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TNO report

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The role of renewable heat technologies in industry – A review of Dutch sectoral industry roadmaps

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Since April 1st ECN and TNO have joined forces.

Summary

As part of the knowledge project of ECN part of TNO (project name: 'Renewable Heat Supply'), a review of the sectoral roadmaps that were developed in 2012 was conducted, in order to gain insights regarding the potential role of renewable heat options in industry and (part of) the services sector. The acquired knowledge of this study will serve as input for further analysis during the later stages of the project.

Industry is the largest user of thermal energy in the Netherlands and is therefore a vital sector in the transition towards a Renewable Heat Supply. Based on the industrial roadmaps, created by the industry in cooperation with RVO, of 2011/2012, an overview was made of the potential perceived fit by each sector of different renewable heat options, as well as an overview of the current incentives promoting such technologies and barriers impeding their adoption.

The industry roadmaps indicate that not all renewable heat options are suited to meet the thermal energy demand of every sector. Local availability of renewable resources, such as geothermal energy or biomass suitable for digestion technologies, and maximum heat temperature of the technologies, are limiting factors. For example, biomass and biogas combustion options are only mentioned by industrial sectors that have access to biomass streams (paper and board, waste water, dairy, and agriculture and horticulture). Industry with high temperature processes (>600°C) on the other hand, such as the steel, glass and chemical sector, have limited renewable options to meet the high temperature demand of these processes (only electrification is mentioned as an option). It's important to note however that although the use of hydrogen is barely mentioned in the roadmaps of 2012, this option has recently gained more attention from industry and is specifically mentioned as a key technology in the proposition of the industry for the 'Climate Agreement'[1].

There are several incentives for the industry to adopt renewable heat options. The perception of consumers, regarding the sustainable image of a company, is often mentioned. The most important incentive, however, seems to be government support (especially subsidies). Additional incentive can be favourable conditions (local renewable resources such as biomass or geothermal heat sources, or a Green Deal). For some sectors, interest in renewable heat is related to the perceived threat of rising gas prices, which has become all the more relevant due to the political decision to halt gas production in Groningen.

However, the lack of a level playing (both European-wide and world-wide), combined with strong pressure from a global market, is hindering investment decisions in renewable heat technologies, which are often

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[1] Klimaatakkoord in Dutch. The Climate Agreement's main target is to reduce greenhouse gas emissions in the Netherlands by 49% (compared to 1990 levels) in 2030 (source: https://www.klimaatakkoord.nl/klimaatakkoord).

more expensive and less proven than conventional technologies, difficult. Lowering the CAPEX of renewable technologies by R&D activities supported by the government, are necessary. Also, governmental financial support in the form of access to capital or subsidies (SDE+) are considered to be vital by industry to ensure the success of renewable heat.

Regarding the potential of renewable heat for industrial processes, it can be concluded that more research is needed in this field. Unlike end-consumers using low-temperature heat, such as households, industry often requires high to very high temperatures, which cannot be supplied by all of the current renewable heat technologies. Also, some renewable heat sources (e.g. geothermal energy and waste heat) are bound by location, which means that the potential of such sources for industry is very dependent on the nearby location of an industrial end-user. The roadmaps provide a general overview per industrial subsector of which renewable technologies have their interest. A more in-depth analysis will be conducted during the upcoming tasks of the Renewable Heat Supply project, to determine the actual potential of renewable heat for industry.

Contents

1 Renewable heat development in industry

1.1 Renewable Heat Supply project

ECN part of TNO started a knowledge project called ‘Renewable Heat Supply project, that focuses on accelerating the use of renewable heat in the Netherlands. Implementation of renewable heat technologies is considered an important condition to achieve a CO_2 neutral energy system. This knowledge project will provide:

- Knowledge regarding the characteristics and potential of sustainable heat options, implementation barriers, current policy instruments and suggestions for additional support mechanisms;
- Knowledge regarding the size of the heat demand;
- Scenarios for sustainable heat supply configurations in 2030 and 2050 that illustrate the relations between heat supply and demand between sectors, and its impact on the total energy system.

This report contains the results of one of the tasks of the Renewable Heat Supply project: a literature review study of the 2012 sectoral roadmaps. These roadmaps provide valuable insights regarding the industry’s point of view regarding renewable heat technologies[2]. The results of the review study provides input for the analyses that will be performed during later stages of the Renewable Heat Supply project.

1.2 General trend in industrial use of renewable heat technologies

Renewable heat technologies have thus far experienced only modest growth in the Netherlands, rising to a mere 5.5% share renewable heat of the total heat consumption in 2015 (CBS 2017). In 2005, the renewable heat share was 2.4%, indicating that the implementation of renewable heat technologies is proceeding at a slow pace. Especially when considering that the doubling between 2005 and 2015 was partly due to a decrease in total heat consumption and that most of the added renewable heat capacity was added in 2014, meaning that there has been almost no growth in 2015.

Especially the industrial sector seems reluctant to adopt renewable heat technologies despite accounting for the largest consumption of heat of all sectors.

In order to achieve a CO_2 neutral energy system, a better understanding is needed of the specific demands for heat in de Dutch industry and how this relates to the potential of renewable heat technologies. Also, insights regarding the barriers that prevent industry, in spite of subsidy (SDE+), from replacing their fossil fuel heat systems with a renewable counterpart, are needed.

[2] Although dating from 2012, the views from industry have not changed significantly. The only exception is the lack of attention for hydrogen, which is currently regarded as an important technology by industry during the Climate Agreement discussions.

1.3 Industrial roadmaps

As part of their agreement with Dutch government to increase their energy efficiency (the so-called 'Meerjarenafspraken Energie Efficientie Verbeteringen' – abbreviated: 'MEE') Dutch industry published roadmaps in 2011 and 2012 that described how the industry planned to increase the level of energy efficiency by 2030. Although the roadmaps focused on energy efficiency, the possibilities of adopting renewable energy technologies were also included. ECN part of TNO has analysed the 18 publicly available roadmaps on the website of the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO) to gain insights regarding the following:

- Which renewable heat technologies can be applied by which sector;
- What are the perceived reasons to invest (or not) in renewable heat technologies;
- What are the perceived opportunities and barriers by the industry to implement renewable heat technologies;
- What actions by the government are needed to help the industry implement renewable heat technologies.

1.4 Scope of this project

This study only focuses on the roadmaps that are available on the RVO website 'Routekaarten en Voorstudies MJA3/MEE[3]' and does not include other roadmaps from other sectors that may be available. Because of this, the household sector and part of the services sector are outside the scope of this study. The total heat demand covered by the sectors that are analysed in this study covers over 40% of the total heat demand in the Netherlands.

Furthermore, the analysis of the roadmaps is limited to qualitative information. Any quantitative information regarding energy saving potentials or renewable heat production is ignored because there is insufficient information regarding the methodology and assumptions used by the makers of the roadmaps, to be able to put these quantitative figures into context.

[3] https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-besparen/meerjarenafspraken-energie-effici%C3%ABntie/publicaties/routekaarten-en-voorstudies

2 The Dutch manufacturing industry

2.1 Heat demand of the industry compared to the other sectors in the Netherlands

In industry, heat is used for space heating and for industrial processes. In 2016, the manufacturing industry was the largest user of heat in the Netherlands with 404 PJ. To put this in perspective, households were second in heat demand with 278 PJ[4], followed by refinery (136 PJ) and services (127 PJ), and finally agriculture and horticulture (111 PJ) (MONIT 2017). Figure 1 provides an overview of the final thermal energy used per sector.

Within the Dutch manufacturing industry, the sector with the largest heat demand is the chemical sector (excluding refineries) with 207 PJ. The food industry is a distant second in terms of heat demand with 57 PJ (of which 16 PJ comes from the diary sector). The other industrial sectors have a heat demand of around 25 PJ or less.

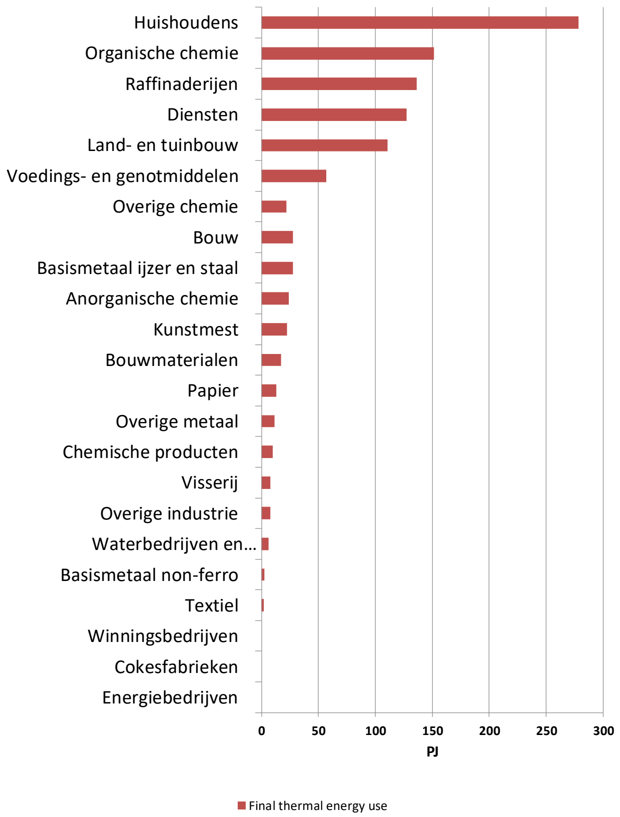

Figure 1: Final thermal energy use Netherlands 2016 (source: ECN database of the National Energy Outlook 2017)

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4 Note that, despite their large heat demand, the sector households, and most of the services sectors, are outside the scope of this study, which focuses on the roadmaps supplied by industry, and some service sectors, to RVO around 2011/2012.

2.2 Temperature levels of heat in industrial processes

Heat use in the household, services and horticulture sector is typically characterized by low temperatures (<100ºC), mainly used for space heating. The industry sector, on the other hand, uses a wide range of different temperatures for their processes. For the most part, these industrial processes use temperatures between 100 and 1000ºC. In some cases, such as for steel and glass production, temperatures above 1000ºC are required. Table 1 provides an overview of the temperature levels per sector.

Table 1: Heat use per temperature level in Dutch sectors in 2006 (ECN 2010)

Temp. (°C)	Industry	of which Chemistry	of which Metal	of which Other	House-holds	Other sectors	of which Agriculture	of which Services	Refineries	Total
<100	53.2	12.3	7.8	33.2	280.1	294.9	89.5	205.5	0	628.2
100-250	70.6	27	0	43.7	0	0	0	0	0	70.6
250-500	83.9	66.2	2.6	15.1	0	0	0	0	45	128.9
500-700	51.5	51.5	0	0	0	0	0	0	48.5	100
750-1000	68.9	63.7	5.2	0	0	0	0	0	0	68.9
>1000	85.2	24.5	36.2	24.5	0	0	0	0	11.5	96.7
Total	413.3	245	51.7	116.5	280.1	294.9	89.5	205.5	105	1093.3

2.3 Economic competitiveness of the Dutch industry

The industrial landscape changes continuously. Based on a myriad of factors such as energy prices, labour costs, market conditions, and tax legislation, a company can choose to expand their business in the Netherlands or move elsewhere. This change in the volume and structure of the industrial sector automatically results in a change in the volume and type of heat demand, which in turn has an impact on the potential heat demand that can be met using renewable heat technologies. This paragraph briefly discusses the competitiveness of the Dutch industry, which to some extent, provides insights regarding the likely growth or decline of each sector in the near future.

The Dutch dairy industry is considered to be in a relatively good position, although due to the liberalisation of the European dairy sector and the phasing out of the milk quota system, the Dutch dairy sector will need some time to adjust itself to more volatile prices (Krebbekx et al. 2011). The NRK (rubber and plastics industry association) does not mention the future perspectives but does indicate that the mature recycling business of the Netherlands is a positive aspect of the Netherlands (Krebbekx et al. 2012). The agriculture and horticulture industry is considered competitive and will likely continue to do well internationally (Rooijers et al. 2015). For the waste water sector, the notion of competitiveness is not relevant, as it provides a service that is a necessity, and that can only be done locally.

There are, unfortunately, also industrial sectors that, although they are for the moment competitive, find themselves in a difficult position. Especially the paper and board, metallurgic, and glass industry note that the Dutch investment climate is unattractive for companies in their sector. The glass sector mentions specifically that several companies have already relocated to low-wage countries (VNG et al. 2012).

3 Which measure for which industrial sector?

3.1 Available renewable heat technologies

There are various renewable energy sources to produce heat that use commercially available technologies (digestion, geothermal installations, biomass-based boilers etc.). In this study we focus on:

- Solid biomass;
- Direct electric[5];
- Geothermal;
- Ambient heat (heat pumps);
- Waste heat[6];
- Solar energy;
- Biogas;
- Hydrogen[7].

In order to be applied in industry, a renewable heat technology using one of the above energy sources has to comply with the specific criteria of the industrial processes. Important technical aspects are:

- Fuel properties (e.g. bulk density, moisture, proximate and ultimate analysis, calorific value, ash properties, and size characteristics);
- Thermal requirement (e.g. heat load, processing temperature, furnace and heat exchanger design, etc.).

Furthermore, there are also non-technical aspects to take into consideration:

- Economics (e.g. cost of available fuels, labour rates, equipment costs);
- Local factors (e.g. operational and construction/maintenance skills, spares availability, roads and local infrastructure, environmental legislation).

Each sector's roadmap contains a different set of measures for renewable heat (see **Table 2**) that, according to the industry, has the most potential to decarbonise heat demand.

[5] Is only renewable if the electricity is produced solely from renewable sources.
[6] Is only renewable if the original source of the waste heat is renewable.
[7] Is only renewable if the hydrogen is produced solely from renewable sources.

Table 2: Potential renewable energy technologies for heating applications as mentioned in the roadmaps (see Table A.1 for the used literature)

No.	Sector	Solid biomass	Direct electric	Geothermal energy	Waste heat	Ambient heat	Solar energy	Biogas	H_2
1	Chemistry	Pellet boilers	Electric boilers, Electric furnaces	Geothermal installation	Heat pumps			Green gas	H_2 is mentioned but only for feedstock applications
2	Textile						Drying process using direct solar energy		
3	Glass industry		Electric furnace						
4	Paper and board industry	Combustion of sludge and rejects	One paper mill is using an electric boiler, but no other plans have been mentioned	Deep geothermal installation	Heat pumps			Digestion (biogas produced out of waste water); Gasifying waste materials	
5	Metallurgical industry								
6	Building ceramics	? [8]			Heat pumps			? [9]	
7	Carpet								
8	Vegetable and fruit processing industry			Geothermal	Heat pumps		Solar thermal collectors	Digestion of residual streams; Purchase of green gas	
9	Waste water chain	Combustion of biomass (paper fibres)		For drying of sludge and heat demand from waste water treatment plant, technology not specified.				Production of green gas and biogas (Supercritical gasification of sludge and digestion of organic content waste water)	

[8] According to ‘Sector Meerjarenplan MJA3 Grofkeramische industrie Periode 2013 - 2016’ this technology is interesting but biogas is not yet available in sufficient quantities.
[9] According to ‘Sector Meerjarenplan MJA3 Grofkeramische industrie Periode 2013 - 2016’ the industry is looking into this technology.

No.	Sector	Solid biomass	Direct electric	Geothermal energy	Waste heat	Ambient heat	Solar energy	Biogas	H_2
10	ICT			Thermal energy storage			Solar thermal collectors		
11	Rubber and plastic industry								
12	Dairy industry							Digestion (CHP + green gas production)	
13	MVO							Digestion (biogas from waste water)	
14	Potato processing industry				Compression heat pump			Digestion	
15	Meat industry				Technology not specified			Technology not specified	
16	University medical centres			Thermal energy storage with heat pumps; Geothermal	Purchase sustainable heat		Solar thermal collectors	Purchase biogas	
17	Higher education								
18	Agriculture and horticulture	Biomass pellet (CHP)		Condition: sustainable supply of CO_2		Heat pumps		Green gas, technology not specified	

3.2 Sectors with high temperature processes - steel, glass and chemical sector

Table 2 shows that according to the roadmaps the steel sector cannot easily find renewable heating options to replace its cokes-based steel production process. The same is true for the glass industry whose roadmap only mentions the development of an electric furnace as an option to produce renewable heat. Electric heat furnaces are also mentioned in the roadmap of the chemistry sector, for naphtha cracking. Stork et al. (2018) specifically notes that the application of electric boilers, geothermal heat, and bio boilers is very difficult at best in naphtha crackers, due to high temperature requirements.

Process temperatures are categorised, based on Wemmers et al. (2011), in this document as:

- Very high temperatures – temperatures over 1000°C
- High temperatures – temperatures between 600°C and 1000°C
- Low temperatures – temperatures below 600°C.

The lack of options for renewable heat production for high, and very high temperatures, is also illustrated in Appendix **Error! Reference source not found.**.

3.3 Sectors with low to medium temperature processes- chemistry, paper and board, waste water chain, and agriculture and horticulture sector

Processes that use low to medium temperature heat can be accommodated by many of the current renewable heat technologies. This is clearly demonstrated by the large amount of renewable heat options mentioned in the roadmaps of the chemistry, paper and board, waste water chain, and agriculture and horticulture sector (see **Table 2**).

3.4 Sectors with organics streams locally available - paper and board, waste water, dairy, and agriculture and horticulture

Sectors that have organic (residual) streams available all mention biogas as a potential renewable heating technology. These sectors are: paper and board, waste water, dairy, and agriculture and horticulture. With the exception of the dairy industry, solid biomass is also included in all roadmaps as potential renewable heating technology. The importance of access to biomass streams is also highlighted by the roadmap of the university medical centers, that considers biomass technologies unattractive due to the complexity of logistics.

The chemical sector has several options available. Pellet boilers and electric boilers can be used to replace gas boilers and produce hot water up to 350^{o}C. Geothermal, although lacking applied research data, is expected to have potential to meet part of the heat demand in the chemistry sector below 200^{o}C. For the high temperature requirements of naphtha cracking, electric furnaces have the potential to replace conventional furnaces.

The horticulture sector has been very active in experimenting with geothermal technology over the last years. This is also reflected in their roadmap. The chemistry, paper and board, and waste water sector, also, mention the use of geothermal heat as part of their strategy to decarbonise, although thus far geothermal heat was not actually used.

4 Motivations and barriers related to renewable heat technologies

4.1 Reasons to invest in renewable heat technology from an industry perspective

4.1.1 Consumer awareness

The industry has noted the growing awareness of consumers regarding sustainability (VNG et al. 2012, VNMI 2011); the required measurement and reporting of the carbon footprint of a company has become an important aspect of today's communication to the customer (The Bridge 2011). This has shed a new light on the potential of renewable heat technologies: the marketing aspect. Governmental agencies have also shown a growing interest in sustainability (Krebbekx 2011).

4.1.2 Availability of energy sources

Local availability of a resource for renewable heat is an important condition for companies to invest in renewable heat.

Local availability of resources is especially relevant for biomass and geothermal heat related projects. The horticulture sector has been very active over the last years in identifying and exploiting locations for geothermal energy. They can be considered the frontrunners in the Netherlands when it comes to geothermal energy use.

4.1.3 Governmental support

The SDE+ financing and/or Green Deals are also mentioned, by several roadmaps, as key influencing factors.

The paper industry has thus far not invested in any geothermal installations but is part of a Green Deal concerning a deep geothermal energy project. Having a continuous and constant demand for heat and being located near the site where the deep geothermal installation will be installed, the papermill Parenco is an ideal end-user of the to be generated renewable heat.

4.1.4 Advantageous circumstances

Building the infrastructure to transport biogas is, in the case of digestion technologies, an important cost aspect. In some cases, different producers of biogas can benefit from the same infrastructure. For example, waste treatment plants in the Energy Valley area have already set up a biogas hub. This could save nearby dairy farms, that consider producing biogas, the costs of building their own network (Krebbekx 2011).

4.1.5 Threat of rising gas prices

Uncertainty regarding the future development of energy prices makes renewable heat technologies more interesting to the industry. The Dutch paper and board industry, for example, specifically notes the threat of fluctuating gas prices (The Bridge 2011). Related to this is the decision of policy makers to phase-out the use of low calorific value gas from Groningen by industry[10]. The metallurgic industry

[10] https://www.installatie.nl/wp-content/uploads/2018/01/briefGroningen.pdf

also notes that an expected shortage in materials and conventional energy carriers are motivating factors to invest more in renewable energy (VNMI 2011).

4.2 Reasons not to invest in renewable heat technology from an industry perspective

Although there are obvious benefits of renewable heat, there are arguments that generally make companies refrain from investing in renewable heat technologies.

4.2.1 Global economics dictates investments

In order to choose to invest in expensive new technologies, with relatively long payback times, strong leadership is required (Stork et al. 2018). To exhibit such leadership can be difficult, even more so when the decision makers are located abroad, as is the case for many companies (Stork et al. 2018, The Bridge 2011), whose decisions are led by global economic developments. Also related to this is the difficulty to find financial resources to do the investments (Krebbekx et al. 2011).

4.2.2 No level playing field

The business case of investing in renewable heat technologies can depend significantly on climate policy and its effect on energy and carbon pricing (Stork et al. 2018). Developments in climate policy are difficult to predict, resulting in uncertainty and making renewable heat technologies less attractive. Especially a level playing field that ensures that Dutch (or European) companies are not put at a disadvantage compared to foreign companies as a result of policy developments, is something mentioned frequently in the roadmaps (Stork et al. 2018, VNG et al. 2012). A concrete example: Germany and Belgium have less stringent legislation regarding the use of waste streams for energy production and allocate more subsidy to such projects than the Netherlands. Because of this it is difficult for Dutch companies to compete for these waste streams (Krebbekx et al. 2011).

4.2.3 Legislation and lack of social acceptance

Renewable heat technologies such as geothermal heat installations require a certain amount of land and room to be installed and to operate. In some cases, this can lead to conflicts with the local municipality: lack of social acceptation (Stork et al. 2018). Strict environmental legislation can also be a hindrance for investors (VNG et al. 2012). For example: a change in legislation is needed to be able to utilise the potential of the digestion and energy recovery of manure and sludge (Unie van Waterschappen et al. 2012).

4.2.4 Lack of available resources

In contrast to electricity, heat cannot easily be transported over long distances. Because of this, a business case can be dependent on the availability of nearby heat user. This can be problematic when the opportunity for a large scale renewable heat installation is bound to a location (e.g. because of the availability of bio-resources) that has little heat demand and no nearby heat demand (Krebbekx et al. 2011). The uncertainty involved in the long-term energy need of the nearby heat user is also a potential barrier.

4.2.5 *Technologies are not commercially available*

Certain technologies require further research and development in order to become technically and economically viable. For the glass industry, for example, the development of a breakthrough in furnace technology is required (VNG et al. 2012). Furthermore, commercially available technologies often have to 'proof' they are reliable, before being fully accepted by industry.

4.2.6 *Energy efficiency technologies*

Finally, energy efficiency technologiescan sometimes be a more economical way to reduce CO_2 emissions than renewable energy technologies. Instead of renewable heat technologies most industrial players have thus far answered the threat of rising gas prices by focusing on energy efficiency (The Bridge 2011).

4.3 Role of the government

To stimulate the adoption of renewable heat technologies, the government is urged to take a more proactive role (Krebbekx et al. 2012). The main types of support needed from the government, according to the roadmaps, are described below.

4.3.1 *Research and development support*

Some technologies that have a high potential (e.g. electric furnaces), are not commercially available yet, and require further development. An attractive investment climate is needed to develop breakthrough technologies (VNG et al. 2012). This should be achieved using long-term guarantees for innovation programmes (Stork et al. 2018).

4.3.2 *Financial resources support*

Supportive financing structures are needed to enable companies access to sufficient financial resources for their investments in renewable heat technologies (Stork et al. 2018).

The government's most essential role, at the moment, is its SDE+ instrument. Subsidies are considered to be an essential condition for renewable heat technologies to be economically feasible (VNMI et al. 2011). The SDE+ is therefore considered as a highly important tool to support renewable energy. The chemistry sector proposes to expand the SDE+ to also include energy efficiency measures and feedstock related measures (Stork et al. 2018).

4.3.3 *Indirect support*

According to Stork et al. (2018) it is important to ensure that there is sufficient skilled labour to implement and operate the renewable energy technologies. Furthermore, companies should be supported in investing in renewable heat by providing the required infrastructure and other ways to facilitate the implementation (Green Deals) (Stork et al. 2018).

5 Concluding remarks

There has been a limited growth in renewable heat in the Netherlands over the past decade, most notably in the sector that accounts for most of the total heat demand: the industry sector. Based on 18 publicly available roadmaps for the industry sector and, part of, the services sector, we can conclude that there are various reasons for industry to invest in renewable heat (e.g. consumer awareness and the threat of rising gas prices). However, the lack of a level playing (even European-wide, let alone world-wide), combined with strong pressure from a global market, is making investment decisions regarding renewable heat technologies, often more expensive and less proven than conventional technologies, difficult. Lowering the CAPEX of renewable technologies by R&D activities supported by the government, are necessary. Also, governmental financial support in the form of access to capital or subsidies (SDE+) are considered to be vital by industry to ensure the success of renewable heat.

Regarding the potential of renewable heat for industrial processes, it can be concluded that more research is needed in this field, within the Renewable Heat Supply project. Unlike households using low-temperature heat, industry often requires high to very high temperatures, which not all renewable heat technologies can supply. Also, some renewable heat sources (e.g. geothermal energy and waste heat) are bound by location, which means that the potential of such sources for industry is very dependent on the nearby location of an industrial end-user. It is interesting to note that recently the role of hydrogen in the energy transition has gained attention from industry. Hydrogen has been specifically mentioned during the Climate Agreement talks and McKinsey (2014) and VEMW (2017) also foresee a potential role for hydrogen to decarbonize industry.

The roadmaps provide a general overview of which technologies are of interest to which industrial subsector, but a more in-depth analysis will be conducted during the later stages of the Renewable heat supply project to determine the actual potential of renewable heat for industry.

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A Roadmaps per sector

Table A.1: Overview of roadmaps

No.	Sector	Source
1	Chemistry	Stork, M., de Beer, J., Lintmeijer, Niki. and B. den Oude (2018), Chemistry for Climate – Acting on the need for speed
2	Textile	Wintermans, J., van den Berg, F., van Hooijdonk, G., Luiken, A., Brinks, G. and H. op den Brouw (2012), Routekaart Textiel 2030
3	Glass industry	VNG, AGC, PPG, OI, Isover, Libbey, Ardagh, AgentschapNL (2012), Routekaart 2030 Nederlandse glasindustrie
4	Paper and board industry	The Bridge (2011), Routekaart VNP
5	Metallurgical industry	VNMI, AVNeG, Alaska Woodhouse Consultancy, BECO (2011), Rapportage routekaart metallurgische industrie
6	Building ceramics	KNB, AgenschapNL (2012), Samenvatting Routekaart 2030 Bouwkeramiek
7	Carpet	Modint, vntf, AgentschapNL (2012), Routekaart Tapijt 2030
8	Vegetable and fruit processing industry	VIGEF, beco, AgentschapNL (2012), Routekaart 2012-2030 Groente- en Fruitverwerkende Industrie
9	Waste water chain	Unie van Waterschappen, VNG, AgentschapNL and DNV (2012) , Routekaart afvalwaterketen
10	ICT	ICT office, AgentschapNL, Atos Consulting (2012), Routekaart ICT 2030
11	Rubber and plastic industry	Krebbekx, J, Duivenvoorde, G., de Wolf, W. and J. Lenselink (2012), Routekaart NRK 2012
12	Dairy industry	Krebbekx, J., Lambregts, E., de Wolf, W., and M. van Seventer (2011), Melk, de groene motor
13	MVO	Bergmans, F., Claassen, F., Gouweloos, R., Lankveld, H., Oudkerk, S. and S. Stekhoven (2012), Routekaart MVO
14	Potato processing industry	DPPA, AgentschapNL (2012), Verwaarding reststromen - Eindrapportage thematische routekaart VAVI
15	Meat industry	AgentschapNL, AKSV, KNS, Heijwo, COV, VNV, DNV, Nepluvi, Productschap pluim & vee, Productschap vee & vlees (2012) Visie op vlees in 2030
16	University medical centres	KplusV, TNO, AgentschapNL (2012) Routekaart UMC
17	Higher education	
18	Agriculture and horticulture	Rooijers, F.J., Schepers, B.L. and S. Cherif (2015), Visie 2030 Glastuinbouw

B Temperature ranges renewable heat technologies

Table B.1: Specific RES-H/C technologies serving the defined temperature levels (Beurskens et al. 2011)

Level	Temperature range	Biomass	Deep geothermal	Heat pumps	Solar thermal	Underground heat/cold storage
H5	> 600°C	Direct firing and substitute natural gas from biomass(bio-SNG)				
H4	200 - 600°C	Direct firing and substitute natural gas from biomass(bio-SNG)				
H3	100 - 200°C	CHP or heat-only from combustion from biomass, municipal solid waste (MSW) or bio-SNG	CHP or direct use of enhanced and conventional deep geothermal		Vacuum collectors	
H2	65 - 100°C	CHP or heat-only from combustion from biomass, municipal solid waste (MSW) or bio-SNG (possibly from anaerobic digestion	Enhanced and conventional deep geothermal		Flat plate collectors	
H1	< 65°C	CHP or heat-only from combustion from biomass, municipal solid waste (MSW) or bio-SNG (possibly from anaerobic digestion	Enhanced and conventional deep geothermal	Aerothermal, geothermal or hydrothermal heat pumps	Flat plate collectors, air-collectors, unglazed collectors	Storage in aquifers or lakes
C3	+10 to +15°C				Flat plate or vacuum collectors combined with a cooling device	Storage in aquifers or lakes
C2	-30 to +10°C					
C1	< -30°C					
Losses	Several temperature levels					