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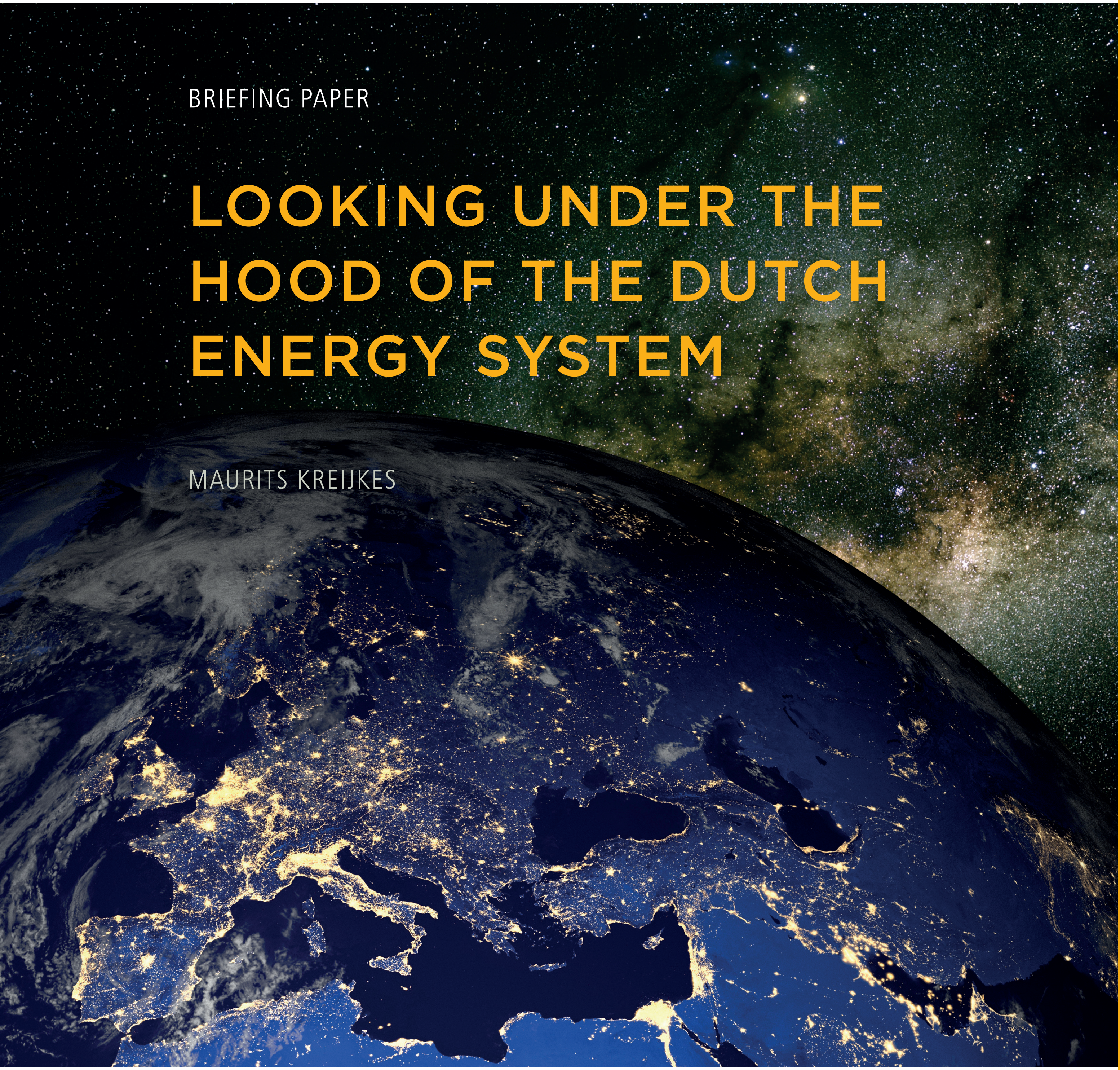

BRIEFING PAPER

LOOKING UNDER THE HOOD OF THE DUTCH ENERGY SYSTEM

MAURITS KREIJKES

CIEP BRIEFING PAPER 2017 | 01

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TITLE
Looking under the hood of the dutch energy system

AUTHOR
Maurits Kreijkes

NUMBER
Briefing paper 2017 I 01

EDITOR
Tom Johnson/Deborah Sherwood

DESIGN
Studio Maartje de Sonnaville

PUBLISHED BY
Clingendael International Energy Programme (CIEP)

ADDRESS
Clingendael 12, 2597 VH The Hague, The Netherlands
P.O. Box 93080, 2509 AB The Hague, The Netherlands

TELEPHONE
+31 70 374 67 00

EMAIL
ciep@clingendaelenergy.com

WEBSITE
www.clingendaelenergy.com

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1 INTRODUCTION

On 7 December 2016, the Dutch government submitted its *Energieagenda* to parliament, setting out a framework for the long-term energy policy of the Netherlands. The *Energieagenda*, which concluded a long process of consultation – including RLI's *Rijk zonder* CO_2 in September 2015, the government's *Energierapport* in January 2016, and the three-month 'Energy Dialogue' following it – outlined a long-term plan to decarbonize the Dutch economy. In the *Energieagenda*, reducing the share of fossil fuels and (partially) electrifying mobility and heating are identified as key to achieving the pledged 80-90% reduction of CO_2 emissions by 2050. Furthermore, the document sees CO_2 reduction as a way to cost efficiently balance the need for renewable energy on the one hand and energy saving on the other.

Insight into the Dutch energy system is needed to understand the magnitude of the transition announced in the *Energieagenda*. The functions of various energy flows in the Netherlands are often misunderstood. For decades, the Netherlands has been a net natural gas exporter, while its oil imports and processing industry serves both domestic and international markets. But its role as an energy transit country is underrepresented in most public debate. This role is important for neighbouring countries, which rely on the availability of flows while in transition themselves. Conversely, energy transition in neighbouring countries also impacts the function of the Netherlands as an energy transit country.

The Dutch energy-intensive economy is part of a larger energy market structure in Northwest Europe (NWE) and of the global commodity trade. This is distinct from many EU member states, which have more nationally-oriented energy systems with limited cross-border flows. The Netherlands has been a substantial natural gas producer and exporter to other EU member states for many decades. Its coastal location, multiple energy infrastructures, and large refining and petrochemical industry have shaped the country's energy system and the wider economy.

The international orientation and integration of the Dutch energy system is clear from its large energy throughput compared to its relatively small energy economy, indicating a contribution to the energy needs of other countries via re-exports. In fact, only a quarter of Dutch energy flows are actually destined for consumption within the Netherlands, leaving three-quarters for exports to EU or third countries.

Energy flows (predominantly oil) already contribute significantly to exports from the Amsterdam-Rotterdam-Antwerp (ARA) harbours. If NWE countries become more reliant on oil product imports, due to changes in inland refining capacities, ARA's importance as an energy gateway for Europe could increase further in the future. At the same time, demand for crude oil and oil products is projected to decline in NWE in the coming decades, as new energy technologies emerge in mobility, heating, and electrical appliances, and so new markets need to be found. Lowering its carbon footprint while maintaining its status in a declining NWE market presents a serious challenge to the position and function of ARA as a transit and processing hub.

Transition implies that the legacy structures of the energy system are part of the process of change, despite their functionality beyond the Netherlands. In this context, it is important to develop a more holistic perspective on current energy production, conversion and consumption in the Netherlands, to better understand what a transition could entail. Which energy carriers are important in which sectors, and what is their share in the energy mix? How do the fossil fuels interact, and how important are domestically produced fuels? This paper puts the importance of and reliance on specific resources into perspective at different levels of aggregation. Chapter 2 explores the in- and outflows of the energy system, breaking down the different forms of imports, exports, production and consumption. In addition, the flows of energy transported as 'molecules' related to 'electrons' provides an interesting comparison. Chapter 3 presents a case study on the Rotterdam industrial cluster, showing trends in low- and high-temperature heat integration. Through this combination of system-level and case-level analysis, *Looking under the hood of the Dutch energy system* provides a close examination of the current energy balance of the Netherlands, and aims to better inform the debate on energy policy in the coming years.

2 ENERGY FLOWS IN THE NETHERLANDS

THE DUTCH ENERGY BALANCE

The Dutch energy balance, as shown using a Sankey diagram[1] in Figure 1, is characterized by its large energy throughput compared to its relatively small energy economy, and hence its contribution to the energy needs of other EU member states, as a transit country. Together with domestic energy production (natural gas), processing and throughput have created a highly industrialized energy-intensive economy, which not only satisfies domestic and NWE demand but also supplies third countries. As a result, some Dutch CO_2 emissions are attributed to oil products refined in the Netherlands but destined for export, giving other countries the privilege of importing oil products without producing processing emissions themselves.[2]

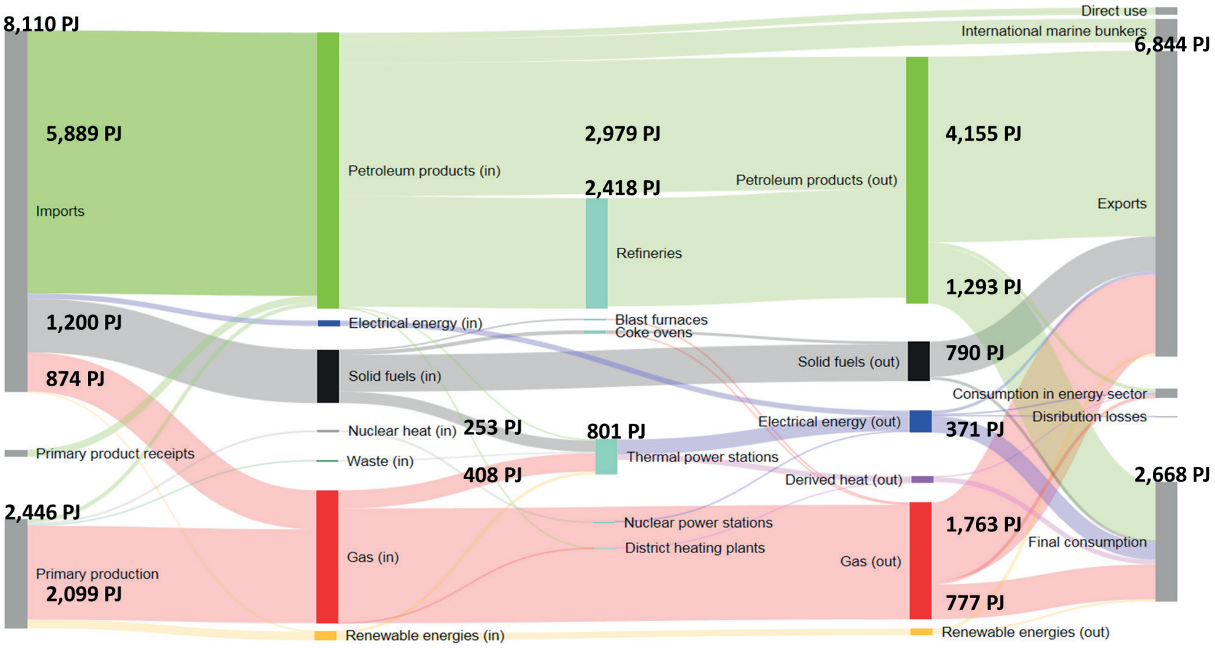

FIGURE 1: DUTCH ENERGY BALANCE 2014[3]

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1 Throughout this publication Sankey diagrams are used to visualize energy balances. The concept of these diagrams and how to 'read' them is explained in Annex A.

2 Border carbon adjustments, intended to address competitiveness concerns and carbon leakage, could stimulate effective climate mitigation. See, for example, Helm, D. (2012), 'The Carbon Crunch: How we are getting climate change wrong and how to fix it'.

3 International marine bunkers are not considered export nor consumption, as these products (mostly fuel oil) are consumed on international waters, used as fuel for the ship and not part of the cargo. Direct use is a special category where crude oil and/or natural gas liquids (NGLs) are consumed outside refineries; these are statistically corrected by the primary product receipts on the left-hand side of the Sankey. Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

IMPORTS

Dutch energy imports mainly consist of petroleum products (crude oil, kerosene, naphtha, diesel, etc.), solid fuels (mostly coal), and gas. Imports account for 76% of inputs in the Dutch energy balance. In other words, the Netherlands imports three times as much energy as it produces domestically. These imports, as Table 1 shows, mainly consist of petroleum products, as a result of the Netherlands' role in throughput and storage; Rotterdam ranks as the world's seventh largest port in terms of cargo tonnage (and the EU's number one port for liquid bulk), while Amsterdam is the number one global gasoline port.[4] Petroleum products going into the energy system are either directly exported (unprocessed), or converted in refining processes, before being exported or consumed domestically.[5] The importing of solid fuels (mostly coal) also contributes to the Netherlands' status as an energy hub, as only a small share is for domestic consumption (e.g. power generation and the iron and steel sectors), leaving the bulk for exports. The port of Rotterdam alone handles 60% of all seaborne coal imports to Europe.[6] Imports of natural gas to the Netherlands are also substantial, though outweighed by domestic production. The Netherlands has excellent gas importing facilities, with its LNG Gate terminal and the extensive (high-calorific) H-gas infrastructure connecting many countries on the continent.

TABLE 1: IMPORT OF ENERGY CARRIERS IN 2014[7]

Total Imports	**8,109 PJ**	**100%**
Petroleum product	5,889 PJ	73%
Solid fuel	1,200 PJ	15%
Gas	874 PJ	11%
Electricity	118 PJ	1%
Renewable energy	21 PJ	0%
Waste	7 PJ	0%

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[4] Based on American Association of Port Authorities 'World port rankings 2014', Port of Rotterdam, 'Top 20 havens van de wereld', and Port of Amsterdam, 'Facts and Figures'.

[5] Petroleum products are defined in Eurostat as all oil products and crudes together. Some of these petroleum products, like crude oil, can be converted by refineries into lighter petroleum products, such as gasoline, kerosene etc.

[6] Based on European Commission (2014), 'In-depth study of European Energy Security'.

[7] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

EXPORTS

The Netherlands exports more energy than it uses in domestic final consumption. High imports and exports illustrate the throughput function of the Netherlands to neighbouring counties such as Germany, as well as other countries both within and beyond Europe. This function is underpinned by the major throughput of petroleum products, as shown in Table 2. Natural gas is the only energy carrier of which the Netherlands was a net exporter in 2014, with the bulk of gas exports coming from domestic production. The net gas export position may change in the future, as a result of controls on production from the Groningen gas field, and the contraction of North Sea production.[8,9]

TABLE 2: EXPORT OF ENERGY CARRIERS IN 2014[10]

Total Export	**6,844 PJ**	**100%**
Petroleum product	4,155 PJ	60.5%
Gas	1,763 PJ	26%
Solid fuel	790 PJ	11.5%
Renewable energy	70 PJ	1%
Electricity	65 PJ	1%
Waste	1 PJ	0%

PRODUCTION

The Netherlands produces only a few types of energy carriers domestically, of which the vast majority is natural gas, as Table 3 shows. This is a result of the discovery of the very large Groningen gas field in May 1959, which triggered rapid growth of natural gas production and consumption.[11]

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[8] The gas production of the Groningen field is capped to 27 bcm per annum by the ruling of the Dutch Council of State, see, for example: http://www.nam.nl/nl/news/news-archive-2016/production-figures-nam-2015.html. In addition, further contraction of North Sea production could occur, as many platforms are scheduled for closure, see, for example EBN, 'Focus on Dutch Oil & Gas 2016'.

[9] As a result of lower Dutch gas exports, neighbouring countries are being forced to gradually convert their systems that are tuned to imported Dutch L-gas towards H-gas quality. Based on Gasterra (2015), 'From L-gas to H-gas', see: http://www.gasterra.nl/en/news/from-l-gas-to-h-gas.

[10] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

[11] The Groningen field had a total production volume of 2,800 bcm, of which 780 bcm could still be produced (December 31, 2012). Based on NAM 'facts and figures', see: http://www.nam.nl/nl/about-nam/facts-and-figures.html#textwithimage_0.

TABLE 3: PRODUCTION OF PRIMARY ENERGY CARRIERS IN 2014[12]

Total production	**2,445 PJ**	**100%**
Gas	2,099 PJ	86%
Renewable energy	191 PJ	8%
Petroleum products	83 PJ	3%
Nuclear heat	44 PJ	2%
Waste	28 PJ	1%

In the decades that followed, smaller on- and offshore gas fields also came into production, adding to total gas production and exports. In addition, The Netherlands produces renewable energy (e.g. biomass, biogas, wind, solar, etc.) and petroleum products. The aggregate of Dutch renewable energy production is more than double the size of domestic crude oil production in terms of energy content.

FINAL CONSUMPTION

Dutch final energy consumption is made up of a diverse blend of energy carriers, as shown in Table 4. The lion's share comes from petroleum products, primarily serving mobility, as most cars and heavy duty vehicles operate with combustion engines.[13] However, historical energy policy choices and resource availability also stimulated widespread use of natural gas, both in industry, as a fuel or feedstock, and for residential heating.

TABLE 4: ENERGY CARRIERS AVAILABLE FOR FINAL CONSUMPTION IN 2014[14]

Total consumption	**2,668 PJ**	**100%**
Petroleum products	1,292 PJ	48%
Gas	777 PJ	29%
Electricity	371 PJ	14%
Derived heat	111 PJ	4%
Solid fuels	65 PJ	2.5%
Renewable energy	50 PJ	2.5%
Waste	2 PJ	0%

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[12] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

[13] Despite the strong growth of electric vehicles, only 4% of all Dutch new sold cars had electric propulsion (including PHEV) in 2014, rising to nearly 10% at the beginning of 2016, see, for example, RVO 'Elektrisch vervoer in Nederland Highlights 2014' and RVO 'Tien procent van de nieuwe auto's kan elektrisch rijden', http://www.rvo.nl/actueel/nieuws/tien-procent-van-de-nieuwe-auto%E2%80%99s-kan-elektrisch-rijden.

[14] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

DUTCH ENERGY CONSUMPTION IN MORE DETAIL

For a more detailed analysis, we can divide Dutch energy consumption into four functions: low- and high-temperature heat, mobility and electricity.[15] A breakdown of energy usage by sector, shown in Figure 2, demonstrates how demand and supply meet; demand comes from the left hand side, and supply of several types of energy carriers from the right, meeting at the dotted line.

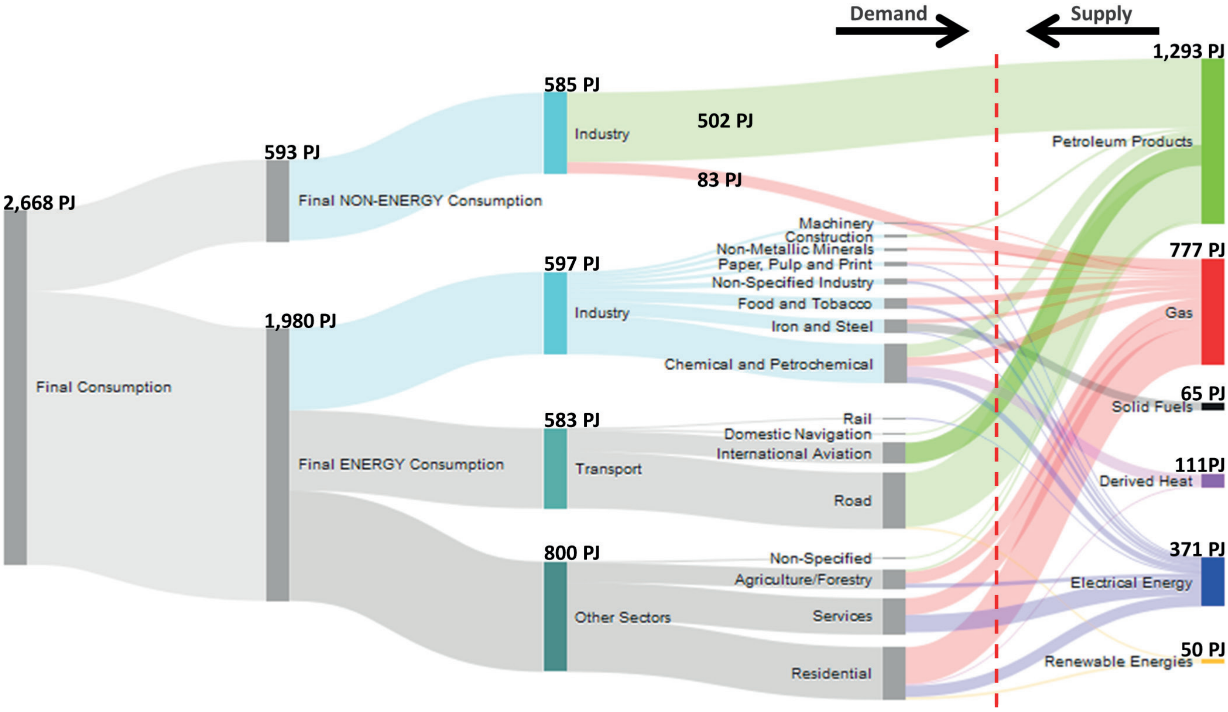

FIGURE 2: DUTCH ENERGY CONSUMPTION 2014[16]

The final consumption of energy can thus be divided into two categories: fuels used for their energetic content, referred to in Figure 2 as ‘final ENERGY consumption’, and fuels used as feedstock, referred to as ‘final NON-ENERGY consumption’. Non-energetic consumption takes place within the industrial sector, using petroleum products (86%) and natural gas (14%) to feed conversion processes.[17]

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[15] These four functions are derived from Ministry of Economic Affairs (2016), 'Energierapport Transitie naar duurzaam', initially introduced by the RLI (2015) report 'Rijk zonder CO_2'.

[16] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

[17] In the Sankey visualization, the energy consumption for conversion is categorized separately, see the upper branch ‘final NON-ENERGY consumption’ in Figure 2. Some of these conversion processes serve chemical product chains (e.g. the production of ammonia or hydrogen).

The petrochemical industry accounts for the most significant share of total industrial energy consumption. In total, the industrial sector makes up 44% of the national consumption of energy carriers, for both conversion purposes and energetic content.[18]

LOW-TEMPERATURE HEAT

Low-temperature heat, broadly defined as all heat under 100°C, can be used for space heating, hot tap water and other heat exchange processes. Heat is an important element of domestic energy consumption, with the services and residential sectors the largest consumers of heat, both in absolute terms and relative to their total energy consumption. Most residential energy consumed in the Netherlands is natural gas (70%), with electricity accounting for most of the remainder (22%). The final 8% consists of small quantities of derived heat (district heating), renewable energies, solid fuels, and even petroleum products.[19] Low-temperature heat is mainly produced using natural gas in highly efficient boilers (see Box 1). Almost all natural gas consumed in the residential and services sectors is used for heating purposes.

Box 1: Efficient decentralized residential heating

Decentralized heating through high-performance boilers (HR-ketel) uses natural gas with an efficiency that easily competes with other heating technologies and district heat networks. State-of-the-art technology uses gas with up to 111% efficiency, measured by lower heating value (LHV).[20] Historical energy policy choices and resource availability have led households to overwhelmingly use natural gas for their residential heating needs. This has created a relatively clean and efficient baseline for residential energy consumption in the Netherlands, compared to other countries where alternative technologies (i.e. combustion of fuel oil or kerosene) are used for residential heating. To put this in perspective, 93% of Dutch households use natural gas for heating,[21] while in Germany only 50% of homes were equipped with a gas heating system at the end of 2015.[22] The remaining 50% are heated using petroleum products, electricity, district heating, renewable energy (mostly biomass), and coal.

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[18] Of all natural gas consumed by Dutch industry, 28% is used for conversion in the (petro)chemical industry, of which more than 55% is used for conversion processes. Based on Eurostat (2017) figures, see, for example: http://ec.europa.eu/eurostat/data/database.

[19] Derived heat is defined as an energy carrier by Eurostat (this can be multiple forms of low-temperature heat such as district heating and hot tap water).

[20] When adopting the more realistic Higher Heating Value (HHV), incorporating the enthalpy of vaporization, most state-of-the-art boilers can actually reach nearly 100% efficiency. Boilers reaching these efficiencies can be found in, for example, the Remeha product brochure 'Moving towards a low carbon future, whatever the application'.

[21] ECN (2015). 'Nationale Energieverkenning 2015' See: https://www.ecn.nl/publicaties/PdfFetch.aspx?nr=ECN-O--15-033.

[22] AGEB (2015). 'Energy Consumption in Germany in 2015' See: http://www.ag-energiebilanzen.de/#ageb_jahresbericht2015_20160418_engl.

HIGH-TEMPERATURE HEAT

High-temperature heat, broadly defined as all heat above 100°C, is essential for industrial heating processes. Industrial heating represents a significant share of Dutch domestic energy consumption, accounting for 80% of final industrial energy consumption.[23] This can be derived heat, or heat supplied directly from energy carriers such as coal, gas, petroleum products or electricity. The chemical and petrochemical industries are the largest consumers of industrial heat; Figure 3 shows the fuel sources used for heat production in both sectors.[24] In addition to conventional sources, the chemical sector generates 2% of its total heat supply from waste incineration. In the petrochemical sector, 46% of heat comes from residual gas, generated on-site as a by-product from refining crude oil.[25] This share has been growing in recent years due to a variety of process optimizations.[26]

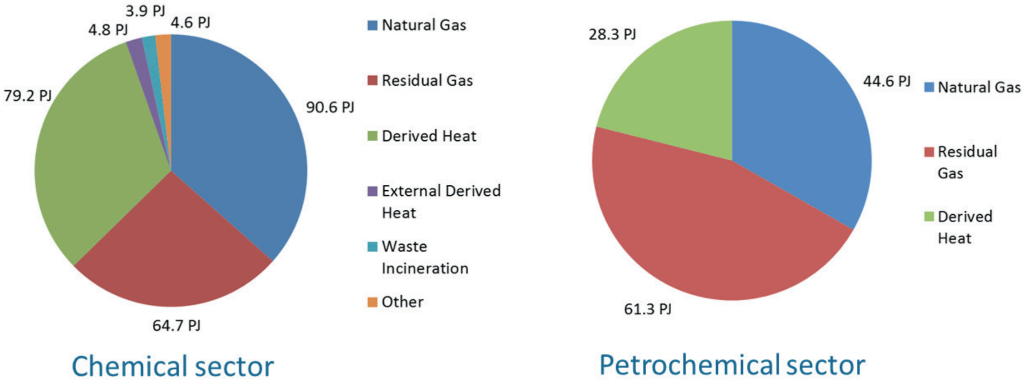

FIGURE 3: FUEL SOURCE FOR HEAT PER SECTOR IN THE NETHERLANDS[27]

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[23] Based on an ECN study (2014) on energy savings in industry: 'ECN R&D plan voor 2014'.

[24] The petrochemical sector consists of six refineries, of which one is located outside the Rotterdam cluster. For the chemical sector the Rotterdam cluster is most important, constituting the majority of the Dutch chemical industry.

[25] Residual gases are gaseous substances resulting from distillation of longer carbon-chains (mostly crude oil), also called refinery gas.

[26] Some refineries have an excess of refinery gas, which is used for their own heating purposes. Shell’s Pernis site, for example, has a surplus of heat which is planned for external use in district heating, amounting to 0.6 PJ annually, equivalent to the consumption of 16,000 households. See, for example, Port of Rotterdam (2016), 'Shell gaat restwarmte aan regio Rotterdam leveren': https://www.portofrotterdam.com/nl/nieuws-en-persberichten/shell-gaat-restwarmte-aan-regio-rotterdam-leveren.

[27] Based on 'Warmte-energie, de motor van de industrie' by Davidse Consultancy, commissioned by VNPI, VNCI, VNP and Deltalinqs.

More than 88% of Dutch industrial heat consumption is high-temperature, and 37% is higher than 750°C.[28] The higher the temperature, the smaller the pool of suitable alternative technologies for heating. For example, the steel sector needs very high-temperature heat for its operations, making it particularly difficult for this sector to realize an energy transition, as technological alternatives are limited, and conventional technologies are mostly based on fossil fuels.

TRANSPORT & MOBILITY

Road traffic, as well as international aviation and domestic navigation, predominantly rely on oil products (e.g. kerosene, diesel and gasoline), which account for 96% of energy used for transport in the Netherlands.[29] Only 3% comes from biofuels, and the final 1% from electricity (mostly for rail).[30] Bio-based energy carriers includes bio-kerosene, bio-gasoline and bio-diesel, which are blended with conventional transport fuels. The EU's 2020 energy strategy sets a target of sourcing 10% of road transport fuels from renewables, as part of the Renewable Energy Directive. The Netherlands currently imposes a biofuels quota of 6.25% on road fuels, just over halfway towards the 2020 target.[31] Other routes toward a less polluting transport sector include the adoption of Electric Vehicles (EVs) on a large scale, provided that the electricity used is clean (see Box 2).

Box 2: Mobility efficiency

Climate change mitigation policies have a significant impact on the oil (processing) sector, as oil is the main source of carbon emissions from mobility.[32] Projections show that oil is set to meet the bulk of European energy demand for transportation up to the year 2040, despite new hybrid and all-electric fully electric cars coming on the market.[33] Tank-to-wheel (TTW) efficiency of hybrid and all-electric vehicles is high compared to TTW efficiencies of combustion engines that use petroleum products; for example, a plug-in hybrid electric vehicle (PHEV) consumes just over half the energy per kilometre of a conventional vehicle, which means a

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[28] Based on an ECN study (2014) on energy savings in industry: 'ECN R&D plan voor 2014'.

[29] International marine bunkers for shipping are not grouped under consumption, in contrast Eurostat places it in a separate category shown in the upper-right corner of the energy balance in Figure 1.

[30] Based on Eurostat (2017) figures, see for example: http://ec.europa.eu/eurostat/data/database.

[31] Argus (2015), 'Analysis: EU biofuels legislative overview', see: http://www.argusmedia.com/Mkting/Bioenergy/Biofuels-Regulation-Update/

[32] See, for example, CIEP Briefing Paper 'The 2015 Climate Negotiations: Interpreting Paris', and ECF (2010), 'Roadmap 2050: a practical guide to a prosperous, low-carbon Europe'.

[33] See, for example, IEA (2016), 'World Energy Outlook 2016', or UK Department of Energy and Climate Change (2014), 'Review of the Refining and Fuel Import Sectors in the UK'.

considerable displacement of fossil fuel as a result of electrifying transport.[34] In other words, 1PJ of electricity produced with solar or wind has the potential to displace around 2PJ of oil product use. However, the ongoing transition toward low-emissions mobility by means of EVs should go hand-in-hand with a low carbon electricity production mix; should EVs run on unsustainably produced electricity (such as coal power), their contribution to climate change mitigation efforts would be questionable.

ELECTRICAL APPLIANCES

The Dutch electricity sector uses a variety of sources, shown in Figure 4. The electricity sector is relatively small compared to the total Dutch energy balance. Fuels used for electricity generation make up only 7.5% of total national energy throughput. Electricity as a secondary energy carrier, including production losses, constitutes an even smaller share (3.2%).[35] In contrast, the throughput of energy from refineries accounts for 23% of the total Dutch energy balance.[36] However, electricity plays a significant role in final energy consumption, as it can be consumed very efficiently for mobility, appliances and heating or cooling.

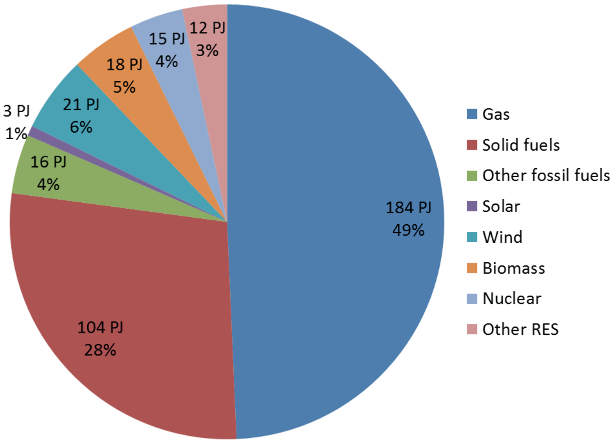

FIGURE 4: THE DUTCH ELECTRICITY PRODUCTION MIX IN 2014[37]

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[34] With PHEV (plug-in hybrid electric vehicles) consuming in the range of 115MJ/100km and DICI (direct injection compression ignition) vehicles consuming in the range of 205MJ/100km. See for example, European Commission, Joint Research Centre, Institute for Energy and Transport (2013). 'Tank-to-wheels report 4.0' p.52.

[35] Placing electricity production in perspective to final consumption, electricity as a secondary energy carrier constitutes a considerable 14% of Dutch final energy consumption (see Table 4).

[36] Based on Eurostat (2017) figures, see, for example: http://ec.europa.eu/eurostat/data/database.

[37] Based on CBS (2017) figures 'Elektriciteit en warmte; productie en inzet naar energiedrager'.

Figure 5 shows the Dutch electricity production sector, including district heating plants, combined heat and power (CHP) units, nuclear power plants and waste incinerators. Thermal power stations generate electricity and derived heat, which are often co-produced; almost all derived heat is a by-product of electricity generation. District heating is an additional source of derived heat, providing heat to households via district heat networks.[38] Heat generated by other means, such as boilers in households or furnaces in industry, is not included in Figure 5.

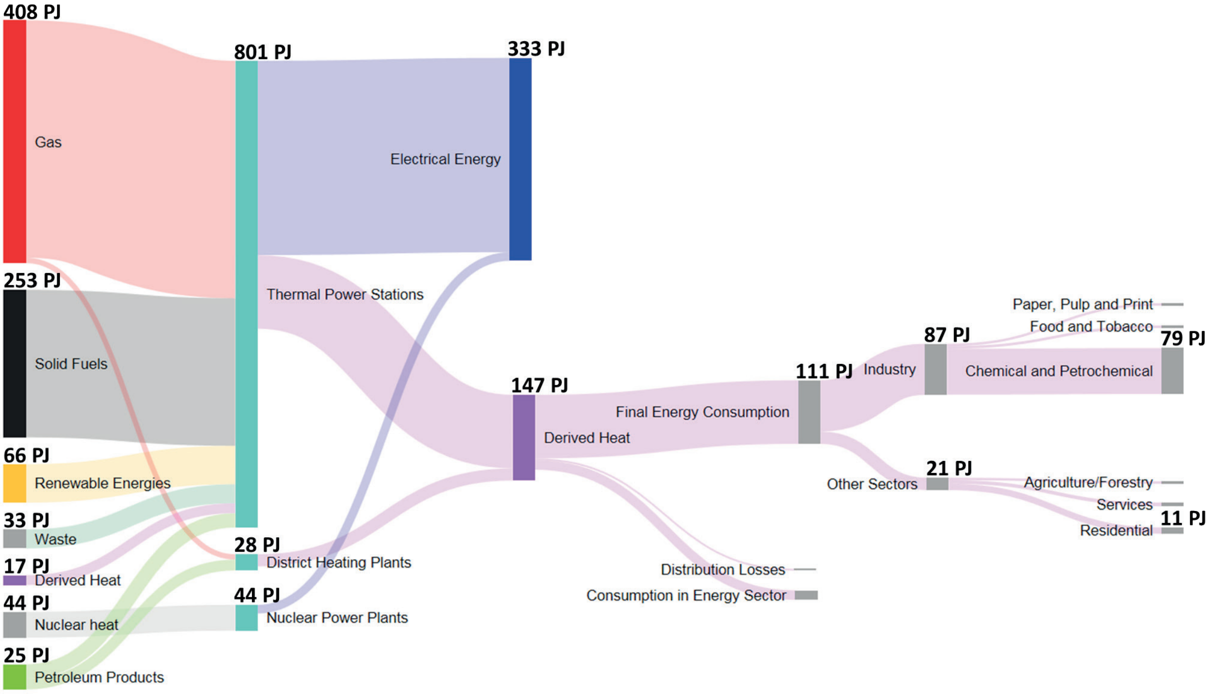

FIGURE 5: DUTCH ELECTRICITY SECTOR AND ITS HEAT PRODUCTION 2014[39]

The flow of derived heat, shown in purple, is consumed by several sectors of the Dutch economy, with the (petro)chemical and residential sectors the largest consumers. The substantial gap between the energy input and output of the thermal power stations is known as energy loss. Some heat is also lost in conversion, transport and self-consumption, with the remaining 76% used in final energy consumption. For more details on energy conversion and losses, see Box 3.

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[38] The gas boilers for district heating are represented as 'District Heating Plants' in Figure 5.

[39] Based on Eurostat (2017) figures, see, for example: http://ec.europa.eu/eurostat/data/database.

Box 3: Conversion efficiencies for thermal power generation

In thermal power generation stations, energy conversion losses occur. When co-generated heat is used rather than disposed, energy efficiency rises. The largest energy losses relate to solid fuels (coal), biomass, and nuclear. These result from low conversion efficiency and only modest utilization of heat as a by-product. Note that wind and solar are not included, as operational fuel input is zero.[40]

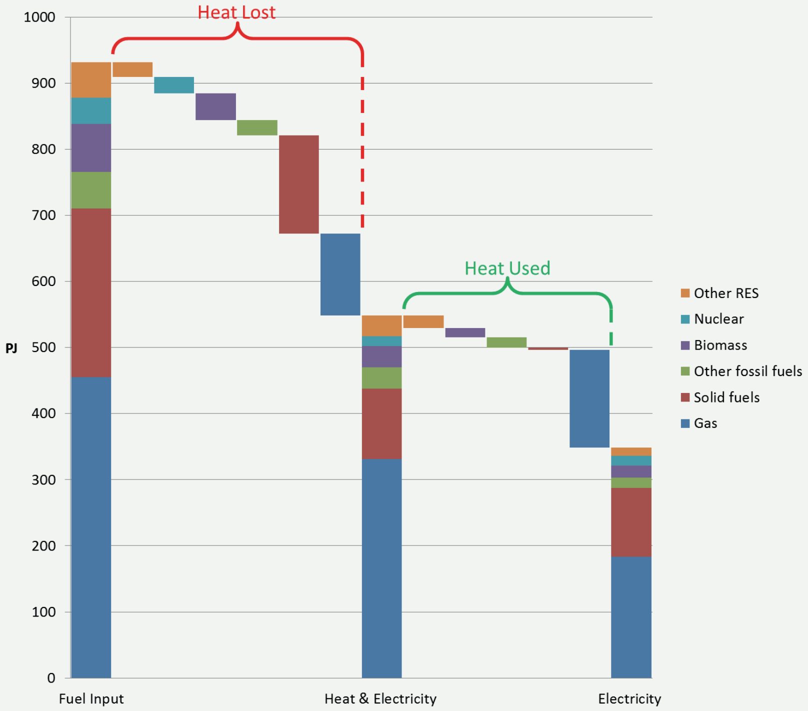

FIGURE 6: CONVERSION LOSSES THERMAL POWER GENERATION PER ENERGY CARRIER IN 2014[41]

Industrial facilities can use derived heat, largely generated by CHP units, in their processes. The chemical and petrochemical sectors account for 89% of total industrial derived heat consumption. CHP units play an important role in the Rotterdam industrial cluster, however, most industrial heating processes directly convert natural gas to heat using boilers and furnaces, which is further elaborated in Chapter 3.[42] The future contribution of CHPs remains to be seen, as the economics of CHP units have weakened with deteriorating electricity prices.

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[40] The contribution of solar and wind to the electricity mix was over 6% in 2014, see Figure 4.

[41] Based on CBS (2014) figures 'Elektriciteit en warmte; productie en inzet naar energiedrager'. Heat and electricity in the middle column of Figure 6 have not accounted for distribution losses and self-consumption.

[42] Note that CHP units are attractive from an environmental perspective, as their CO_2 profile is better than electricity supplies from the grid and industrial on-site steam generation using fossil fuels.

CHARACTERISTICS OF THE DUTCH ENERGY SYSTEM IN A EUROPEAN CONTEXT

THE EU ENERGY BALANCE

The distinctiveness of the Dutch energy system becomes clear when placed in the wider context of the EU energy system. As one might expect, the aggregate energy balance of the EU's 28 member states, shown in Figure 7, includes a broad range of energy carriers. Petroleum products represent the largest share of imports (63%), followed by gas (23%), solid fuels (11%), electricity, renewable energy and waste imports.[43]

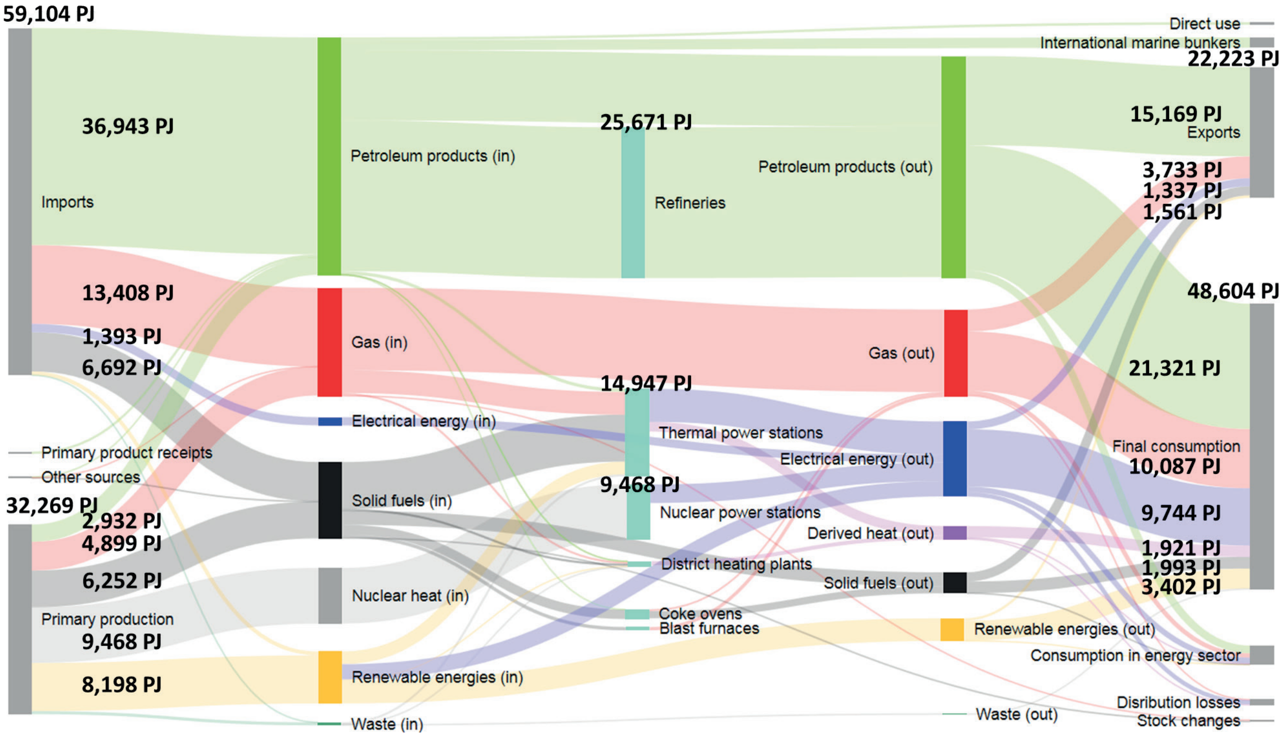

FIGURE 7: EU ENERGY BALANCE 2014[44]

The production of energy carriers within the EU is evenly distributed, with nuclear heat and renewable energies the largest elements, followed by conventional fossil fuels.[45] The proportion of fossil fuels produced within the EU is relatively small in

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[43] The imports and exports of Figure 7 are flows going to and from the EU; internal trade is not shown.

[44] Based on Eurostat (2017) figures, see, for example: http://ec.europa.eu/eurostat/data/database.

[45] The breakdown of EU's energy production is as follows: nuclear heat (29.5%), renewable energies (25.5%), solid fuels (19.5%), gas (15%), petroleum products (9%) and waste (1.5%). Note that nuclear heat is utilized at efficiencies of slightly more than 33% in the Rankine cycle, resulting in a useful electricity supply of only a third of the initial heat energy.

relation to the fossil fuels EU countries consume. Though there are exceptions (e.g. the Netherlands' net gas exports), domestic fossil fuels production in most member states is not sufficient to satisfy consumption. Renewable energy, on the other hand, is largely both produced and directly consumed domestically within member states (e.g. biomass combustion for residential heating). The mix of renewables used for electricity production is dominated by hydropower, with wind and solar contributing smaller shares.[46] Total EU energy consumption consists predominantly of petroleum products, followed by gas and electricity, with solid fuels (coal), renewables, derived heat and waste constituting only small proportions of consumption.[47] While Figure 7 aggregates the 28 EU countries, it is not representative of the member state level, where individual countries are likely to have different energy balances.

DIFFERENCES WITH THE NETHERLANDS

Dutch gas production and exports are exceptional in the EU, where the Netherlands is one of few member states to produce significant quantities of gas, and is the only net exporter. The Netherlands is also more focused than other member states on the re-export of commodities, with a relatively large throughput of petroleum products in proportion to its total energy balance. While the EU as a whole refines 63% of all imported petroleum products, the Netherlands refines only 39%, leaving the majority of imported petroleum products to be exported again.[48] Nevertheless, Dutch refinery throughput is significant, contributing over 9% of the EU total. Because the Netherlands has an important transit function, and facilities for trading and storage, the proportions of import and export are different from other EU member states. Of all energy leaving the Dutch energy system, 64% is exported, compared to an EU average of 24%. Other NWE countries, such as Germany (13%), France (11%), the UK (25%), and Belgium (34%) all export less. The EU (including the Netherlands) exported 358m tonnes of petroleum products to non-EU countries in 2014, while the Netherlands alone exported 98m tonnes to EU and non-EU countries.[49]

Other differences in production are also significant; some EU countries produce a large share of nuclear heat and renewable energies, which are both marginal in the Netherlands. This is due to its small number of nuclear reactors, a lack of hydropower,

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[46] Concentrating further on renewable energy in the EU shows that the bulk of its production consists of waste and biomass (16%), whereas other renewable sources such as hydropower (4.2%), wind (2.8%), solar (1.6%) and geothermal (0.8%) have smaller shares in the total energy production mix. Eurostat, 'Renewables EU28 Electricity production 2014', see, for example: http://ec.europa.eu/eurostat/statistics-explained/images/d/dc/RENEWABLES-EU28-ELECTRICITY-PRODUCTION-2014.png.

[47] Eurostat, 'Consumption of Energy', see, for example: http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy, also the consumption in Figure 7.

[48] The export share is even higher, as a large proportion of Dutch oil products are also exported after domestic refining.

[49] Based on Eurostat (2017) figures 'Exports - oil - annual data', see: http://ec.europa.eu/eurostat/data/database.

and the meagre adoption of biomass, while wind and solar power, though growing, are still at an early stage of development.[50] Conversions within the energy system are also different in the Netherlands, which is characterized by its large refining industry. While the energy intake of EU's refining (25,671PJ) and electricity production sectors (24,415PJ) are roughly equal, the Dutch refining sector (2,418PJ) is more than three times the size of its electricity production sector (845PJ).[51] This contrast becomes even sharper when measuring electricity output instead of energy input. In sum, the most important factors in the uniqueness of the Netherlands' energy economy are the domestic resource availability of natural gas, its extensively developed energy infrastructures, and its coastal location including the critical ports of Rotterdam and Amsterdam.[52]

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[50] The Netherlands has a significantly low share of nuclear electricity production capacity in contrast with other EU countries, such as France. Almost all electricity in France is produced in nuclear power plants. The Netherlands produces only 4% of its electricity with nuclear power. Based on Eurostat (2017) figures.

[51] Note that the energy output of the EU's electricity production plants is slightly more than half that of the refining sector. This is due to conversion losses in electricity plants. However, some of the derived heat from electricity plants is utilized for final consumption, increasing their efficiency, and the efficiency of electricity consumption is greater than the efficiency of petroleum products consumption.

[52] Within the EU the ARA cluster is exceptional in terms of refining capacity, petrochemical integration, port and storage facilities. See, for example, van den Bergh, Nivard & Kreijkes (2016), 'Long-term Prospects for Northwest European Refining'.

3 CASE STUDY: HEAT IN THE INDUSTRIAL CLUSTER OF ROTTERDAM

The industrial cluster of Rotterdam is an important part of the Dutch energy economy, with an advanced exchange of heat and products. The cluster's experience of and plans for heat integration, presented in this chapter as a case study, could provide relevant lessons for other industrial clusters throughout Europe.

The Rotterdam industrial cluster has strong demand for high- and low-temperature heat. Throughout the Rotterdam port area, numerous industrial facilities consume and/or produce heat while handling flows of crude oil, oil products, chemicals, iron ore, coal, dry bulk, containers, cars, etc.[53] Many flows of petroleum products, chemicals and heat are integrated, linking various companies through cluster-wide infrastructure, and plans for further heat integration could significantly improve the cluster's energy efficiency.

The cluster is of great importance to the Dutch economy, contributing €21bn of added value (more than 3% of Dutch GDP) and 180,000 jobs.[54] However, the cluster's emissions account for 19% of national CO_2 emissions, producing 32m tonnes in 2014.[55] Table 5 provides an overview of large energy consumers and producers in the cluster.

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[53] The industrial cluster of Rotterdam also includes the port of Moerdijk and parts of Dordrecht.

[54] Based on Port of Rotterdam (2016). See: https://www.portofrotterdam.com/nl/nieuws-en-persberichten/havenbedrijf-vindt-dat-rli-verkeerde-conclusie-trekt. The Dutch GDP was €677Bln in 2015.

[55] Kernteam Versterking Industriecluster Rotterdam/Moerdijk (2016), 'Samen werken aan een cluster in transitie: Actieplan Versterking Industriecluster Rotterdam/Moerdijk'.

TABLE 5: LARGE ENERGY CONSUMERS AND PRODUCERS IN THE ROTTERDAM CLUSTER[56,57]

Petrochemical	Chemical and biofuels	Utilities
5 Oil refineries (88% of NL)	42 Chemical sites (50% of NL)	9 Gas-fired power plants
6 Refinery tank terminals	4 Biofuel plants (56% of NL)	3 Coal-fired power plants (biomass co-combustion)
9 Independent tank terminals	5 Refineries for edible oil	1 LNG terminal
	16 Chemical and bio tank terminals	1 Biomass power plant
		1 Waste treatment facility

INTEGRATED HEAT BALANCE OF THE ROTTERDAM INDUSTRIAL CLUSTER

An overview of the heat balance in the cluster is shown in Figure 8. The cluster's heat production has four sources: 1) heat from waste incineration, 2) heat from CHP units, 3) heat from furnaces and boilers, and 4) derived heat. Derived heat is recovered from industrial processes (e.g. using heat exchangers), and is often generated and reused on-site. Heat produced with furnaces and boilers uses natural gas and residual gases as its energy sources.[58] The largest primary energy carrier for industrial heat in the cluster is natural gas, with the cluster accounting for 6.7% of national natural gas consumption.[59]

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[56] Idem.

[57] Port of Rotterdam: 'Facts & Figures Energy port and Petrochemical cluster 2016'. The small speciality 'refinery' of ExxonMobil lubricants is not included in Table 5 since there is no distillation capacity present.

[58] Residual gases are gaseous substances resulting from distillation of longer carbon-chains (mostly crude oil), also called refinery gas.

[59] The secondary gas consumption of the Rotterdam cluster is 2.53 billion cubic metres. The primary consumption of natural gas may be even higher, as heating via derived heat may also use natural gas in the initial process. Note that this only concerns gas for heating; gas is also used for chemical conversion. Dutch natural gas consumption was 38 billion cubic metres in 2015. Based on CBS (2017) figures 'Aardgasbalans; aanbod en verbruik', also see: http://unit-converter.gasunie.nl/.

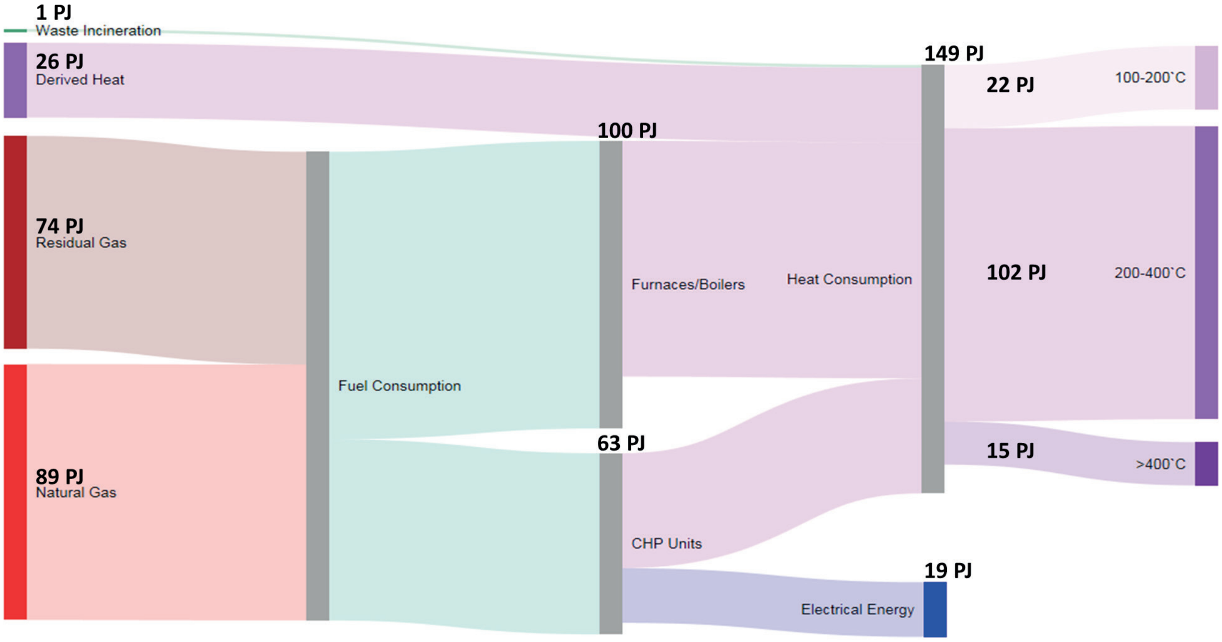

FIGURE 8: HEAT BALANCE ROTTERDAM CLUSTER[60]

The cluster's heat consumption, on the right-hand side, is split into different temperature levels. Most of the consumed heat (68%) is between 200°C and 400°C, with a smaller share of 10% above 400°C, and approximately 15% between 100°C and 200°C. This heat consumption equates to 149PJ per annum, of which 7% are losses. In total, heat makes up 74% of the port's primary energy consumption.[61] In terms of energy content, the Rotterdam cluster's annual heat consumption is almost three times greater than the Dutch government's target for onshore wind power in 2020.[62] The heat balance illustrates that heat is mainly produced using natural gas and residual gas, with derived heat a significant but much smaller input. A potential trend in the chemical and petrochemical sectors is the decline of industrial heat supplied by CHP units;[63] the supply of heat from CHP units is expected to shrink by 38% by 2020, from 40PJ to 25PJ per annum, as a result of low electricity prices due to overcapacity in the electricity sector.[64] Consequently, more and more heat production is moving on-site, using furnaces and boilers.

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60 Eurostat data is not available at cluster level, so data is provided from a survey carried out by Davidse consultancy. This is a survey of Rotterdam's largest chemical and petrochemical factories, covering approximately 90% of the heat consumption and production in the cluster. 'Warmte-energie, de motor van de industrie' is executed by Davidse Consultancy, commissioned by VNPI, VNCI, VNP and Deltalinqs.

61 This heat consumption constitutes approximately 52% of the energy consumption of the national petrochemical and chemical sector with a total energy consumption of 282 PJ in 2014. The port of Rotterdam has a total primary energy consumption of 201PJ per annum. Based on Eurostat (2017) figures and 'Warmte-energie, de motor van de industrie' by Davidse Consultancy, commissioned by VNPI, VNCI, VNP and Deltalinqs.

62 The ECN (2013) 'Toelichting inschatting korte-termijneffecten Energieakkoord op hernieuwbare energie' states that a 6000MW onshore wind capacity would produce 54PJ per year. Note that the numbers are included for reasons of comparison only.

63 Dijk, B. (2015), 'Gascentrales in voortbestaan bedreigd', Financiële Dagblad, 26-11-2015, http://fd.nl/ondernemen/1124474/gascentrales-in-voortbestaan-bedreigd.

64 Structural low electricity prices create a less attractive business case to produce a combination of heat and electricity.

HIGH-TEMPERATURE HEAT IN THE ROTTERDAM INDUSTRIAL CLUSTER

The Rotterdam harbour has a high-temperature heat infrastructure, comprising a system of pressurized steam pipelines. This system is considerably less extensive than low-temperature heat networks; high-temperature heat infrastructures tend to be less extensive due to high investment costs and large distribution losses. In most cases, on-site steam production is integrated with continuous processes where pressurized steam is directly transported and consumed. Storing pressurized steam in large quantities is technologically unfeasible due to energy losses and physical constraints. Companies producing and consuming high-temperature heat are often located close to each other, benefiting from synergies in terms of interaction and product exchange. The exchange of heat between companies is usually arranged via long-term bilateral contracts, as loss of temperature restricts an open market structure from emerging. The economics of CHP units are difficult due to low electricity prices, as illustrated by the recent bankruptcy of Rijnmond Energie, which delivered steam to the neighbouring Shell Pernis refinery.[65] Table 6 lists all CHP units present in the Rotterdam cluster and their nameplate capacity.

TABLE 6: CHP CAPACITY IN THE ROTTERDAM CLUSTER[66]

CHP Company	**Customer(s)**	**Electricity (MW)**	**Steam (Tonnes/Hr)**
Air Liquide Pernis	Shell Nederland Raffinaderij, Eneco	300	800
Air Products/Electrabel	Air Products	96	225
Air Liquide Rozenburg steam & power Cogen A & B	Huntsman, Lyondell, ENECO, Air Liquide	88	240
Air Liquide Rozenburg steam & power Cogen C	Air Liquide	48	120
Indorama Ventures Europe utility island	Indorama Ventures Europe, Eneco	28	65
Uniper Utility Center Maasvlakte Leftbank (UCML)	Lyondell Basell, LNG GATE Terminal, Neste Oil	80	162
AVR Biomassa Energie Centrale (BEC)	Emerald Kalama Chemical, Tronox (Industrial process temperature)	21	80
AVR Waste Incinerator	Warmte Bedrijf Rotterdam, Eneco (District heating temperature: 120°C)	105	450
Rijnmond Energie (Bankrupt)	Shell, Argos Tank Terminal, Eneco	820	135

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[65] Dijk, B. (2015), 'Gascentrales in voortbestaan bedreigd', Financiële Dagblad, 26-11-2015, http://fd.nl/ondernemen/1124474/gascentrales-in-voortbestaan-bedreigd.

[66] The table does not show steam or heat generated on-site using boilers and furnaces. Based on, Port of Rotterdam: 'Facts & Figures Energy port and Petrochemical cluster 2016' and 'Facts and Figures 2007', Visser & Smit Hanab, 'Stoompijp Botlek West' and Rotterdam Climate Initiative: 'Co-siting: efficiënt energie- en grondstoffengebruik'.

An advantage of heat production by CHP units is the flexibility of transporting gas to a desired location for conversion to heat, which significantly reduces energy losses during transport compared to other heating means (i.e. heat infrastructures). Proximity to the desired location, therefore, is crucial. The CHP facilities of the Rotterdam cluster, shown in Figure 9, are all located close to chemical and petrochemical sites (shown in purple). Note that only CHP units are shown, and other means of producing industrial heat (e.g. direct heating, furnaces or on-site boilers) are not included.

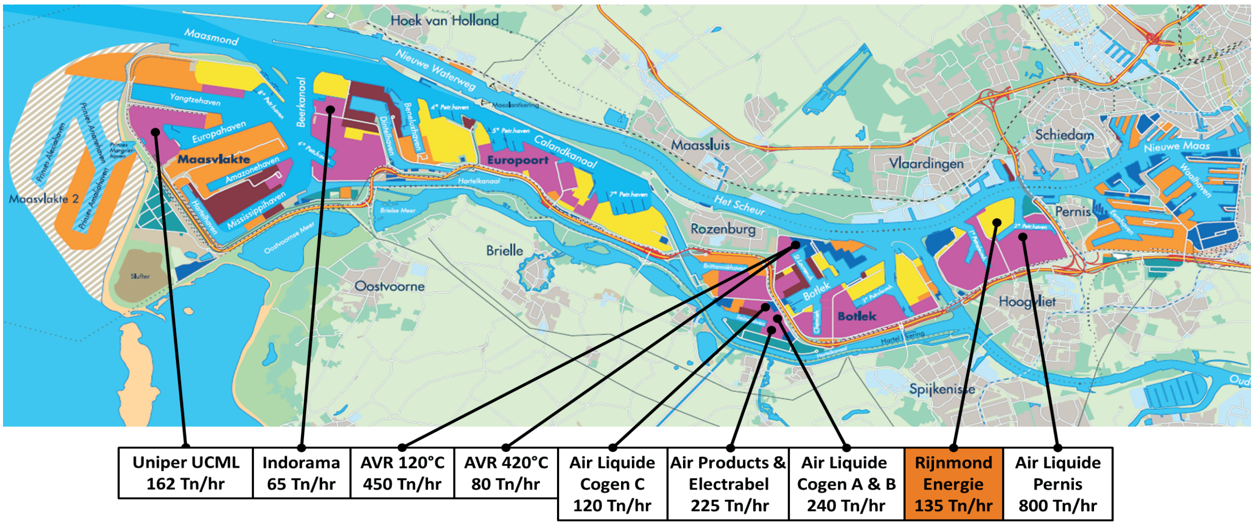

FIGURE 9: CHP LOCATIONS AND CAPACITIES IN THE ROTTERDAM CLUSTER[67]

In some exceptional cases, high-temperature heat is transported over a longer distance. An example is the steam infrastructure connecting the AVR BEC to Emerald Kalama Chemical (EKC) over a distance of 2km. Plants along the infrastructure can inject or withdraw steam depending on their needs.[68,69]

The exchange of high-temperature heat is only achievable at controlled and relatively steady production and consumption rates. Contracts for high-temperature heat

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[67] In orange the bankruptcy of the Rijnmond Energie CHP unit, which had a steam production capacity of 135 tonnes per hour, is represented. The accumulated steam production capacity of all CHPs in the Rotterdam cluster is equal to 1,786MW of capacity. See for example: http://www.tlv.com/global/TI/calculator/superheated-steam-table.html.

[68] This infrastructure transports industrial process steam at a temperature of 400°C and a pressure of 40bar over a length of 2km. The steam infrastructure project realizes a CO_2 reduction of 200k tonnes per year. See for example, van Gansewinkel Groep (2013), 'Factsheet AVR'.

[69] Visser & Smit Hanab, 'Stoompijp Botlek West'.

supply are often bilateral, with long-term obligations and remuneration schemes for sunk infrastructural costs. The limitations to high-temperature heat storage are considerable, whereas the exchange of low-temperature heat is more flexible thanks to its storability.

LOW-TEMPERATURE HEAT IN THE ROTTERDAM INDUSTRIAL CLUSTER

The Rotterdam cluster has a more developed low-temperature heat infrastructure, transporting heat from the AVR waste incinerator through the port to the residential areas of Rotterdam.[70] This low-temperature heat network, which measures 43km, feeds into the district heating network (shown as 5 in Figure 10), from which a separate distribution infrastructure operated by Nuon supplies Rotterdam households.[71]

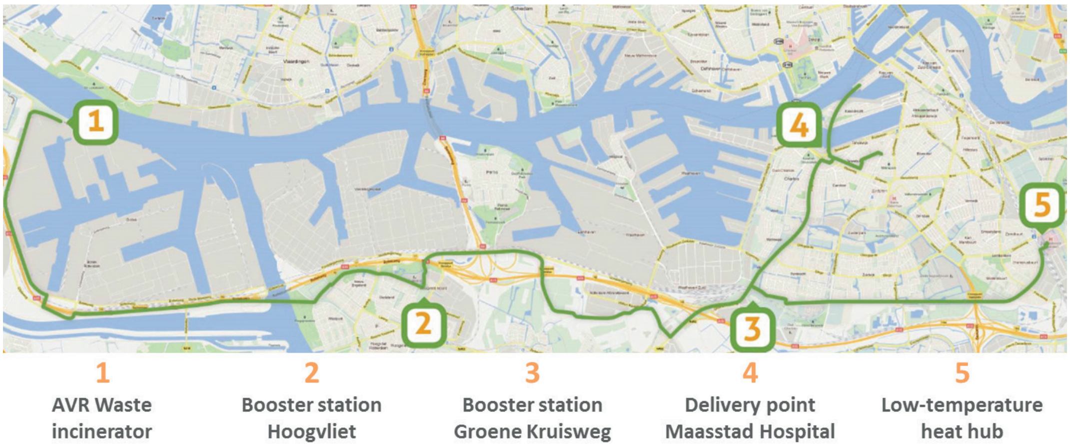

FIGURE 10: HEAT INFRASTRUCTURE IN THE ROTTERDAM HARBOUR[72]

The heat delivered to residential areas from AVR is pressurized water, at temperatures between 90 and 120°C, depending on the ambient temperature.[73] These temperatures are reached using residual heat from industrial processes. The heat can be stored in large insulated vessels for approximately eight hours, at storage temperatures of around 70°C, which can later be raised by gas-fired booster stations for insertion into the district heat infrastructure.

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[70] Kernteam Versterking Industriecluster Rotterdam/Moerdijk (2016), “Samen werken aan een cluster in transitie: Actieplan Versterking Industriecluster Rotterdam/Moerdijk”.

[71] The target set by Nuon is to connect 150,000 households with residential heat by 2030, supplied with heat from the industrial cluster. See, for example, http://co2-reductierapporten.nuon.com/rotterdam/resultaten-2015.

[72] Warmtebedrijf Rotterdam (2016), see: http://www.warmtebedrijfrotterdam.nl/warmtetransportnetwerk/.

[73] In winter the water temperature will be approximately 120°C, as distribution losses are bigger, and approximately 90°C in summer. The water is kept under pressure to stay in a liquid phase. See, for example, ECOFYS (2014) on the cascade of heat: 'Warmteladder Afwegingskader warmtebronnen voor warmtenetten'.

There is potential to grow the exchange of low-temperature heat in the Rotterdam cluster, and plans to expand the current heat infrastructure are advanced. Several options for new infrastructure are being considered: 1) infrastructure on the west side of the harbour connecting directly to The Hague; 2) infrastructure connecting via the city of Rotterdam to The Hague; and 3) a further extension throughout the harbour, as shown in Figure 11.[74]

This last option is particularly important. While residential areas were the target of the initial low-temperature heat network, these plans would also supply heat to industry. Industrial demand for low-temperature heat requires interconnection with the heat infrastructure, with bidirectional flows, allowing industrial firms both to consume and supply heat.[75] Firms could connect their sites to the infrastructure, and either feed in their surplus heat, or extract heat as required.[76]

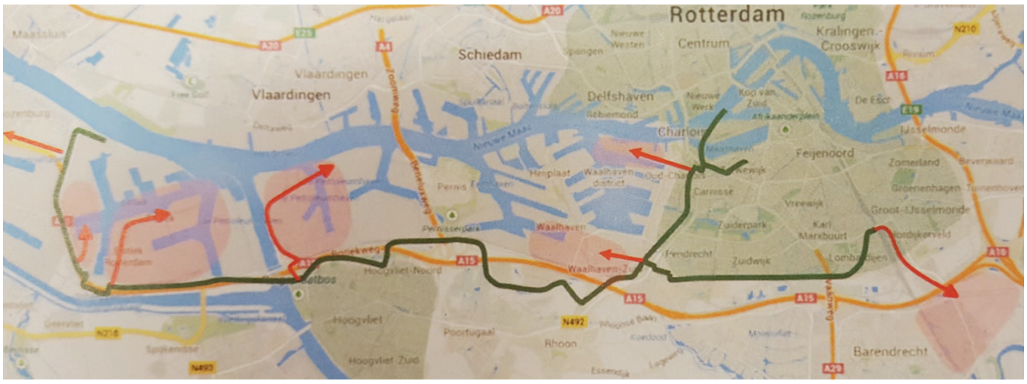

FIGURE 11: POTENTIAL DEVELOPMENT (IN RED) OF THE ROTTERDAM LOW-TEMPERATURE HEAT INFRASTRUCTURE[77]

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[74] Kernteam Versterking Industriecluster Rotterdam/Moerdijk (2016), 'Samen werken aan een cluster in transitie: Actieplan Versterking Industriecluster Rotterdam/Moerdijk'.

[75] Warmtebedrijf Rotterdam optimizes demand and supply for low-temperature heat by matching heat profiles of companies. See, for example: http://www.warmtebedrijfrotterdam.nl/maatwerk/.

[76] The Shell Pernis site, for example, has a surplus of heat which is planned for external use for district heating, amounting to 0.6 PJ annually, equivalent to the consumption of 16,000 households. Port of Rotterdam (2016), 'Shell gaat restwarmte aan regio Rotterdam leveren', see, for example: https://www.portofrotterdam.com/nl/nieuws-en-persberichten/shell-gaat-restwarmte-aan-regio-rotterdam-leveren.

[77] This picture is based on a handout of Warmte Bedrijf Rotterdam (2015), http://www.warmtebedrijfrotterdam.nl/

The red areas on the map show potential extensions of the existing heat infrastructure.[78] These extensions would diversify the functions of the infrastructure, not only supplying the city of Rotterdam with surplus heat, but also facilitating the exchange of low-temperature heat within the cluster. Industrial low-temperature heat surpluses are often discharged into the environment, while other nearby industrial facilities may be in need of low-temperature heat. The consumption of natural gas for industrial heat could be reduced by this exchange, and low-temperature heat could be consumed more efficiently overall. Resorting to cascading[79] heat and using shorter distribution distances, would ensure more efficient use of heat, lowering the cluster's energy consumption and its CO_2 emissions. For a high-energy industrial cluster like Rotterdam, this could be a significant step forward.

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[78] The additional connections to the heat infrastructure are located in the regions surrounding: Vondelingenplaat, Botlek, Waalhaven, Eemhaven and east of Rozenburg (Warmte Bedrijf Rotterdam, 2015).

[79] Cascading heat is a method using multi-stage temperature intervals of exchanged heat surpluses and deficits. For example, some units in an industrial cluster have surplus heat, while others have deficits and need additional heat. The heat balance in the cluster can be optimized, by recovering surplus heat via heat exchangers, and use it in the units with heat deficits. Temperature differences between exchanged heating and cooling loads are minimized in order to optimize heat recovery.

4 CONCLUSION

The unique energy balance of the Netherlands is characterized by a large energy throughput relative to its energy economy, contributing to the energy needs of other EU member states via re-exports. Only a quarter of Dutch energy flows are actually destined for consumption within the Netherlands, leaving three-quarters for exports. Its high domestic natural gas production makes the Netherlands the only net gas exporter in the EU.

The Netherlands has, the highest export share of energy (66%) of all EU member states. This is a result of its very large throughput of petroleum products (crude and oil product), which are mainly exported. The share of petroleum products destined for domestic refining is much lower than in other EU member states; yet, the Netherlands makes up over 9% of total EU refinery throughput. Coal is also important for commodity throughput, with the port of Rotterdam handling 60% of all seaborne coal imports to Europe.

The Netherlands functions as a very large export, refining, storage and trade centre for NWE, in which the cluster of Rotterdam is of crucial importance. Trends in energy consumption and heat optimization within the cluster, as described in this study, may serve as an example to other clusters throughout Europe. The Rotterdam cluster consumes the majority (74%) of its energy as heat, and the production portfolio and consumption profile of high- and low-temperature heat within the cluster is changing. The supply of high-temperature heat from CHP units is expected to decrease by up to 38% by 2020, and while some units will continue production for as long as contractual agreements oblige, companies with internal heat production capacity have the option to switch to internal heat supply (e.g. boilers) when long-term contracts expire. In addition, the exchange of low-temperature heat is increasing via the extension of existing heat networks, reducing the need to use valuable high-calorific energy sources to produce low-temperature heat. Further extension could result in more efficient production and consumption of heat by cascading temperatures, lowering the cluster's energy consumption and its CO_2 emissions.

Debates on the transition to a low-carbon economy often focus on the electricity sector, but other energy carriers should not be overlooked. To reduce CO_2 emissions beyond 80-90% of the 1990 level, the national low- and high-temperature heat (residential and industrial heat) and mobility sectors also need to become part of the transition policy. For example, heat is a significant part of energy consumption in most member states; a quarter of Europe's total final energy consumption is industrial, of which the majority (73%) is used for heating and cooling.[80] The risk of a mismatch between the various types of energy demand and supply is significant if we ignore the dynamics of the deeply integrated energy systems in the Netherlands and the wider NWE. The current role of natural gas and its vast infrastructure is not easily replaced, as the availability of feedstock is important for industry and other sectors.[81] Governments must recognize the important economic role that energy-intensive sectors play in their national economies, while also encouraging new energy technologies to grow. The position of the Netherlands' energy-intensive economy, and in particular the Rotterdam cluster, will be strengthened if the energy transition focuses not only on making strides in renewables in the electricity sector, but also stimulates process optimizations, innovations and sustainable developments in the cluster, which may contribute to a lower carbon economy as well.

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[80] EC (2016), 'Towards a smart, efficient and sustainable heating and cooling sector', http://europa.eu/rapid/press-release_MEMO-16-311_en.pdf.

[81] For example, suggestions to decouple Dutch households from the gas infrastructure might prove problematic as renewables supplies are not yet in place or are not reliable enough to meet the energy demand for residential heating.

ANNEX A: METHODOLOGY

Throughout this paper, Sankey diagrams are used to visualize the energy balances of the Netherlands and the EU. These diagrams are based on Eurostat statistics for the year 2014, the latest available.[82] Subsequently, these energy balances help to zoom in on the structure of energy consumption. By further simplifying the model, excluding smaller energy flows, a clearer aggregate picture appears.[83]

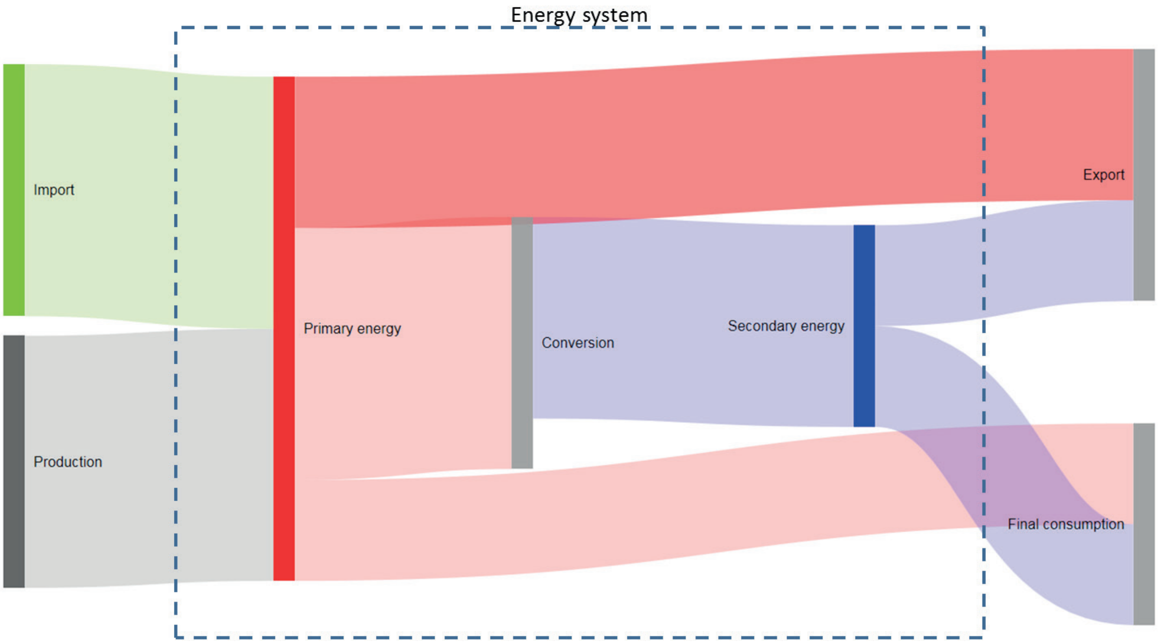

FIGURE 12: CONCEPTUAL SANKEY DIAGRAM

Figure 12 shows a conceptual model of a Sankey diagram. This format is applied to all energy balances in this paper. The Sankey diagram should be read from left-to-right. In this example, two flows of energy carriers are entering the energy system (blue shaded box), with energy imports at the upper-left corner, and domestic energy production at the lower-left corner. Within the energy system, primary energy

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[82] Eurostat has statistics on the size of energy flows by all energy carriers throughout each process (conversion, consumption, transportation etc.) of each country in the European Union. See, for example: http://ec.europa.eu/eurostat/data/database.

[83] These visualizations are modelled by programming in R, using the programme RStudio. Energy flows with a non-significant amount have been omitted in the visualizations, flows <10 PJ per annum are not showed in the visualizations, and numbers are rounded to hundreds. The total joules still add up, as the excluded flows are incorporated in the calculations.

carriers (any raw material e.g. biomass, coal, crude, gas etc.) are converted into a secondary energy carrier (e.g. electricity, oil product, derived heat, etc.). At the right-hand side, two flows of energy carriers are leaving the system, with energy exports at the upper-right corner and final consumption of energy in the domestic economy at the lower-right corner. The **final energy consumption** or 'final consumption' in Figure 12 is the energy consumed by the end-user, excluding energy used by the energy sector (e.g. in deliveries and transformation losses). **Primary energy** carriers can be consumed directly, for example by burning biomass in a stove to obtain heat, or transformed into **secondary energy** carriers such as electricity.[84] It is important to note that the energy carrier **petroleum products** is the aggregate of crude oil and oil products combined, thus including liquids such as kerosene, naphtha, diesel and gasoline.

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[84] Eurostat (2016), 'Consumption of energy'. See for example: http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy.

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VISITING ADDRESS
Clingendael 12
2597 VH The Hague
The Netherlands

POSTAL ADDRESS
P.O. Box 93080
2509 AB The Hague
The Netherlands

TEL +31 (0)70-374 67 00
www.clingendaelenergy.com
ciep@clingendaelenergy.com