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Options for decarbonising the steam supply of the Dutch paper and board industry

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Summary

The Dutch paper and board industry is an energy-intensive sector that is actively searching for possibilities to reduce greenhouse gas emissions and to become more sustainable. In the production processes, large amounts of steam are used for drying. In the long term, the paper and board industry may be able to implement breakthrough technologies that do not require any steam. This report focuses on the medium term (up to 2030) and aims to give an overview of options for decarbonisation of the steam supply.

The structure of this report

This report consists of two parts. The first part gives an overview of data on the paper and board industry of the Netherlands in 2015. This part discusses production processes, material consumption, energy consumption, energy production, greenhouse gas emissions and production costs. To obtain this overview, the VNP, the KCPK and ECN part of TNO have compiled a dataset with detailed information on the Dutch paper and board mills.

The second part of the report discusses alternative technologies for the steam supply. Lux Research has made an inventory of technology options for a drop-in replacement for natural-gas fired steam boilers that produce steam of up to 200 ºC. The results of Lux Research give insights into the costs and efficiencies of these technologies and explain where these technologies are being developed.

The possible role of these alternative technologies is discussed, based on expected developments in the energy system as a whole, such as the developments of energy prices, electricity generation and energy infrastructure.

The paper and board industry in the Netherlands

In 2015, about 68% of the Dutch paper and board production consisted of packaging paper (corrugated board, solid board and folding boxboard), 28% of graphic paper (based on virgin and recovered fibre), and 4% of sanitary paper.

There were 21 mills with a combined production capacity of approx. 2,900 kton per year. The mills realised an average capacity utilisation of 92%. The annual production capacity of the individual mills ranged from 5,000 to 600,000 tons per year. Large mills typically produce bulk products, whereas smaller mills tend to produce more specialised products. Except for one, all of the paper mills are part of a larger corporate group.

Paper and board production consists of the production and preparation of the fibres, formation of the paper, and drying. The thermal drying of the paper accounts for most of the steam use.

This report presents figures on energy and emissions in 2015:

- Ten paper mills used combined heat and power (CHP) installations to cover (part of) their steam demand. The total electrical capacity of these

installations was 217 MW_e and the total thermal capacity was 496 MW_{th}. The total fuel input was 14.7 PJ.
- The final electricity consumption in the Dutch paper and board industry was 4.6 PJ. The total electricity generation by CHP installations was 4.1 PJ.
- The total consumption of steam/heat was 12.5 PJ of which 62% (7.8 PJ) was produced by CHP installations.
- The total ETS emissions of the paper and board plants in the Netherlands in 2015 amounted to 1,054 kton CO_2-eq.

The MIDDEN knowledge network

The data that have been collected on the paper and board industry contribute to the data system of the MIDDEN knowledge network. The MIDDEN project aims to support industry, policy makers, analysts and the energy sector in their common efforts to achieve deep decarbonisation of the Dutch energy-intensive industry.

The MIDDEN data system will contain information on Dutch industrial companies that participate in the Emissions Trading System (ETS), on different options to reduce the emissions of CO_2 and the conditions under which this is possible.

Alternative technologies for steam production

Lux Research has selected some of the most promising technology options for a drop-in replacement for natural-gas fired steam boilers that produce steam of up to 200 ºC. For the selected technologies, Lux Research has collected data and made estimations regarding their likely future performance.

The following technologies have been studied:
- **Heat pump recovering waste heat**: Heat from the environment or a reservoir is raised to a higher temperature level using electricity.
- **Direct electric heating**: Steam can be produced using direct electric heating. This is not much different from an electric kettle, just operating on a much larger scale and at higher temperatures and pressures.
- **Hydrogen combustion**: The industry could buy hydrogen and burn that instead of natural gas.
- **Electrolysis**: Rather than buying hydrogen, companies could generate hydrogen on-site using electrolysis and then burn the hydrogen to generate the desired temperature.
- **Biomass gasification based CHP system**: Biomass is gasified and the gas is used to run a CHP unit.

Other options (such as geothermal energy, waste heat from nearby industry and biogas) can play an important role in decarbonisation of the steam supply as well. Lux Research has explained the considerations for the technology selection. Geothermal energy has not been selected as it is only applicable to industry that is located in a suitable place. The possibility to use waste heat from nearby industry depends on the availability of suppliers of waste heat. Biogas is considered to be a viable option, but the added value of selecting biogas was considered to be limited, as there are already many studies on using biogas.

Discussion

The goal that has been set for the Dutch Climate Agreement is to reach a reduction of the national emission of greenhouse gases by 49% in 2030 (compared to 1990). The current European ambition is to reach a reduction of 80 to 95% in 2050. Such reduction targets can only be reached through major changes in the energy system of the Netherlands.

The role of electrification

This report has looked into three technologies than can contribute to electrification of the steam supply of the industry: heat pump systems, direct electric heating and electrolysis.

Electrification using electrical heat pumps can give rise to significant energy efficiency improvements compared to natural gas boilers. Research and development efforts are ongoing to reduce the capital expenditures and to increase the output temperatures.

Electrification using resistors or electrolysis does not lead to substantial energy efficiency improvements, but can still result in emission reduction when combined with CO_2-free electricity generation.

The first phase of electrification may take place using hybrid systems. Such systems can use the solar and wind energy that would otherwise be lost through curtailment.

The role of hydrogen

Compared to electricity, hydrogen has some advantages and some disadvantages. It is easier to store hydrogen and to transport it with high energy density. Production of hydrogen from electricity can help to make use of surpluses of solar and wind energy.

A disadvantage is that the energy consumption increases because the chain efficiencies are typically lower. The use of hydrogen usually requires considerable measures on the side of the energy consumers and changes to infrastructure.

The technology to use and produce hydrogen is already available (e.g. electrolysis, hydrogen burners), but these technologies are often not yet competitive with the current (fossil) alternatives.

The role of biomass

Biomass has many applications in the energy production and in the energy demand sectors. It can be used for the production of heat, hydrogen, electricity, biofuels and for specific industrial processes.

The use of biomass waste streams (e.g. using the biomass gasification technology discussed in this report) is an interesting option. The availability of such waste streams is however limited. Through the use of other types of biomass, such as imported wood pellets, a larger share of the heat demand can be fulfilled.

From a long-term perspective, the large scale use of biomass in the industry can be logical, especially because biomass in combination with CCS can result in negative emissions. However, CCS can only be applied when the scale is sufficiently large, such as at large industrial point sources or industrial agglomerations.

The use of biomass in the industry instead of fossil fuels offers the possibility to reduce CO_2-emissions. It is however very important to guarantee the sustainability of the biomass and to limit the greenhouse gas emissions in the supply chain.

The role of geothermal energy

The industry has only limited experience with geothermal energy. A large amount of heat is available in the deep underground. The extent to which this heat can be used in the industry depends on the location and possible side effects. Geothermal energy often plays a role in cost-optimal solutions for deep decarbonisation of the industry.

The role of waste heat

Industrial locations can use waste heat from other industry when the waste heat supplier is nearby enough and heat distribution infrastructure is available. In clusters of industrial activity it is often possible to match supply and demand of waste heat. The industry can also deliver waste heat to other sectors.

General conclusion

This report discusses promising drop-in replacements for natural-gas fired steam boilers in the industry. It does not provide a complete overview of technological options for decarbonisation of the steam supply.

The success of such technologies is dependent on future developments in the energy system and energy policies, which are often uncertain. Changes may be required to energy generation, distribution and infrastructure. There will not be one technological solution that can be applied in all cases.

The climate challenge for the energy-intensive industry is large. In order to meet the climate challenge, a better overview of the current production methods and possible sustainable improvement options for the Dutch industry is vital. To bring more clarity to these issues, cooperation with the industry is essential.

Samenvatting

De Nederlandse papier- en kartonindustrie is een energie-intensieve sector die actief op zoek is naar mogelijkheden om de uitstoot van broeikasgassen te verminderen en te verduurzamen. In de productieprocessen worden grote hoeveelheden stoom gebruikt om te drogen. Op lange termijn kan de papier- en kartonindustrie mogelijk doorbraaktechnologieën toepassen waar geen stoom voor nodig is. Dit rapport richt zich op de middellange termijn (tot 2030) en heeft als doel een overzicht te geven van mogelijkheden voor decarbonisatie van de stoomvoorziening.

De structuur van dit rapport

Dit rapport bestaat uit twee delen. Het eerste deel geeft een overzicht van gegevens over de papier- en kartonindustrie in Nederland in 2015. Dit deel bespreekt productieprocessen, materiaalverbruik, energieverbruik, energieproductie, broeikasgasemissies en productiekosten. Om dit overzicht te maken hebben de VNP, het KCPK en ECN part of TNO een dataset samengesteld met gedetailleerde gegevens over de Nederlandse papier- en kartonfabrieken.

Het tweede deel van het rapport bespreekt alternatieve technologieën voor de stoomvoorziening. Lux Research heeft een inventarisatie gemaakt van technologische opties die een één-op-één vervanging kunnen zijn van aardgasgestookte stoomketels die stoom produceren tot 200 ºC. De resultaten van Lux Research geven inzicht in de kosten en efficiëntie van deze technologieën en lichten toe waar deze technologieën ontwikkeld worden.

De mogelijke rol van deze alternatieve technologieën wordt besproken op basis van verwachte ontwikkelingen in het energiesysteem als geheel, zoals de ontwikkeling van energieprijzen, de elektriciteitsopwekking en de energie-infrastructuur.

De papier- en kartonindustrie in Nederland

In 2015 bestond ongeveer 68% van de productie van de Nederlandse papier- en kartonindustrie uit verpakkingsmateriaal (golfkarton, massief karton, vouwkarton), 28% uit grafisch papier (op basis van primaire vezels en gerecyclede vezels), en 4% uit sanitair papier.

Er waren 21 fabrieken met een totale productiecapaciteit van ongeveer 2.900 kton per jaar. De fabrieken realiseerden een gemiddelde bezettingsgraad van 92%. De jaarlijkse productie van de individuele fabrieken varieerde van 5.000 tot 600.000 ton per jaar. Grote fabrieken produceren meestal bulkproducten, terwijl kleinere fabrieken meestal meer gespecialiseerde producten maken. Op één na waren alle fabrieken onderdeel van een grotere ondernemingsgroep.

Papier en kartonproductie bestaat uit de productie en voorbereiding van de vezels, de vorming van papier en droging. Het thermisch drogen van het papier is verantwoordelijk voor het grootste deel van het stoomverbruik.

Dit rapport presenteert gegevens over energie en emissies in 2015:

- Tien fabrieken maakten gebruik van warmtekrachtkoppeling (WKK) om te voorzien in (een deel van) hun stoomvraag. Het totaal elektrisch vermogen van deze installaties was 217 MW_e en het totaal thermisch vermogen 496 MW_{th}. De totale brandstofinzet was 14,7 PJ.
- Het finaal verbruik van elektriciteit in de Nederlandse papier- en kartonindustrie was 4,6 PJ. De totale elektriciteitsopwekking met WKK-installaties was 4,1 PJ.
- Het totale verbruik van stoom/warmte was 12,5 PJ, waarvan 62% (7,8 PJ) geproduceerd werd met WKK-installaties.
- De totale ETS emissies van de papier- en kartonfabrieken in Nederland waren in 2015 1.054 kton CO_2-eq.

Het MIDDEN kennisnetwerk

De data die zijn verzameld over de papier- en kartonindustrie dragen bij aan het datasysteem van het MIDDEN kennisnetwerk. Het MIDDEN project heeft als doel om de industrie, beleidsmakers, onderzoekers en de energiesector te ondersteunen in hun gezamenlijke doel om diepe decarbonisatie in de Nederlandse energie-intensieve industrie te bereiken.

Het MIDDEN datasysteem zal informatie bevatten over Nederlandse industriebedrijven die deelnemen aan het emissiehandelssysteem ETS, over verschillende mogelijkheden om de emissie van CO_2 te verminderen en de voorwaarden waaronder dit mogelijk is.

Alternatieve technologieën voor stoomproductie

Lux Research heeft enkele van de meest veelbelovende technologie-opties geselecteerd die een één-op-één vervanging kunnen zijn voor aardgasgestookte stoomketels die stoom produceren met een temperatuur tot 200 ºC. Voor de geselecteerde technologieën heeft Lux Research data verzameld en inschattingen gemaakt van waarschijnlijke toekomstige eigenschappen.

De volgende technologieën zijn onderzocht:

- **Terugwinning van restwarmte met een warmtepomp**: Warmte uit de omgeving of een reservoir wordt met behulp van elektriciteit in temperatuur verhoogd.
- **Directe elektrische verwarming**: Met directe elektrische verwarming kan stoom worden geproduceerd. Dit verschilt niet veel van een elektrische ketel, maar dan op een grotere schaal en bij hogere temperatuur en druk.
- **Verbranding van waterstof**: De industrie kan waterstof inkopen en verbranden in plaats van aardgas.
- **Elektrolyse**: In plaats van de inkoop van waterstof kunnen bedrijven ter plekke waterstof maken met elektrolyse. De waterstof kan dan worden verbrand om de gewenste temperatuur te bereiken.
- **WKK-systeem op basis van vergassing van biomassa:** Biomassa wordt vergast en het gas wordt gebruikt als brandstof voor een warmtekrachtkoppelingseenheid.

Andere opties (zoals geothermie, restwarmte van nabije industrie en biogas) kunnen ook een belangrijke rol spelen in de decarbonisatie van de stoomvoorziening. Lux Research heeft de overwegingen ten aanzien van de selectie van de technologieën toegelicht. Geothermie is niet geselecteerd omdat het alleen toepasbaar is voor industrie op een geschikte locatie. De mogelijkheid om restwarmte van nabije industrie te gebruiken hangt af van de aanwezigheid van aanbieders van restwarmte. Biogas wordt als een algemeen haalbare optie gezien, maar de toegevoegde waarde van het selecteren van biogas is als beperkt gezien omdat er al veel studies over het gebruik van biogas beschikbaar zijn.

Discussie

Het doel dat is gesteld voor het Nederlandse Klimaatakkoord is om in 2030 een reductie van de nationale broeikasgasemissies te bereiken van 49% (ten opzichte van 1990). De huidige Europese ambitie is om in 2050 een reductie van 80 tot 95% te bereiken. Dergelijke reductiedoelstellingen kunnen alleen worden bereikt door grote veranderingen in het Nederlandse energiesysteem.

De rol van elektrificatie

In dit rapport zijn drie technologieën onderzocht die kunnen bijdragen aan elektrificatie van de stoomvoorziening van de industrie: warmtepompsystemen, directe elektrische verwarming en elektrolyse.

Elektrificatie door middel van elektrische warmtepompen kan leiden tot significante energie-efficiëntieverbeteringen vergeleken met aardgasketels. Onderzoek- en ontwikkelingsinspanningen zijn er op gericht om de kapitaalkosten te verlagen en de uitgangstemperaturen te verhogen.

Elektrificatie door middel van weerstandsverwarming of elektrolyse leidt niet tot substantiële energie-efficiëntieverbeteringen, maar kan toch resulteren in emissiereductie in combinatie met CO_2-vrije elektriciteitsopwekking.

De eerste fase van elektrificatie kan plaatsvinden met hybride systemen. Dergelijke systemen kunnen gebruik maken van zonne- en windenergie die anders verloren zou gaan door curtailment.

De rol van waterstof

Vergeleken met elektriciteit heeft waterstof enkele voor- en nadelen. Het is gemakkelijker om waterstof op te slaan en met hoge dichtheid te transporteren. De productie van waterstof uit elektriciteit kan helpen om overschotten van zonne- en windenergie te benutten.

Een nadeel is dat het energieverbruik toeneemt omdat de ketenefficiëntie doorgaans lager is. Het gebruik van waterstof maakt meestal aanzienlijke aanpassingen bij energieverbruikers en veranderingen aan de infrastructuur noodzakelijk.

De technologie om waterstof te gebruiken en te produceren is al beschikbaar (bijvoorbeeld elektrolyse en waterstofbranders), maar deze technologieën zijn vaak nog niet concurrerend met de bestaande (fossiele) alternatieven.

De rol van biomassa

Biomassa heeft veel toepassingen in de energieproductie- en energieverbruikssectoren. Het kan worden gebruikt voor de productie van warmte, waterstof, elektriciteit, biobrandstoffen en voor specifieke industriële processen.

Het gebruik van biomassareststromen (bijvoorbeeld met de biomassavergassingstechnologie die wordt besproken in dit rapport) is een interessante optie. De beschikbaarheid van dergelijke reststromen is echter beperkt. Door het gebruik van andere soorten biomassa, zoals geïmporteerde houtpellets, kan een groter aandeel van de warmtevraag ingevuld worden.

Vanuit een lange-termijn perspectief kan het gebruik van biomassa in de industrie logisch zijn, in het bijzonder omdat biomassa in combinatie met CCS kan leiden tot negatieve emissies. CCS is echter alleen toepasbaar bij voldoende schaalgrootte, zoals bij grote industriële puntbronnen of industriële agglomeraties.

Het gebruik van biomassa in de industrie in plaats van fossiele brandstoffen maakt het mogelijk om de CO_2-uitstoot te verminderen. Het is echter wel van groot belang om de duurzaamheid van de biomassa te garanderen en de hoeveelheid broeikasgassen die vrijkomt in de keten te beperken.

De rol van geothermie

De industrie heeft maar beperkte ervaring met geothermie. In de diepe ondergrond is een grote hoeveelheid warmte beschikbaar. De mate waarin deze warmte kan worden toegepast in de industrie hangt af van de locatie en mogelijke neveneffecten. Geothermie speelt vaak een rol in kosten-optimale oplossingen voor diepe decarbonisatie van de industrie.

De rol van restwarmte

Industriële locaties kunnen restwarmte van andere industrie benutten als de restwarmteleverancier dichtbij genoeg is en warmtedistributie-infrastructuur aanwezig is. In clusters van industriële activiteit is het vaak mogelijk om aanbod en vraag van restwarmte bij elkaar te brengen. De industrie kan ook restwarmte leveren aan andere sectoren.

Algemene conclusie

Dit rapport bespreekt veelbelovende opties voor één-op-één vervanging van aardgasgestookte stoomketels in de industrie. Het biedt geen compleet overzicht van decarbonisatie van de stoomvoorziening.

Het succes van dergelijke technologieën is afhankelijk van toekomstige ontwikkelingen in het energiesysteem en energiebeleid, die vaak onzeker zijn. Er kunnen aanpassingen nodig zijn aan de energie opwekking, distributie en infrastructuur. Het zal niet zo zijn dat er één technologische oplossing is die in alle gevallen kan worden toegepast.

De klimaatuitdaging voor de energie-intensieve industrie is groot. Om de uitdaging succesvol aan te gaan is het essentieel om beter inzicht te krijgen in de huidige productiemethodes en de mogelijke verduurzamingsopties voor de Nederlandse industrie. Om hierover meer duidelijkheid te scheppen is samenwerking met de industrie essentieel.

Contents

Introduction

The Dutch paper and board industry is an energy-intensive sector that is actively searching for possibilities to reduce greenhouse gas emissions and to become more sustainable. In the production processes, large amounts of steam are used for drying. In the long term, the paper and board industry may be able to implement breakthrough technologies that do not require any steam. This report focuses on the medium term (up to 2030) and aims to give an overview of options for decarbonisation of the steam supply.

The energy transition requires completely new approaches. The industry is willing to invest in new methods of production, but is hindered by a lack of insight into developments in the energy system as a whole. There is also uncertainty about characteristics of technologies that are in an early stage of development. These uncertainties make it difficult to determine which technological options are the most attractive and how the limited financial resources for development can best be spent.

This report consists of two parts. The first part gives an overview of information on the paper and board industry of the Netherlands in 2015, which discusses production processes, material consumption, energy consumption, energy production, greenhouse gas emissions and production costs. To obtain this overview, the VNP, the KCPK and ECN part of TNO have compiled a dataset with detailed information on the Dutch paper and board mills.

The second part of the report discusses alternative technologies for the steam supply. Currently, boilers and combined heat and power (CHP) installations are generally used to produce steam. Lux Research has made an inventory of alternatives that may contribute to decarbonisation in the medium term. The results of Lux Research give insights into the costs and efficiencies of these technologies and explain where these technologies are being developed.

The possible role of these alternative technologies is discussed, based on expected developments in the energy system as a whole, such as the developments of energy prices, electricity generation and energy infrastructure.

1 The paper and board industry in the Netherlands

The Dutch paper and board mills produce different end products, use various input materials and are also different in their energy consumption and production.

This chapter provides an overview of information on the Dutch paper and board industry for the year 2015, with respect to:
- Product categories and production capacities;
- Production processes, specific energy consumption and material use;
- Energy consumption, energy production and greenhouse gas emissions;
- Investments, market prices of materials and operating and maintenance costs.

1.1 Methodology for data collection

For this report, ECN part of TNO, the *Royal Association* of Dutch Paper and Paperboard (VNP) and the Knowledge Centre for Paper and Cardboard (KCPK) have compiled a dataset with information about the Dutch paper and board industry. Most of the data have been obtained from an existing dataset of the VNP containing data on capacities, energy, materials and emissions in 2015. The data has been gap filled and corrected, and, in some cases, aggregated and rounded off to prevent confidentiality issues.

The MIDDEN knowledge network

The data that have been collected on the paper and board industry contribute to the data system of the MIDDEN knowledge network. The Dutch industry has to reduce its greenhouse gas emissions significantly in the coming years, and will eventually have to achieve a way of carbon-free production. The climate challenge for the energy-intensive industry is large. In order to meet this challenge, a better overview of the current production methods and possible sustainable improvement options for the Dutch industry is vital. This can only be done in cooperation with the industry.

That is why PBL and ECN part of TNO have initiated the knowledge network MIDDEN, in which industrial companies can combine their practical knowledge on the possibilities for CO_2-reduction and support the decisions for a Climate agreement.

MIDDEN stands for *Manufacturing Industry Decarbonisation Data Exchange Network*. The MIDDEN data system will contain information on Dutch industrial companies that participate in the Emissions Trading System (ETS), on different options to reduce the emissions of CO_2 and the conditions under which this is possible. MIDDEN has broad support of branch organisations and the government.

The MIDDEN project aims to support industry, policy makers, analysts and the energy sector in their common efforts to achieve deep decarbonisation of the Dutch energy-intensive industry. MIDDEN will become available for all knowledge workers, the industry and decision makers in the public domain. MIDDEN will make it possible to conduct consistent quantitative studies for deep CO_2-reduction in regions, sectors and material chains. PBL and 'ECN part of TNO' have asked for support of universities, RVO, NEa and CBS. The Ministry of Economic Affairs, the TKI Energy and Industry and Netbeheer Nederland are also involved in MIDDEN.

1.2 Product categories and production capacities

The Dutch paper and board industry produces different types of paper and board, each with their own characteristics (e.g. in terms of thickness and strength). These characteristics determine the possibilities for application.

In 2015, about 68% of the Dutch paper and board production consisted of packaging materials (corrugated board, solid board and folding boxboard), 28% of graphic paper (based on virgin and recovered fibre), and 4% of sanitary paper.

Product categories

For the data collection, the types of paper and board produced in the Netherlands were categorised as follows[1]:

- **Graphic paper**: The high quality of printing and writing paper used in e.g. magazines requires primary fibre pulp. The quality is related to the end product, as consumers demand a certain whiteness and brightness. This type is dominated by chemical pulping because of the requirement for a high level of brightness and good strength;
- **Graphic paper made from recovered paper:** Similar to graphic paper but produced from recovered paper. Mainly used for applications such as leaflets;
- **Corrugated board**: Corrugated board can consist of different combinations of layers of sheets produced from recovered pulp, mechanical pulp and chemical pulp. In the Netherlands mainly recovered pulp is used. This type of paper has a wide variety of applications but is mostly used for packaging;
- **Solid board**: Solid board consists of 100% recovered paper and has multiple applications e.g. book covers and food plates. Because of its applications, it does not require deinking;
- **Folding boxboard**: Folding boxboard can consist of different types of fibres and is typically used as packaging material of various food products. In the Netherlands this paper grade consists of recovered paper and mechanical pulp. Because of its application, the outer layer needs to be representative; the layers therefore undergo either deinking steps or bleaching;
- **Sanitary paper**: Sanitary paper can be produced from primary fibre or recovered fibre, and is used to produce e.g. toilet paper and tissues. The primary fibre is generally from chemical pulp. Sanitary paper needs to be strong, absorbent and soft.

[1] The categorisation and descriptions are based on the PhD thesis 'Energy use in the paper industry' [1]. Note however that the category 'newsprint' has been replaced by 'paper made from recovered paper', since newsprint is no longer produced in the Netherlands.

Production and production capacities

Figure 1 shows the production capacity per product type in 2015. The product types that take the largest shares of the production capacity are corrugated board (37%), solid board (25%), graphic paper (20%) and graphic paper from recovered paper (10%).

The production volumes, the number of mills and the number of paper machines are presented in Table 1. In 2015, there were 21 mills with a total production capacity of approx. 2,900 kton per year. The mills realised an average annual capacity utilisation of 92%.

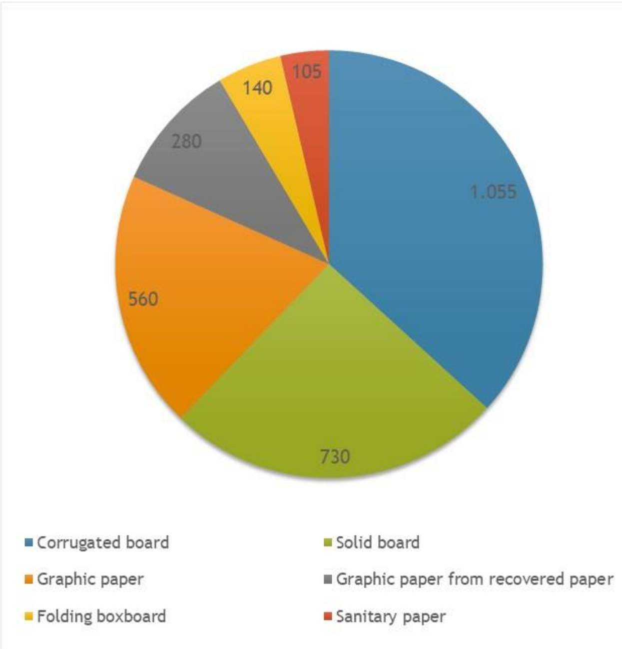

Figure 1. Paper machine capacity by product type in 2015 (kton/yr) (source: adapted VNP data)

Table 1. The number of mills, paper machine capacity, production and the number of paper machines by product type in 2015 (source: adapted VNP data)

Product type	Number of mills	Paper machine capacity (kton/yr)	Production (kton/year)	Number of paper machines
Corrugated board	4	1,055	992	22[2]
Solid board	7	730	655	11
Graphic paper	6	560	510	10
Graphic paper from recovered paper	1	280	252	1
Folding boxboard	1	140	133	1
Sanitary paper	2	105	97	4
Total	**21**	**2,870**	**2,639**	**49**

The annual production capacity of the individual mills ranged from 5,000 to 600,000 tons per year (see Table 2). Large mills typically produce bulk products, whereas smaller mills tend to produce more specialised products. Except for one, all of the paper mills are part of a larger corporate group.

[2] Note that this figure cannot be compared directly to the other categories, as it includes the machines of a paper mill that has a very different production process.

Table 2. Production sites in the paper and board industry in 2015 (source: adapted VNP data)

Product category	Name of production site	Corporate group	Town/locality	Production capacity (ton/year)
Corrugated board	DS Smith Paper De Hoop Mill	DS Smith	EERBEEK	350,000
	Huhtamaki Nederland BV	Huhtamaki	FRANEKER	35,000
	Papierfabriek Doetinchem B.V.	Papierfabriek Doetinchem B.V.	DOETINCHEM	70,000
	Smurfit Kappa Roermond Papier B.V.	Smurfit Kappa	ROERMOND	600,000
Folding boxboard	Mayr-Melnhof Eerbeek B.V.	Mayr Melnhof	EERBEEK	140,000
Graphic paper	Crown Van Gelder B.V.	Andlinger Company	VELSEN	240,000
	Marsna Paper B.V.	Marsna	MEERSSEN	5,000
	Papierfabriek Schut B.V.	Exacompta Clairefontaine SA	HEELSUM	5,000
	Sappi Maastricht BV	Sappi	MAASTRICHT	280,000
	VHP Ugchelen B.V.	VHP	UGCHELEN	5,000
	W.A. Sanders Coldenhove Holding B.V.	Neenah	EERBEEK	25,000
Graphic paper from recovered paper	Parenco B.V.	H2 Equity Partners	RENKUM	280,000
Sanitary paper	SCA Hygiene Products Cuijk B.V.	Essity	KATWIJK A/D MAAS (NB)	60,000
	Van Houtum Holding B.V.	WEPA	SWALMEN	45,000
Solid board	Eska Graphic Board Hoogezand	Andlinger Company	HOOGEZAND	170,000
	Eska Graphic Board Sappemeer	Andlinger Company	SAPPEMEER	110,000
	Smart Packaging Solutions B.V.	VPK Packaging Group	LOENEN	70,000
	Solidus Solutions Board B.V. loc. Bad Nieuweschans	Solidus Solutions	BAD NIEUWESCHANS	120,000
	Solidus Solutions Board B.V. locatie Coevorden	Solidus Solutions	COEVORDEN	110,000
	Solidus Solutions Board B.V. locatie Hoogkerk	Solidus Solutions	HOOGHERK	90,000
	Solidus Solutions Board B.V. locatie Oude Pekela	Solidus Solutions	OUDE PEKELA	60,000

1.3 Production processes, specific energy consumption and material use

Paper and board production consists of the production and preparation of the fibres, formation of the paper, and drying. The thermal drying of the paper accounts for most of the steam use. The specific electricity consumption varies much more between paper types than the specific steam consumption. Depending on the required quality and characteristics of the end-product, each paper and board type uses a different set of material inputs.

Production processes

The production process consists of the production of pulp (from wood or recovered paper), and the production of paper or board. In the Netherlands, there is, with the exception of one mill, no pulp production from wood. The pulp is produced from either recovered paper or from imported virgin fibre. Therefore, the energy consumption in the Dutch paper and board industry is almost exclusively due to paper and board production processes.

For virgin fibres the preparation step consists mainly of refining of the fibres to create the required characteristics of the fibres for the paper or board product. For pulp produced from recovered paper, cleaning steps are required to remove unwanted elements (plastics, ash etc.) and, in some cases, de-inking and dispersion steps to remove int.

The pulp (~1% dry matter content) is then spread over the wire to form paper. After the press section, in which water is mechanically removed, the pulp (with now a dry matter content of ~50%) is guided over hot cylinders for thermal removal of the remaining water. For some products a coating is applied after the (pre) drying section to increase the strength or to improve the writability of the product. In the case of applying a coating, the paper, or board, is dried again using another set of cylinders (after-drying section).

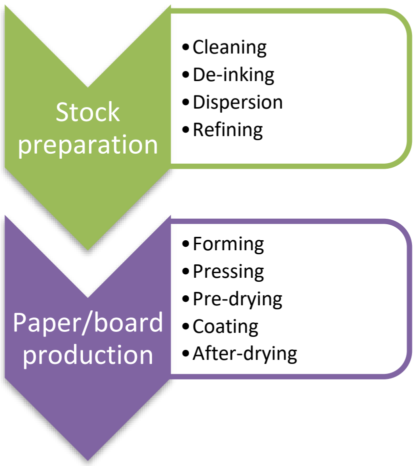

Figure 2. Steps in the paper and board production process

Steam is used to attain the required dry matter content of the end product. The steam temperature varies between 150 and 180°C (see Table 3). The steam is typically produced using a boiler or a combined heat and power (CHP) installation.

Table 3. Overview of used steam temperature per paper type (source: adapted VNP data)

Company name	Steam temperature drying section (max) [°C]	Steam pressure drying section (max) [barg]
Corrugated board	180	10
Graphic paper	150	5
Sanitary paper	165	7
Solid board	180	10
Folding boxboard	180	10
Graphic paper made from recovered paper	150	5

Specific energy consumption

Analysis of the data shows that the process step with the highest energy consumption is the drying step. The specific energy consumption for the drying step generally varies between 3.6 and 6.2 GJ/ton, and depends on the dry matter content of the pulp before going into the drying section, the need for coating, and the amount of energy recovery from the heat coming out of the drying section [1]. After evaporation of the water, the energy (in the form of waste heat) is only partially recovered via heat exchangers, due to a lack of application possibilities.

The specific electricity consumption varies much more between paper types than the specific steam consumption, as can be seen in Figure 3. The specific electricity consumption in the stock preparation can be high if (for quality reasons) deinking and dispersion is required, as is the case for graphic paper produced from recovered paper, and for sanitary paper.

Solid board and corrugated board production use relatively little electricity compared to their heat consumption, whereas sanitary paper and graphic paper made from recovered paper use a relatively large amount of electricity (mostly related to the energy required for the deinking steps of these mills).

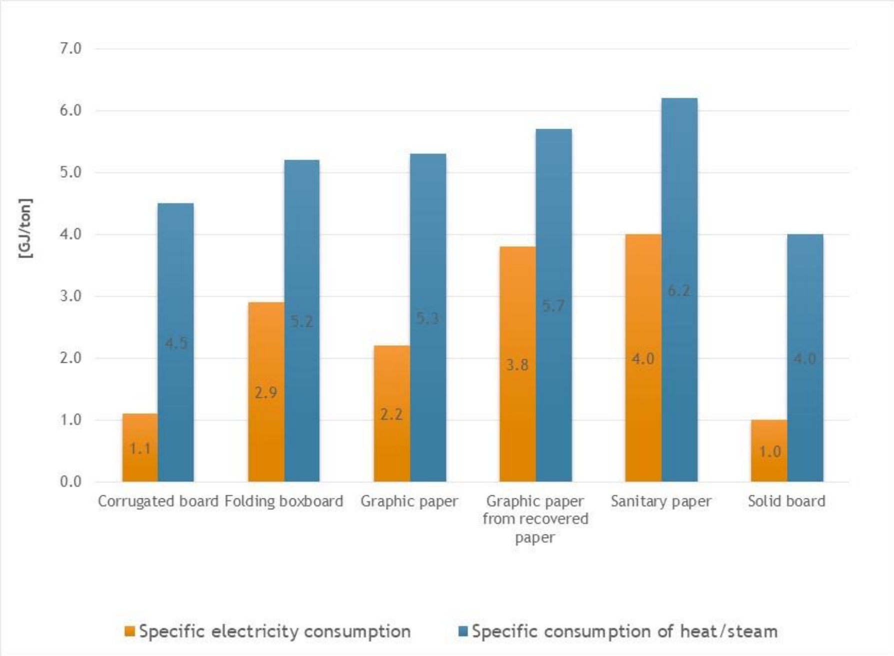

Figure 3. Specific energy consumption of heat/steam and electricity per product type in 2015 (source: adapted VNP data)

Material use

Depending on the required quality and characteristics of the end-product, each paper and board type uses a different set of material inputs (see Table 4). Graphic paper uses virgin pulp (chemical pulp) in order to obtain the required brightness, but also uses a large amount of filler material ($CaCO_3$). Folding boxboard also uses virgin fibre, but it uses mechanical pulp instead of chemical pulp. The other paper and board products are produced almost completely from recovered paper. Many mills also apply a coating to provide their product with strength or writability qualities. Especially maize or potato starch is utilised for coating.

Table 4. Overview of material consumption per paper type in 2015 (source: adapted VNP data)

	Recovered paper	Virgin fibre	Other
Corrugated board	96%		4%
Folding boxboard	32%	61%	7%
Graphic paper		63%	37%
Graphic paper made from recovered paper	89%		11%
Sanitary paper	99%		1%
Solid board	100%		

1.4 Energy consumption, energy production and greenhouse gas emissions

Energy consumption per mill

Figure 4 gives an overview of the steam/heat consumption and the final electricity consumption per mill. It demonstrates the large differences in scale between the mills. The bulk producing corrugated board and graphic paper mills (both virgin fibres and recovered paper based) have a significantly larger need for energy than the other mills. This is in stark contrast to the more specialised paper mills that produce a larger variety of products in much lower quantities.

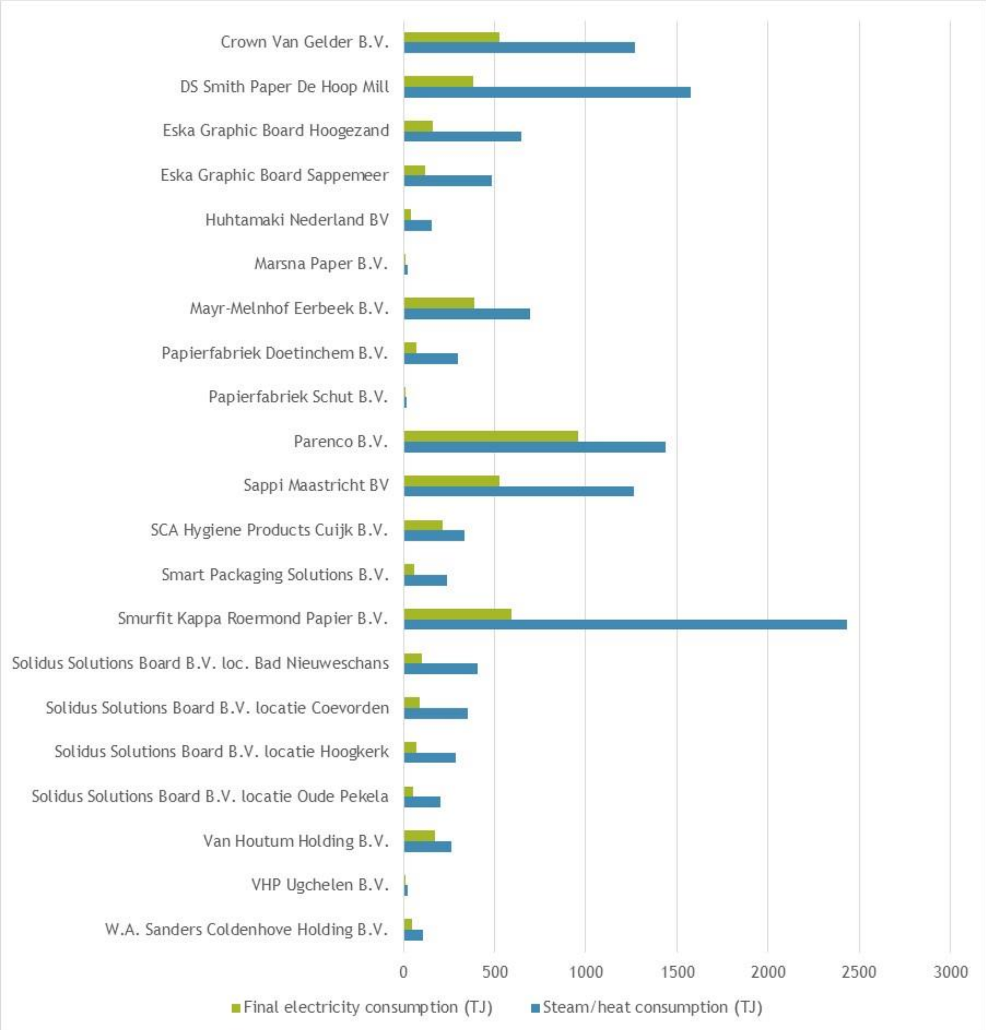

Figure 4. Overview of steam/heat consumption and final electricity consumption per mill in 2015 (source: adapted VNP data)

Combined heat and power (CHP)

In 2015, ten paper mills used combined heat and power (CHP) installations to cover (part of) their steam demand. The total thermal capacity of these installations was 496 MW_{th} and the total electrical capacity was 217 MW_e. The total fuel input was

14.7 PJ. The total electricity production was 4.1 PJ and the total steam/heat production was 7.8 PJ.

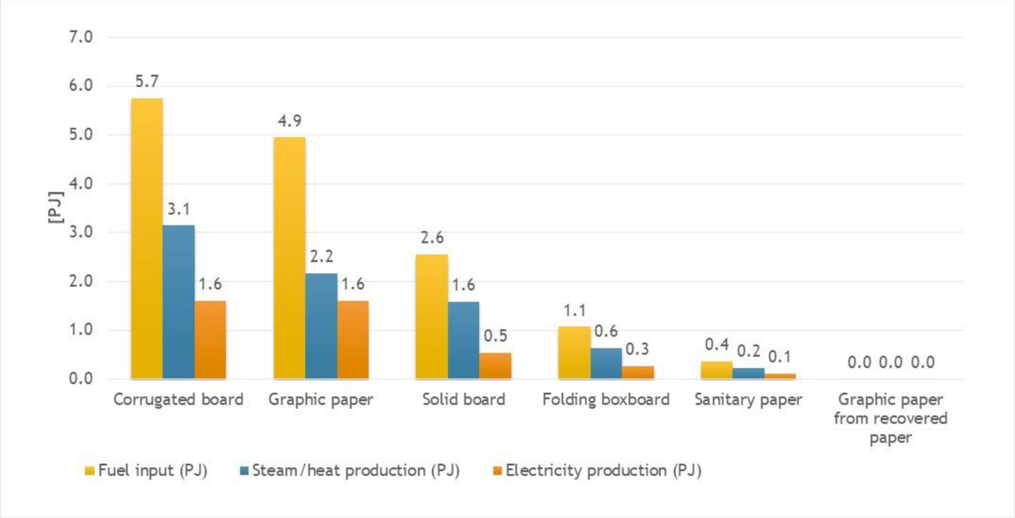

Figure 5. Fuel input, steam production and electricity production of CHP installations in 2015 (source: adapted VNP data)

	Electrical CHP capacity [MW_e]	Thermal CHP capacity [MW_{th}]
Graphic paper	93	213
Corrugated board	84	131
Solid board	24	115
Folding boxboard	13	22
Sanitary paper	4	15
Graphic paper from recovered paper	0	0
Total	**217**	**496**

Figure 6. Electrical and thermal capacity of CHP installations in the paper and board industry in 2015 (source: adapted VNP data)

According to Statistics Netherlands (CBS), in 2015 there were 25 CHP-installations in the Dutch paper and board industry with a total electrical capacity of 309 MW_e.[3] The Dutch paper and board industry has previously invested heavily in combined heat and power installations to meet their energy demand. Due to unfavorable gas and electricity prices, some of these have been decommissioned, and therefore no longer appear in the database of the VNP, but are still included in the statistics of CBS.

3 Source: Elektriciteit; productie en productiemiddelen, Statistics Netherlands (CBS) (preliminary data for 2015).

Final electricity consumption

The final electricity consumption in the Dutch paper and board industry was 4.6 PJ in 2015. The total electricity generation by CHP installations was 4.1 PJ. Part of the electricity produced by the CHP installations is sold to the grid.

For the product types 'Graphic paper' and 'Corrugated board', there are several mills whose production of electricity (by their CHP installations) exceeds their final electricity consumption. The net electricity consumption of these mills is negative.

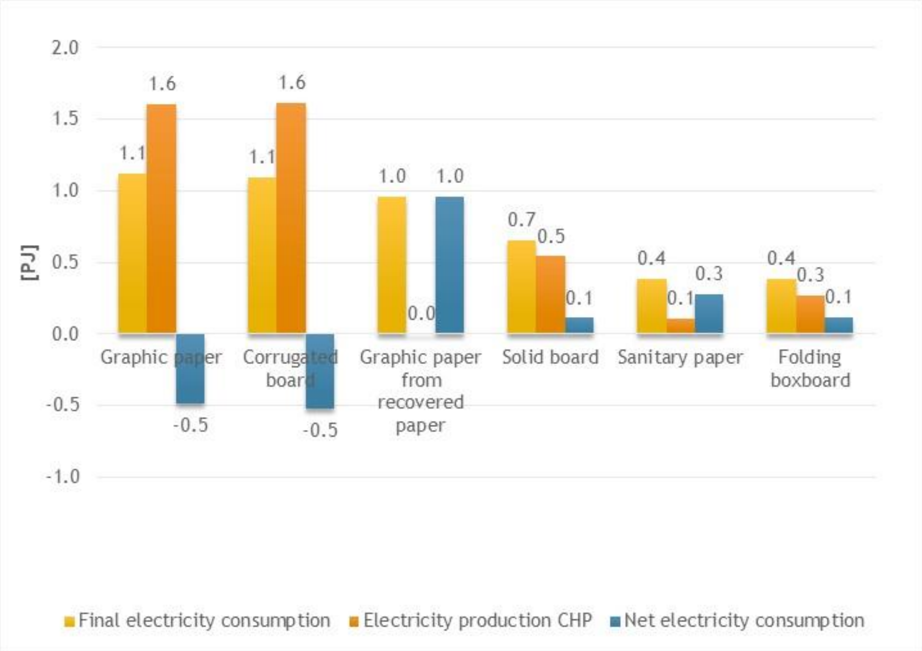

Figure 7. Final electricity consumption, electricity production of CHP and net electricity consumption per product type in 2015 (source: adapted VNP data)

Steam/heat consumption

Figure 8 shows the consumption of steam/heat per product type in 2015. The total consumption of steam/heat was 12.5 PJ of which 62% (7.8 PJ) was produced by CHP installations.

Most boilers and CHPs in the Dutch paper and board industry use natural gas to convert water into steam. One mill uses deinking sludge and biomass as fuel input. Aside for steam production, natural gas is also used for other forms of drying. Mills producing sanitary paper blow hot air against the paper in the drying section. There is one mill producing a type of packaging board that does not use any cylinders but uses mostly hot air for the drying of its products.

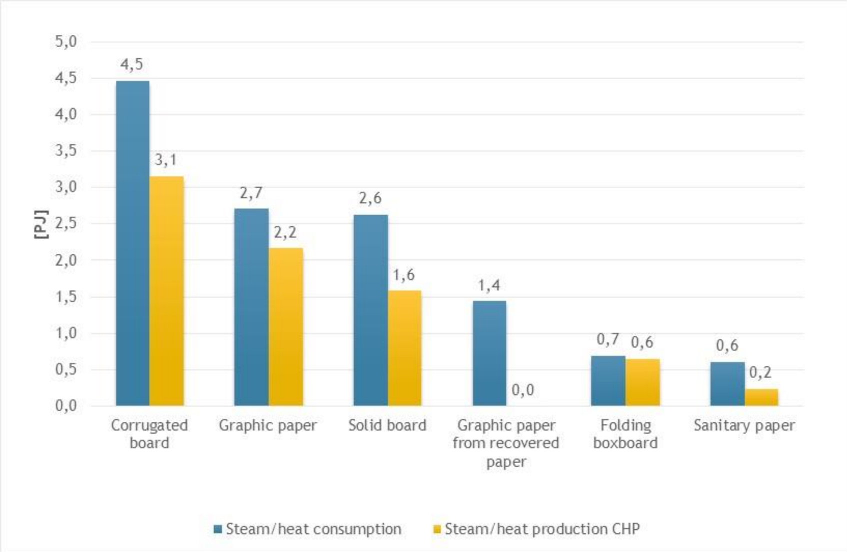

Figure 8. Steam/heat consumption and steam/heat production of CHP per product type in 2015 (source: adapted VNP data)

Greenhouse gas emissions

The greenhouse gas emissions of the paper mills that participate in the EU Emissions Trading System (EU ETS) are publicly available (see Table 5). The dataset of the Dutch Emissions Authority (NEa) has been linked to the dataset which has been compiled for this study.

In 2015, the total ETS emissions of the paper and board plants amounted to 1,054 kton CO_2-eq. Only VHP Ugchelen B.V. and Papierfabriek Schut B.V. did not participate in the ETS.

Table 5. Overview of ETS emissions per production site (source: Dutch Emissions Authority (NEa))

Production site	Town/locality	ETS emissions 2015 [kton CO_2-eq.]
DS Smith Paper De Hoop Mill	EERBEEK	216.5
Smurfit Kappa Roermond Papier B.V.	ROERMOND	162.7
Sappi Maastricht BV	MAASTRICHT	151.3
Crown Van Gelder B.V.	VELSEN	142.7
Mayr-Melnhof Eerbeek B.V.	EERBEEK	67.6
Eska Graphic Board Hoogezand	HOOGEZAND	59.6
Solidus Solutions Board B.V. loc. Bad Nieuweschans	BAD NIEUWESCHANS	37.4
Eska Graphic Board Sappemeer	SAPPEMEER	32.8
Solidus Solutions Board B.V. locatie Oude Pekela	OUDE PEKELA	24.3
Van Houtum Holding B.V.	SWALMEN	23.4
Solidus Solutions Board B.V. locatie Coevorden	COEVORDEN	21.9
Papierfabriek Doetinchem B.V.	DOETINCHEM	20.2
SCA Hygiene Products Cuijk B.V.	KATWIJK A/D MAAS (NB)	19.5
Parenco B.V.	RENKUM	18.8
Solidus Solutions Board B.V. locatie Hoogkerk	HOOGHERK	17.2
Huhtamaki Nederland BV	FRANEKER	12.9
Smart Packaging Solutions B.V.	LOENEN	12.6
W.A. Sanders Coldenhove Holding B.V.	EERBEEK	10.1
Marsna Paper B.V.	MEERSSEN	2.7
VHP Ugchelen B.V.	UGCHELEN	-
Papierfabriek Schut B.V.	HEELSUM	-
Totaal		**1054.2**

Figure 9 shows the share of each product type in the EU ETS greenhouse gas emissions of the paper mills in 2015. The contributions of production of corrugated board (42%) and graphic paper (31%) are the largest.

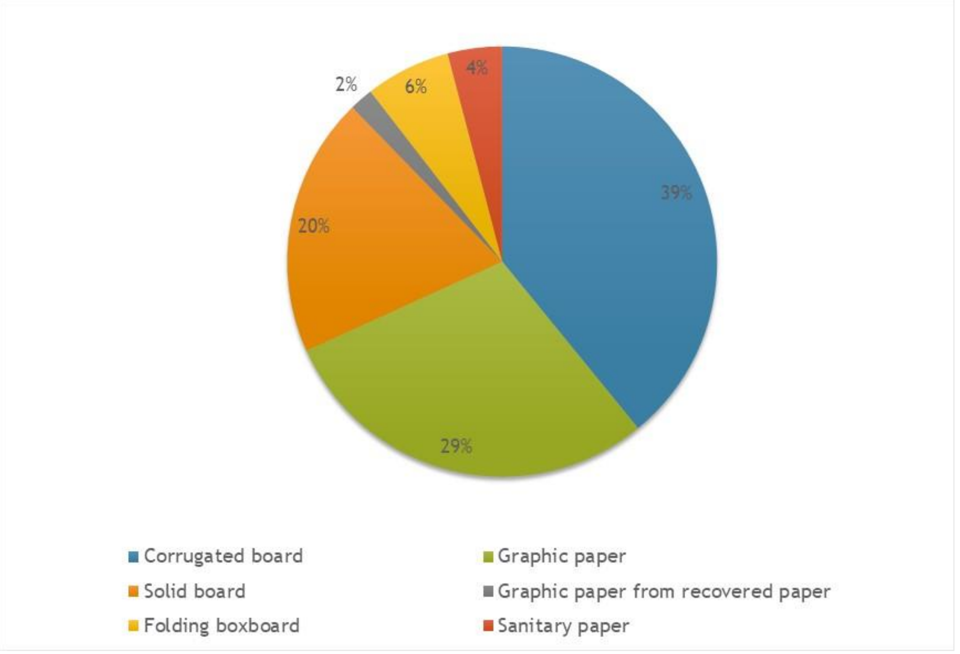

Figure 9. Share of ETS greenhouse gas emissions per product type in 2015 (source: adapted VNP data and NEa data)

1.5 Investments, market prices and O&M costs

In 2015, the paper and board industry had 3,896 employees and a total revenue of 1.7 billion EUR [2]. A large share of the total cost of paper and board production comes from the cost for raw materials. This section also discusses investments and operation and maintenance (O&M) costs.

Investments

The paper and board industry is a sector that is characterised, for the most part, by bulk production. The investments per paper machine can exceed half a billion euro (see Table 6). The frame of the paper machine can generally last a very long time, but its individual components (wire section, presses, drying hood, cylinders, etc.) need to be replaced more regularly. An overhaul is assumed to take place every 15 years.

Investments are necessary for the stock preparation as well as the paper machine. Table 6 shows that the paper machine equipment, consisting of the heavy machinery needed to form, press and dry the paper and high speed drives, is far more capital intensive than the equipment required for the stock preparation. The table also shows that larger paper machines are less expensive than smaller ones, when compared per installed unit of capacity.

Table 6. Investment costs for paper machines and stock preparation (source: estimate by VNP)

	Capacity (ton/yr)	Investment (mln euro)	Investment per unit of annual capacity (euro/ton)
New paper machine	80,000	250	3,125
New paper machine	400,000	500	1,250
New paper machine	500,000	600	1,200
Stock preparation	400,000	3.0	8
Stock preparation	500,000	4.0	8

Market prices for materials

Much of the production cost in paper and board production is related to the cost of raw materials [3]. Note that the prices for virgin fibres can be higher, per ton, than the market price of the graphic paper for which it is the feedstock. The reason for this is that a significant amount of the input material for these types of paper consists of fillers, which cost far less, thereby compensating for the price of the pulp.

Table 7. Market prices for materials in 2017 (source: VNP)

Material	Market price (€/ton)
Old paper (mixed)	129
Pulp; Cellulose, Northern bleached softwood kraft (NBSK)	788
Pulp; Cellulose, Bleached eucalyptus kraft pulp (BEKP)	836
Graphic paper	628
Newsprint	431
Uncoated mechanical	550
Coated mechanical	619
Uncoated woodfree	811
Coated woodfree	729
Corrugated board	629
Containerboard Virgin fibre	699
Containerboard Recycled Paper	559
Sanitary paper (Frankrijk)	920
Solid board	375
Folding boxboard	891
Cartonboard coated duplex	1,065
Cartonboard White-lined chipboard	717
Specialty paper	900

Operation and maintenance costs

Operation and maintenance (O&M) costs[4] are an important part of the operational costs in paper and board production. Estimates for the operation and maintenance costs (see Table 8) were provided by the Knowledge Centre for Paper and Cardboard (KCPK), using a report of the Technopolis Group [3]. The O&M costs are relatively high for sanitary paper and relatively low for corrugated board.

Table 8. Assumptions on operating and maintenance costs (source: KCPK)

[€2014/ton_product]	Operating and maintenance costs (O&M)
Corrugated board	64
Graphic paper	84
Sanitary paper	132
Solid board	94
Folding boxboard	94
Graphic paper made from recovered paper	83

[4] The costs for energy and raw materials are not included in the O&M costs.

2 Alternative technologies for steam production

In the report “Taking the C out of steam”, Lux Research presents an inventory of technologies that could replace boilers in the industry [4]. This chapter gives an overview of the selected technology options. It considers the technology characteristics and the cost of generating steam. The results are discussed in the context of the targets for greenhouse gas emissions reductions in the industry.

2.1 Overview of selected technologies

Lux Research has selected some of the most promising technology options for a drop-in replacement for natural-gas fired steam boilers that produce steam of up to 200 ºC. Table 9 gives a brief description of these technologies.

Table 9. Technology options selected by Lux Research. Source: [4].

Technology	Description	Maturity
Direct electric heating	Steam can be raised using direct electric heating. This is not much different from an electric kettle, just operating on a much larger scale and at higher temperatures and pressures.	Scaling. Electric steam boilers exist and are commercially available.
Electrolysis	Rather than buying hydrogen, companies could generate hydrogen on-site using electrolysis and then burn the hydrogen to generate the desired temperature.	Introduction. The first large-scale electrolysers are now being deployed.
Biomass gasification based CHP system	Biomass is gasified and the gas is used to run a CHP unit.	Introduction. A couple of commercial gasification based CHP units exist. This technology is on the brink of market introduction.
Heat pump recovering waste heat	Heat from the environment or a reservoir is raised to a higher temperature level using electricity.	Scaling for low temperature, still development for temperature above 80 ˚C.
Hydrogen combustion	The industry could buy hydrogen and burn that instead of natural gas.	Scaling. The technology to combust hydrogen is available and used in many applications already.

Other options (such as geothermal energy, waste heat from nearby industry and biogas) can play an important role in decarbonisation of the steam supply as well. Lux Research has explained the considerations for the technology selection [4]. Geothermal energy has not been selected as it is only applicable to industry that is located in a suitable place. The possibility to use waste heat from nearby industry depends on the availability of suppliers of waste heat. Biogas is considered to be a viable option, but the added value of selecting biogas was considered to be limited, as there are already many studies on using biogas.

For the selected technologies, Lux Research has collected data and made estimations regarding their likely future performance. Table 10 summarizes the characteristics of the technology options.

Table 10. Characteristics of technology options. Source: [4]

	Direct electric heating	Electrolysis	Biomass gasification based CHP system	Heat pump recovering waste heat	Hydrogen combustion
CAPEX equipment only	0.15 EUR per W steam output	1.36 EUR per W steam output	2.66 EUR per W steam output	0.2 EUR per W thermal output	0.1 EUR per W steam output
CAPEX including installation	0.45 EUR per W steam output (high because of electricity connection)	2.50 EUR per W steam output	4.80 EUR per W steam output	0.5 EUR per W thermal output	0.25 EUR per W steam output
Effective COP	-	-	-	3.5	-
Refurbishment interval of the installation	10 years	10 years	15 years	10 years	20 years
Electric output	-	-	0.875 W per W steam output	-	-
Overall energy efficiency	90%	73%	67% (energy used from biomass input)	-	85% (on HHV)

The characteristics are based on an installation size of 15 MW and a 2,000 units production volume. Calculations based on these characteristics can give rough insights into the possible effects and costs of applying the technologies. In reality, the characteristics will depend on the specific application, such as the required steam temperature and other aspects of the production process.

Figure 10 shows how much fuel or electricity is needed to produce 1 GJ of steam with each of the selected technology options. The figure only shows the net energy consumption at the production site. Energy that is consumed elsewhere (for example to produce electricity or hydrogen) is not included. The biomass-based CHP system produces electricity, and therefore has a net output of electricity. Using electrolysis (to produce hydrogen which is then burned) requires more electricity than direct use of electricity for heating.

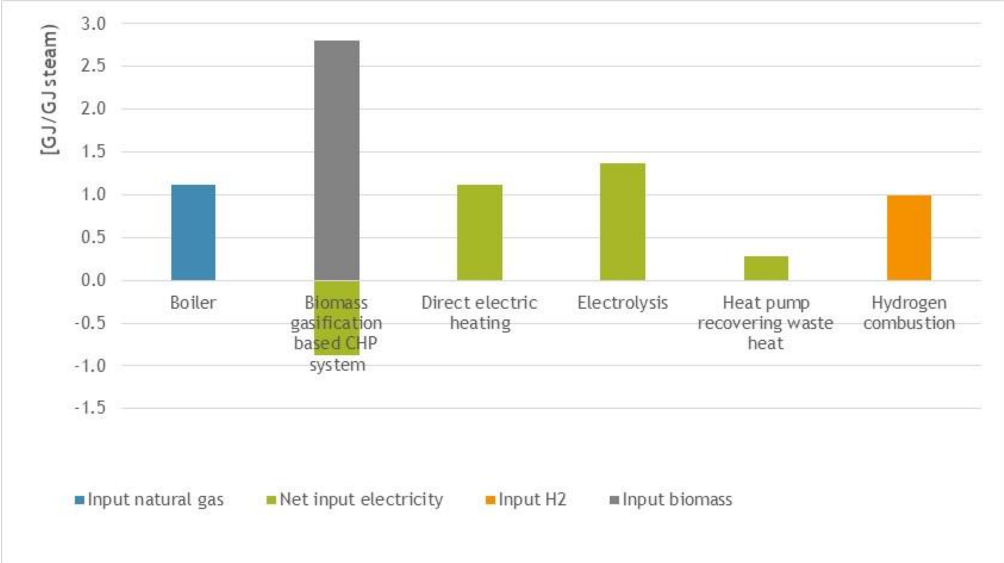

Figure 10. Consumption of fuel/electricity to produce 1 GJ of steam for the selected technologies based on the technology characteristics in [4] and boiler efficiency of 90%.

2.2 Development of energy and CO_2 prices

The future developments of the natural gas, electricity and CO_2 prices are highly uncertain. The energy and CO_2 prices used in this report are based on the reference scenario of the National Energy Outlook 2017 (NEV 2017) [5].

The NEV 2017 provides insight into developments in the Dutch energy system in an international context. The reference scenario incorporates external factors, such as the economy, demographics and fuel and CO_2-prices. The reference scenario has two policy alternatives. Here, the policy alternative ‘Proposed policy measures’ (VV) is used.

Two scenario variants are used for a sensitivity analysis (see [6]):
- ‘VV-H’ is a scenario variant with higher energy and CO_2 prices.
- ‘VV-L’ is a scenario variant with lower energy and CO_2 prices.

Figure 11 shows the development of the natural gas price in the reference scenario (VV) and the two scenario variants. In the reference scenario, the natural gas price is expected to increase but there is a substantial bandwidth. The long term price developments for natural gas are based on projections of the International Energy Agency (IEA). The bandwidths for the natural gas price are based on the long term WLO outlook [7].

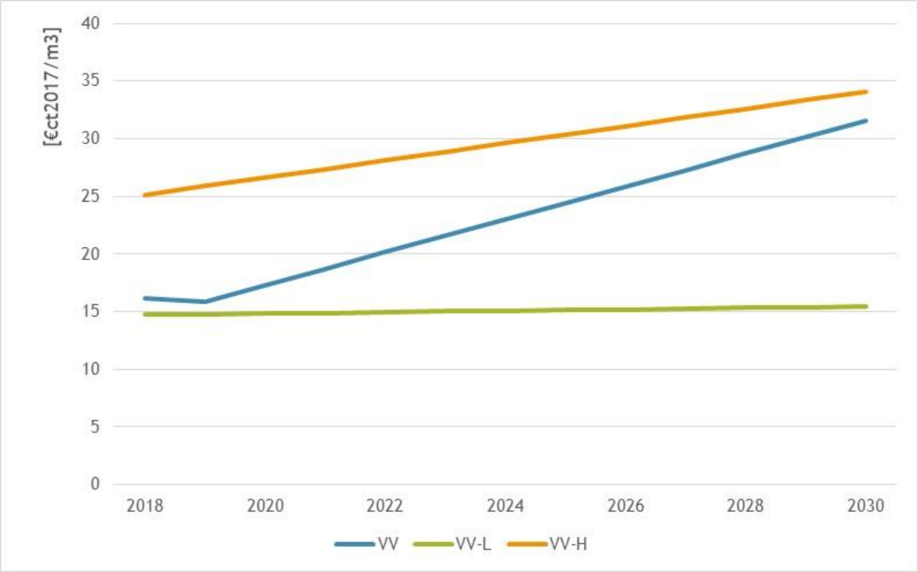

Figure 11. Development of the natural gas price per scenario variant. Source: [6]

The CO_2-price is expected to remain low in the near future (see Figure 12), but increasing scarcity of emission allowances is projected to drive up the CO_2-price in the longer term. The uncertainty bandwidth for the CO_2-price in 2030 ranges from 12 to 79 euro/ton.

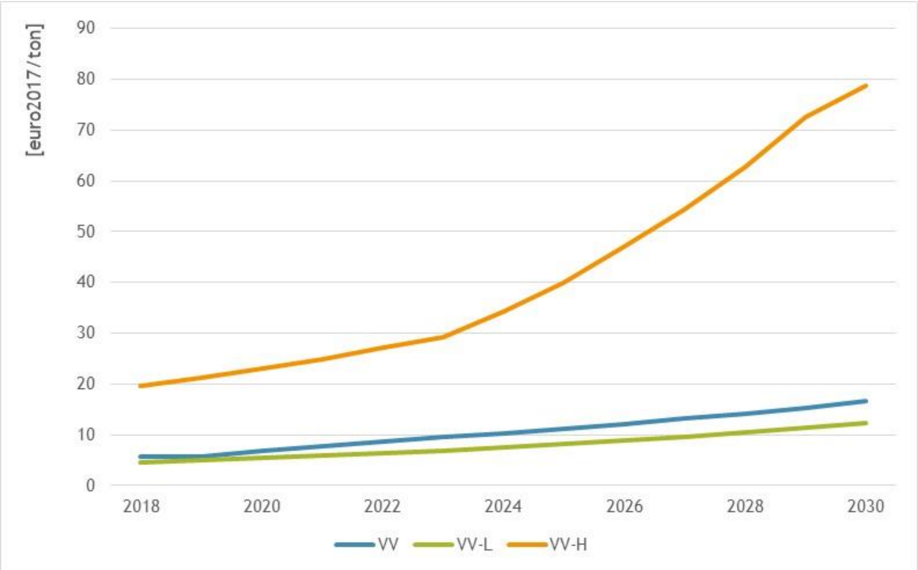

Figure 12. Development of the CO_2 price per scenario variant. Source: [6]

Fuel and CO_2 prices are important determining factors for the electricity price. The growth of renewable electricity generation has an important impact as well. Developments in other countries are of increasing importance for the Dutch trade balance of electricity and the electricity prices, because of increasing interconnection capacities and integration of the European energy markets. Figure 13 shows the development of the electricity prices in the reference scenario (VV) and the two scenario variants.

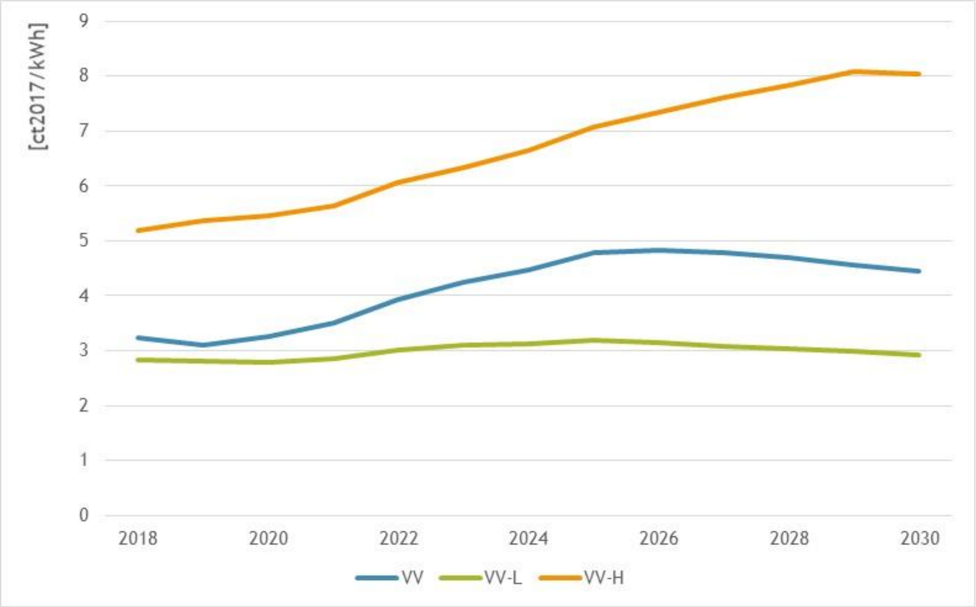

Figure 13. Development of the electricity price per scenario variant. Source: [6]

2.3 Results per technology

Based on the technology characteristics and the price scenarios, capital costs, fuel costs, electricity costs and CO_2-costs have been calculated for each technology.

Direct electric heating

The technology ‘direct electric heating’ uses a large electric resistor to produce steam. Water and electricity are entering the system and steam is leaving. The overall emission reduction that can be realised depends on the CO_2-intensity of electricity generation.

Electrolysis

The technology ‘electrolysis’ is similar to hydrogen combustion, but in this case the hydrogen is generated on-site using electricity from the grid. An electrolyser produces hydrogen and oxygen that then feeds a boiler which has been retrofitted with hydrogen burners. The burner can use oxygen or enriched air, which results in less degradation of the boiler capacity and a higher efficiency.

Biomass gasification based CHP system

Pulp and paper plants have side streams of reject materials and other biomass materials that do not end up in the final paper and board products. For the technology option ‘Biomass gasification based CHP system’, it has been assumed that the residues are fed into a gasifier coupled to a gas engine. The system supplies heat (steam) and electricity. The gas that is generated needs to be of sufficient quality to be used in gas engines. The application of the technology is limited by the availability of reject materials and other biomass materials.

Heat pump recovering waste heat

The technology ‘heat pump recovering waste heat’ uses waste heat of about 60°C in combination with a heat pump to generate steam of 120°C. Heat pumps are more efficient than direct electric heating.

Hydrogen combustion

For the technology option ‘hydrogen combustion’, it has been assumed that burners of natural gas boilers are replaced by burners using hydrogen. Hydrogen is burned using air. This technology does not require major investments, but it means that a more expensive fuel has to be bought.

Figure 14 shows the capital costs per technology per unit of steam. The biomass gasification based CHP system and the electrolysis require the largest investments per unit of capacity. The capital costs have been calculated using a discount rate of 10% in an annualised net present value calculation. It was assumed that the annual number of full-load hours is 8,000 for each of the technologies. In reality, the number of full-load hours may vary from year to year and depend on the situation.

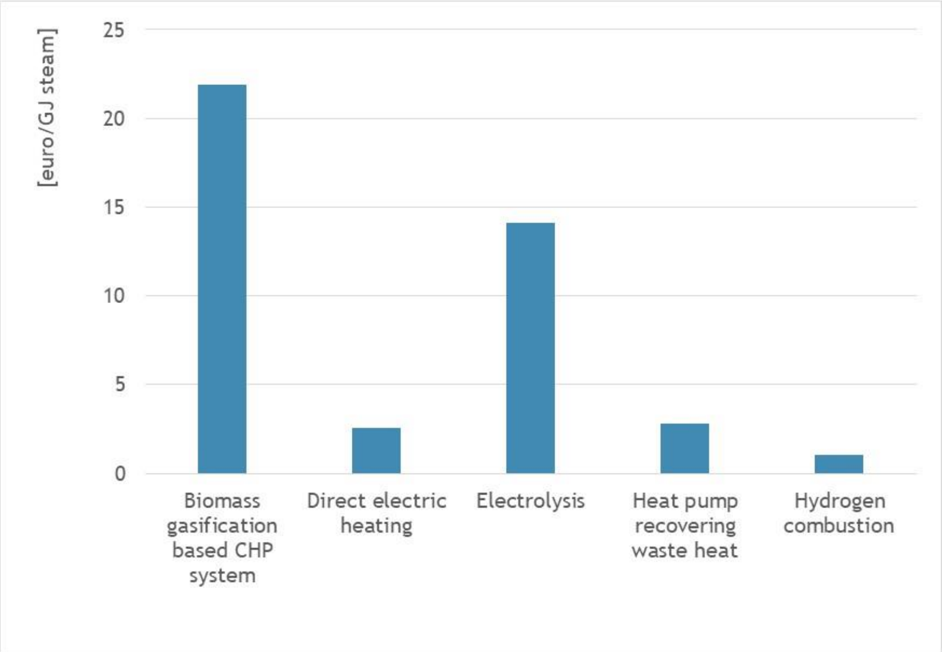

Figure 14. Capital costs per technology per unit of steam (based on [4] and additional assumptions)

Figure 15 shows the energy and CO_2 costs per technology per unit of steam. It has been assumed that the installations become operational in 2025 and therefore energy and CO_2 prices for the years 2025 onwards have been used.

Of the three electricity-consuming technologies, the energy costs for the heat pump system are the lowest. The heat pump has an effective COP of 3.5 and therefore uses less electricity than the direct electric heating system (with overall efficiency of 90%) and the electrolysis system (with overall efficiency of 73%).

The net energy costs of the biomass gasification based CHP system are negative. It has been assumed that the avoided costs for disposing of reject materials is 80 euro/ton (with a range of 60-100 euro/ton).[5] For this CHP system, there are also benefits from the sales of electricity. The required investment for this technology is relatively high. The attractiveness depends on the quantity and the price of available reject materials and other biomass materials.

For the production of hydrogen, several routes and technologies exist. Currently, steam methane reforming (SMR) of natural gas is the most widely applied technology. Other options include electrolysis of water and the production hydrogen from biomass [8] The costs of hydrogen depend strongly on the situation and availability of infrastructure. For hydrogen delivery (based on steam methane reforming with CCS) costs of 2.2 euro/kg hydrogen are assumed.[6]

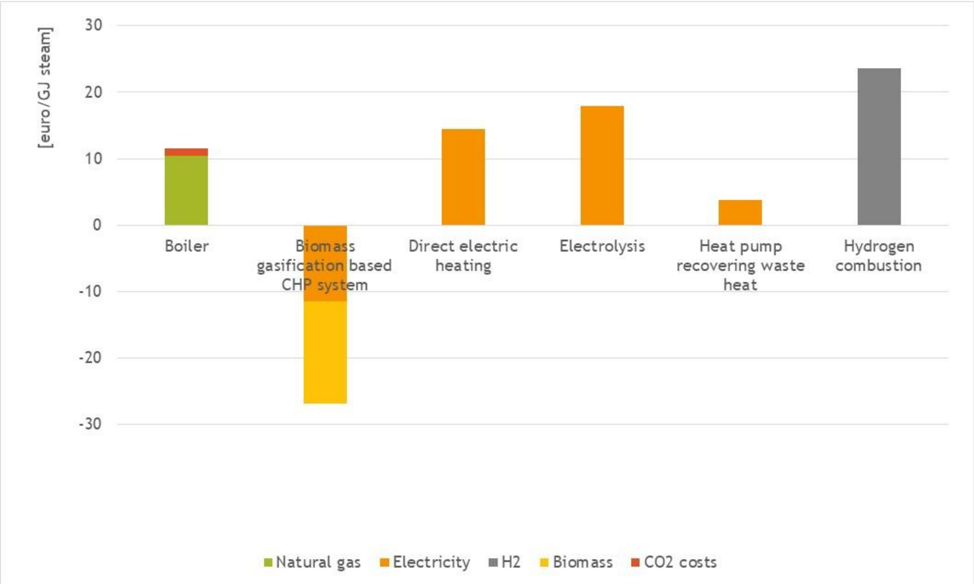

Figure 15. Net energy and CO_2 costs per technology per unit of steam (scenario VV) (based on [4] and additional assumptions)

Figure 16 shows the results of a sensitivity analyses for lower and higher energy and CO_2 prices. The VV-scenario is the scenario with implemented and proposed policies of the National Energy Outlook 2017. VV-H is a scenario with higher prices and VV-L is a scenario with lower prices.

[5] The lower heating value of the reject materials is assumed to be 14.6 MJ/kg.

[6] The lower heating value of hydrogen is 120 MJ/kg. The production costs of hydrogen are assumed to be 1 €/kg H_2. With large-scale production of hydrogen through SMR, the natural gas makes up 70-80% of production costs (~0.75 €/kg H_2). [8]

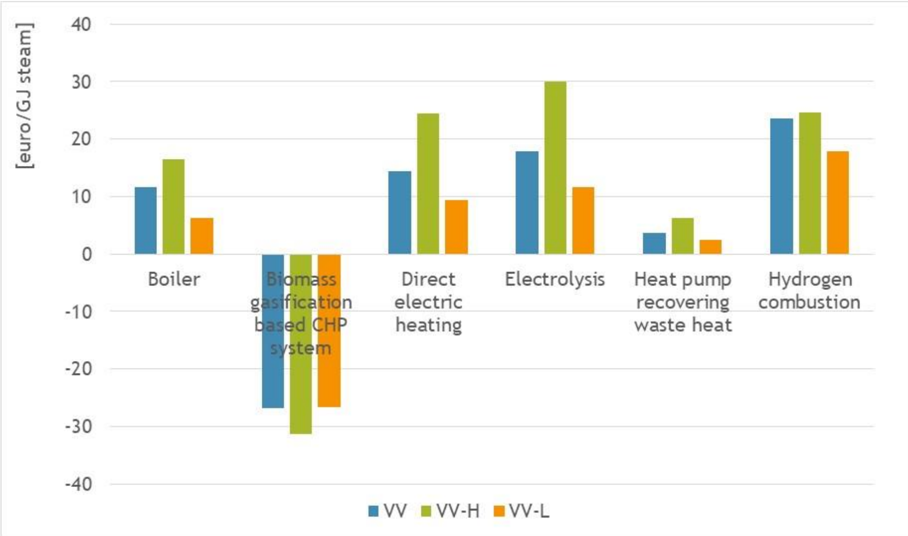

Figure 16. Energy commodity costs and CO_2-costs for heat generation per technology in the VV, VV-L and VV-H scenario's

Figure 16 does not provide a full overview of the costs of application of the technologies. There are several cost components that have not been quantified, such as the energy taxes, energy tariffs, operating and maintenance costs, subsidies. Many technology characteristics depend on the specific situation in which the technology is applied. The figure therefore only gives rough insights into the energy cost differences between the technologies.

2.4 Discussion

The goal that has been set for the Dutch Climate Agreement is to reach a reduction of the national emission of greenhouse gases by 49% in 2030 (compared to 1990). The current European ambition is to reach a reduction of 80 to 95% in 2050. Such reduction targets can only be reached through major changes in the energy system of the Netherlands.

To support the negotiations on the Climate Agreement, PBL has written a report on the most recent insights regarding the cost effectiveness (expressed in euro per ton avoided CO_2) of different CO_2-emission reducing measures and the potential for emission reduction in 2030 [9]. PBL concludes that energy efficiency improvements, electrification of the heat demand, CCS and the use of biomass are important options for emission reduction in the industry up to 2030.

This section discusses the potential role of available options to reduce the greenhouse gas emissions from the production of steam in the industry.

The role of electrification

This report has looked into three technologies than can contribute to electrification of the steam supply of the industry: heat pump systems, direct electric heating and electrolysis.

Electrification using electrical heat pumps can give rise to significant energy efficiency improvements compared to natural gas boilers. In the paper industry, waste heat is available from the dryer sections at approximately 60 °C. Because the required steam temperatures in the paper industry are lower than in most other energy-intensive industrial sectors, heat pumps are a good match. Research and development efforts are ongoing to reduce the capital expenditures and to increase the output temperatures.

Electrification using resistors or electrolysis does not lead to substantial energy efficiency improvements, but can still result in emission reduction when combined with CO_2-free electricity generation.

In the near future, electrification may not always lead to emission reduction, because the emissions from electricity generation are still substantial. However, the National Energy Outlook 2017 shows a clear downward trend in fossil electricity generation. It is projected that over half of all electricity will be generated by renewables in 2025 and it is expected that this share will rise to two-thirds in 2030 [5].

This trend is caused by a decrease of fossil generating capacity in the Netherlands and an increase of renewable electricity generation, in the Netherlands as well as in countries such as Germany. The transport capacity between the Netherlands and surrounding countries increases, which allows for more exchange of (renewable) electricity. This means that less conventional generation is needed for periods with low renewable generation.

The first phase of electrification may take place using hybrid systems. These systems allow to choose between direct electric heating and fossil heating (depending on the price of electricity). Such systems can use the solar and wind energy that would otherwise be lost through curtailment. The profitability and emission reduction potential of these systems depend on developments in the electricity market.

The PBL study “Verkenning van klimaatdoelen” presents analyses made with two integral energy models for the Netherlands [10]. The models calculate a cost optimal configuration of the energy system, using an emission reduction of 80 or 95% in 2050 as a boundary. In all variants, there is a clear shift from the use of fuels to the use of electricity. PBL concludes that electrification is a robust component of the energy transition.

The role of hydrogen

Compared to electricity, hydrogen has some advantages and some disadvantages. It is easier to store hydrogen and to transport it with high energy density. Production of hydrogen from electricity can help to make use of surpluses of solar and wind energy.

A disadvantage is that the energy consumption increases because the chain efficiencies are typically lower. Production of hydrogen from electricity has an efficiency of approximately 70%. [10] The use of hydrogen usually requires considerable measures on the side of the energy consumers and changes to infrastructure.

In cost-optimal solutions for long-term deep decarbonisation in the “Verkenning van klimaatdoelen” study, hydrogen production takes place predominantly from electricity (electrolysis of water) or from natural gas with carbon capture and storage (CCS) [10]. By conversion of natural gas to hydrogen and applying CCS, CO_2 emissions can be avoided.

The technology to use and produce hydrogen is already available (e.g. electrolysis, hydrogen burners), but these technologies are often not yet competitive with the current (fossil) alternatives [8].

The role of biomass

Biomass has many applications in the energy production and in the energy demand sectors. It can be used for the production of heat, hydrogen, electricity, biofuels and for specific industrial processes.

The use of biomass waste streams (e.g. using the biomass gasification technology discussed in this report) is an interesting option. The availability of such waste streams is however limited. Through the use of other types of biomass, such as imported wood pellets, a larger share of the heat demand can be fulfilled.

From a long-term perspective, the large scale use of biomass in the industry can be logical, especially because biomass in combination with CCS can result in negative emissions [9]. However, CCS can only be applied when the scale is sufficiently large, such as at large industrial point sources or industrial agglomerations.

The use of biomass in the industry instead of fossil fuels offers the possibility to reduce CO_2-emissions. It is however very important to guarantee the sustainability of the biomass and to limit the greenhouse gas emissions in the supply chain. A growing demand for biomass in other countries can make it difficult to obtain enough sustainable biomass. It can also drive up biomass prices. This is the reason that the use of biomass is not necessarily a robust element of a cost-effective reduction package according to PBL’s study into cost-optimal long-term solutions [10].

The role of geothermal energy

The industry has only limited experience with geothermal energy. A large amount of heat is available in the deep underground. The extent to which this heat can be used in the industry depends on the location and possible side effects. Geothermal energy often plays a role in cost-optimal solutions for deep decarbonisation of the industry [10].

The role of waste heat

Industrial locations can use waste heat from other industry when the waste heat supplier is nearby enough and heat distribution infrastructure is available. In clusters of industrial activity it is often possible to match supply and demand of waste heat. The industry can also deliver waste heat to other sectors.

General conclusion

This report discusses promising drop-in replacements for natural-gas fired steam boilers in the industry. It does not provide a complete overview of technological options for decarbonisation of the steam supply.

The success of such technologies is dependent on future developments in the energy system and energy policies, which are often uncertain. Changes may be required to energy generation, distribution and infrastructure. There will not be one technological solution that can be applied in all cases.

The climate challenge for the energy-intensive industry is large. Policy makers need information to create effective policies to stimulate the energy transition. The industry requires information to draw up roadmaps and gain a better understanding of the advantages and disadvantages of decarbonisation options. In order to meet the climate challenge, a better overview of the current production methods and possible sustainable improvement options for the Dutch industry is vital. To bring more clarity to these issues, cooperation with the industry is essential.

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