will start 400 billion of euros of investments by loans, loan guarantees and by capital investments. (Härmälä, Roiha, Salminen, Halme, Kettinen, Ali-Yrkkö, Pajarinen & Ylhäinen, 2021). Summary of different EU fundings is presented in Table 10.

Table 10. Summary of EU Funds. (Elaborated from Business Finland, 2021a; Business Finland, 2021b; Business Finland, 2021c; European Commission, 2021g; European Commission, 2021h; European Union, 2021i; European Union, 2021j; European Union, 2021k; European Union, 2021r; Härmälä et al., 2021)

Fund	Budget [€]	Target group	Timeline [years]
Horizon of Europe	95 billion	Research and innovation. 35 % of budget is shared to climate objectives.	2021–2027
Innovation Fund	20 billion	Low-carbon technologies in energy intensive industries, carbon capture and utilization (CCU), carbon capture and storage (CCS), innovative renewable energy generation and energy storage	2020–2030
Modernisation Fund	14 billion	10 lower-income member states of EU for transition to climate neutrality by improving the energy efficiency and modernize energy systems	2021–2030
LIFE-program	5.4 billion	Nature and biodiversity, Circular economy and quality of life, Climate change mitigation and adaptation & Clean energy transition	2021–2027
InvestEU	400 billion by loans, guarantees for loans and capital investments	For small and medium sized companies to support sustainable infrastructure, research, innovation and digitalization and social investment and skills	2021–2027

5.3 Directives (RED, EED, IED, ETD & Gas directive)

Renewable energy directive (RED) was established first time in 2009 by European Commission (European Union, 2021g). There were settled target of 20 % share of energy from renewable resources of final consumption by 2020 in EU (European Union, 2009). Later the RED revised in 2018 to get the targets of 2030 of cutting emissions at least 40 % by 1990 levels to 2030 year and to keep the EU as global leader in renewables. The target

by 2030 was to have the 32 % renewable energy resources of final consumption in EU (European Union, 2018; European Union, 2021g). In 2009 established RED is called RED 1 and 2018 reviewed RED is called RED 2. The new proposal of revision in 2021 for the RED is so called "RED 3". (European Union, 2021g). The target mentioned in proposal for "RED 3" is to have at least 40 % renewable energy share of final energy consumption in EU by 2030 (European Commission, 2021b).

Proposal of the "RED 3" was established in July 2021 to support new climate package "Fit for 55". Proposal's aim is to reduce EU's energy dependency and to be involved in the technological and industrial leadership to create jobs and economic growth in EU. In proposal, there are mentioned energy taxation directive (ETD) and alternative fuel directive as well as fuel quality directive revisions. Natural gas is mentioned for traffic use to increase the refueling points and in the future for hydrogen. Industry heating and cooling covers 25 % of total energy consumption in the EU. 91% of industries' heating and cooling is implemented by fossil fuels. It is important that investment decisions are supporting the future targets even after year 2030. Industries need to switch production as renewable energy resource based and are not only fueled with renewable energy - they need to use renewables also as raw materials. Hydrogen is mentioned as an example solution for future. (European Commission, 2021b)

First, the energy efficiency directive (EED) was established in 2012 to reach goal of 20 % energy saving of EU's primary energy consumption by 2020 and making energy efficiency improvements after year 2020. (2012/27/EU). In 2018 the EED's target settled as 32,5 % energy consumption reduction by 2030 to meet the Paris agreement law's goals published in 2015 (2018/2002/EU). A new proposal includes EU primary energy consumption reduction to be 39 % and final energy consumption reduction of 36 % by 2030. New EED is focusing on sectors with high energy-saving potential. The aim is to increase energy efficiency especially in heating and cooling, industries, and energy services. (European Parliament, 2021) EED will ensure more effective interlinks and synergies with

other EU policies. There are several interlinks to other directives e.g RED and pricing measures like EU ETS and Energy Taxation directive (ETD). (European Parliament, 2021)

For heating and cooling EED has linked to RED because both need the strategy of Energy Sector Integration. EED was revised as well to ensure new 2030 targets of 55 % GHG reduction (European Union 2021h). Heating and cooling is mentioned as one of the focus area in RED 3 and new EED. Heating and cooling should be improved by waste heat recovery and by other technologies for rising energy efficiency. (European Commission, 2021c). In 2021 proposal of EED: 2012/27/EU, the abbreviation of heating and cooling can be described as coating drying process by mentioned way:

Proposal of EED 2012/27/EU, Article 2, p. 75 (European Commission, 2021c)

“efficient heating and cooling’ means a heating and cooling option that, compared to a baseline scenario reflecting a business-as-usual situation, measurably reduces the input of primary energy needed to supply one unit of delivered energy within a relevant system boundary in a cost-effective way, as assessed in the cost-benefit analysis referred to in this Directive, taking into account the energy required for extraction, conversion, transport and distribution.”

In the proposal of EED 2012/27/EU, the energy efficient first principle is mentioned. Energy efficiency improvement of coating drying can be shown by following proposal of EED 2012/27/EU, Article 3(1), p. 76 (European Commission, 2021c)

“1. In conformity with the energy efficiency first principle, Member States shall ensure that energy efficiency solutions are taken into account in the planning, policy and major investment decisions related to the following sectors:

(a) energy systems, and

(b) non-energy sectors, where those sectors have an impact on energy consumption and energy efficiency.”

Abbreviation of non-energy sector is unclear in the proposal of EED. If understanding the board and paper industry to be included the abbreviation of energy systems, then “Energy efficiency first principle” should be taken into action. Energy systems is defined as following in proposal of EED 2012/27/EU Article 2(3), p. 71 (European Commission, 2012c)

“‘energy system’ means a system primarily designed to supply energy-services to satisfy the demand of end-use sectors for energy in the forms of heat, fuels, and electricity.” Otherwise, there is proposed to include all sectors in “The energy efficiency first principle.”

Coating drying energy efficiency improvement would be a part of the regulation as mentioned in Proposal of EED 2018/2002 recital 2(11) (adapted), p. 29 (European Commission, 2012c) if following will come into effect:

“The energy efficiency first principle ⇒ is an overarching principle that ⇔ should be taken into account ⇒ across all sectors, going beyond the energy system, at all levels, including in the financial sector. Energy efficiency solutions should be considered as the first option in policy, planning and investment decisions, ⇔ when setting new rules for the supply side and other policy areas. ⇒ While the energy efficiency first principle should be applied without prejudice to other legal obligations, objectives and principles, they should also not hamper its application or exempt from applying the principle. ⇔ The Commission should ensure that energy efficiency and demand-side response can compete on equal terms with generation capacity.”

EU Taxonomy regulation is mentioned in proposal of EED 2018/2002 recital 3(12), p. 30 to be included for financial activities to be filled the “energy efficiency first principle” by following:

“(12) Energy efficiency should be recognized as a crucial element and a priority consideration in future investment decisions on the Union's energy infrastructure. ⇒ The energy efficiency first principle should be applied taking primarily the system efficiency approach and societal perspective into consideration. Consequently, it should help increase the efficiency of individual end-use sectors and of the whole energy system. Application of the principle should also support investments in energy efficient solutions contributing to environmental objectives listed in Regulation (EU) 2020/852 of the European Parliament and of the Council. ⇐”

Regulation 2020/852/EU, article 9 lists the taxonomy of sustainable finance terms of environmental objects which are presented on chapter 5.4.

Industrial efficiency directive (IED) was published in 2010 to reduce environmental and human impacts from industrial emissions. IED will be upgraded in near future. There will be settled Best Available Technology (BAT) for industries to reduce energy consumption by classification of energy performance levels. (European Union 2020; European Commission 2021c) Current Energy Taxation directive (ETD) entered into force in 2003. ETD is about to align the taxation of energy products and electricity. (Valmet internal, 2021)

Gas directive 2009/73/EC is part of a third energy package which launched in 2008. The third energy package aim was to improve the functioning of European internal energy market. (European Union 2021p). There is an inconsistency with climate neutral-program and gas directive because fossil fuels support continues while climate-program has been published. Gas directive needs to be updated to support renewable gases instead of fossil fuels. Supporting renewable gases could jump-start implementation of renewable gases. (Euractiv, 2021a)

The EU Commission launched public consultation on Gas directive 2009/73/EC and Gas Regulation 715/2009/EC revision in Spring 2021 as a part of the “Fit for 55”. The target is to decarbonise the gas sector and prepare the hydrogen strategy. Proposals of

regulation revision will take a place in the end of year 2021. The regulation revision target is to update EU gas markets to focus on hydrogen and low carbon gases in the gas grids as a part of the wider energy system integration. Renewable gases can be produced off-grid or can be connected to grids. Direct electrification is mentioned to decarbonize energy demand but in areas where electrification is not possible, gaseous fuels can be a part of energy system. (European Union, 2021q)

5.4 EU Taxonomy of sustainable finance & Green bond standard

EU Taxonomy of sustainable finance has a significant role if seeking funds of new investments. If considering a to be applicable to seek finance from EU or if considering filling the criteria of sustainable activity, investment or activity should be **Taxonomy-aligned**. (Valmet internal, 2021)

EU taxonomy is needed to define what is meant by sustainable concept. EU taxonomy is created to show common classification system for sustainable economic activities for EU's climate and environmental objectives. The EU Taxonomy regulation was published in 2020. (European Union, 2021o). For climate change mitigation and adaptation the EU taxonomy will be applicable as from January 2022 and for other objectives as from January 2023. EU taxonomy applies to companies under the non-Financial Reporting Directive (NFRD) which will revise as mandatory Corporate sustainability reporting (CSRD). (European Commission 2021f). The EU Taxonomy has impacts on investors and issuers within EU and beyond. (European Union, 2020b)

EU Taxonomy lists six environmental terms in regulation 2020/852/EU, Article 9:

- 1. Climate change mitigation*
- 2. Climate change adaption*
- 3. The sustainable use and protection of water and marine resources*
- 4. The transition to circular economy*
- 5. Pollution prevention and control*
- 6. The protection and restoration of biodiversity and ecosystems.*

(2020/852/EU; European Union, 2021o)

In addition of environmental terms there are listed four conditions for economic activities needs to meet to recognize for **Taxonomy-aligned**:

- *Making a **substantial contribution** to at least one environmental objective*
- ***Doing no significant harm** to any other environmental objective*
- *Complying with minimum social safeguards*
- *Complying with the **technical screening criteria**.*

(European Commission, 2021e)

Technical screening criteria is defined by delegated act which is decided by EU Commission. First delegated act on climate objectives sets criteria on economic activities for most relevant sectors achieving climate neutrality and delivering climate change adaptation. Sectors including the delegated act are energy, forestry, manufacturing, transport and buildings. There will be other delegated acts related to environmental goals. Delegated acts will be updated over the time as necessary. (European Commission, 2021e)

Substantial contribution ensures economic activity either has a positive environmental impact or reduces remarkable negative impacts on the environment, for example to GHG emissions on climate change mitigation or adaptation. (European Commission, 2021e)

Do No Significant Harm (DNSH) principle refers that at least 1 term of six terms of environmental objectives is met, but this term can't be in inconsistency with other terms. The term which met the environmental objective should be at least in same level as other listed terms. All terms listed in environmental objectives need to be observed. (Valmet internal, 2021). Figure 49 describes the EU taxonomy of sustainable finance principle.



Figure 49. EU Taxonomy of sustainable finance. (European Union, 2020b)

A European Green Bond Standard (EUGBS) is a proposed regulation on voluntary standard to finance sustainable investments. Green bonds are already in use for energy production and distribution, resource-efficient housing and low-carbon transport infrastructure. (European Union, 2021p) EUGBS will be opened to issuers from EU and non-EU. Issuers are, as an example, corporates, sovereigns and financial institutions. Issuers must allocate 100% of the funds raised by their bond to meet economic activities of EU Taxonomy. EUGBs can support companies by funding long-term taxonomy-aligned projects or transition towards taxonomy-alignment or to transition activities settled from EU taxonomy. (European Commission, 2021f)

5.5 EU Emissions trading system (EU ETS)

The European Union's Emissions Trading System (EU ETS) is a cap-and-trade program. EU ETS is the first ETS system in the world launched in 2005. (Ellerman, Marcantonini & Zaklan, 2014). In a cap-and-trade system a "cap" is defined for GHG emissions each year per allowances. Allowances can be traded if there is no need to use them. EU ETS includes all EU countries and in addition Iceland, Liechtenstein and Norway and is covering 40% of GHG emissions in EU. (European Union, 2021d) The number of ETS systems are increasing globally. Today ETS systems are operating or are under development in Canada, China, Japan, New Zealand, South Korea, Switzerland, and United States. European

Commission has given expert support to develop ETS systems in other areas. The EU ETS legislation allows linking to other ETS systems. The EU and Switzerland has agreement of ETS linking and the EU and Australia have considered to link their ETS systems. The agreement to enhance co-operation on emissions trading between EU and China signed in 2018. Carbon markets are mentioned in Paris Agreement as well. (European Union, 2021). So far, the EU ETS program is divided to 4 phases during the era of ETS. Revision of the phase 4 for years 2021–2030 linear reduction factor of CO₂ emissions is 4,2 %. (Valmet internal source, 2021)

GHG emissions from powerplants, industries and aviation including EU ETS are limited by a “cap” of emission allowances. Companies receive or buy allowances which can be traded. The cap is decreased every year by EU Commission. European Union Allowance (EUA) gives the right to emit one ton of CO₂ or the equivalent amount of other GHG, nitrous oxide (N₂O) and perfluorocarbons (PFCs). (European Union, 2021) EUA price increased first time over 50 euros/tCO₂ in May 2021 (Reuters, 2021b). Figure 50 is shown the EUA price development from 1.1.2020 to 1.4.2021.

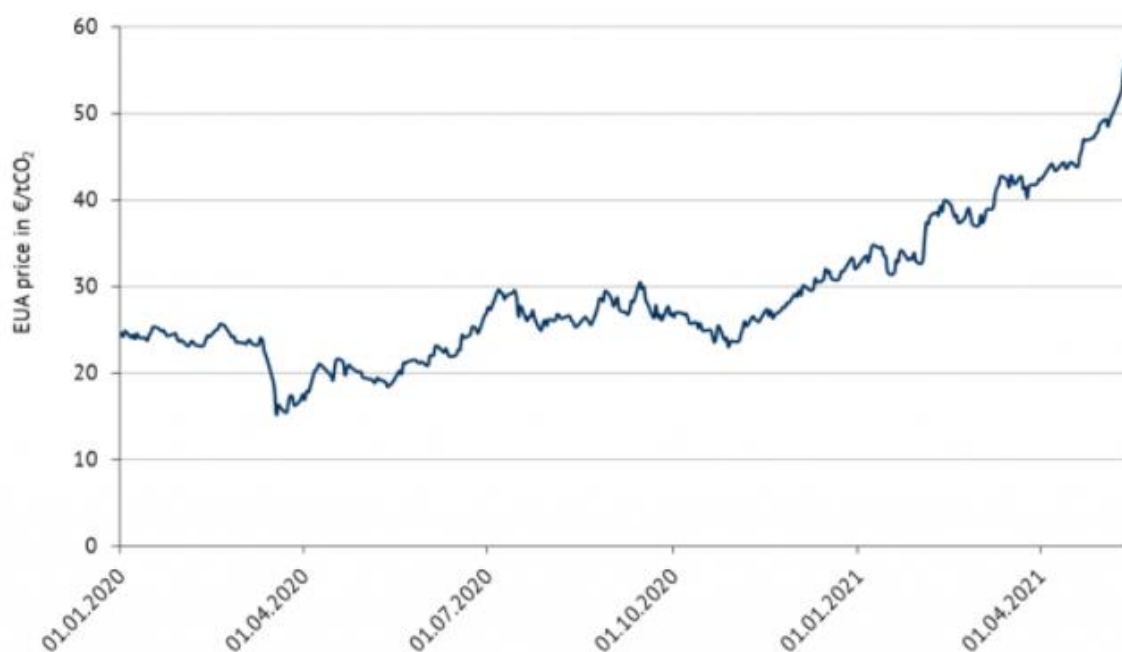


Figure 50. EUA price development. (Energypost, 2021)

60 % of EU's GHG emissions are from sectors which are not included in the EU ETS system. They are called non-ETS sectors. Target is to cut 30% emissions from non-ETS sectors by 2030. Effort sharing regulation (ESR) can allow countries flexibility to have allowances from EU ETS to non-ETS if the following definitions are filled: national reduction targets are significantly above the EU average and reduction potential by country or country did not allocate any EUAs for free industrial installations in 2013. Countries which have the access to use flexibility to EU ETS are Austria, Belgium, Denmark, Finland, Ireland, Luxembourg, the Netherlands, Malta and Sweden. There is also an option to bank, borrow, buy or sell emission allowances. If emissions are lower than annual emission allocation, the surpluses can be banked for later years use. If emissions are higher than annual limit, member can borrow allowances from following year. Emission allowance trading is possible with other members of European Union. (European Union, 2021m)

There is a risk of carbon leakage outside the EU area while climate-neutral actions are tightened and price of EUA is increasing. Carbon leakage means transferring carbon-intensive production to countries where producing carbon is inexpensive or EU production is replaced by more carbon-intensive imports. "Fit for 55" package includes proposal of Carbon Adjustment Mechanism (CBAM) as a solution to carbon leakage outside of the EU. (European Union 2021n; European Commission, 2021d)

CBAM concept means that EU businesses need to pay a carbon adjustment for imports of certain goods. In the first phase the sectors included to the CBAM are cement, iron and steel, aluminium, fertilizer and electricity. The second phase will include other sectors. Pulp and paper industry is not currently included in the CBAM. (Valmet internal source, 2021)

By comparing the carbon trading prices between different ETS there can be seen that EU ETS has the most expensive price for emission allowance. Price comparison of ETS in 1st of April 2021 are shown in Figure 51. (Statista, 2021c)

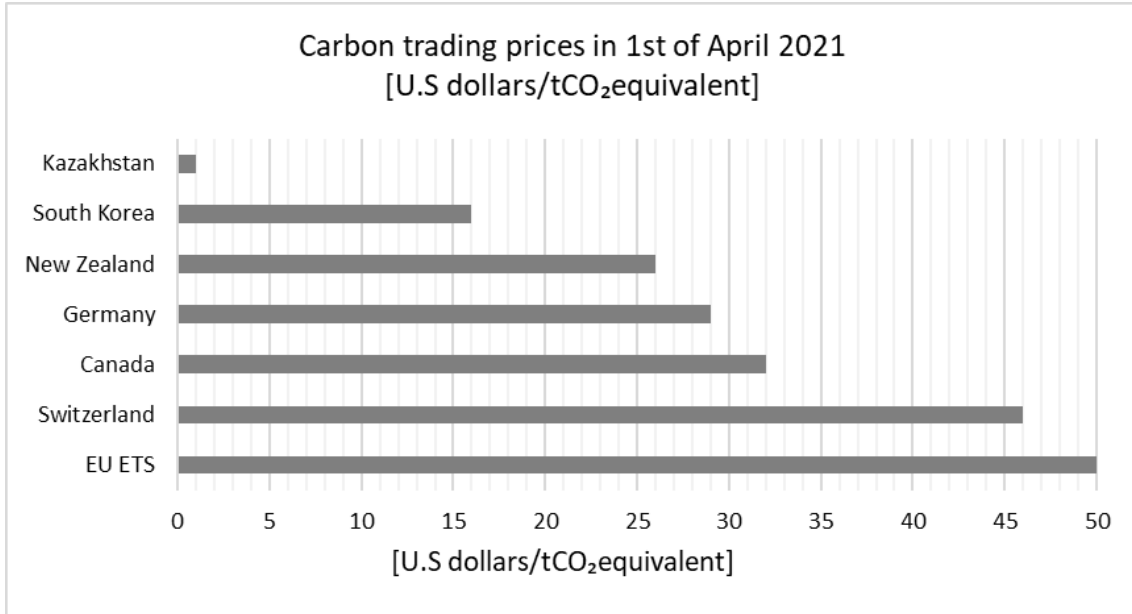


Figure 51. Carbon trading prices in 1st of April 2021. (Elaborated from Statista, 2021c)

5.6 EU regulations and finance for CO₂ reduction in coating drying

If considering applying the finance from the EU, the investment should be taxonomy-aligned if the funding is linked to EU taxonomy. Major part of the European Investment Bank's (EIB) finances are linked to EU taxonomy but there are also finances which are not committed to EU Taxonomy e.g. Innovation fund and Horizon Europe. (Valmet internal 2021)

The CO₂ reduction in coating drying can be shown as "heating and cooling" in EED revision. Heating and cooling sector is mentioned to be supported to reduce GHG emissions. "Heating and cooling" can be assumed also as heat recovery if considering term waste heat. (Valmet internal 2021) Other objective to be supported is "energy efficiency first principle" if it will be filled to include all sectors as it is proposed in the revision of EED. Considering the "energy efficiency first principle" the coating drying efficiency improvements should be supported by the EU because of the support for investments of energy efficiency mentioned in 2018/2002 recital.

CEPI has introduced the energy intensive sectors to be excluded from the scope of the Energy Taxation Directive because of the risk of carbon leakage (CEPI 2021b). EUA carbon prices are affecting the steel price and investments cost in the EU. If steel is more inexpensive outside the EU, the steel is imported inside the EU but the price of investment increases. If investment is implemented only outside the EU, the price of investment is more inexpensive than in the EU. There can be even 1 % difference between prices of investment inside the EU and outside the EU. 1% difference of investment costs has an influence on investment decision. (Valmet internal, 2021)

In the proposal of EED, energy efficiency will be increased in heating and cooling, industries, and energy services. (European Parliament, 2021). There are many EU fundings supporting energy efficiency increase. Coating drying energy efficiency improvements can be shown as increasing energy efficiency. Some of the fundings are only for medium or small enterprises. But fundings which might be feasible to coating drying improvements are at least Horizon of Europe, Innovation fund and modernisation fund in selected countries.

6. Practical examples of CO₂ reduction in coating drying

CO₂ reduction topic is considered in Valmet's customers points of view. Customer interviews related to CO₂ reduction were arranged. A Finnish forest industry company's coating drying CO₂ emissions are studied as a customer case example.

6.1 A Finnish forest industry company's example of coating drying CO₂ emissions

A Finnish forest industry company has set a target to achieve fossil free mills by 2030 with zero CO₂ emissions. One solution to reduce CO₂ emissions in the company's roadmap is to implement a change to the coating drying fuel. A board machine in one of the company's mills is producing three different coated folding boxboard grades which have a total production capacity per year of 190 000 tons of board. Produced board grades are for packaging, food, healthcare and graphic end uses.

The board machine has 4 coating stations. For coating drying heating, there are IR dryers, air dryers and drying cylinders. The IR dryers' primary heat resources are electricity and gas, the air dryer's heat resource is gas and cylinders' heat resource is steam. In addition to the coating dryers there is yankee cylinder equipped with hood which consumes natural gas as a heat resource.

Actual consumption of natural gas for coating drying in the board machine was 21 846 MWh in 2020. (Customer's information). By calculating the CO₂ emissions of coating drying by actual consumption, the total CO₂ emissions of coating drying were 4 369 tons of CO₂ in 2020. With a production of 185 486 t/a in 2020 (FisherSolve Next, 2021) and considering the typical running hours per year as 8000 hours, the CO₂ emissions for coating drying by natural gas consumption were 23,6 kgCO₂/FMT of FBB.

6.2 Board and paper producers' thoughts on CO₂ reduction

Paper or board mill's equipment supplier's CO₂ emissions are considered as a part of the value chain of board or paper manufacturing. For scope 3 based emissions, the equipment supplier CO₂ emissions are included into calculations. Value chain CO₂ emissions proportion is larger than purchased energy based CO₂ emissions. (Valmet's customer interview, personal conversation, 2021-06-04).

Companies' energy efficiency actions are reported every year in consequence of efficiency objectives defined by Confederation of Finnish Industries (EK). In the long term, the specific energy per produced ton of board or paper decreases while energy efficiency is increased by upgrading paper or board machine's equipment to become more energy efficient. Consumers are also interested in to know how much energy is used for the end product. CO₂ reduction pressures come mainly from consumers. (Valmet's Customer interview, personal conversation, 2021-03-19) Consumer behavior is affecting the packaging industry. Sometimes the outlook of the package can affect the consumer purchase decision or the customer can be more interested if recycled materials are used. All packages can't be produced by recycled material because of quality properties especially if the end use is to package food products. (Valmet's Customer interview, personal conversation, 2021-03-24)

Considering the option to change primary energy resource from NG to other less CO₂ emissions producing option there are a lot of challenges. It is more feasible that energy efficiency is increased by using lost heat from Infrared dryer to air float dryer by heat recovery to achieve less emissions. Many mills are located near natural gas networks. If biogas would be available from the natural gas network, it would be feasible but is likely that biogas price will increase in the future. (Valmet's Customer interview, personal conversation, 2021-03-19) On the other hand current biogas production is not enough to cover consumption in Europe. There are not enough raw materials. The lack of biomass will increase the need for electrification. (Valmet's Customer interview, personal conversation, 2021-03-16). Board or paper machine electrification has investment of costs of

millions of euros, but electrification is feasible. Today the question is, is there CO₂ free electricity available for an inexpensive price. (Valmet's Customer interview, personal conversation, 2021-03-19)

If considering a new board or paper line, steam could be option to achieve less emissions. The drying temperature achieved with steam is lower but drying can be reached by raising the machine line length which is not so expensive in new projects but when considering the existing solution of dryer type change to drying by only steam, it is not an option. (Valmet's Customer interview, personal conversation, 2021-03-19)

7. Conclusions and recommendations

The increasing number of coated products will increase the CO₂ emissions in coating drying. This work covered the calculation of the amount of CO₂ from the heating energy consumption in coating drying and gas consumption in 2020 and researched two future scenarios of CO₂ emissions in coating drying by 2025. Scenario 1 was Business As Usual and Scenario 2 was 20 % energy efficiency increase of coating drying.

Total Global CO₂ emissions of heating energy consumption in coating drying including EU area were 882 ktCO₂/a in year 2020. Total coating drying gas consumption based CO₂ emissions including EU area were 722 ktCO₂/a in 2020. CO₂ emissions of coating drying heating energy consumption in EU area were 187 ktCO₂. Total coating drying gas consumption based CO₂ emissions in EU area were 141 ktCO₂.

CO₂ emissions can be showed by average EU car's annual emissions. Considering the amount of CO₂ in coating drying heating energy consumption (187 ktCO₂) in EU area in 2020, it can be shown as 163 771 pieces of EU cars annual CO₂ emissions.

In Scenario 1, the emissions are increasing as the same proportion of production as in year 2020. The increasing amount of CO₂ emissions in coating drying energy consumption will increase 17 % until 2025 compared to baseline year 2020. CO₂ emissions in coating drying energy consumption will increase if actions to increase energy efficiency won't be made.

In Scenario 2 of 20 % reduction of CO₂ emissions can be seen that emissions can be decreased even if the production of coated grades increases if improvements are made to coating drying energy efficiency. This means that CO₂ emissions of coating drying energy consumption in 2025 will be approximately 26 % less than if improvements are not made to energy efficiency in coating drying by 2025.

Customer interviews showed that CO₂ emission reduction is important to study. Packaging products' End Users are conscious to know energy consumed for manufacture the product, CO₂ emissions of product and if the product includes recycled material. More feasible option for customers related the interviews were to improve energy efficiency instead of change primary heating energy resource of coating drying. Customer case example showed that one of the Finnish Forest industry company's coating drying gas consumption based emissions were 4 369 tons of CO₂ in year 2020.

The CO₂ emissions of the coating drying process will increase if there will not be any modifications to existing coating dryers or if fossil fuels used the primary energy source for coating drying are not changed to less GHG emission producing alternative fuels. Alternative fuel modifications are more expensive than modifications of energy efficiency in coating drying. (Valmet internal, 2021)

GHG emissions in the future should decrease by tightening regulations of industries but on the other hand fundings of different technologies are needed to mitigate emissions. Policy makers need to adopt mandatory regulations for decarbonization in different sectors of industries. Especially rising carbon price of ETS systems has one of the main effects on markets. In the next three to five years adopting the changes will provide market signals to enable industries to adapt methods towards low-carbon production. Policies should be achieved by global perspective. (IEA, 2021) European Union has a significant role in GHG emissions mitigation and adaptation. EU decisions lead the markets globally e.g. ETS systems.

Some virgin-integrated board or paper mills are already self-sufficient within energy, improvements should be taken into action in non-integrated mills and in mills which are producing board or paper by recycled raw materials e.g in Central Europe. (CEPI, 2021b; See Appendix 8.)

Energy efficiency improvements has a significant role in emissions mitigation and adaptation (Kähkönen et al., 2019). Valmet can improve energy efficiency in coating drying by 20 % by nozzle upgrades, nozzle optimization, dryer upgrades or modification of dryers by heat recovery systems. (Valmet internal source, 2021) EU regulations and proposal of regulations included in “Fit for 55”-package presents that energy efficiency must be increased before further, larger actions related to “Energy Efficiency First Principle”. There is proposed to include all sectors involved to “Energy Efficiency First principle” in proposal of EED. This could mean that in the board and paper industry investments, the first action to be supported is energy efficiency increase before further actions. Funds which should align the EU Taxonomy is proposed to support investments in energy efficiency increase.

Confederation on pulp and paper industries CEPI lists a few policy recommendations to board and paper industry sector:

- Mobilizing EU funding programmes e.g. Innovation Fund
- Excluding the scope of Energy Taxation Directive of energy intensive industries because of carbon leakage risk
- Mills which are using the recycled fibres, the natural gas is competitive.

(CEPI, 2021b)

8. Summary

This work was concentrated on to present the amount of CO₂ of coating drying based on 2020 year's data of gas consumed in coating drying in global and EU area. Gases in use of coating drying are NG, LNG and LPG. In addition, the work calculated the heating energy consumption in coating drying in 2020 by global area and EU area. Heating energy consumption in coating drying may consist of gas, electricity and steam. There were arranged customer interviews related to CO₂ emission reduction and researched the EU regulations and fundings in the coating drying point of view.

Based on this thesis, the following assumptions could be made:

- CO₂ emissions in 2020 year were as an average in global area by coating drying heating energy consumption: 882 ktCO₂, and in EU area 187 ktCO₂. The proportion of average coating drying heating energy consumption ktCO₂emissions by gas were 722 ktCO₂ in globally, and in EU area 141 ktCO₂.
- According to the future scenarios of coating drying CO₂ emissions: the amount of CO₂ can be decreased by approximately 26 % if there will be done improvements to achieve 20 % increase of coating drying energy efficiency compared to scenario where improvements are not made to heating energy efficiency increase in coating drying by 2025.
- Customers do not seem to be enthusiastic to change primary energy source to achieve CO₂ reduction. More feasible way than primary energy source change is to improve energy efficiency in coating drying e.g by heat recovery.
- EU regulations and fundings aligned in EU Taxonomy can support the coating drying energy efficiency improvements if there can be shown the coating drying energy efficiency improvement to be included in "the energy efficiency first principle" which is proposed in new EED.

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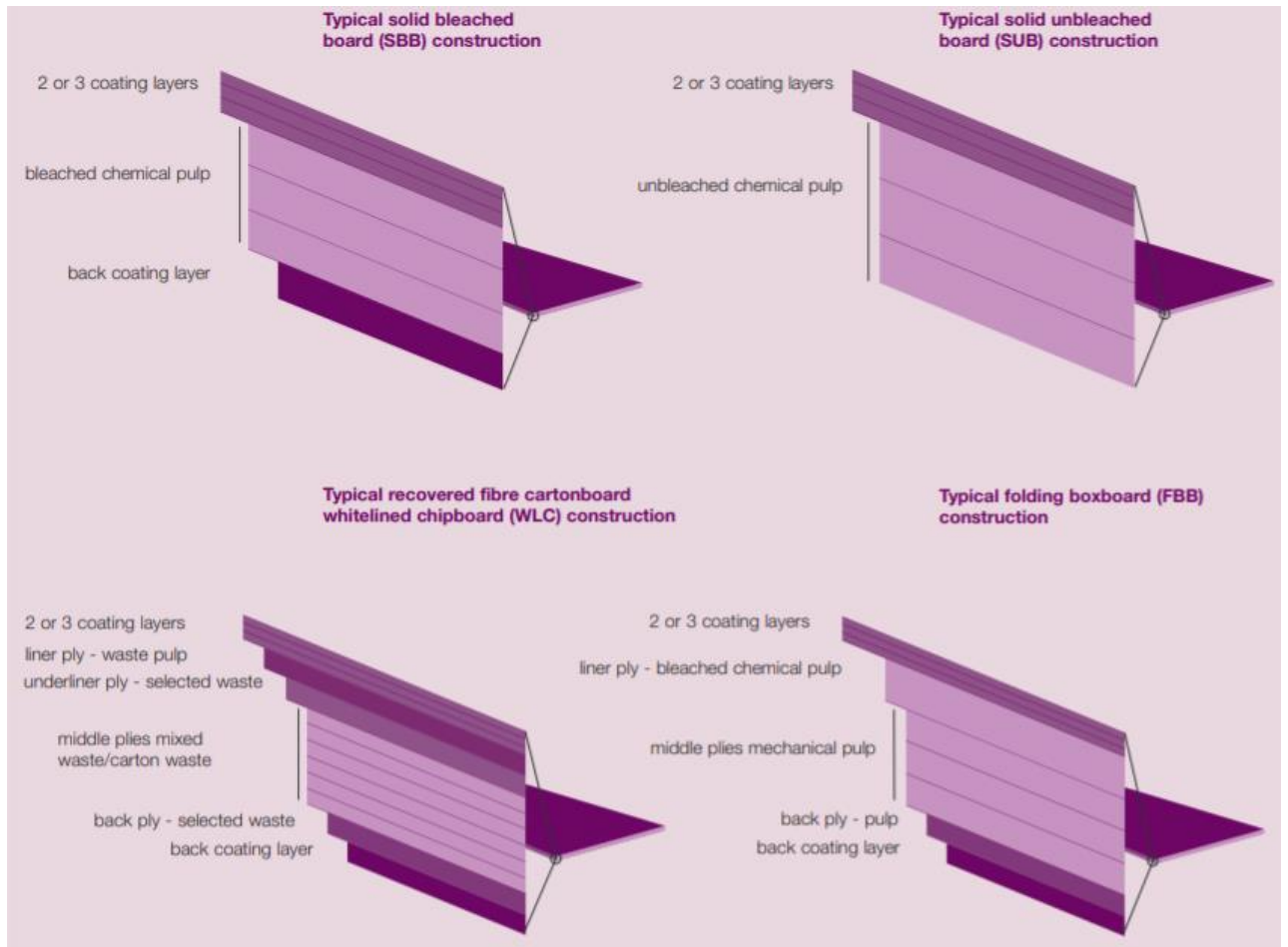
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Appendices

Appendix 1. Grades

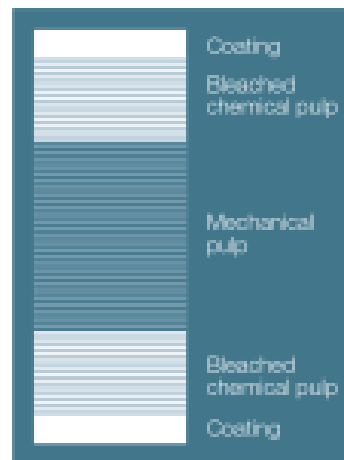


(Procarton 2021)

Folding Box Board (FBB, GC1), white back, multiply construction

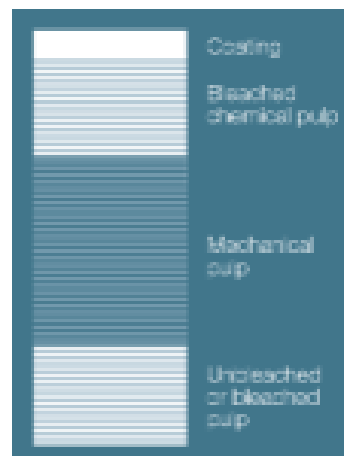
FBB, white back, is made from layers of mechanical pulp sandwiched between layers of bleached chemical pulp.

The top layer is pigment coated. The back is thicker than FBB, cream back, and can also be pigment coated.



Folding Box Board (FBB, GC2), cream back, multiply construction

FBB, cream back, is made from layers of mechanical pulp sandwiched between layers of bleached chemical pulp.



(Holmen Iggesund 2021)

Appendix 2. Dry solids contents and coating color amounts by grades

Grade	Top ply						Back ply				
	Pre coating		middle coating		Top coating		Pre coating		Top coating		
	g/m ²	%	g/m ²	%	g/m ²	%	g/m ²	%	g/m ²	%	
FBB GC1	9	65-67	7	65-67	11	63-65	NA	NA	9	65-67	back sizing
FBB GC2	11	65-67	NA	NA	11	63-65	NA	NA	1	10	
SBS C1S	9	65-67	7	65-67	11	63-65	NA	NA	9	65-67	
SBS C2S	11	65-67	NA	NA	11	63-65	11	65-67	11	63-65	
WLC GD2	11	65-67	9	65-67	11	63-65	NA	NA	1	10	back sizing

WLC GD2 value amounts are used also for CWTL, CRB and SUK grades calculations.

Appendix 3. Total basis weights by grades for calculations

All grades			
Specific energy consumption kJ/kgH ₂ O. (4500 kJ/kgH ₂ O - 6500 kJ/kgH ₂ O)	Value		
Average	5500		
FBB GC1		FBB GC2	
Total basis weight (Modeled basis weight) [g/m ²]	248,00	Total basis weight (Modeled basis weight) [g/m ²]	248,00
WLC		CWTL	
Total basis weight (Modeled basis weight) [g/m ²]	222,72	Total basis weight (Modeled basis weight) [g/m ²]	222,72
CRB		SUK	
Total basis weight (Modeled basis weight) [g/m ²]	287,68	Total basis weight (Modeled basis weight) [g/m ²]	316,04
SBS C1S		SBS C2S	
Total basis weight (Modeled basis weight) [g/m ²]	233,15	Total basis weight (Modeled basis weight) [g/m ²]	233,15
Total basis weights are production weightened averages from FisherSolve Next modelled total basis weights			
Other information: Valmet internal			

Appendix 4. CO₂ emission factors of NG, LNG, and LPG

Statistics Finland		FUEL CLASSIFICATION 2021		To be applied from year 2021 data onwards				
		Previous fuel code	Fuel-specific unit	CO ₂ default emission factor	Default oxidation factor in combustion	Default net calorific value (as fired)	Default gross calorific value (as fired); for natural gas and biomethane only	
				[t/TJ]		[GJ/unit]	[GJ/unit]	
11.10	LPG (Liquefied petroleum gas)	1112	t	64,9	1,0	46,3		
13 Natural gas								
13.10 Natural and liquefied natural gas								
13.10	Natural gas	1311	1000 m ³	55,4 *	1,0	36,58	* 40,56	
13.10	Liquefied natural gas (LNG)	1312	t	55,8	1,0	49,3	54,66	

Appendix 5. CO₂ emission factors

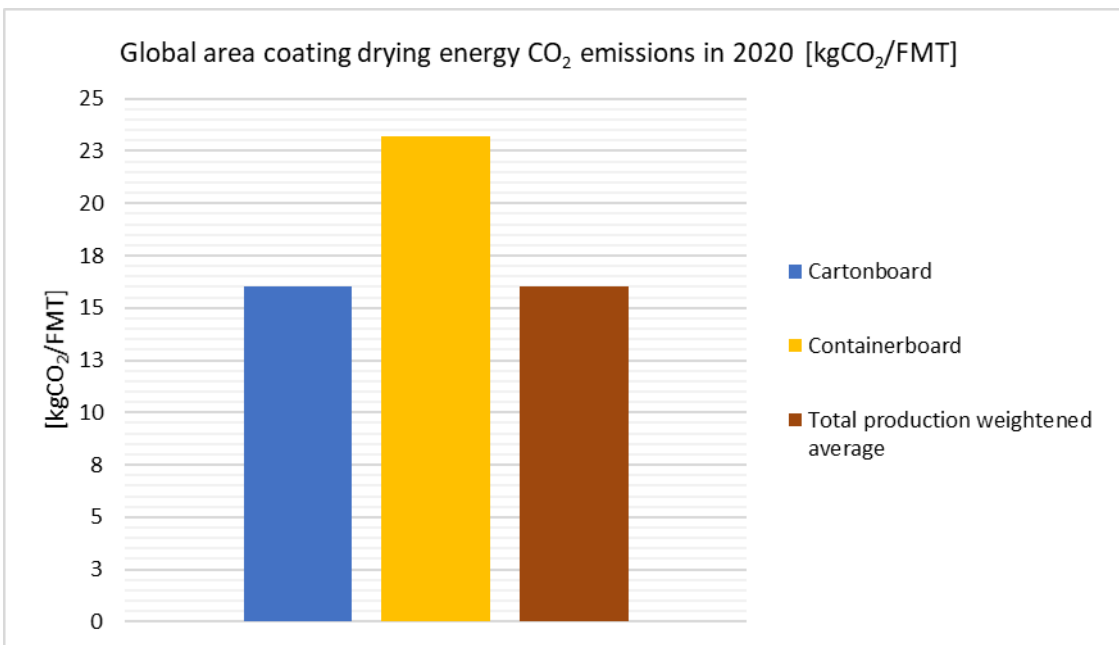
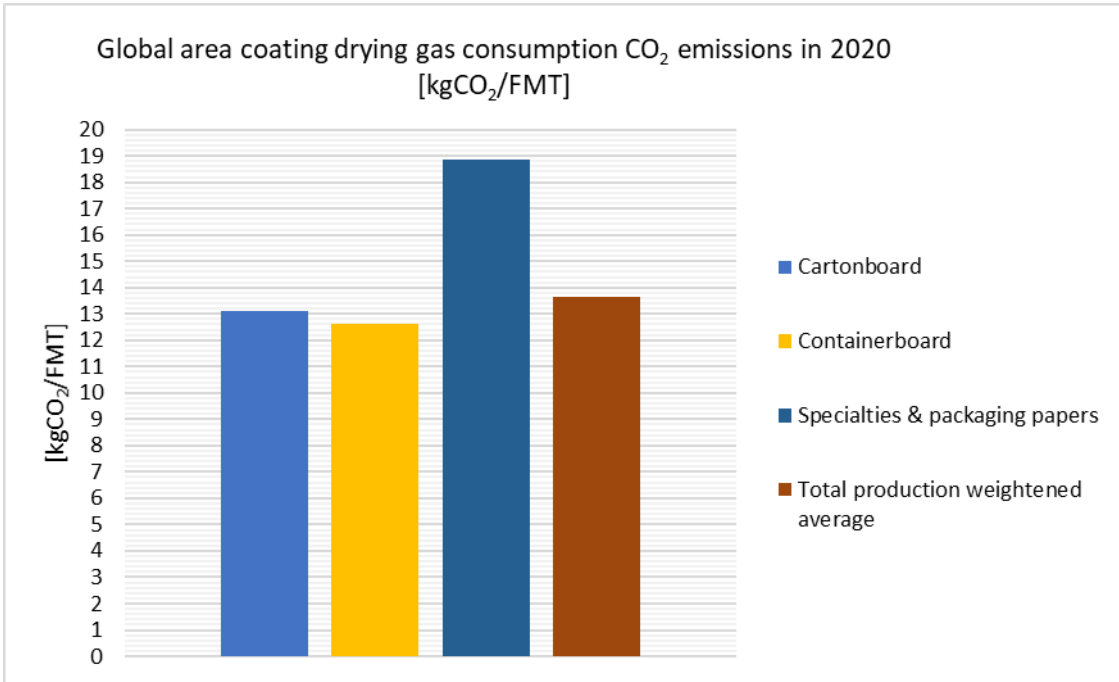
Table 2: Default Emission factors for renewable energy sources

Renewable energy		Standard ² (IPCC, 2006)	LCA ³ up to 2007 ⁵	LCA ⁴ 2008-2015 ⁵ (current update)		
Energy classes ¹	IPCC denomination <i>Carbon neutrality</i>	t CO ₂ /MWh	t CO ₂ -eq /MWh	t CO ₂ -eq /MWh		
Plant oil	Other Liquid Biofuels	<i>cn</i>	0	0.001	0.182 ^a	0.182 ^a
		<i>ncn</i>	0.287	0.302	0.484	0.484
Biofuel	Bio-gasoline	<i>cn</i>	0	0.001	0.207 ^a	0.207 ^a
		<i>ncn</i>	0.255	0.256	0.462	0.462
	Biodiesels	<i>cn</i>	0	0.001	0.156 ^a	0.156 ^a
		<i>ncn</i>	0.255	0.256	0.411	0.411
Other biomass	Biogas	<i>ncn</i>	0.197	0.197	n.a.	0.284 ^b
	Municipal wastes (biom. fraction)	<i>cn</i>	0	0.007	0.106	0.106 ³
		<i>ncn</i>	0.403	0.410	0.416	0.420
	Wood (/Wood waste)	<i>cn</i>	0	0.007	0.013	0.017 ^c
		<i>ncn</i>	0.403	0.410	0.416	0.420
	(Wood/) Wood waste	<i>ncn</i>	0.403	0.410	0.184 ³	0.184 ³
Other primary solid biomass	<i>ncn</i>	0.360	0.367	n.a.	n.a.	
Solar thermal		0	0	n.a.	0.040 ^d	
Geothermal		0	0	n.a.	0.050 ^d	

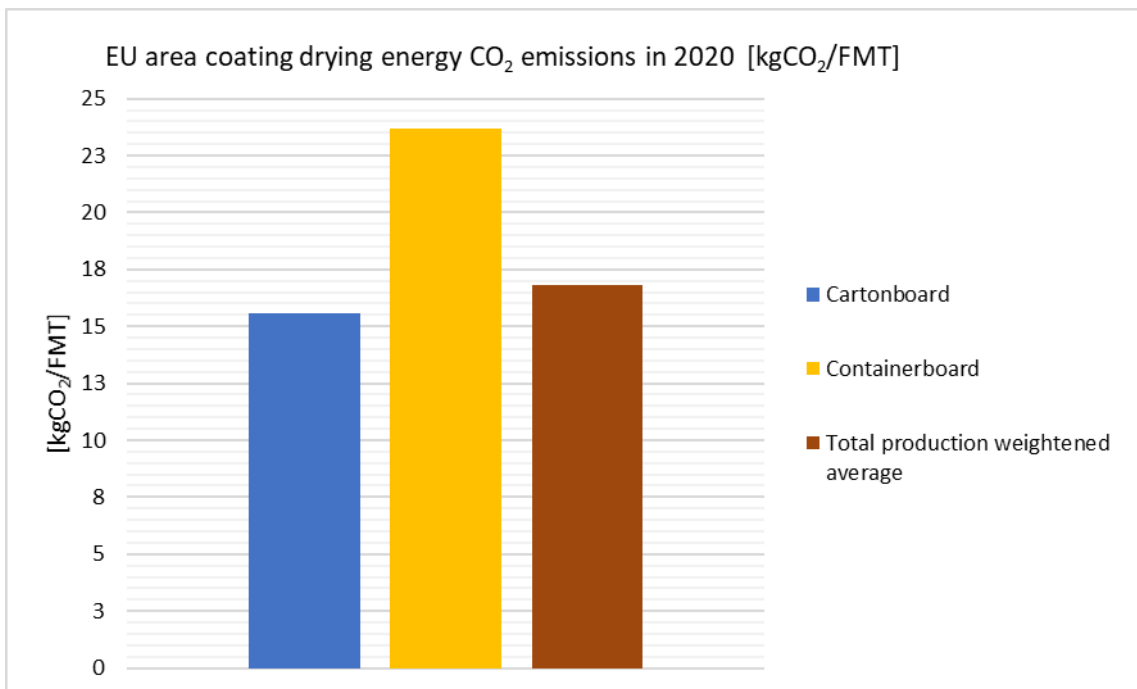
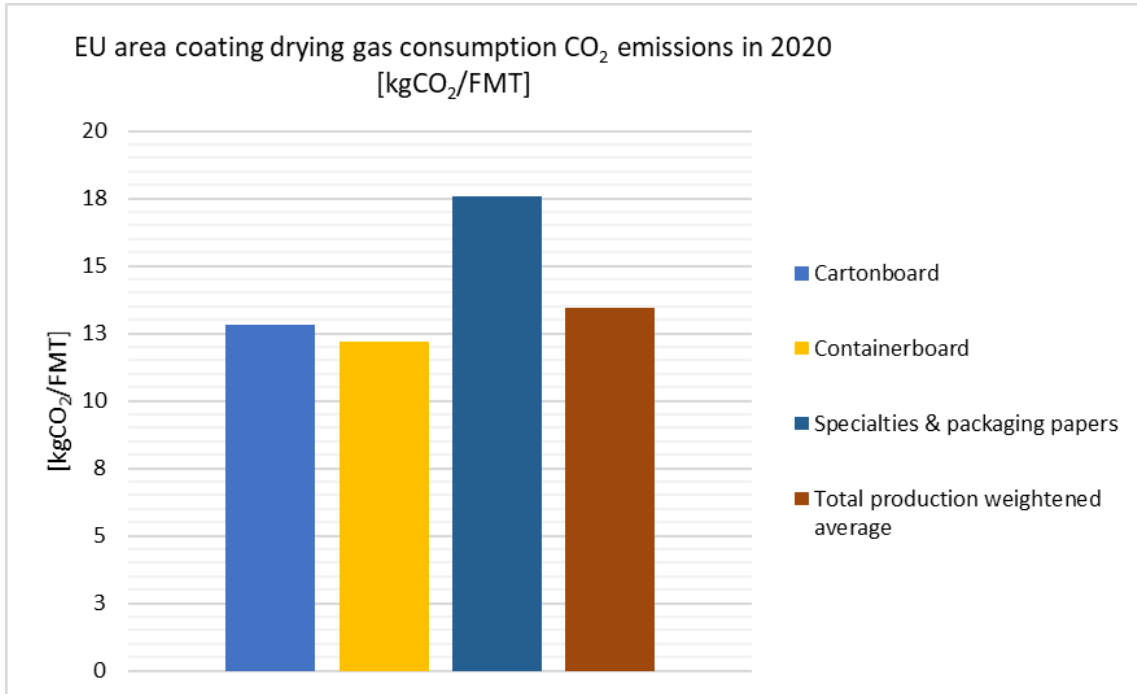
¹Default energy carriers of CoM SECAP on-line template. ²Standard emission factors should be reported zero if the biofuels/biomass meet CO₂ neutrality criteria (*cn*) in terms of CO₂ emissions versus CO₂ assimilation by plants; For fuels that do not meet carbon neutrality criteria (see Koffi et al., 2017), the *ncn* (not carbon neutral) IPCC (2006) default emission factors reflecting the carbon content, potentially further corrected for the carbon assimilation, should be used (excluding emissions from the supply chain, which are included in the LCA factor). The sources of LCA values are ³ELCD (2009) and ⁴ELCD v3.2 (ELCD, 2015) databases except ^aBertoldi et al. (2010), ^bEcoinvent world value for the year 2015, ^cNEEDS database and ^dAmponsah et al. (2014). ⁵The validity range applies to the baseline year, i.e. to the year of the so-called Baseline Emission Inventory (BEI), whereas for the monitoring emission inventories (MEIs), the same emission factors should be applied. The LCA factors for emissions from plant oil, biogasoline (bioethanol) and biogas have been checked for consistency against the values reported in the EU Renewable Energy Directive. See also Koffi et al. (2017) on the use of local versus CoM default emission factors.

Appendix 6. CO₂ emissions in coating drying of major grades per produced ton of board or paper

Global area:



EU area:



Appendix 7. CO₂ emissions in coating drying in 2020 of sub grades per produced ton of board or paper

EU coating drying heating energy consumption:

						[kgCO ₂ /FMT]
		Mt/a production	Energy			
		Baseline	CO2 emissions kt/a			FACTOR TO FIGURE
			2020 CO ₂ emissions kt/a	kgCO ₂ per produced tonne	Total per major grades [kgco2 per produced tonne]	Total production weighted average
Major grade	sub grade	EU				
	FBB		4,9	73,4	15,0	16,8
	CRB		3,3	49,0	14,8	
	SUK		0,3	4,7	15,7	
Cartonboard	SBS		0,9	19,3	21,5 15,6	
Containerboard	CWTL		1,7	40,3	23,7 23,7	
Specialties & packaging	Specialty & Packaging p		1,9		0,0 0,0	

EU coating drying gas consumption:

						[kgCO ₂ /FMT]
		Mt/a production	Gas			
		Baseline	CO2 emissions kt/a	kgCO ₂ per produced tonne	Total per major grades [kgco2 per produced tonne]	FACTOR TO FIGURE
			2020 CO ₂ emissions kt/a			Total production weighted average
Major grade	sub grade	EU				
	FBB		4,9	66,1	13,4847	13,4
	CRB		3,3	39,1	11,8509	
	SUK		0,3	2,4	8,0802	
Cartonboard	SBS		0,9	13,0	14,4790 12,8338	
Containerboard	CWTL		1,7	20,7	12,1778 12,1778	
Specialties & packaging	Specialty & Packaging p		1,9	33,4	17,5985 17,5985	
	Sum = total		13	141,3	77,6710	
	Average				22,1917	

Global coating drying heating energy consumption:

						[kgCO ₂ /FMT]
		Mt/a production	Energy			
		Baseline	CO2 emissions kt/a	kg co2 per produced tonne	Total per major grades [kgco2 per produced tonne]	FACTOR TO FIGURE
			2020			Total production weighted average
Major grade	Sub grade	Global				
	FBB		18,2	270,3	14,8	16,0
	CRB		24,4	367,1	15,0	
	SUK		2,9	35,1	12,1	
Cartonboard	SBS		6,1	128,4	21,1 16,0	
Containerboard	CWTL		3,5	81,2	23,2 23,2	
Specialties & packaging	Specialty & Packaging papers		5,9			

Global coating drying gas consumption:

					[kgCO ₂ /FMT]	
		Mt/a production	Gas			
		Baseline	CO2 emissions kt/a	per produced tonne	FACTOR TO FIGURE	
		2020			Total per major grades [kgco2 per produced tonne]	Total production weighted average
Major grade	Sub grade	Global				
	FBB	18,2	264,0	14,5	13,65825729	
	CRB	24,4	309,4	12,7		
	SUK	2,9	28,3	9,8		
Cartonboard	SBS	6,1	76,0	12,5	13,1	
Containerboard	CWTL	3,5	44,2	12,6	12,6	
Specialties & packaging	Specialty & Packaging papers	5,9	111,3	18,9	18,9	

Appendix 8. Mill types

Mill	Definition
Integrated Mill	A mill that produces some or all of it's own Fiber Furnish. Within the Fisher Database, there are three types of Integrated mills: Virgin Integrated, Recycled Integrated and Virgin & Recycled Integrated.
Non-Integrated Mill	A mill that uses only purchased Chemical, Mechanical and/or Recycled Market Pulp. No 'raw' fibers are processed in the mill, including Pulp Substitutes which are considered a Recycled Fiber.
Recycled Integrated	A Recycled Integrated mill produces some or all of the Recycled Fiber Furnish for the mill, and does not produced any Chemical or Mechanical Pulp. These mills can also purchase some Chemical, Mechanical or Recycled Market Pulp.
Virgin & Recycled Integrated	A Virgin & Recycled Integrated mill produces either Chemical and/or Mechanical AND Recycled Pulp to supply some or all of the furnish for the mill. These mills can also purchase some Chemical, Mechanical or Recycled Market Pulp.
Virgin Integrated	A Virgin Integrated mill produces either Chemical and/or Mechanical Pulp to supply some or all of the furnish for the mill. These mills can also purchase some Chemical, Mechanical or Recycled Market Pulp.

Source: FisherSolve Next 2021

Appendix 9. GHG emission scopes

Term	Definition
CO ₂ from Biomass Fuel Combustion	GHG Emission of CH ₄ and N ₂ O during combustion of biomass fuels, all reported as their CO ₂ equivalent.
CO ₂ from Fossil Fuel Combustion	GHG Emission of CO ₂ , CH ₄ and N ₂ O during combustion of fossil fuels, all reported as their CO ₂ equivalent. Also called as Scope 1 emission.
CO ₂ from Non-GHG Biomass	CO ₂ emission from combustion of biomass. It is not considered as GHG emission since it is assumed to be carbon neutral. The values are included for information and additional insight.
CO ₂ from Purchased Energy	GHG Emission attributed to the purchased or grid supplied electricity. Also called as Scope 2 emission. It depends largely on generation process and fuels used. Use of fossil fuels results in GHG emission. Nuclear, Wind, Solar and Hydroelectric processes do not generate GHG.
CO ₂ from Raw Materials	GHG Emissions associated with production and transportation of purchased raw materials and fuels.
CO ₂ from Transportation	GHG emission during transportation of products (market pulp or paper). Truck, Rail, Intermodal, Ocean Container and Ocean Break Bulk are the possible transportation modes.
Scope 1 GHG	All direct emissions at the site. CO ₂ from Fossil Fuel Combustion (CO ₂ , CH ₄ and N ₂ O from combustion of fossil fuels, expressed in CO ₂ equivalent) and CO ₂ from Biomass Fuel Combustion (CH ₄ and N ₂ O from combustion of biomass fuels, expressed in CO ₂ equivalent)
Scope 2 GHG	Indirect emission due to Purchased electricity. CO ₂ from Purchased Electricity.
Scope 3 GHG	All indirect emissions (purchased electricity excluded). CO ₂ from Raw Materials and CO ₂ from Transportation of products when destination is chosen.

Source: FisherSolve Next 2021