Potential for heating and cooling efficiency in the Brussels-Capital Region

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Potential for renewable heating and cooling efficiency in the Brussels-Capital Region

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1. Introduction

The European Union has made combating climate change one of its priorities. Among a large body of legislation, Directive 2018/2002 (amending Directive 2012/27) has set itself the objective of increasing the energy efficiency of the European Union by at least 32.5% by 2030. Article 14 of the Directive requires Member States (and each region in the case of Belgium) to determine their potential for high-efficiency cogeneration and efficient heating and cooling networks. This study is part of the implementation of Article 14 as well as of Annexes VIII and IX of the Directive modified by Delegated Regulation 2019/826 of 4 March 2019.

A first analysis of this type was carried out in 2015 (PWC, 2015). This study updates the results and conclusions. To this end, the change in the demand for heat and cooling is analysed in Section 2. Section 3 maps the demand for heating across the whole of Brussels. Section 4 presents the current energy and climate policies in Brussels. The potential for high-efficiency cogeneration in the region is presented in Section 5. Section 6 analyses and compares the different technical solutions available to cover heating and cooling needs. Section 7, meanwhile, emphasises the comparison of collective heating solutions (heating networks).

This study aims to respond to specific European demands but also to help the Brussels-Capital Region to project itself into a completely carbon-free future. This is why Section 8 contains a SWOT analysis (strengths, weaknesses, opportunities, threats) of the Brussels strategy for the decarbonisation of heating and cooling production and proposes a series of priority policies to be implemented now and in the longer term to achieve this ambitious objective.

2. Description of demand for heating and cooling

How much energy is needed in the Brussels Region and how will it change in the future? The aim of the analysis presented in this section is to determine and characterise the energy demand in order *ultimately* to identify the potential for energy supply, e.g. via heat networks and/or cogeneration.

The demand to be characterised represents the quantity of useful energy that can be replaced by an alternative source, i.e. that part of the energy needs for heating and cooling which are said to be substitutable. This concerns:

- for heat: heating and domestic hot water needs
- for cooling: air conditioning requirements.

Cooking is thus assumed to be non-substitutable.

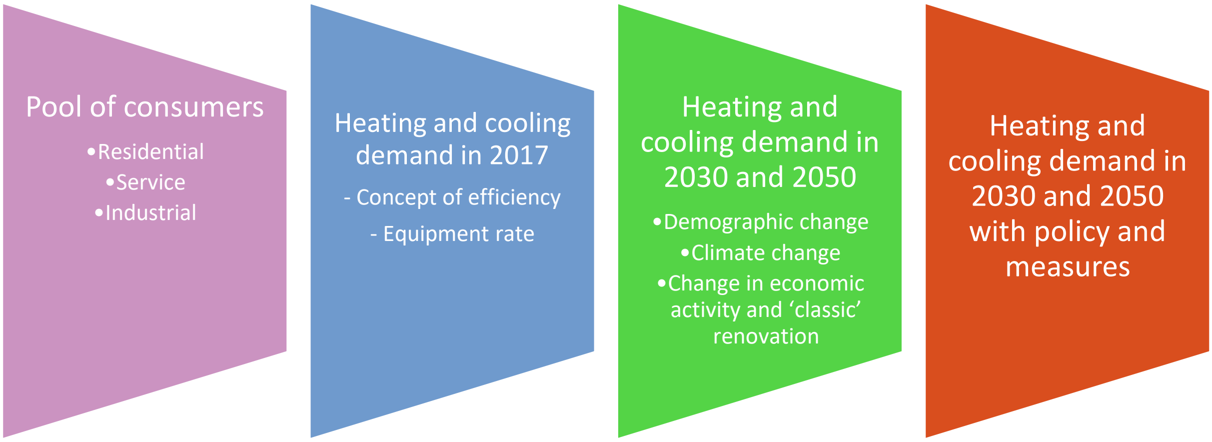

Figure 1: Schematic diagram of the estimate calculation of the current and future demand for heating and cooling

2.1. Calculation methodology

The 2017 Brussels sectoral energy balance sheets served as a basis for this task. These reports include data on energy consumption. The data and indicators required are different according to the sectors concerned (residential, service and industrial). We will therefore detail the methodology followed in each sector.

2.1.1. Residential

For the residential sector, the energy consumption linked to the heating of buildings and the production of domestic hot water is identified from the regional report on energy consumption by type of energy carrier and by type of use.

Dwelling type	Purpose	Diesel	Gas	Coal	Butane propane	Wood	Cogen heat.	Geo-	Solar heating	Heat pump (heat)	Electricity	Total
All housing	**All**	**815**	**5 202**	**22**	**47**	**51**	**17**		**5**	**5**	**1 354**	**7 518**
All housing	Specific electricity										1 025	1 025
All housing	Cooking	-	139	-	2				-	-	113	254
All housing	Sanitary hot water	28	784	0	1				5	0	142	959
All housing	Supplementary heating	-	-	18	-	34			-	-	21	73
Subtotal excluding heating	Total excluding heating	28	923	18	2	34	-	-	5	0	1 301	2 312
Primary heating of apartments	Central heating	586	2 383	0	20	-	17			3	32	3 041
Primary heating of apartments	Decentr. heating.	7	363	2	12	0				0	11	396
Single-family homes Primary heating	Central heating	190	1 367	0	0.08	-				1	7	1 574
Single-family homes Primary heating	Decentr. heating.	4	166	2	4	16				1	3	196
Heating sub-total	Total heating	788	4 279	4	45	16	17	-	-	5	53	5 206
Total heating and excluding heating		**815**	**5 202**	**22**	**47**	**51**	**17**	**-**	**5**	**5**	**1 354**	**7 518**

Table 1: Residential consumption matrix constructed on the basis of Brussels energy balance sheets, 2017 [GWh]

This consumption table is then cross-referenced with a matrix of representative efficiency by use and by energy carrier. The last work then consists of normalising the results relating to the heating (central and supplementary) according to the degrees.days (DJ).

Dwelling type	Purpose	Diesel	Gas	Coal	Butane propane	Wood	Cogen heat.	Geo-	Solar heating	Heat pumps (electricity)	Electricity
All housing	Specific electricity										
All housing	Cooking						1.00	1.00	1.00	1.00	
All housing	Sanitary hot water	0.65	0.65	0.65	0.65				1.00		0.80
All housing	Supplementary heating	0.75	0.83	0.70	0.83	0.75			1.00		1.00
Subtotal excluding heating	Total excluding heating										
Primary heating of apartments	Central heating	0.80	0.90	0.75	0.88	0.85	1.00				1.00
Primary heating of apartments	Decentr. heating.	0.80	0.90	0.75	0.88	0.85					1.00
Single-family homes Primary heating	Central heating	0.80	0.90	0.75	0.88	0.85					1.00
Single-family homes Primary heating	Decentr. heating.	0.75	0.83	0.70	0.83	0.75					1.00

Table 2: Efficiency matrix (source: ICEDD technical expert report)

The 2017 regional consumption relating to the production of cooling is available in the assessments. By multiplying it by an average coefficient of performance (COP) of 3, we obtain the demand for cooling. It should be noted that at this stage, the cooling needs of the residential sector remain very limited but that the situation could change in the future with the increase in average temperatures and the modification of living comfort standards.

2.1.2. Service

The methodology followed to calculate the heating and cooling needs in the service sector is identical to that used in the residential sector. The sectoral energy balance sheets (service sector and energy production) have made it possible to redefine a consumption matrix by sub-sector and by energy carrier. It should be noted that hospitality and catering, included in the 'trade' sub-sector in the energy balance sheets, was extracted from the latter to make it a separate category so that the specific energy uses of this sector could be specified. For this we have drawn on the results of the 'HORECA' (hospitality and catering) focus conducted by ICEDD in 2019 for the 2017 assessment year for the Brussels energy balance sheets (ICEDD, 2019).

Service sector	Electricity	Natural gas	Petroleum products and others	Heating	**Total**
Wholesale and retail trade	582.1	483.7	84.2	41.2	**1 191.2**
Hospitality and catering	113.3	257.4	4.7	0.0	**375.4**
Transport and communication	387.0	111.7	6.6	1.9	**507.2**
Banks, insurance and corporate serv.	876.3	625.6	202.3	0.075	**1 711.8**
Education	119.1	293.5	36.2	23.9	**472.6**
Health	232.1	332.7	16.2	54.7	**635.7**
Culture sports	63.5	56.4	0.0	14.3	**134.2**
Other services	137.3	271.9	13.5	12.0	**434.6**
Administration	561.6	453.4	46.1	9.1	**1 070.2**
Agro	1.8	4.6	0.0	0.0	**6.4**
Energy/water	94.0	94.0	7.9	169.7	**365.7**
Total for service sector	**3 168.1**	**2 985.1**	**417.6**	**334.3**	**6 905.2**

Table 3: Energy consumption in the service sector in 2017 [GWh]

This consumption must then be broken down by use. To this end, the results of a study carried out by the University of Antwerp on consumption per use in the service sector (STEM) were considered as was the study on the distribution of electrical uses in the service sector in Wallonia (ICEDD, 2014).

As for the residential sector, these data are then cross-referenced with a matrix of efficiency by use and by energy carrier constructed on the basis of the expertise of the ICEDD and theoretical efficiency data from the PEB and Energie+ calculation methods.

The heat produced by the renewable installations (from the Brussels region's 'production' energy balance sheets) is added to these requirements and divided between heating and domestic hot water (DHW) requirements.

The total heating needs thus obtained are then normalised from a climatic point of view.

	%	**Fuel uses**		
	Heating	**Hot water**	**Other**	**Total**
Handicrafts	93%	7%	0%	100%
Wholesale and retail trade	93%	7%	0%	100%
Public lighting	0%	0%	0%	0%
Public transport excluding lighting	86%	10%	4%	100%
Banking, insurance	92%	8%	0%	100%
Education	94%	5%	1%	100%
Academia, research	94%	5%	1%	100%
Health	63%	22%	14%	100%
Culture and sports	86%	10%	4%	100%
Other services	86%	10%	4%	100%
Administration	92%	8%	0%	100%
Water energy	86%	10%	4%	100%

Table 4: breakdown of fuel use by use (STEM)

% **USES OF ELECTRICITY**

	Lights	**Heating**	**Hot water**	**Cooking**	**Cooling**	**Air conditioning**	**Circulating pumps**	**Office automation**	**Other**	Total
HANDICRAFTS	40%	2%	2%	0%	16%	11%	6%	0%	23%	100%
WHOLESALE AND RETAIL TRADE	40%	2%	2%	0%	16%	11%	6%	0%	23%	100%
PUBLIC LIGHTING	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%
TRANSPORT AND COMMUNICATION, EXCLUDING LIGHTING.	23%	4%	0%	0%	0%	9%	8%	0%	55%	100%
BANKING, INSURANCE	35%	2%	0%	0%	0%	13%	15%	25%	10%	100%
EDUCATION	61%	2%	0%	0%	4%	9%	9%	9%	5%	100%
ACADEMIA, ESEARCH	61%	2%	0%	0%	4%	9%	9%	9%	5%	100%
HEALTH	32%	1%	0%	0%	0%	8%	6%	0%	53%	100%
CULTURE AND SPORTS	23%	4%	0%	0%	0%	9%	8%	0%	55%	100%
OTHER SERVICES	23%	4%	0%	0%	0%	9%	8%	0%	55%	100%
ADMINISTRATION	35%	2%	0%	0%	0%	13%	15%	25%	10%	100%
WATER ENERGY	10%	0%	0%	0%	0%	0%	0%	0%	90%	100%

Table 5: Breakdown of electricity consumed by use in the service sector, ICEDD

For hospitality and catering, specifically, we have considered the following distributions ((ICEDD, 2019)):

RESTAURANTS[1]

	ELECTRICITY							
	HEATING	LIGHTING	DHW	COOKING	VENTILATION	COOLING	OFFICE AUTOMATION	TOTAL
	23%	23%		6%	8%	37%	3%	100%
	GAS							
	HEATING	LIGHTING	DHW	COOKING	VENTILATION	COOLING	OFFICE AUTOMATION	TOTAL
	21%		27%	52%				100%

2.1.3. Industry

The Brussels industrial report on energy consumption has been reworked to group together the sub-sectors of activity by code ‘NACE 3 digit[2]’. For each of the main sectors thus reconstructed, a percentage is assigned, representing the proportion of fuel used for 'substitutable heat’ purposes (Table 6). Substitutable heat is heat with temperature levels that are low enough to be covered by an alternative technical solution (heat pumps, etc.). Hence, it covers space heating, DHW, etc. It can be noted that this portion of substitutable heat is very low in certain sectors such as the iron and steel industry or even for non-metallic minerals which use high-temperature furnaces (> 1 000 °C). However, it should be added that the Brussels-Capital Region is not affected much by these high-temperature heat needs due to the small size of its industrial sector. We then consider an efficiency of

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[1] https://newlook.dteenergy.com/wps/wcm/connect/dte-web/home/save-energy/business/tips+by+business/restaurant according to US EIA

[2] The classification **N**ACE stands for **N**omenclature statistique des **A**ctivités économiques dans la **C**ommunauté **E**uropéenne (Statistical Classification of Economic Activities in the European Community), a classification system for economic activities

85%[3] to move from energy consumption to the concept of demand.

NACE 3	SUB-BRANCH	% SUBST. HEAT
100	STEEL INDUSTRY	0.05
200	NON-FERROUS MINERALS	0.05
300	ORGANIC AND INORGANIC CHEMISTRY	0.72
300	CHEMISTRY	0.72
500	OTHER POWER SUPPLY	0.70
600	TEXTILE	0.76
700	PRINTING PAPER	0.92
800	METAL MANUFACTURING (NOT SPECIFIED)	0.57
900	OTHER INDUSTRIES	0.53
0	Office	1.00

Table 6: Percentage of substitutable heat in Brussels industry (source: ICEDD)

It should be noted that consumption related to the steel industry and non-metallic minerals referenced in the Brussels-Capital Region is exclusively the result of office activities. It was therefore assumed that establishments in these sectors have consumption profiles comparable to private offices.

To determine the breakdown by use of the electricity consumed by industrial branch, a study carried out by the ICEDD in collaboration with the industrial federations gives the following breakdown:

Federation	Air-conditioning	Heating	Lighting	Process cooling	HVAC	Information technology	Packaging	Heat pump	Ventilation	Other
FEVIA	2.9%	0.0%	12.0%	21.5%	0.2%	0.1%	2.7%	0.0%	0.6%	60.1%
ESSENSCIA	0.4%	0.8%	9.0%	13.5%	5.8%	0.1%	0.4%	0.0%	0.0%	69.9%
Other	1.0%	0.9%	5.8%	0.5%	0.3%	0.4%	0.9%	0.0%	0.4%	89.7%
FIV-GSV-FEBELCEM-Chaux	0.1%	0.0%	2.6%	0.5%	0.0%	0.0%	0.3%	0.0%	0.0%	96.5%
Extractive industry	0.0%	0.8%	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	97.1%
FEDUSTRIA-FETRA-AGORIA-FEBELGRA	3.9%	2.4%	15.9%	1.4%	1.2%	1.6%	3.1%	0.0%	1.6%	69.0%

Table 7: Breakdown by use of electricity consumption in industry (source ICEDD).

To switch from energy consumption to the need for cooling, a COP of 3 is applied for applications linked to HVAC (ventilation, air conditioning) and an average value of 2 for the production of cold linked to 'processes'. (architecture et climat, s.d.).

2.2. Current demand

By applying the methodology described above, we can calculate the current demand for heating and cooling per use for the three main consuming sectors.

As a reminder, the figures presented below represent standardised demands (and not consumption).

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[3] This 85% efficiency is chosen arbitrarily to take account of the presence in the industry of a range of heating installations (ovens, boilers) with varied performances.

	Demand - By use							
2017 (GWh)	Total primary heating	Supplementary heating	Sanitary hot water	Cooking	Air conditioning	Refrigeration / (cooling process)	Other electrical uses	TOTAL
Service	3 093.6		289.4	141.8	1 075.4	343.7	2 515.7	**7 459.6**
Housing	4 891.9	63.0	646.5	254	26.8	530.0	1 025.2	**7 437.4**
Industry	194.0				32.0	24.3		**250.3**
Total	8 179.5	63.0	935.9	395.8	1 134.1	898.0	3 540.9	15 147.3

Table 8: Current heating and cooling demands by sector and by use

Only part of this demand can be substituted by alternative technical solutions such as cogeneration or an efficient heating and/or cooling network (Table 9).

	Demand for heating		**Demand for cooling**	
2017 (GWh)	Total heating requirement	Substitutable heat (= total - cooking)	Cooling requirement	Substitutable cooling (= airco only)
Service	3 525	3 383	1 419	1 075
Housing	5 855	5 601	557	27
Industry	194	194	56	32
Total	**9 574**	**9 179**	**2 032**	**1 134**

Table 9: Sectoral heating and cooling demands (total and substitutable)

The overall heating needs (i.e. the total heating demand) (9.57 TWh) represent 60.6% of the total energy demand of the 3 sectors, for all types of demands combined, which shows the importance of these needs in the report on energy consumption.

Substitutable refrigeration is, by definition, associated with air conditioning and it is mainly concentrated in the service sector (95%).

2.2.1. Residential

According to the methodology specified in the previous paragraphs, the standardised substitutable needs of the residential sector in the Brussels-Capital Region amount to 5 601 GWh for heat and 27 GWh for cooling for the year 2017 (Table 9).

The details of the standardised heating and cooling needs, whether or not they are substitutable, by energy carrier and by type of housing, are in Table 11.

From the calculations and elements worked on in this task, it is possible to estimate the specific real final consumption and the actual portion specific to heating.

The average consumption per dwelling linked to heating available in the detail of the Brussels energy balance sheets is 8 271 kWh for apartments and 20 690 kWh for houses. Considering the current average surface areas[4], we can determine the average specific consumption of housing in the Brussels-Capital Region (Table 10).

	Average heating consumption per type of dwelling in 2017 [kWh]	Average area per type of accommodation [m²]	Average specific consumption per dwelling [kWh / m²]
Apartment	8 271	76	109
House	20 690	176	118

Table 10: Average specific consumption per dwelling in the Brussels-Capital Region in 2017

By considering the areas available in the land register matrix of the Brussels-Capital Region for apartments and houses, we calculate a weighted average final consumption linked to heating and auxiliaries of 113 kWh/m² /year.

This final consumption is then normalised in order to remove the influence of the variation in climate from one year to another. Finally, we apply an average efficiency calculated for the whole of the demand in order to obtain a specific heating need for the average Brussels dwelling (apartment + house). The value thus calculated is 99 kWh/m²/year.

For Section 4, we will work on the basis of this consumption in order to compare them with the specific consumption target for Brussels housing of 100 kWh/m²/year set in the Renovation Strategy.

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[4] Information from Bruxelles Environnement

Year	Dwelling type	Purpose	Diesel	Natural gas	Coal	Butane propane	Wood	Cogen steam.	Heat (Geo)	Heat (HP)	Heat (Sol. Therm.)	Electricity	**Total**
2017	All housing	Specific electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 025.2	**1 025.2**
2017	All housing	Air conditioning										26.8	**26.8**
2017	All housing	Refrigeration/Freezing										530.0	**530.0**
2017	All housing	Cooking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
2017	All housing	Sanitary hot water	18.04	509.67	0.01	0.38	-	-	-	0.12	4.69	113.55	**646.5**
2017	All housing	Supplementary heating	-	-	13.61	-	27.46	-	-	-	-	21.97	**63.0**
2017	*Primary heating of apartments*	*Central heating*	498.6	2 281.2	0.2	18.9	0.0	18.6	0.0	3.3	0.0	33.6	**2 854.5**
2017	*Primary heating of apartments*	*Decentr. heating.*	6.2	347.6	1.3	11.0	0.4	0.0	0.0	0.3	0.0	11.9	**378.7**
2017	Primary heating of apartments	Total heating apartment	504.8	2 628.8	1.5	29.9	0.4	18.6	0.0	3.6	0.0	45.5	**3 233.1**
2017	*Single-family homes Primary heating*	*Central heating*	*162.0*	*1 308.6*	*0.2*	*7.9*	*0.0*	*0.0*	*0.0*	*0.7*	*0.0*	*7.7*	**1 487.2**
2017	*Single-family homes Primary heating*	*Decentr. heating.*	*3.3*	*146.6*	*1.3*	*3.9*	*12.6*	*0.0*	*0.0*	*1.2*	*0.0*	*2.7*	**171.6**
2017	Single-family homes Primary heating	Total heating house	165.3	1 455.3	1.5	11.8	12.6	0.0	0.0	1.8	0.0	10.4	**1 658.7**
2017	Primary heating	Central heating	660.7	3 589.8	0.5	26.8	0.0	18.6	0.0	4.0	0.0	41.2	**4 341.7**
2017	Primary heating	Decentr. heating.	9.5	494.2	2.6	14.9	13.0	0.0	0.0	1.5	0.0	14.6	**550.2**
2017	Primary heating	Total prim. heating	670.1	4 084.0	0.031	41.7	13.0	18.6	0.0	5.5	0.0	55.9	**4 891.9**
2017	Total	Total excluding heating	18.0	509.7	13.6	0.4	27.5	0.0	0.0	0.1	4.7	1 717.5	**2 291.5**
2017	Total	Total heating	670.1	4 084.0	0.031	41.7	13.0	18.6	0.0	5.5	0.0	55.9	**4 891.9**
2017	Total	need for substitutable heat	688.2	4 593.7	16.7	42.1	40.4	18.6	0.0	5.6	4.7	191.4	**5 601.4**
2017	Total	need for substitutable cooling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8	**26.8**
2017	**Total**	**Total**	**688.2**	**4 593.7**	**16.7**	**42.1**	**40.4**	**18.6**	**0.0**	**5.6**	**4.7**	**1 773.4**	**7 183.4**

Table 11: Standardised demand for heating and cooling for the residential sector based on consumption in 2017 (GWh)

2.2.2. Service

According to the same methodology, the standardised substitutable heating and cooling needs of the service sector in the Brussels-Capital Region amount to 3 383 GWh (3 093 289) for heat and 1 075 GWh for cooling on the assessed consumption from 2017.

in GWh LCV	DEMAND - By use (standardised)						Heating requirement		Cooling requirement	
Service sector	Total heating	Sanitary hot water	Cooking	HVAC refrigeration	chilling	other uses	Total heating requirement	Substitutable heat	Total cooling requirements	Substitutable cooling
Wholesale and retail trade	552.2	37.3	0.0	192.1	227.0	404.0	589.6	589.6	419.1	192.1
Hospitality and catering	93.9	46.5	141.8	27.2	104.8	0.0	282.2	140.4	132.0	27.2
Transport and communication	106.5	7.8	0.0	150.9	0.0	333.7	114.4	114.4	150.9	150.9
Banks, insurance and corporate serv.	738.5	43.5	0.0	341.8	0.0	744.9	782.0	782.0	341.8	341.8
Education	320.1	11.4	0.0	30.4	11.8	106.0	331.5	331.5	42.2	30.4
Health	258.4	71.3	0.0	57.7	0.0	259.6	329.7	329.7	57.7	57.7
Culture sports	62.7	5.5	0.0	17.8	0.0	57.5	68.2	68.2	17.8	17.8
Other services	250.9	19.5	0.0	38.4	0.0	130.7	270.3	270.3	38.4	38.4
Administration	456.7	26.5	0.0	219.0	0.0	477.4	483.2	483.2	219.0	219.0
Agro	3.8	0.3	0.0	0.0	0.0	2.0	0.041	0.041	0.0	0.0
Energy/water	249.8	19.9	0.0	0.0	0.0	0.0	269.7	269.7	0.0	0.0
Total for service sector	3 093.6	289.4	141.8	1 075.4	343.7	2 515.7	3 524.9	3 383.1	1 419.0	1 075.4

Table 12: heating and cooling demand from the service sector by branch of activity in the Brussels-Capital Region: by vectors and uses

2.2.3. Industry

The industrial sector, which is relatively small in the Brussels-Capital Region, has, according to the same calculation methodology, substitutable standardised needs of 194 GWh for heating and 32 GWh for cooling on the basis of the 2017 assessed consumption (Table 13).

in GWh LCV, 2017

	Demand - heating need	Demand - cooling need	Demand - process cooling		
Sector industry	Substitutable heating	Substitutable cooling		Other ‘elec’ uses	Other ‘fuel’ uses
STEEL INDUSTRY	0.0	0.0	0.0	0.5	0.0
NON-FERROUS	0.1	0.1	0.4	32.3	3.3
CHEMISTRY	27.4	0.3	7.1	18.9	21.5
NON-METALLIC MINERALS	0.3	0.0	0.0	2.2	0.1
FEEDING	33.6	7.1	35.3	39.9	27.9
TEXTILE	5.0	0.1	0.0	0.7	3.5
PAPER	18.5	3.5	0.8	26.2	7.9
METAL MANUFACTURING	64.8	12.2	2.9	90.4	78.6
OTHER INDUSTRIES	44.3	8.7	2.0	64.2	60.7
TOTAL INDUSTRY	194.0	32.0	48.6	275.2	203.5

Table 13: Substitutable demand from Brussels industry

2.3. Reduction of needs by setting up the target of 100 kWh/m²/year

How can we estimate the reduction in heat requirements that can be expected following the implementation of the target for primary specific consumption (DHW included) of 100 kWh/m²/year of the Renovation Strategy (see Section 4)?

By subtracting the share of DHW estimated at 20 kWh/m²/year, we obtain a specific primary consumption linked to heating of 80 kWh/m²/year. This can be converted into final energy and is then worth 76 kWh/m²/year.

If we compare this figure of 76 kWh/m²/year with the results of Section 2.1.1, the reduction in heating needs would be 24%.

However, it is important to note that we start from real consumption to estimate a real specific need of 99 kWh/m²/year (section 2.1.1). In addition, we consider as a starting point a specific theoretical consumption data, calculated on the basis of the PEB methodology (the objective of the Renovation Strategy mentioned above).

We know that the difference between the values estimated by this method and the measured consumption can be relatively large even if it is reduced for high-performance buildings, which is thus the case for buildings after renovation.

However, a study carried out by the BBRI and Architecture et Climat (Architecture_et_Climat & CSTC, 2018), estimates that the final specific consumption measured for recent high-performance buildings still remains, on average, 30% lower than that estimated by these calculation methods.

If we apply this reduction to the specific needs calculated for heating (76 kWh), we obtain a heat requirement of 53 kWh/m²/year which represents a reduction of 46% compared to the 99 kWh/m²/year estimated in 2017 (see Section 2.2.1).

2.4. The change in demand in a BAU renovation scenario.

The change in demand for 2030 and 2050, in a Business As Usual (BAU) scenario, is calculated on the basis of the assumptions described below.

For the residential sector:

- Residential heating demand is divided into two distinct parts: demand in existing buildings and demand in new buildings.
    - The first of these will decrease from the year 2018 on the basis of a renovation rate of 1% of housing and a reduction in the heating needs of renovated housing by 46%[5] compared to the initial situation.
    - The heating requirement for new buildings is considered equal to 15 kWh/m²/year (target in place linked to the PEB), the number of m² depends on the change in the number of households and the average m² of current housing. In these scenarios, and within the limited framework of this study, we did not consider a possible change in the average surface area of new homes.
- The change in the demand for DHW depends on the change in the population (source: IBSA). In doing so, it is considered that the DHW requirement is constant per person.
- We also assumed an improvement in the overall efficiency of heating and DHW equipment, considering a renewal rate of the installations of 3% per year. This assumption leads to an improvement in energy consumption by 11.6% in 2050 compared to 2017.
- In this study, we have assumed that the demand for cooling is only influenced by the change in the number of households. The reason for this simplifying assumption is linked to the fact that the demand for cooling is linked not only to the increase in temperatures but above all to changes in sunshine. Under these conditions and even if average temperatures will increase by 2050, it is very difficult to estimate the increase in specific demand for cooling per dwelling.

For the service sector:

- In the same way as for the residential sector, the demand for heating is divided between existing buildings and new buildings.
    - The first of these will decrease from the year 2018 on the basis of a renovation rate of 1% of service sector buildings and a reduction in the heating needs of renovated service sector buildings by 46% compared to the initial situation (at this stage we have considered the same reduction as for residential). This gives an annual improvement of 14.2 GWh/year.
    - The heating requirement for new buildings is considered equal to 15 kWh/m²/year (target in place linked to the PEB), the number of m² depends on the evolution of the number of jobs and the number of average m²/FTE[6] available for the year 2017 in the energy balance sheets. In these scenarios, we have not considered any change in this average number of m²/FTE.
- We also assumed an improvement in the overall efficiency of heating and DHW equipment, considering a renewal rate of the installations of 3% per year. This assumption leads to an improvement in energy consumption by 11.6% in 2050 compared to 2017.
- The change in the demand for DHW and the demand for substitutable cooling (linked, as was mentioned, to air conditioning) are connected to change in the number of employees in the Brussels Region (IBSA and Stabel data, extrapolated to 2050).

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[5] This is an improvement identical to that calculated by the implementation of performance linked to the renovation strategy (see Section 2.3), except that the renovation rate is equal to that observed today.

[6] Full-time equivalent

- Changes in other demands are influenced by changes in GDP, including 'specific electricity' demand.

For the industrial sector:

- The demand for heating and cooling in industry is assumed to evolve in the same way as the evolution of the overall Gross Domestic Product (GDP) (BFP and Institute of National Accounts, 2020)

The application of these different assumptions makes it possible to obtain the following tables which give the change in the total demand for heating and cooling by 2050 in the residential sector (Table 14), the service sector (Table 15) and industry (Table 16).

Residential uses - Renovation 1%	**2017**	**2020**	**2025**	**2030**	**2040**	**2050**
Total substitutable demand	**5 628**	**5 621**	**5 514**	**5 406**	**5 196**	**4 984**
Total substitutable heating	5 601	5 594	5 486	5 378	5 168	4 956
Total substitutable cooling	27	27	27	27	28	28
Primary heating - existing	4 892	4 865	4 746	4 627	4 389	4 150
Auxiliary heating - existing	63	64	64	65	65	66
Primary heating - new	-	13	17	22	32	42
Cooking	254	258	259	261	264	267
Sanitary hot water	646	652	659	665	682	697
Specific electricity	1 025	1 035	1 045	1 055	1 081	1 106
Cooling - Air conditioning	27	27	27	27	28	28
Cooling - refrigeration	530	538	541	544	550	556

Table 14: Change in demand for heating and cooling in the residential sector in the Brussels-Capital Region with a renovation rate of 1%/year (GWh)

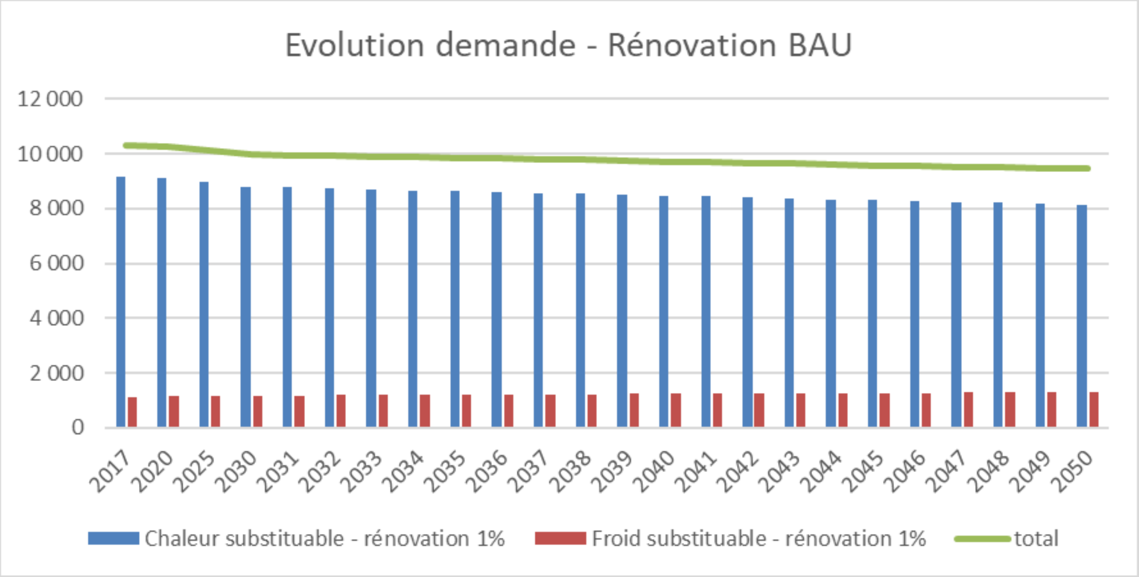
Service sector uses - Renovation 1%	**2017**	**2020**	**2025**	**2030**	**2040**	**2050**
Total substitutable demand	**4 458**	**4 433**	**4 372**	**4 350**	**4 295**	**4 234**
Total substitutable heating	3 383	3 346	3 283	3 227	3 112	2 994
Total substitutable cooling	1 075	1 087	1 089	1 123	1 184	1 240
Existing heating	3 094	3 051	2 980	2 909	2 766	2 624
New heating	-	2	7	13	23	32
Total DHW	289	293	296	306	322	338
Cooking	142	130	150	158	186	223
Cooling - Refrigeration.	344	316	365	382	449	541
Cooling - Air conditioning	1 075	1 087	1 089	1 123	1 184	1 240
Others (specific electricity)	2 516	2 314	2 669	2 798	3 290	3 958

Table 15: Change in demand for heating and cooling in the service sector in the Brussels-Capital Region with a renovation rate of 1%/year (GWh)

Industrial uses	**2017**	**2020**	**2025**	**2030**	**2040**	**2050**
Total substitutable demand	**226**	**208**	**228**	**228**	**230**	**230**
Total substitutable heating	194	178	196	196	198	198
Total substitutable cooling	32	29	32	32	33	33
Substitutable heat	194	178	196	196	198	198
Other uses (fuels)	203	187	206	206	207	208
Other uses (electricity)	275	253	278	278	281	281
Cooling air-conditioning	32	29	32	32	33	33
Process cooling	49	45	49	49	50	50

Table 16: Change in heating and cooling demand in the industrial sector in the Brussels-Capital Region (GWh)

If we look only at substitutable demands, we see that the heating demand goes from 9.8 TWh in 2017 to 8.1 TWh in 2050 and that the cooling demand increases slightly from 1.1 to 1.3 TWh over the same period. The total demand for substitutable heating and cooling therefore drops from 10.3 TWh to 9.5 TWh between 2017 and 2050 (see graph below).



	Change in demand - Renovation BAU
	Substitutable heating - renovation 1%
	Substitutable refrigeration - renovation 1%
	Total

Figure 1: Change in the demand for substitutable heating and cooling in the Brussels-Capital Region between 2017 and 2050 with a renovation rate of 1%/year (GWh)

2.5. The change in demand in an accelerated renovation scenario

We can recalculate the change in the demand for heating and cooling in the different sectors, assuming, this time, that the annual rate of renovation of residential and service sector buildings goes from 1 to 3% as provided for in the last Brussels Regional Policy Statement (RPS). The other calculation assumptions are kept unchanged.

With this acceleration in the renovation rate of buildings in Brussels, we can calculate that the demand for substitutable heating in 2050 amounts to 3 528 GWh in the residential sector (Table 17) and 2 054 GWh in the service sector (Table 18). On the other hand, the industrial sector is not expected to be affected by this acceleration of the renovation strategy.

Residential uses - Renovation 3%	**2017**	**2020**	**2025**	**2030**	**2040**	**2050**
Total substitutable demand	**5 628**	**5 621**	**5 276**	**4 930**	**4 243**	**3 556**
Total substitutable heating	5 601	5 594	5 248	4 902	4 215	3 528
Total substitutable cooling	27	27	27	27	28	28
Primary heating - existing	4 892	4 865	4,508	4 150	3 436	2 722
Auxiliary heating - existing	63	64	64	65	65	66
Primary heating - new	-	13	17	22	32	42
Sanitary hot water	646	652	659	665	682	697
Cooking	254	258	259	261	264	267
Specific electricity	1 025	1 035	1 045	1 055	1 081	1 106
Cooling - Air conditioning	27	27	27	27	28	28
Cooling - refrigeration	530	538	541	544	550	556

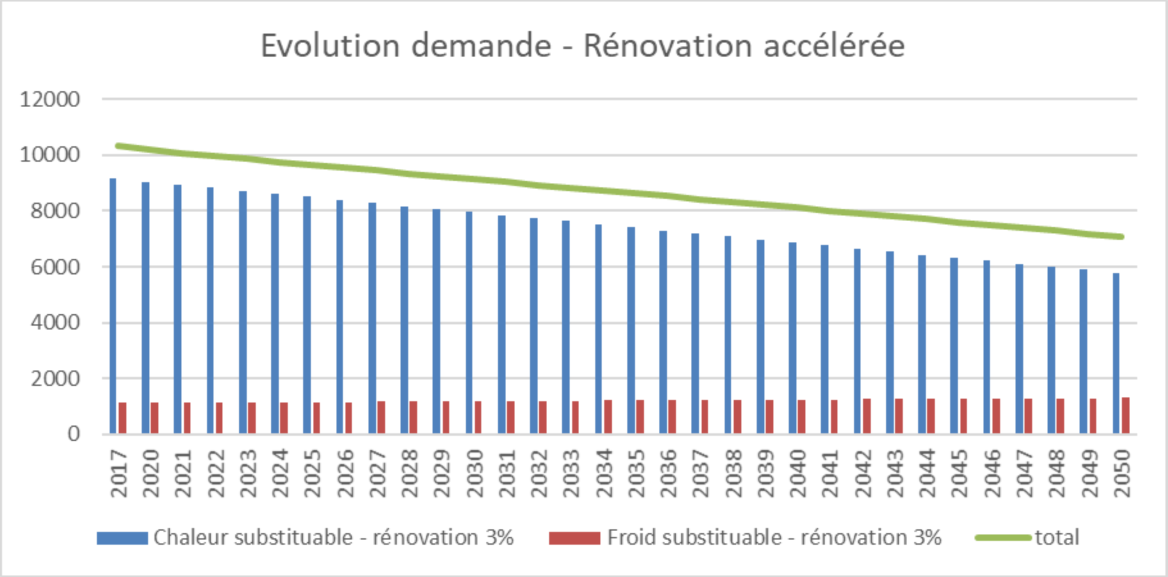
Table 17: Change in demand for heating and cooling in the residential sector in the Brussels-Capital Region with a renovation rate of 3%/year (GWh)

Service sector uses - Renovation 3%	**2017**	**2020**	**2025**	**2030**	**2040**	**2050**
Total substitutable demand	**4 458**	**4 348**	**4 144**	**3 980**	**3 641**	**3 295**
Total substitutable heating	3 383	3 260	3 055	2 857	2 457	2 054

Total substitutable cooling	1 075	1 087	1 089	1 123	1 184	1 240
Total existing heating	3 094	2 966	2 752	2 539	2 112	1 685
Total new heating	-	2	7	13	23	32
Total DHW	289	293	296	306	322	338
Cooking	142	130	150	158	186	223
Cooling - refrigeration.	344	316	365	382	449	541
Cooling - air conditioning	1 075	1 087	1 080	1 082	1 081	1 075
Others (specific electricity)	2 516	2 314	2 669	2 798	3 290	3 958

Table 18: Change in demand for heating and cooling in the service sector in the Brussels-Capital Region with a renovation rate of 3%/year (GWh)

We can then calculate the overall change in substitutable heating demands in this scenario of accelerated building renovation. This time the demand for substitutable heating goes from 9.8 TWh in 2017 to 5.8 TWh in 2050 (Figure 2). It is these 5.8 TWh of the substitutable heating demand that must be ensured by low-carbon production means (see Sections 6 and 7).

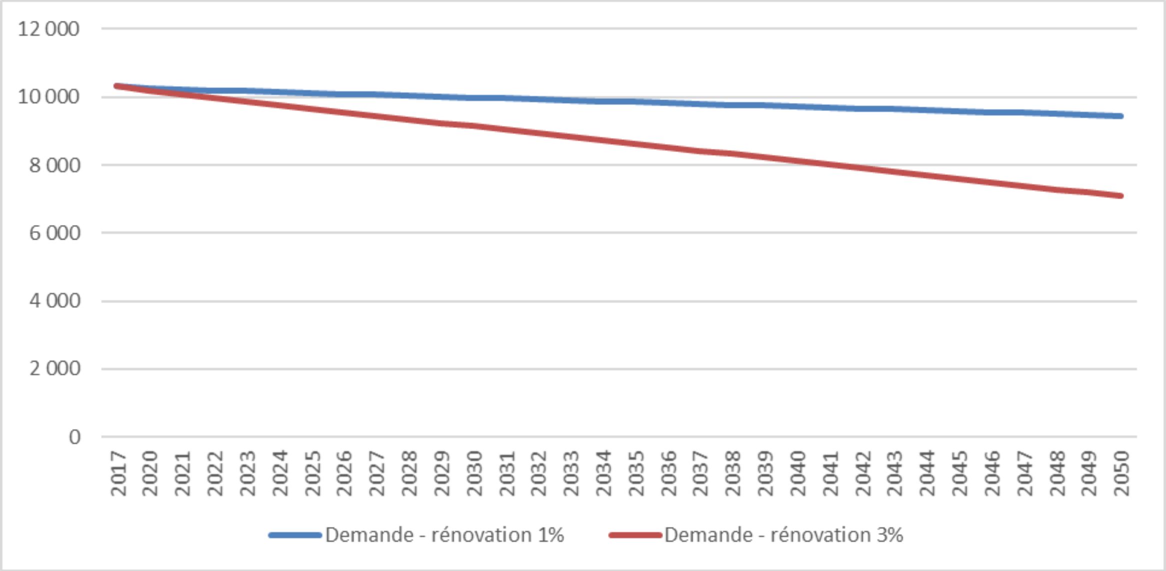


	Change in demand - Accelerated renovation
	Substitutable heating - renovation 3%
	Substitutable refrigeration - renovation 3%
	Total

Figure 2 : Change in the demand for substitutable heating and cooling in the Brussels-Capital Region between 2017 and 2050 with a renovation rate of 3%/year (GWh)

2.6. Comparison between the two scenarios

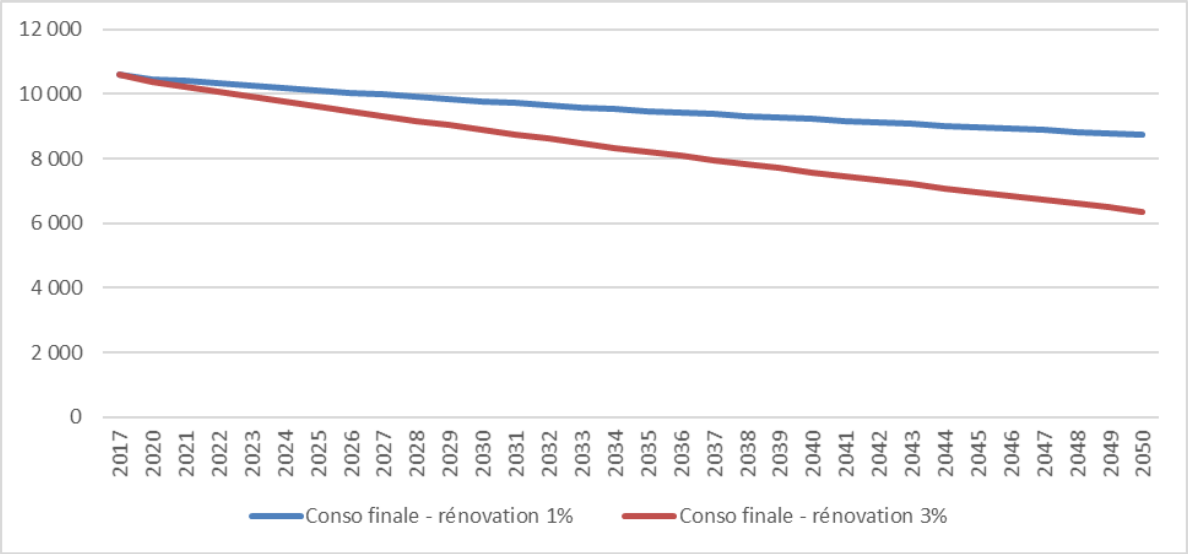
The following graphs show the difference between the two building renovation scenarios studied (renovation rate of 1% per year or 3% per year). The first graph shows the change in the demand for heating and cooling from 2017 to 2050.



	Demand - renovation 1%
	Demand - renovation 3%

Figure 3: Change in demand for heating and cooling in the Brussels-Capital Region in two building renovation scenarios

It is also possible, by using the same efficiency assumptions, to calculate the final consumption induced by these demands for substitutable heating and cooling.



	Final consumption - renovation 1%
	Final consumption - renovation 3%

Figure 4: Change in energy consumption linked to demand for heating and cooling in the Brussels-Capital Region in two building renovation scenarios

It can be noted that the final consumptions are lower than the aggregated demands. This result is due to demand and final consumption linked to cooling. Indeed, the coefficient of performance of a refrigeration machine is greater than one, which implies a final energy consumption that is lower than the demand.

3. Description of demand for heating and cooling

3.1. Methodology for mapping of needs

3.1.1. Estimation of needs

To map the substitutable needs for heat and cold for heating, DHW and cooling in the residential, service and industrial sectors, it was first necessary to estimate these (see Section 2).

For the residential sector, we have considered the land register matrix transmitted by Finance FPS. This matrix includes all the cadastral plots and, possibly, a description of the building. We have reworked the matrix to associate the surface area of the building (data from the matrix) with a specific need linked to the demand for heating and DHW heat. We were able to differentiate the total areas of apartments and houses as well as the demand in order to have additional precision.

On the basis of the assessment and the work carried out in Section 2, we know the total heating requirement for all houses and apartments. By dividing this information by the total areas of houses and apartments we obtain specific requirements for each of them.

For the DHW, we calculated a ratio giving the DHW needs / m² inhabited. These specific needs are then used to estimate a heating requirement and an individual DHW requirement for each of the land register lines corresponding to apartments or houses.

For their part, the demand for heat and cooling of the service and industrial sectors was calculated on the basis of figures from the energy balance sheets.

3.1.2. Spatial mapping of needs

Once the requirements estimate had been made, the mapping was carried out using ArcGIS software. Depending on the case, it was necessary to reconcile the requirements of plots in the land register or the individual consumption of service and industrial establishments with the statistical sectors in which they are located. As part of this exercise, we have used the Belgian Lambert 1972 projection system.

A. Energy density of heating and cooling requirements

For the residential sector, the available heating and cooling requirements were defined by plot in an Excel table. Each plot is associated with a CaPaKey[7], making it possible to identify them precisely. As several consumption points can nevertheless be associated with a CaPaKey, we first grouped the consumptions by CaPaKey by aggregating them.

Although we had the consumption data of the plots, it was also necessary to associate this consumption with its spatial location. For this, we first used two layers listing the plots in the land register and their location (*Bpn_CaPa_BRU*[8]), as well as the statistical sectors and their location (ICEDD file).

Then the first step in ArcGIS was to create a geometric intersection between these two types of features. For that, we used the command ‘intersect’ between the layers. In this way, we have associated each plot with a statistical sector of the region.

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[7] Unique key of the plot in the land register

[8] Downloaded from the following site: https://eservices.minfin.fgov.be/myminfin-web/pages/cadastral-plans?_ga=2.208903122.1579110607.1613388656-2003494290.1610609443

Since a plot can be located straddling several statistical sectors, the operation also made it possible to create pieces of plots - associated with a single statistical sector - and to calculate the proportional area of these pieces of plots.

Thanks to this, we have calculated the area ratio - area of the piece of plot compared to the area of the entire plot - which will allow us to avoid double counting of consumption data.

We then reconciled the consumption estimates per plot with the plot mapping file using CaPaKey. Finally, we calculated the share of energy consumption of each piece of plot via the area ratio before grouping these results by statistical sector.

As we know the area of the statistical sectors, the results were expressed in GWh/km² and illustrated by the Figure 2 which gives the density of the heating requirements of the residential sector. Five consumption categories were created using the Jenkins natural thresholds method[9].

For the service and industrial sectors, a similar approach has been conducted to reconcile the data available to us with their place of consumption. The data are thus grouped according to statistical sectors. Once again, we expressed the energy density by reducing these results to GWh/km² and five consumption categories were created according to the Jenkins natural thresholds method. These results are illustrated in Figure 3 for heating demands and Figure 4 for cooling demands.

B. Other

Four other maps were produced for a better overview of the important consumption points in the region. Here are the details of what we have achieved based on the order of presentation of the maps.

First, we sought to identify the statistical sectors located within a radius of one kilometre around the Neder-Over-Heembeek incinerator to determine the benefit of extending the heating network to recover the waste heat from this installation[10]. To that end, we created a buffer zone with a radius of one kilometre on ArcGIS. Figure 5 illustrates the statistical sectors which, at a minimum, intersect the radius of one kilometre from the incinerator. These sectors are coloured according to their heat energy density, taking into account the combination of heat consumption data for the residential, service and industrial sectors.

It can be seen that the incinerator is not ideally placed to develop a heating network there since the closest statistical sectors consume very little heat. This is a fairly normal situation since we avoid building this type of installation in the immediate vicinity of housing. In any case, the phasing out of the incinerator planned by the Brussels authorities (see Section 4) greatly limits the value of a heating network centred around this installation.

Second, a similar exercise was carried out by creating 1km buffer zones on either side of the canal to identify the potential for creating a 4th generation network that could be installed along this waterway. For this exercise, we first had to vectorise the canal through ArcGIS and split the single carrier into multiple carriers that are 1 km in length. This method is essential for creating several buffer zones around the same carrier. Then, we pooled the heat needs for the residential, service and industrial sectors again. By summing up the needs grouped within each of these zones, we seek to identify which zones are the most energy-intensive in terms of heating requirements or even the most relevant in order to install a heating network. Figure 6 shows the results of this exercise, expressed here in GWh. It is important to note that since several zones can overlap, the same consumption data can be counted in several zones. However, similarly to what has been done for Figure 2 and Figure 3, we applied a consumption per unit area ratio to reflect the proportion of each sector actually located

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[9] ArcGIS provides the following definition: 'Class thresholds are created in such a way as to optimise the grouping of similar values and to maximise the differences between classes. The features are divided into classes whose boundaries are defined where there are large differences in the data values'.

[10] With a net heat production estimated at 166 GWh in 2017 against a sale of heat to the network of only 2.2 GWh (and 0.7 GWh to the service sector), a residual potential exists to extend the network given the quantity of heat that can be distributed.

in the buffer zone.

Third, the energy density of the demand for heating for the three consuming sectors (service, residential and industry) was estimated for the entire region in areas of 1 km square. The objective here is to determine the most worthwhile areas of 1 km² for the construction of district heating networks (see Section 7). To do this, we created a grid of the region by squares of 1km² using the ArcGIS 'Create a grid' tool. By following the same procedure as explained previously via the 'intersect' tool, the energy density of the demand for heat can be calculated for each of these meshes (Figure 7). On analysing this map, we see, without surprise, that the most worthwhile areas for the installation of heating networks are concentrated in the centre of the Brussels-Capital Region, which will not be without problems in regard to both available space and air quality.

Finally, on the basis of the information provided by the regulator, we have drawn up an inventory of cogeneration installations active in the Brussels-Capital Region, commissioned before 2019. We have identified 175, which are represented by thermal power categories such as (see Figure 8). We have added the NOH incinerator to this map. In addition, we have also included the open (ATES) and closed (BTES) geothermal installations. These were extracted from the site of Bruxelles Environnement[11].

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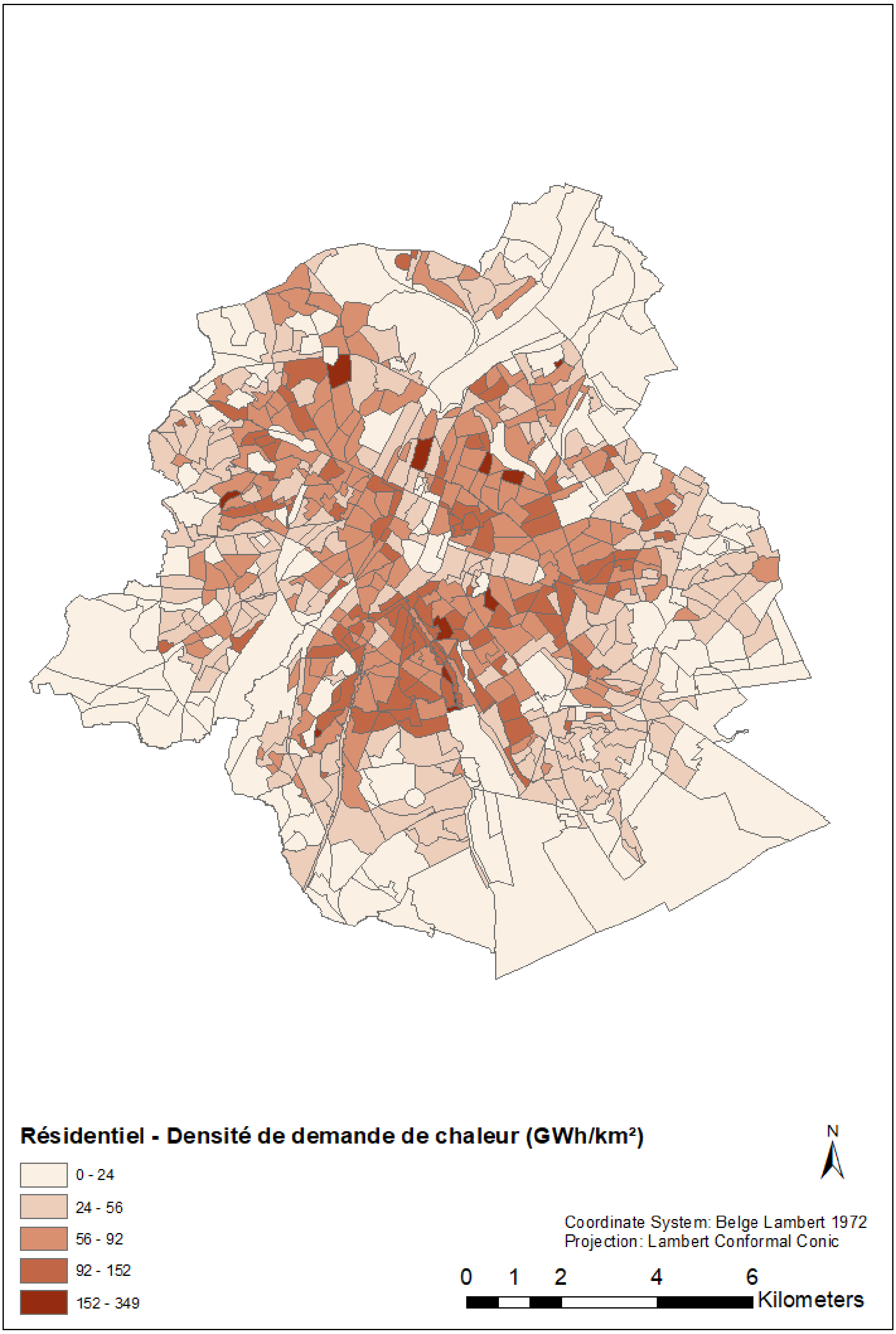
[11] The GIS data was imported into the QGIS mapping software through a WMS link available at the following URL: https://environnement.brussels/content/acces-aux-donnees-cartographiques

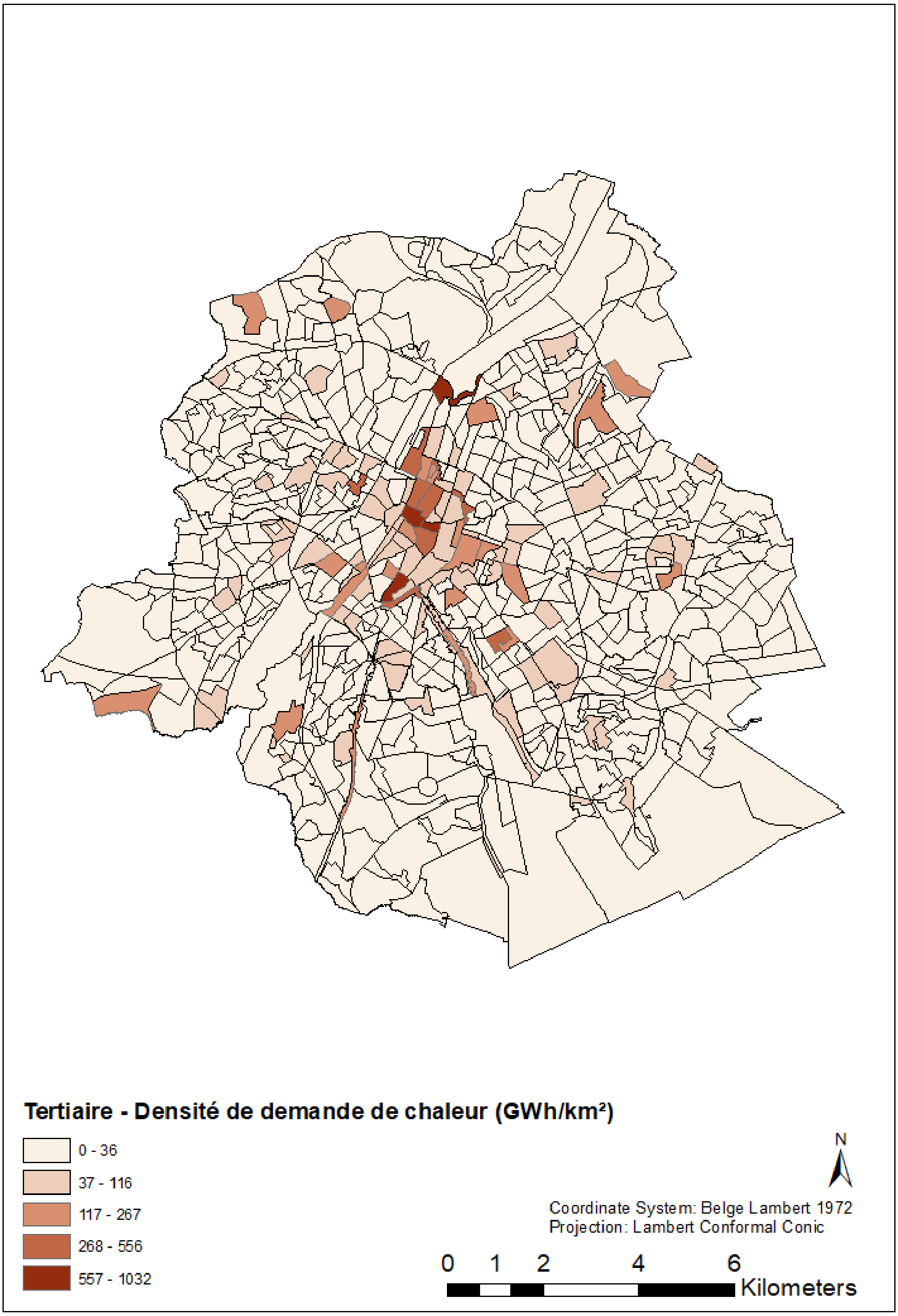
3.2. Key findings



	Residential - Heating demand density (GWh/km^2)
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic

	Kilometres

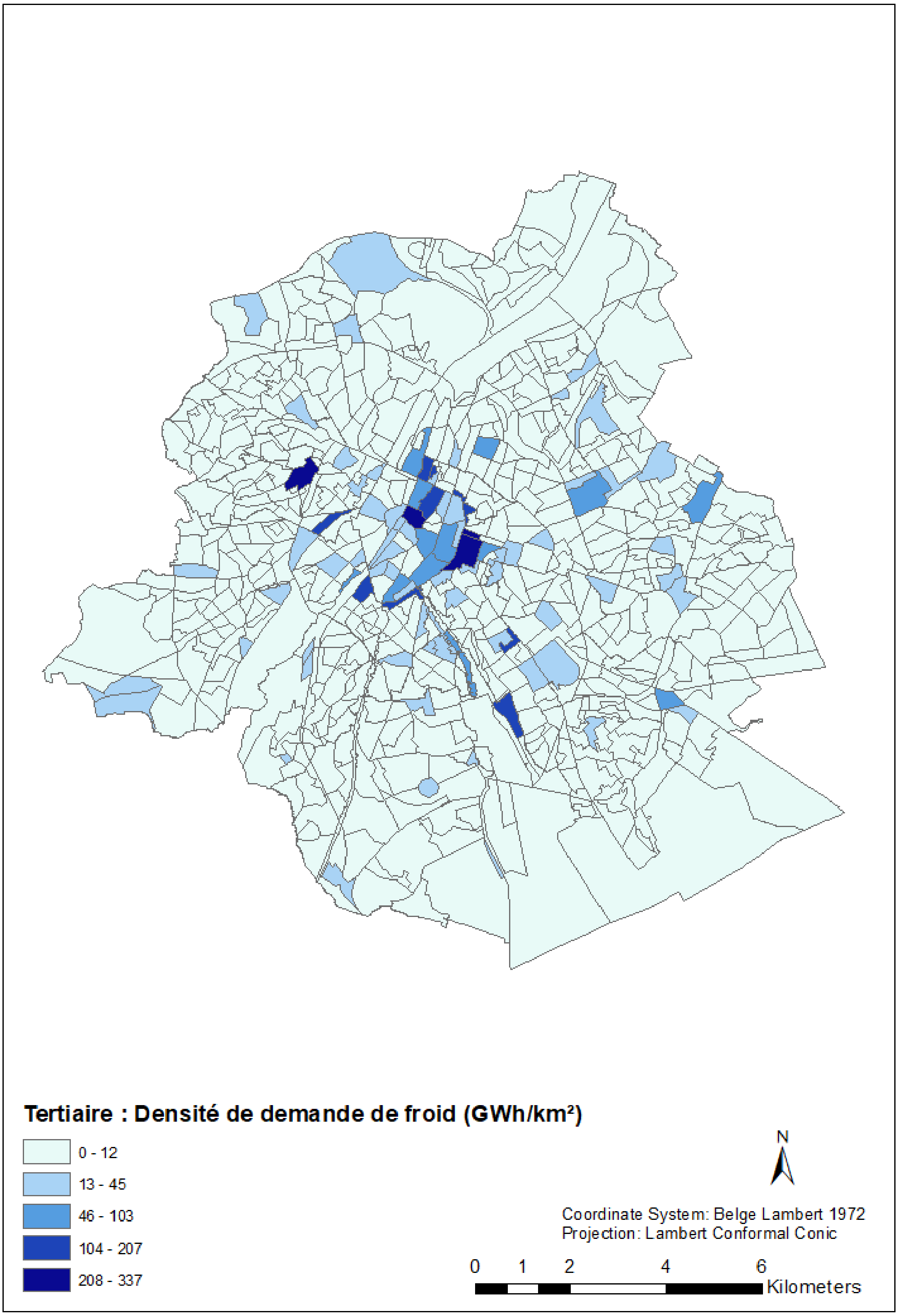
Figure 2 : Density of residential sector's demand for heating by statistical sector (GWh/km²)



	Commercial - Heating demand density

	(GWh/km^2)
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic
	Kilometres

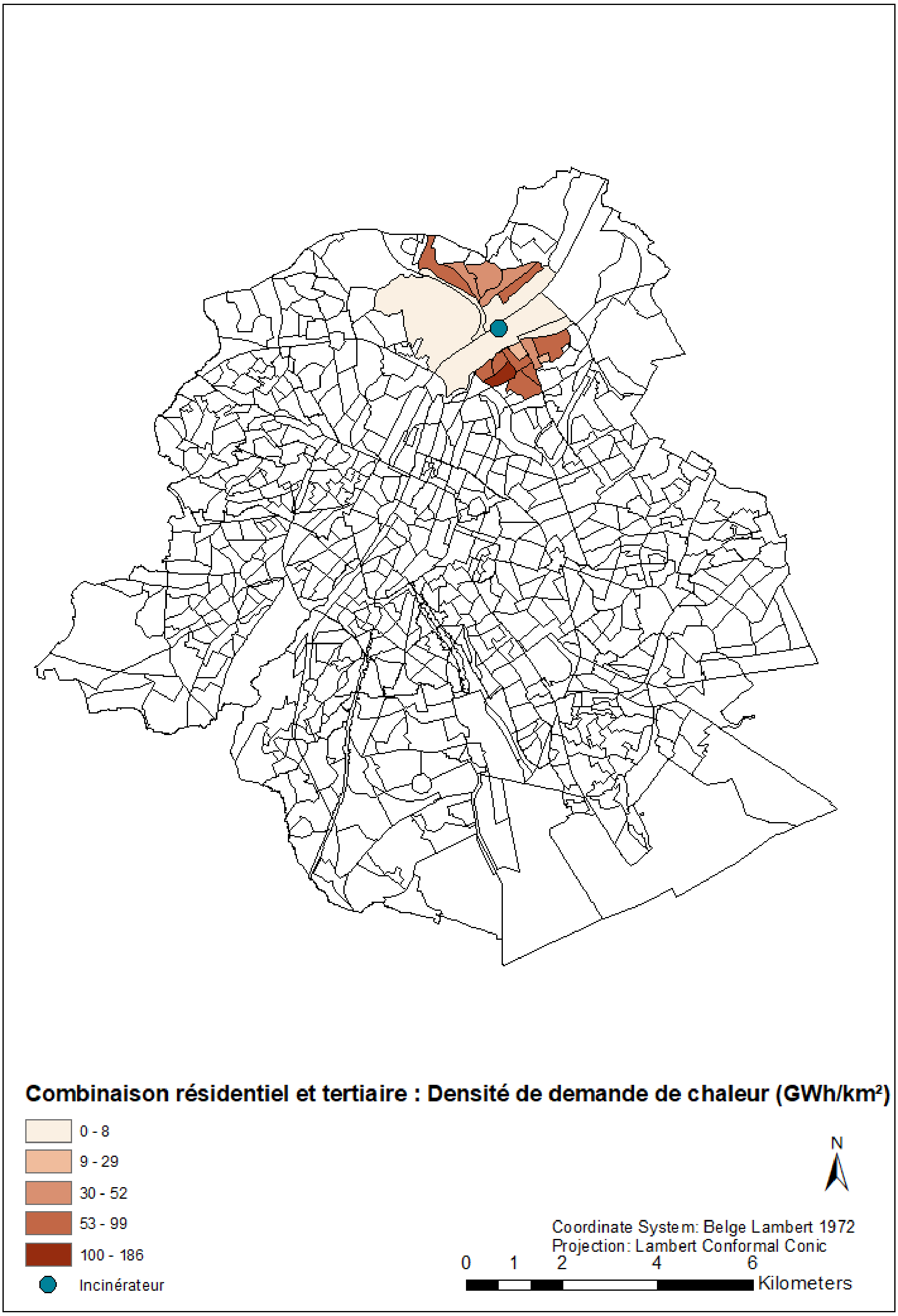
Figure 3 : Density of the service and industrial sectors' demand for heating by statistical sector (GWh/km²)



	Commercial: Cooling demand density (GWh/km^2)
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic

	Kilometres

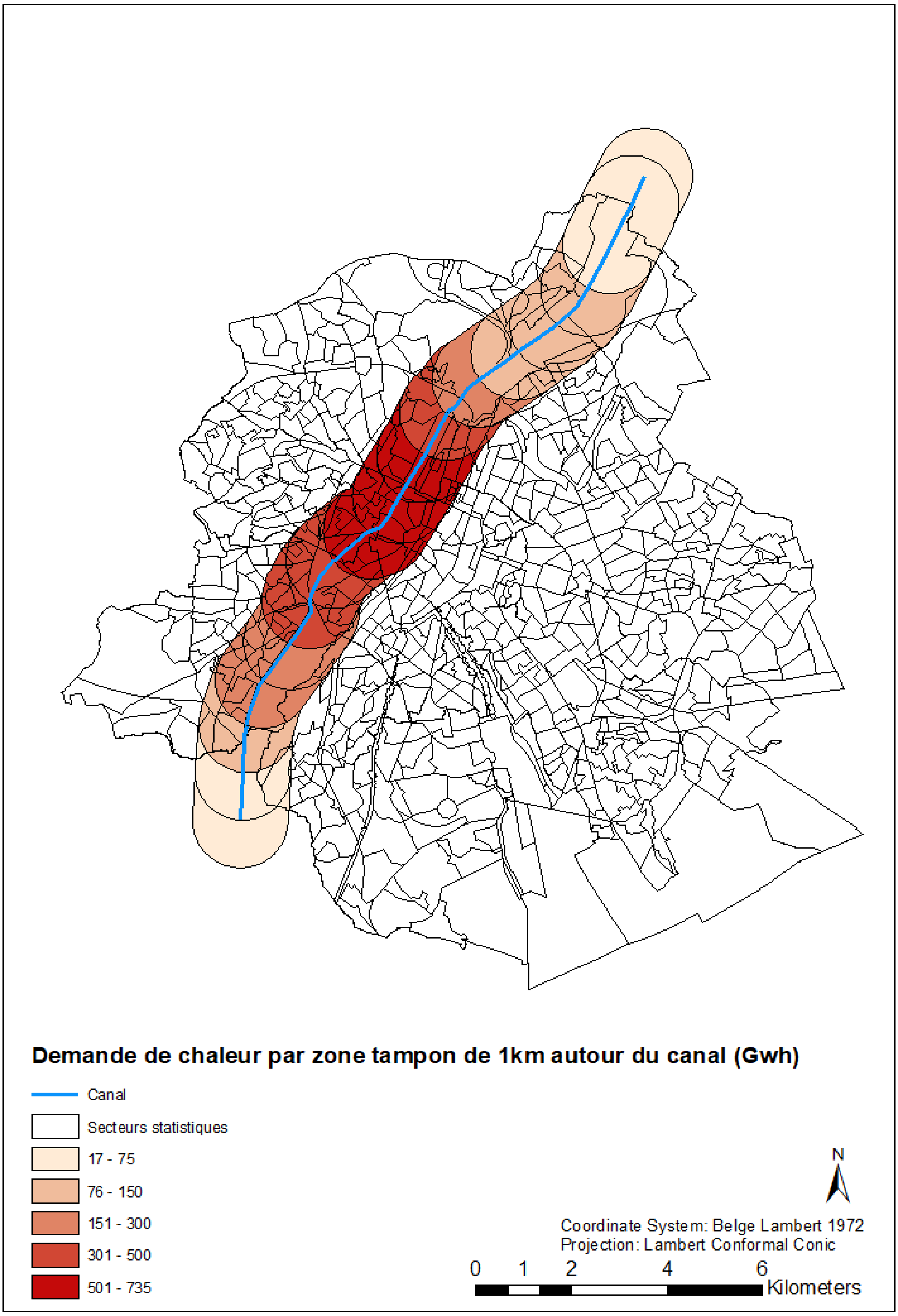
Figure 4 : Density of demand for cooling in the service and industrial sectors by statistical sector (GWh/km²)



	Residential and service combination: Heating

	demand density (GWh / km^2)
	Incinerator
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic
	Kilometres

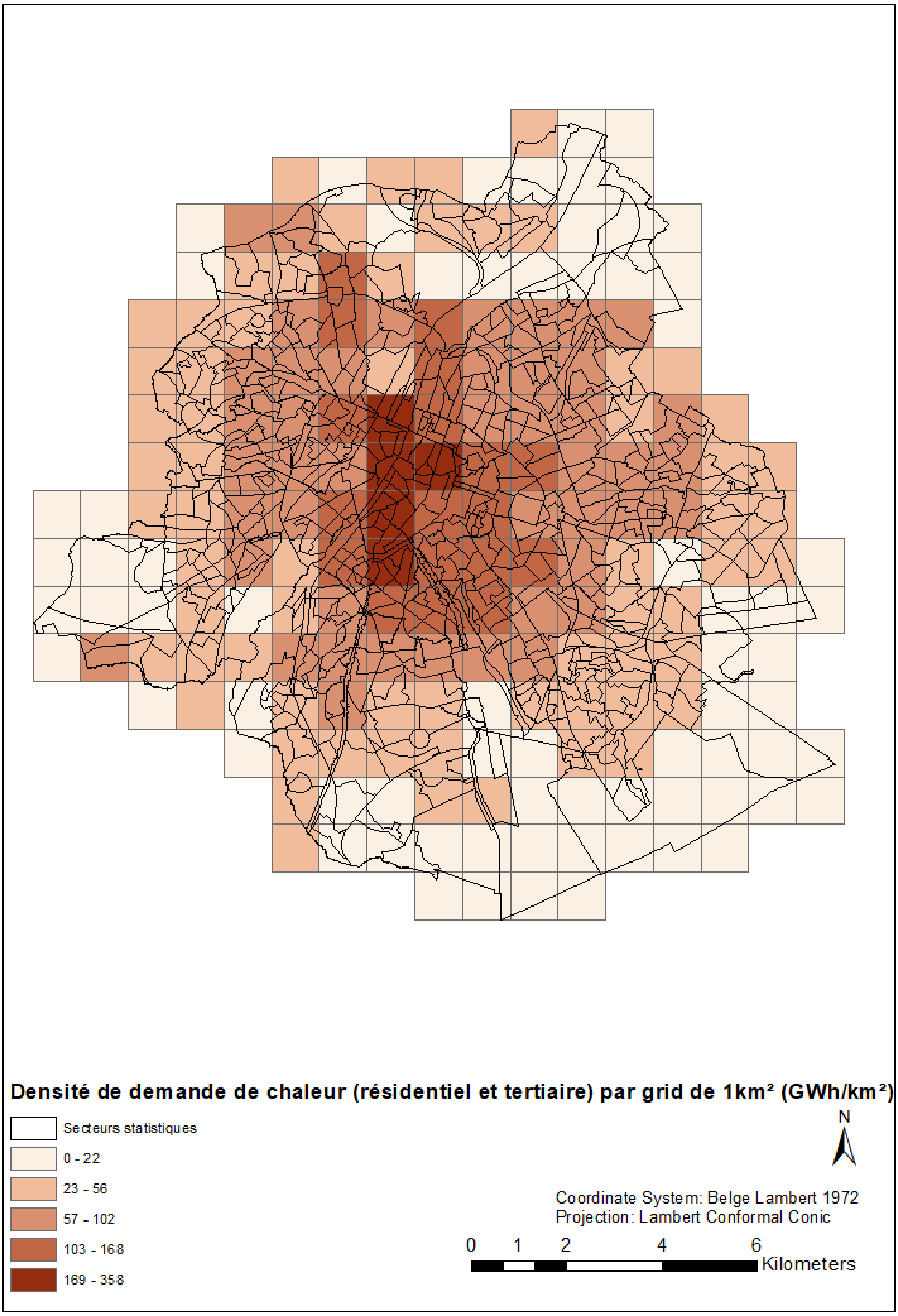
Figure 5 : Density of demand for heating in the residential, service and industrial sector by statistical sector within a radius of one kilometre of the Brussels-energy incinerator (GWh/km²)



	Heating demand by 1km buffer zone around the canal (Gwh)
	Canal

	Statistical sectors
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic
	Kilometres

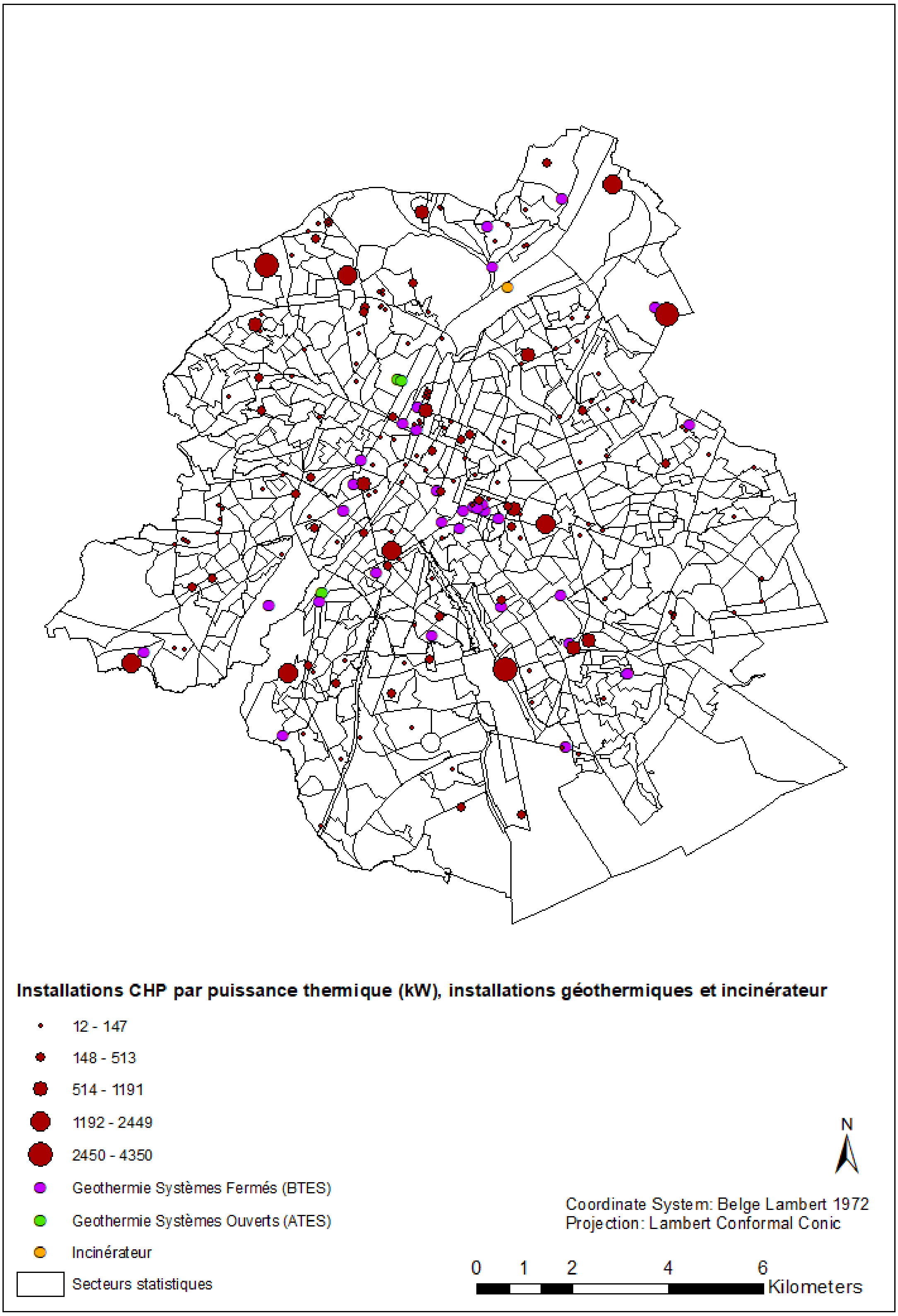
Figure 6 : Demand for heating of the residential, service and industrial sectors by buffer zone of one kilometre on both sides of the canal (GWh)



	Density of demand for heating (residential and service) per grid of 1km2 (GWh/km^2)
	Statistical sectors

	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic
	Kilometres

Figure 7 : Density of demand for heating in the residential, service and industrial sectors per square kilometre of one km² (GWh/km²)



	CHP installations by thermal power (kW), geothermal installations and incinerator
	Geothermal Closed Systems (BTES)

	Geothermal Open Systems (ATES)
	Incinerator
	Statistical sectors
	Coordinate System: Belgian Lambert 1972
	Projection: Lambert Conformai Conic
	Kilometres

Figure 8 : Inventory of CHP installations (by thermal energy power in kW), NOH incinerator and closed and open geothermal installations in the Brussels Region

4. Current objectives, strategies and policies

4.1. The climate situation: time for action

Since the United Nations Framework Convention on Climate Change in 1992, concerns related to the increase in average temperatures on Earth have become more and more pressing. In recent years, we have seen an increase in the frequency and severity of extreme weather events that appear to be directly related to the change in our greenhouse gas (GHG) emissions. In Belgium, this translates concretely and for the moment, by a succession of scorching periods and droughts which impact both our way of life and also certain economic activities such as forest management or agriculture.

In this context of global emergency, the COP 21 led, in December 2015, to the signing of the Paris Agreement.[12.] This is the first universal agreement on climate change, unlike the Kyoto Protocol, whose GHG emission reduction targets did not concern developing and emerging countries. The Paris Agreement aims to limit global warming to less than 2 °C by the end of the century and to continue efforts to limit warming to 1.5 °C. To do this, it aims to reach a peak in global emissions as quickly as possible and then a reduction in them to achieve a balance between emissions and absorptions after 2050. The Agreement is based, among other things, on the voluntary commitments of all the signatory Parties, including Europe and Belgium. However, it should be noted that the latter are not subject to any binding measure in the event of non-compliance with commitments.

4.2. European, Belgian and Brussels objectives

4.2.1. European objectives[13]

A. Background

In order to contribute to the provisions established during the Paris Agreement, the European Union (EU) has put in place a series of targets broken down over three different time scales, namely 2020, 2030 and 2050. As the former have become obsolete and the latter involve outright carbon neutrality, only the strategic objectives established for the 2030 horizon, in the '2030 Framework for Climate and Energy Actions', are detailed below.

B. Objectives

1. Reduction of greenhouse gas (GHG) emissions by 2030 by 55% across the whole of Europe compared to 1990. This objective has not yet been the subject of changes in European legislation.
   The old goal of reducing GHG emissions in 2030 by 40% compared to the 1990 level is broken down into two distinct sub-objectives:
   - 43% decrease in GHG emissions compared to 2005 for sectors covered by the Emissions Trading System (ETS).
   - 30% reduction in GHG emissions compared to 2005 for sectors not covered by the ETS system.

   While the first sub-objective is part of a European framework, the situation is different for the second, which is national in scope. Indeed, for sectors not subject to the ETS system,

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[12] https://unfccc.int/fr/process-and-meetings/l-accord-de-paris/qu-est-ce-que-l-accord-de-paris

[13] https://ec.europa.eu/clima/policies/strategies/2030_fr#:~:text=Objectifs%20cl%C3%A9s%20pour%202030%3A,'au%20moins%2032%2C5%20%25

Europe has distributed the GHG reduction target among its member states in regulation 2018/842. For example, Belgium has been forced to reduce GHGs in non-ETS sectors by 35% compared to 2005.

2. Increasing the share of renewable energy (RES) in final energy consumption to 32%
3. An improvement of least 32.5% in energy efficiency (EE). This measure, unlike the first two, is indicative and not binding.

4.2.2. The situation in Belgium

A. Background

As Belgium is a federal state, powers in the area of energy and climate have been divided between the various federated entities during various state reforms. While the latter retains control over matters that cannot be divided up and require an overall assessment, the Regions have inherited competences directly linked to the consumption and production of energy in their respective territories. Table 19[14] includes, in a non-exhaustive manner, the distribution of the main energy/climate competences.

Federal State	Regions
Prospective energy study	Public gas distribution
Nuclear fuel cycle	New sources of energy (except nuclear)
Energy production, including offshore	Remote heat distribution networks
Energy transport	Distribution and local transmission of electricity
Taxation (taxes, excise duties, etc.)	Distribution tariff
Large energy supply and storage infrastructures	Rational use of energy as well as energy recovery by industries and other users

Table 19: Distribution of energy skills

According to the rules of European climate governance, Belgium adopted a PNEC 2021-2030 (National Energy Climate Plan) at the end of 2019[15]. The latter defines the important stages of the energy and climate transition, for each competent federated entity, in line with the European strategic objectives listed above for 2030.

B. Objectives

The objectives currently established at the national level are:

1. 35% reduction in GHGs in non-ETS sectors compared to 2005.
2. Increasing the share of renewable energy (RES) in final energy consumption to 17.5%
3. With the European objective in terms of energy efficiency given as an indication, the PNEC has translated it in terms of energy savings into final energy consumption and it amounts to 12% over the entire national territory.[16]

It should be noted that the recent agreement of the Federal Government plans to reduce Belgium's

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[14] https://climat.be/politique-climatique/belge/nationale/competences

[15] https://www.plannationalenergieclimat.be/fr

[16] This saving was established by comparing two projections of consumption in 2030:
- The first is based on a model reflecting the energy use trend as determined in 2007 (Baseline Subsidy Model 2007);
- The second takes into account the measures detailed in the PNEC to improve the EA.

GHG emissions by 55% compared to 1990[17]. The figures of the Belgian PNEC are therefore subject to change.

4.2.3. Brussels-Capital Region (BCR)

A. Background

In the Brussels contribution to the Belgian PNEC, the Brussels Capital Region (BCR) has detailed the objectives and measures specific to its territory that it undertakes to implement during the period 2021-2030. This contribution is intended to be consistent with the previous energy and climate strategies in Brussels.

For these measures to be part of a long-term effort, the Government of the BCR has also adopted a long-term strategy which aims for carbon neutrality in 2050.

B. Objectives

The objectives of the BCR are listed below:

1. There are two components to reducing GHG emissions:
   a. 40% reduction in direct GHG emissions compared to 2005.
   b. Willingness to significantly reduce indirect emissions[18]. Even if these are not taken into account in international commitments, the BCR aims to equip itself, from 2021, with a means to better assess this type of emissions and to establish a detailed future policy regarding them.
2. Increasing renewable energy production to a net figure of 1170 GWh in 2030. This figure breaks down into extra muros production set at 700 GWh and intra muros production of 470 GWh.

Unit: GWh	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
E-RES	234.66	239.33	244.36	249.78	255.58	270.51	271.17	281.33	292.06	303.48
Solar PV	99.76	105.38	111.31	117.58	124.2	139.9	150.3	161.17	172.59	184.68
Municipal waste	112.79	111.84	110.94	110.09	109.27	108.5	107.75	107.04	106.35	105.68
Biogas	13.12	13.12	13.12	13.12	13.12	13.12	13.12	13.12	13.12	13.12
Liquid fuels	8.99	8.99	8.99	8.99	8.99	8.99	/	/	/	/
C&H RES	136.12	138	139.93	144.2	148.57	153	152.19	157.03	162.08	167.44
Heat pumps	27.32	27.97	28.64	30.62	32.61	34.61	36.68	38.8	40.98	43.27
Solar heating	16.72	17.84	19.04	21.29	23.63	26.04	28.6	31.28	34.11	37.12
Municipal waste	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
Biogas	28.32	28.32	28.32	28.32	28.32	28.32	28.32	28.32	28.32	28.32
Solid fuels	57.21	57.32	57.38	57.42	57.46	57.48	57.51	57.55	57.59	57.65
Liquid fuels	5.47	5.47	5.47	5.47	5.47	5.47	/	/	/	/
Total	370.78	377.33	384.29	393.98	404.15	423.51	423.36	438.36	454.14	470.92
Annual variation		1.74%	1.81%	2.46%	2.52%	4.57%	-0.04%	3.42%	3.47%	3.56%
Cumulative increase		1.74%	3.55%	6.01%	8.52%	13.09%	13.06%	16.48%	19.96%	23.52%

Table 20: Projected renewable energy production in the BCR by 2030

Table 20 illustrates the climate and energy policies that the BCR undertakes to put in place in its contribution to the PNEC to ensure an increase in the share of RES in final energy

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[17] https://www.belgium.be/sites/default/files/Accord_de_gouvernement_2020.pdf

[18] The term 'indirect emissions' refers to emissions that are not generated directly by a consumer (when heating their house, or driving a car, etc.), but to those which were necessary for the manufacture of a consumer good, a means of energy production or a service. Hence, greenhouse gas emissions linked to the manufacture of a car, the construction of a wind turbine or even the storage of data in the cloud are indirect emissions. According to the Low Carbon 2050 study by Climact, indirect emissions from BCR are 5 times greater than its direct emissions.

consumption. By way of comparison, the BCR projects local production of 330 GWh from renewable sources in 2020.

The Region's wish to reduce household and professional waste production by 20% by 2030, coupled with the long-term phasing-out of the Neder-Over-Heembeek (NOH) incinerator, results in a direct drop in the production of energy from municipal waste in the coming years.

The issues related to air quality, which has both climatic and sanitary repercussions, mean that the BCR will begin to phase out coal and fuel oil from, respectively, 2021 and 2025. These same concerns apply to renewable fuels from biomass such as wood[19] which are not part of the Brussels medium-term strategy. Although it is already forbidden to heat with wood when the air quality is poor, the BCR is studying the advisability of banning the installation of central heating equipment using wood or its derivatives. This desire is reflected in Table 20 by the stability of the figures for the production of heat energy from solid fuels.

Despite these measures, the Region's decision to actively promote the implementation of more environmentally friendly technologies, mainly through photovoltaic and thermal panels as well as heat pumps (HP), mean that the BCR is counting on a 23.5% increase in RES between 2021 and 2030. It is important to note that Table 20 does not take into account the potential represented by heating networks within the Brussels conurbation. Indeed, the opportunities offered by BCR in this regard are numerous[20] and will also be the subject of specific studies.

3. Reducing final energy consumption by 21% compared to 2005

   In terms of energy efficiency, the objective is to achieve an annual saving of 159 GWh by 2030 (i.e. a decrease of 0.8% year-on-year).

4.3. The specificities of the Brussels-Capital Region

The characteristics of the Brussels-Capital Region make it a unique area, which the energy and climate strategy must take into account if it is to be effective.

The high population density and the urban character of the region mean that most energy consumption comes from buildings in general, with a share of 38%[21] attributed to the residential sector and 35% to the service sector. It is therefore hardly surprising that the Brussels renovation strategy[22] is the keystone of the Brussels policy for reducing GHG emissions.

These measures must, however, take into account several particularities of Brussels real estate: the share of tenants and co-ownership. In fact, the proportion of housing occupied by owners in BCR is the lowest in the kingdom (39% in 2011[23]). In addition, many apartment buildings are managed in co-ownership, which often complicates the decision-making process for energy renovation projects.

It is also useful to take stock of the particularities of the socio-economic situation of the BCR. In fact, it has the highest unemployment rate[24] and the lowest per capita income[25] in Belgium. Among the direct consequences of these parameters, it is notable that 13.4% of the Brussels population suffered from fuel poverty in 2015 and 43 000 households were looking for social housing in 2019. Furthermore, according to a 2017 census, 44% of these are also considered 'very energy-intensive' and must be

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[19] https://environnement.brussels/thematiques/batiment/quest-ce-que-lenergie-verte/produire-votre-propre-energie-verte/biomasse

[20] Report on *The realisation of a study of the efficiency potential in terms of heating and cooling in the BCR*, produced by PWC, at the request of Bruxelles environnement

[21] 2017 energy balance sheet of the Brussels-Capital Region

[22] Strategy for reducing the environmental impact of existing buildings in the Brussels-Capital Region by 2030-2050, adopted by the BCR Government on 25 April 2019

[23] https://www.census2011.be/idk/idk2_fr.html

[24] https://statbel.fgov.be/fr/themes/emploi-formation/marche-du-travail/emploi-et-chomage

[25] https://environnement.brussels/lenvironnement-etat-des-lieux/rapports-sur-letat-de-lenvironnement/synthese-2011-2012/contexte-0

treated urgently.

The impact of transport, which accounts for 22% of Brussels emissions, also justifies the adoption by the Region of a policy based on reducing individual mobility needs and improving the performance of the existing vehicle fleet. The gradual withdrawal of heat engines and their partial replacement by zero-emission vehicles are among the measures that the Region wants to undertake.

The share of industries (3%) in GHG emissions confirms that this is a relatively small sector in the Brussels agglomeration. In addition, the BCR is very strongly dependent on the outside for its energy supply just like it is, moreover more generally, for its consumer goods and its food.

A final point concerns the small area of the territory and the proximity of an international airport (complicating the installation of wind turbines), plus desire to tackle the phasing-out of the NOH waste incinerator over the long term[26]. In effect, these elements limit the renewable energy production capacities of the Region. On the other hand, the specific urban nature of the region offers interesting avenues for the deployment of other technologies such as the creation of heating networks. In the longer term, the deployment of syngas[27] could be facilitated by the presence of a very extensive gas distribution network. However, this will require these new fuels to prove their relevance as economic sources of energy and to show that they can be used safely for consumers and installations. The natural gas distribution network could limit the role of renewable energies in the field of heating and cooling if natural gas (fossil) solutions remain more competitive than renewable alternatives.

4.4. Brussels climate and energy policy in residential and service sectors

As mentioned in the previous paragraph, the BCR's residential and service renovation strategy will be crucial in its fight against global warming. It is based on four key documents:

- The Brussels renovation strategy, adopted by the Government in April 2019, clearly and comprehensively defines the objectives set by the Region for 2030 and 2050. These are detailed in the form of 34 action sheets, the aim of which is to reduce polluting emissions from the region's real estate assets in an efficient but also affordable manner.
- The Brussels contribution to the Belgian PNEC, which summarises, among other things, the guidelines set in the renovation strategy.
- The 2019-2024 Regional Policy Statement (RPS), a section of which is devoted to the renovation of buildings and the related financing mechanisms.
- The Contribution of the Brussels-Capital Region to the 2050 national strategy for reducing greenhouse gas emissions

From these different sources, three major strategic axes emerge:

- The increase in the renovation rate, which targets 3 to 5% per year
- Improving the quality of renovations
- Rational use of energy in buildings

4.4.1. Objectives

A. Residential

In terms of residential renovation, the BCR objective is ambitious but realistic with an average specific consumption of 100kWh/m²/year for the entire housing stock by 2050.

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[26] Joint General Policy Statement of the Government of the Brussels-Capital Region and of the Joint -Commission for the Communities, or RPS 2019-2024

[27] Synthetic hydrogen or methane, obtained by methanation of hydrogen (4H2 CO2 <-> CH4 2H2O). If hydrogen is produced from carbon-free energy, synthesis gas which can also be considered as carbon-free is obtained,

While this figure seems less restrictive than that of the Walloon Region[28], it seems more suited to the various realities on the ground with which the Brussels region is confronted, namely:

1. The current state of Brussels buildings, with 92% of the real estate predating 1970. A significant portion of this real estate will never be able to meet passive standards in terms of energy consumption.
2. The fact that the investments to be devoted to the energy renovation of buildings are increasingly higher as the energy performance improves. In other words, although the first improvement measures are often inexpensive, the cost of the measures which allow to approach the passive standards can quickly become very expensive to implement.
3. The role played by individual behaviour is key to establishing a rational use of energy in a building and must be weighed against the cost of an overly ambitious objective.

This objective also faces several difficulties intrinsic to the BCR in terms of real estate renovation, mentioned in the previous chapter. The multiplicity of players (tenants, social tenants, landlords, co-owners, residents' organisations, etc.) implying, de facto, a multiplicity of solutions.

The costs inherent in improving energy efficiency must not lead to an increase in rental prices either, and thus risk accentuating an already high level of energy poverty in Brussels.

The professional building sector will also need to be trained and adopt more sustainable and environmentally friendly working methods. As each accommodation is specific, it will have to adapt and establish specific measures on a case-by-case basis. In this respect, it is worth noting the number of listed buildings requiring special treatment in the BCR[29].

To avoid imposing too heavy financial constraints on owners and overburdening renovation professionals, the Region will ensure the implementation from 2021 of a legislative framework imposing a segmentation of renovation work for all the residential buildings in its territory following an interval of 5 years. Following the mandatory completion of the energy audit (which has a deadline of 2025), the owners will therefore choose five measures, among those deemed to be priorities, and will break them down according to the time limits set out in Table 21.

Objectives	Works
2025	Creation of the housing PEB certificate
2030	Deadline for one of the 5 compulsory measures to choose from
2035	Deadline for the second of the 5 compulsory measures to choose from
2040	Deadline for the third of the 5 compulsory measures to choose from
2045	Deadline for the fourth of the 5 compulsory measures to choose from
2050	Deadline for the fifth of the 5 mandatory measures

Table 21: Deadlines for residential renovations

For collective housing, owners will be responsible for meeting deadlines for work on the scale of their property, and renovations involving the entire building will be the responsibility of the condominium.

B. Service

The objective defined for the service sector is carbon neutrality for all buildings with regard to heating, lighting, cooling and domestic hot water production.

Once again, the diversity of this sector (from small commercial areas to large open-space offices and

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[28] 85kWh/m²/year

[29] Register of protected immovable heritage in the Brussels-Capital Region, Brussels Urbanism and Heritage Directorate of Monuments and Sites, 2019

university hospitals) will require the implementation of multiple strategies in order to cover all the buildings concerned.

The objectives set by the BCR (both residential and service) will thus only be achieved by a general mobilisation of all the players involved (public authorities, professionals, citizens). While the challenge is sizeable, the resulting consequences will be, in the long run, largely beneficial to society: a healthier region, which is more respectful of its environment and a net creation of jobs (estimated at 12 900)[30].

4.5. Key pillars of the Brussels policy to combat its GHG emissions

4.5.1. Renovation of the buildings

In order to facilitate the implementation of its renovation strategy and the achievement of its objectives, the BCR has equipped itself with various tools and measures, the main ones of which are listed and briefly explained below.

A. Establishment of a one-stop shop

This measure targets both individuals (owners and occupants) in the residential sector and service sector players. It aims to set up a one-stop-shop (OSS) to facilitate building renovation procedures.

For the residential sector, two major elements are the focus of this system, namely the establishment of a full support service (information, diagnostics, technical assistance, etc.) as well as awareness of the rational use of energy through a single point of contact.

For the service sector, the objective is to strengthen the current structure of the Sustainable Building Facilitator service to make it the only entry point for sustainable renovation.

Sheets 13 and 20 of the building renovation strategy are devoted to this point.

B. Creation of a roadmap for residential buildings

A roadmap will be established and enforced to clarify the steps to be taken by residential property owners to comply with the energy requirements. This roadmap, which is detailed in Sheet 14, is made up of two distinct sections:

- The mandatory PEB 3.0, which will set the technical renovation steps to ensure that the energy efficiency objective determined by the Region is ultimately achieved.
- If a building permit is required, a renovation plan will also be created in synergy with building experts with the aim of:
    - Making an initial diagnosis
    - Listing the work to be carried out over the long term, whether globally or sequentially

C. Establishment of a housing passport

Each BCR building will also be allocated a housing passport, as mentioned in Sheet 26. Its aim is to centralise the administrative and technical data of each building on a digital platform. The owners will thus have free access to all the necessary information for their property or properties and will be able to authorise third parties, with prior agreement, to access the passport. In the future, it could also be used by the authorities to ensure that the building complies with the standards in force.

4.5.2. Improving energy efficiency at key moments for the building or its inhabitants

The key moments of the building (acquisition, succession, etc.) constitute interesting opportunities to be seized in terms of improving its energy performance. To this end, Sheet 15 sets out the BCR's strategy for making the most of the opportunities offered by these pivotal moments in three major

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[30] https://environnement.brussels/thematiques/batiment-et-energie/bilan-energetique-et-action-de-la-region/strategie-renovation

ways:

- Awareness/communication/training component of the various players involved
- Funding component to optimise the raising of funds linked to the renovation
- Regulatory component through an obligation to provide information on the part of professionals in the sector

A. Awareness of sustainable building occupancy and communication tools

Sheet 17 of the building renovation strategy aims to make residents aware of the optimal use of energy in their homes, by targeting:

- High energy performance buildings (HEP), where poor management can lead to a significant difference between theoretical and actual consumption as well as to undesirable health consequences. To do this, the resources of the services active in supporting the use of HEP buildings will be reinforced and a platform for energy exchange energy in terms of appropriate uses will be set up by Bruxelles Environnement (BE).
- All buildings in general, by raising awareness among occupants by integrating their ranking in terms of consumption in relation to the Brussels average into the energy bill and by issuing any warning signals.

As it is aware that a strategy cannot be effective without exemplary communication, in Sheet 25 the BCR details the campaign it intends to carry out on this subject. This campaign, structured over an initial period of 4 years, will ensure consistency between the actions of the renovation strategy.

B. Social Housing

To reduce energy poverty, the BCR will stipulate in the management contracts of the SLRB (Société de Logement de la Région de Bruxelles - Housing Society of the Brussels Capital Region) and SISP (Sociétés Immobilières de Service Public - Public Service Real Estate Companies) that all major renovations of social housing directly comply with the energy efficiency objectives. Faced with the urgency of the situation, the Government also undertakes to renovate 36 758 social housing units by the end of the current legislature, i.e. in 2024.[31].

C. The case of condominiums

The case of condominiums will be dealt with by creating a multidisciplinary body specifically dedicated to this task: the Condominium Facilitator, who will be integrated into the existing structure of the sustainable building facilitator. In addition to this reinforcement, a web interface dedicated to the cases of condominiums will be launched on the BE site.

4.5.3. Beyond the renovation of buildings

The building renovation strategy is also part of a long-term vision that goes beyond just improving the energy performance of buildings. The Region wishes, in fact, to remodel itself by making the development of sustainable districts a focus of its policy. All citizens must therefore be able to access certain quality infrastructures, such as schools, green spaces or even commercial areas, within a walking distance of not more than 10 minutes from their home.

In this context, the transformation of the region into a ‘polycentric’ city is at the heart of the Brussels strategy, which seeks to better distribute the population and activities over the whole of its territory.

Architectural measures and a greening programme will accompany this development focused on districts to take into account the impacts of such developments on biodiversity, flooding, noise, the

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[31] Housing Emergency Plan (PUL), 2020-2024, presented by the Brussels Government on 7 January 2021.

quality of the landscape and access to light. An attempt will be made to mitigate the inevitable consequences of global warming (in particular the resurgence of scorching summers) by the creation of islands of freshness and by the use of a maximum of reflective and non-absorbent heat materials.

These measures will be carried out using a sustainable and circular construction approach. Not only will the focus be on material recovery and better management of waste from development work, but local jobs will be promoted.

4.5.4. Mobilisation of financial resources

To achieve these objectives, considerable financial resources will have to be put into play. For the renovation of the building alone, the estimated costs amount to 28.8 billion euro. The BCR is therefore relying on the establishment or revision of several mechanisms aimed at mobilising the necessary funds, which cannot come exclusively from the public sector.

Firstly, the already existing energy subsidy system will be reviewed. The subsidies will be adapted to take into account the obligations set by the renovation strategy (system of additional subsidies in the case of a group renovation or in advance of deadlines, specific subsidy for the valuation of heat pumps, etc.).

Secondly, the Brussels Green Loans, or prêts verts bruxellois (PVBs), which provide a loan to finance improved energy performance at a rate of 0 to 2% depending on income, will be capped in the short term at 1%. The framework for PVB-related investments will also be broadened to include work indirectly related to energy renovation. In the medium term, the PVBs will be granted in accordance with the stages defined during the energy audit of the PEB 3.0. The repayment period may be extended to take into account the return on investment linked to energy innovation. To reduce the burden of repayments, the energy bonuses will be directly deducted from the amounts to be borrowed.

Taxation will also be adapted. The modulation of registration, gift or inheritance rights as well as the temporary reduction of the property withholding tax will make it possible to make the best use of the key moments of buildings, provided that a comprehensive renovation strategy is carried out.

Finally, the BCR will support citizen cooperatives of third-party investors, mindful of their lasting and local impact, by participating either directly in the financing of renovation projects, or by granting specific loans at advantageous rates.

4.5.5. Scheduled exit from fossil fuels

With the objective of striving for carbon neutrality by 2050, a scheduled exit from fossil fuels is essential. This revolves around several well-defined deadlines:

2021: Prohibition of the installation of any coal-fired device

- 2025: Prohibition of the installation of oil-fired heating devices on the regional territory. A subsidy bonus is granted from 2021 for the dismantling of an oil-fired boiler and its replacement by a high-performance boiler, a heat pump or a solar water heater.
- **2030:** Termination of support for the production of electricity from cogeneration plants running on natural gas. Consideration will be given to the possibility of banning the installation of cooking, heating and hot water appliances using natural gas or butane/propane from 2030 onwards, in consultation with the sector and with due attention to the issue of energy dependency and the resulting economic and social impacts.

To support the termination of the use of these fossil energy sources, the focus will be on other means of production that are more respectful of the environment and suitable to the urban character of the

BCR. Heat pumps (HP) as well as thermal and photovoltaic panels[32] will be given preference. The expansion of energy bonuses and the strengthening of the related support services will be the spearheads of the Brussels strategy in this area.

4.5.6. Development of the circular economy

The development of the circular economy is a major tool that the BCR aims to promote in combating global warming. In addition to reducing the indirect emissions associated with it (reuse, recycling, zero waste, etc.), this circularity reduces our dependence on external imports of raw materials. The region's economic resilience is thus strengthened and the impact of logistics transport is reduced.

From 2030, the Region will therefore only support economic models aiming at exemplary circularity. To do this, it will comply with the measures established in 2016 in the PREC (Regional Plan for Circular Economy) [33] :

- Transforming environmental issues into economic opportunities.
- Relocating the economy to Brussels with the aim of producing locally where possible, reducing travel, optimising the use of the territory and creating added value for the people of Brussels.
- Helping create jobs.

In the construction sector, BCR will continue to develop the TOTEM (Tool to Optimise the Total Environmental impact of Materials) tool and will ensure the application of the strategies established in the short and medium term relating to its gradual deployment to building professionals. In a large database, the TOTEM tool compiles information relating to the environmental impact of several construction materials over their entire lifespan (raw material sampling, manufacturing process, transport, use, recycling, etc.) . TOTEM thus allows players to ensure an ecological and sustainable selection of construction materials, thereby contributing to the development of circular construction.

In addition to this digital software, the Region is committed to continuing the efforts initiated within the BAMB (Building As Material Banks) project, which aims to promote circularity within the construction sector by taking into account the dimension of reversibility from the design of the project, the reuse of materials and the sharing of information between building professionals.

The aspect of the sustainability of new infrastructures will thus be taken into account through the various energy tools (PEB), circulars (BAMB) and materials selection (TOTEM) that are implemented. Specific clauses incorporating these elements will be included in the specifications of future projects so as to deeply anchor the ecological aspect in the construction sector.

A final point studied concerns the dismantling of buildings[34] and waste recovery. Preliminary stages aiming to establish the merits of the demolition/reconstruction and to quantify the environmental cost which is linked to it vis-à-vis a renovation, will be developed. Additional regulations will be established to set up a pre-demolition inventory and promote selective deconstruction[35].

4.5.7. Public authorities setting an example

Stricter PEB measures will be imposed on public buildings in order to promote their exemplary nature and, by 2030, the use of the TOTEM tool will be generalised to all public buildings.

The SolarClick and NRClick programmes will be continued. The first of these aims to equip properly insulated and oriented roofs of public buildings with photovoltaic panels. 85 000 m^2 panels will be installed over a period of 3 years from 2020, for a total capacity of 12.5 MWp. NRClick aims to support

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[32] Especially in a BIPV - Building Integrated PhotoVoltaics configuration

[33] https://www.circulareconomy.brussels/a-propos/le-prec/

[34] It is estimated that 5% of the country's buildings are in such poor condition that effective renovation is impossible.

[35] During dismantling, the materials that can be reused are dismantled before proceeding with the overall demolition.

municipalities in improving the energy performance of public buildings. Its objectives are a 15% reduction in gas consumption in buildings and a 5% reduction in their electricity consumption. A synergy between these two programmes will be encouraged, for instance with the supply of heat pumps by photovoltaic electricity.

Even though these measures also target regional public authorities, they are part of a broader dynamic of supporting the Municipalities and thus encouraging them to implement a real strategy for the renovation of buildings on their territory. Support will thus be provided both directly to the Municipalities vis-à-vis this strategy as well as to municipal officials who will be involved in the planning permit procedures so that they can take the requirements in terms of sustainability into account.

4.5.8. Training professionals

The ambitious goals set by the BCR cannot be achieved without high-quality, trained professionals in sufficient numbers. To do this, training programmes will be adapted and will focus on techniques relating to the establishment of a society that is more respectful of its environment, such as sustainable construction or technologies linked to the production of green energy. As these sectors are constantly evolving, continuous training will also be set up in order to keep the capacities of building professionals up to date.

This is a real opportunity for the creation of new quality jobs. This is why these new skills should also be available to job seekers. An ‘Employment-Environment-Finance’ Alliance will be set up in order to bring together the various stakeholders in the building sector and make them work together in a coherent manner.

4.5.9. Innovation for the energy transition

To ensure the permanent innovation of the measures put in place by the Government, a laboratory for the sustainable renovation of buildings in Brussels, called ‘RenoLab’ will be created. This will stimulate innovation using several concrete methods:

- Launch of calls for projects to test and improve the renovation-related tools developed by BCR.
- Launch of calls for projects on well-defined themes (acoustics, materials, HVAC, etc.) in order to collect as much information as possible about them and to be able, if necessary, to develop the most relevant implementation strategies.
- Launch of calls for projects concerning a target audience (co-owners, for example) with the aim, once again, of analysing, observing and proposing modifications to the related measures.

This laboratory will ensure continuous management of this data and will make it available to those involved in renovation. It will also serve as a platform for exchanges where they can share their experiences and good practices.

5. Technical and economic potential of cogeneration in the Brussels-Capital Region

From a perspective of rational use of energy, cogeneration appears to be a technology to be promoted. It is thus essential to carry out a potential study, taking into account the current context; a potential broken down into a technical potential and an economic potential.

This task therefore focused on developing a software tool making it possible to define the cogeneration potential in the Brussels-Capital Region on the basis of data on individual energy consumption of establishments in the industrial and service sector (Sibelga data) depending on the various current technical, economic and regulatory parameters.

For each establishment, the software determines the 'optimal' size of a cogeneration unit and the associated profitability. This bottom-up approach, then extrapolated to the entire sector, is also contrasted with a top-down approach that takes into account the different sectors as a whole and assesses the convergence of the two approaches. This working method and the software tool give reliable results which can be used to estimate the potential number of cogeneration units still to be installed in the Brussels-Capital Region and consequently the electricity production of these installations and the number of green certificates they can produce.

The assumptions used to estimate the potential are 'conservative'. On the one hand, the efficiency of the reference boiler is estimated at 90% PCS while many boilers reach or exceed 95%. A '*Demand Side Management* factor of 30% is also taken into account (Measurements for rational use of energy in the building[36]). Finally, the calculation tool does not consider the possibility of running the motor at part load and does not retain the possibility of putting smaller units in parallel.

This section of the report presents the general methodology for calculating this potential and some results that can be drawn from it. It should be noted that beyond these proposed results, BE will be able to test all the hypotheses it deems relevant to refine its knowledge of the potential for cogeneration in the Brussels-Capital Region or to predict the effect of a particular incentive measure, for example, an increase in the price of green certificates. The software tool has, in fact, been designed in a completely transparent and open manner.

However, in spite of everything, we must be aware that this is an approach which remains very global and which does not take into account the many specificities of the establishments studied.

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[36] Defined in accordance with Brussels Environment procedures as part of the environmental permit application.

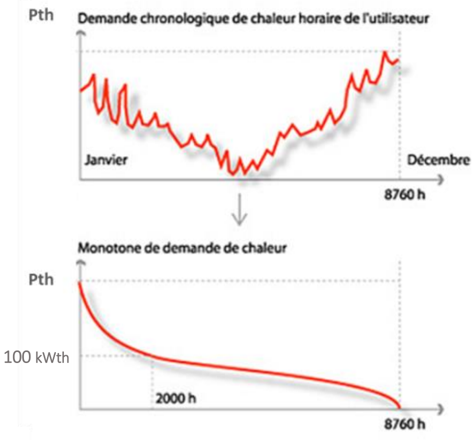
5.1. General working methodology

The estimate of the cogeneration potential is based on a dual approach known as bottom-up and top-down. The bottom-up approach starts from the individual situation of a series of service, industrial and multi-family housing establishments, as known from the energy surveys carried out annually by the ICEDD on behalf of the Brussels-Capital Region and distributed by sector of activity. The top-down approach analyses the industrial, service and housing sectors as a whole.

5.1.1. BOTTOM UP

From consumption data[37] (gas and electricity consumption data, NACE code) of Brussels professionals, the work consisted in carrying out an initial sizing of a cogeneration unit, based on the energy data of each establishment. From the fuel consumption, a net annual heat requirement has been estimated taking into account the thermal efficiency of the installation (estimated at 90% on PCS), the share of heat that can actually be cogenerated and a rational utilisation factor for the energy (or *Demand Side Management*), considered equal to 30%. This factor of 30% was chosen to correspond to the logic considered in the procedures related to environmental permit applications in Brussels. This value of 30% means that establishments which are equipped with cogeneration must first reduce their thermal consumption by 30%. If this objective of reducing needs is not achieved, the cogeneration thus estimated will be undersized. Remember that an undersized cogeneration installation represents a shortfall in both energy and finance but does not pose a major technical problem, unlike an oversized installation which, in this case, will never operate optimally or even not operate at all.

From the NACE codes, establishments can be divided into sub-sectors of activity (first 2 digits of the NACE code). Each sub-sector is then associated with one of the 13 known standard thermal profiles. These 13 typical thermal profiles are used in various cogeneration sizing tools. They allow the net annual heat requirement to be distributed over time, hour by hour, according to the choice of profile. The decreasing classification of the chronological heating requirement curve thus obtained gives the monotonic heat curve. The curve gives the number of hours where the demand for heating corresponds to the power defined on the ordinate, i.e. on the graph below: the demand for heating is at least 100 kWth for 2000 hours per year.



	Pth
	User's chronological hourly demand for heating

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[37] Sibelga anonymised data.

	January
	December
	8 760 h
	Monotonic demand for heating
	Pth
	100 kWth
	2 000 h
	8 760 h

Figure 9: from the demand curve to the monotonic demand for heating. (Energie-Plus and ICEDD)

The sizing rule for cogeneration is that which maximises the production of thermal energy. In other words, it is a question of choosing the rectangle (the base corresponds to the number of hours of operation of the cogeneration and the height its thermal power) with the largest area under the monotonic heat curve. This is a purely ‘energy’ dimensioning.

Note that this sizing method is fairly conservative. Choosing a rectangle under the monotonic heat curve implies that it is assumed that the cogeneration will operate at full load for a certain number of hours. In practice, however, cogeneration units can operate up to a partial load of 80% without significant loss of efficiency, and therefore increase their operating time.

In addition, we do not consider the possibility of operating in cascade with several small cogeneration units rather than a single large one, whereas such an operation not only increases energy production.

The next step is to calculate the profitability of the cogeneration to be installed in each establishment studied. Now that the size and duration of operation of the cogeneration are known individually for each establishment, it remains to calculate the profitability of the project. The gains from cogeneration can be found on several levels.

1. The first is the saving on the electricity bill. We have assumed that the electricity produced by cogeneration will no longer have to be purchased at the average price currently paid by the consumer (in 2018, to be more precise). Any surplus is sold on the network at an average price of €0.025/kWh.
2. The second is the heat gain. We have assumed that the heat produced by cogeneration will no longer have to be supplied by the existing thermal installation at the average price currently paid by the consumer (in 2018 to be more precise).
3. The third is the saving on the fuel bill after cogeneration. We have assumed that the increase in fuel consumption of the establishment compared to the situation without cogeneration makes it possible to negotiate a better price in terms of fuel for the entire establishment, according to a declining curve as illustrated below and calculated according to reference costs (CREG).
4. The fourth is the gain from the sale of green certificates (GCs). We have taken into account the full formula and a unit valuation price of €93 per GC. Please note, that we have considered the multiplier coefficients for cogeneration installations in the multi-family housing sector.

It then remains to deduct cogeneration expenses, which are also at several levels.

5. The first is the cost of purchasing fuels for cogeneration, depending on the type of technology. We assumed a lower purchase price if the fuel used was the same as that used before cogeneration, according to the declining curve presented in paragraph 5.2.4. On the other hand, we have considered average costs for 2005 for other types of fuels (wood, vegetable oils, etc.).
6. The second is the additional cost of the back-up fuel when the cogeneration uses another fuel (renewable, for example)
7. The third is the additional cost of back-up electricity. We have assumed an average purchase

price corresponding to a lower quantity of electricity purchased from the network after cogeneration according to the declining curve presented in paragraph 5.2.4.

8. The fourth is the cost of upkeep and maintenance of the cogeneration unit.

The difference gives the net annual gain for the project.

By dividing the net investment, with any subsidies deducted, by this net annual gain, we obtain the simple payback time (SPP) of the cogeneration project. The calculation of the Net Present Value (NPV) as well as the Internal Rate of Return (IRR) takes into account the evolution of this net annual gain over the years.

The next step is to determine the energy potential and the economic potential of cogeneration in the Brussels-Capital Region. The energy potential is calculated by adding up all the cogeneration units that are appropriate for installation from an energy standpoint [38]. Secondly, the economic potential only includes projects for which the simple payback time is less than a certain previously defined maximum. In the context of this study, the return time used is 5 years.

It should be noted that these energy and economic potentials are based on the energy consumption of current companies, assuming a reduction in thermal needs of 30%. However, they do not take into account a possible change in the heating needs of these establishments in the future linked, for example, to a change in activity. The potentials also do not take into account the deposits of renewable fuels available (co- (sub) -organic products, waste, etc.).

For the industrial sector, the companies known individually that have been the subject of an individual calculation of cogeneration potential represent 50.6% of the total consumption of fuels in this sector. To obtain the potentials for the entire industrial sector, we then multiply the energy and economic potentials by this factor 1/0.506.

For the service sector, in the same way, the bottom-up analysis covers 61% of all energy consumption in this sector. In multi-family housing, this extrapolation rate is 31%.

The final results of this approach, which are presented in the results below, are therefore results based on individual estimates and then extrapolated to all sectors.

5.1.2. TOP DOWN

The top-down approach makes it possible to determine the representativeness of the bottom-up approach for the service and multi-family housing sectors. We apply the ‘reverse’ logic for this.

In fact, unlike the previous approach, we start directly from the overall consumption of the sector and we try to deduce a global cogeneration potential.

To this end, the results of the bottom-up approach are used for extrapolation. Using them we calculate the sectoral ‘average cogeneration’ (average thermal power, average efficiency, average energy costs before and after installation of the equipment), as well as the share of Net Heat Needs (BNeC) which can be covered by cogeneration with a SPP of less than 5 years. These elements are then applied to overall sectoral consumption.

Considering the extreme variability of profiles and needs specific to the industrial sector, the top-down approach was not applied there, since associating a single average installation with the entire sector would have been unrepresentative.

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[38] If an establishment has a high electricity demand but very low demand for heating, it can be considered that installing cogeneration there is not relevant from an energy standpoint (apart from any economic concept).

5.2. Assumptions or simplifying procedures

5.2.1. General assumptions

It is important to remember that the software which determines the technical and economic potential, both by means of the bottom-up approach and the top-down approach, does not take into account temporal changes. The software estimates what is potentially achievable under current market conditions.

5.2.2. Modelling of the service and industrial sectors

A. Individual data

The first step was to list the establishments whose individual consumption is known. We worked on a SIBELGA data table[39] which includes more than 85 000 establishments in the service sectors (public and private), industries, collective and independent housing buildings. The energy, gas and electricity data, which served as a basis for the study, are those for 2018. NACE codes were also available for a large number of establishments in this file.

It is obvious that all the data have not been used, and a cut-off rule has been applied: only users whose gas consumption is greater than 85 000 kWh of gas have been taken into account. This figure is determined by the smallest cogenerator available on the market. Indeed, if we consider 85 000 kWh * 0.85% which we divide by 1 500h of operation at full load, we obtain a heating power of 48 kW. Considering that a cogeneration will represent around 25% of this heating power, we obtain 12 kW of thermal power for the cogeneration which is precisely the smallest power available on the market. For some establishments whose NACE data were missing, this threshold was raised to 100 000 kWh to limit the work of reconstructing the file.

B. Typical thermal profiles

The bottom-up approach requires modelling the energy behaviour of companies in the different sectors considered. To do this, it is therefore assumed that all the establishments in each service or industrial sector taken into account have the same thermal consumption profile. All of the more than 6 000 establishments taken into account are therefore divided into a set of sub-sectors of activity (NACE). The profiles of the different sectors taken into account are shown in Table 22.

Annex 1 explains the sizing methodology associated with each typical thermal profile.

	Profile
Type 1	Daytime, 5 days a week (offices, schools, personal services)
Type 2	Daytime, 6 days a week (shopping, culture)
Type 3	Daytime, 7 days a week (sports centres)
Type 4	Continuous, 7 days a week (care, catering)
Type 5	Daytime, 5 days a week (SME, laundry, dry cleaners, regular consumption)
Type 6	Daytime, 7 days a week (multi-family housing)
Type 7	Industry 1: 7 days a week; 3 breaks; 10 months/year (steel, lime, MNF)
Type 8	Industry 2: chemistry profile (PRAYON type)
Type 9	Industry 3: parachemistry profile (L'OREAL type)
Type 10	Industry 4: sugar mill profile (WANZE type)
Type 11	Industry 5: other food profile (KRAFTFOODS type)
Type 12	Wood drying pallet industry
Type 13	Paper industry

Table 22: List of service and industrial sectors taken into account

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[39] These data are used only within the precise framework of this study. They have been anonymised and the results are presented in aggregate form.

C. Industry and service sector segmentation

Table 23 gives the branch of activity (Industry, commerce, etc.), the sub-branch code (NACE 2 digit) and the type of associated thermal profile (see Table 2). The annex to this report on the functions of the tool details the parameters associated with the different profiles that enable the sizing of a cogeneration installation.

SECTORS	NACE 2 digit	SubSector	Associated profile type
INDUSTRY	10	Food	11
	11	Beverages	11
	12	Tobacco	11
	13	TEXTILE	5
	14	Apparel	5
	15	Leather / shoes	5
	16	Woodworking	12
	17	Paper/cardboard	13
	18	Printing	13
	20	Chemistry	7
	21	Pharma	9
	22	Manufacture of rubber and plastic products	7
	23	Manufacture of other non-metallic mineral products	7
	24	Manufacture of basic metals	7
	25	Manufacture of fabricated metal products, except machinery and equipment	7
	26	Manufacture of computer, electronic and optical products	5
	27	Manufacture of electrical equipment	5
	28	Manufacture of machinery and equipment n.e.c.	7
	29	Construction and assembly of motor vehicles, trailers and semi-trailers	7
	30	Manufacture of other transport equipment	7
	31	Furniture	5
	32	Other industry	5
	35	Steam elec production	1
	36	Capture	1
	38	Waste	1
	41	Real estate construction	1
	42	GC	1
	43	Specialised construction	1
TRADE	45	Wholesale trade and commission trade	2
	46	Wholesale trade (except vehicles)	2
	47	Retail trade (excluding supermarkets)	2
	55	Hospitality and catering- accommodation	4
	56	Hospitality and catering - catering	2

TRANSPORT AND COMMUNICATION	49	Land transport and transport via pipelines	1
	50	Water transport	1
	52	Warehousing and support services for transportation	1
	53	Postal and courier activities	1
	58	Editing	1
	59	Prod film, TV	1
	60	TV media broadcast	1
	61	Tele-comm	1
Private Offices - BANKS INS AND SERV. TO BUSINESSES	62	Computer programming, consultancy and related activities	1
	63	Information services	1
	64	Financial service activities, except insurance and pension funding	1
	65	Insurance, reinsurance and pension funding, except compulsory social security	1
	66	Activities auxiliary to financial services and insurance activities	1
	69	Legal and accounting activities	1
	70	Activities of head offices; management consultancy	1
	71	Architectural and engineering activities, technical testing and analysis;	1
	72	Scientific research and development	1
	73	Advertising and market research	1
	74	Other specialised professional, scientific and technical activities	1
	75	Veterinary activities	1
	77	Rental and leasing activities	1
	78	Employment activities	1
	79	Travel agency, tour operator reservation service and related activities	1
	80	Security and investigation activities	1
	81	Services relating to buildings; landscaping	1
	82	Office administrative services and other business support activities	1
EDUCATION	85	Education	1
CARE AND HEALTH	86	Human health activities	4
	87	Medico-social and social activities with accommodation	4
	88	Social work activities without accommodation	4
CULTURE AND SPORTS	90	Creative, arts and entertainment activities	2
	91	Libraries, archives, museums and other cultural activities	2
	92	Gambling and betting activities	2
	93	Sports activities and amusement and recreation activities	3
	94	Activities of membership organisations	1

OTHER SERVICES	96	Other personal service activities	1
	97	Activities of households as employers of domestic personnel	1
ADM. PUBLIC AND INTERNATIONAL.	99	Activities of extraterritorial organisations and bodies	1
	84	Public administration and defence; compulsory social security	1
MULTI-FAM. HOUSING	68	Multi-family housing - condominiums	6

Table 23: List of sectors taken into account in the calculation of the cogeneration potential in the Brussels-Capital Region

NB: For industrial sectors, the cogenerable heat ratios are taken from a study carried out by the ICEDD. Account is taken of the fact that industries have thermal needs, which cannot be ‘cogenerated’ such as those that occur at excessively high temperatures such as in furnaces or even those linked to specific steam needs, etc.

5.2.3. Types of installation available in the tool.

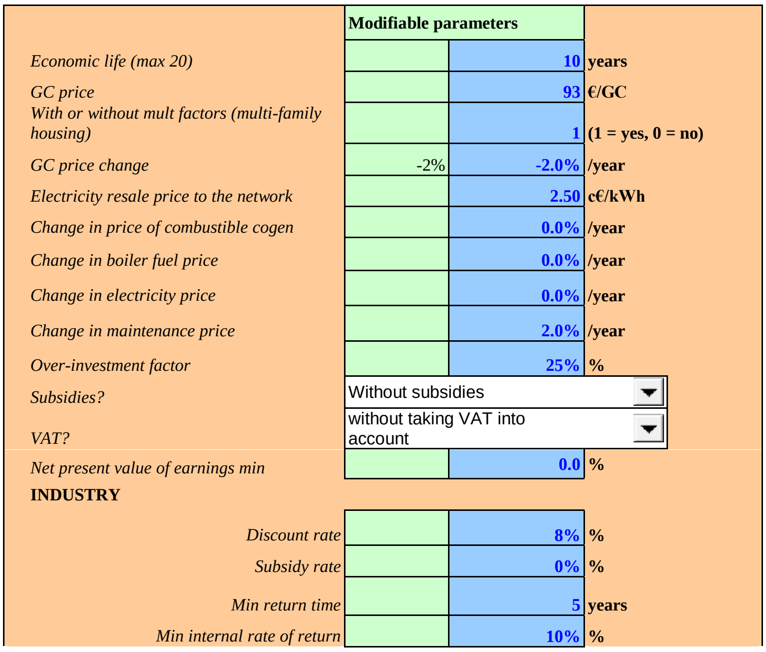
A simulation of the cogeneration potential is possible based on the following technologies:

- engine with pure vegetable oil;
- recycled vegetable oil engine;
- wood engine - gasification
- biodiesel engine;
- biogas engine;
- natural-gas-fired engines;
- syngas engine
- biomethane engine;
- diesel engine;
- gas turbine - hot water - with post-combustion;
- gas turbine - hot water - without post-combustion;
- gas turbine - steam - with post-combustion;
- gas turbine - steam - without post-combustion;

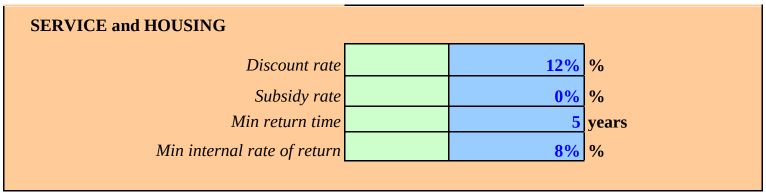
It should be noted at this stage that the most widely used technology in cogeneration applications in the Brussels-Capital Region, by far, is that of the engine powered by natural gas.

5.2.4. Economic parameters

The table below shows the main parameters of an economic nature considered during the simulations. The values indicated in blue can be modified by the user of the calculation file.



	Modifiable parameters		
Economic life (max 20)		**10**	**years**
GC price		**93**	**€/GC**
With or without mult factors (multi-family housing)		**1**	**(1 = yes, 0 = no)**
GC price change	-2%	**-2.0%**	**/year**
Electricity resale price to the network		**2.50**	**c€/kWh**
Change in price of combustible cogen		**0.0%**	**/year**
Change in boiler fuel price		**0.0%**	**/year**
Change in electricity price		**0.0%**	**/year**
Change in maintenance price		**2.0%**	**/year**
Over-investment factor		**25%**	**%**
Subsidies?	Without subsidies		
VAT?	without taking VAT into account		
Net present value of earnings min		**0.0**	**%**
INDUSTRY			
Discount rate		**8%**	**%**
Subsidy rate		**0%**	**%**
Min return time		**5**	**years**
Min internal rate of return		**10%**	**%**

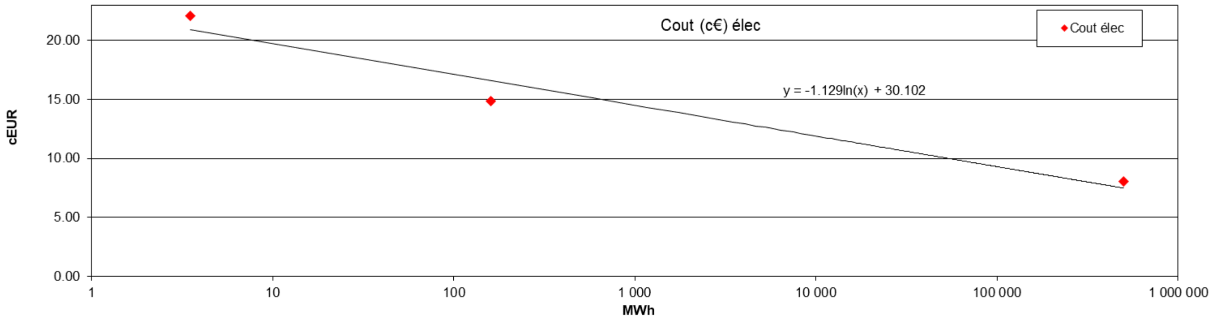


SERVICE and HOUSING			
Discount rate		12%	%
Subsidy rate		0%	%
Min return time		5	**years**
Min internal rate of return		8%	%

In this table, we can note that

- The price of green certificates is considered to be €93[40].
- The price of resale of electricity to the network, in the event of overproduction, is set at €0.025/kWh.
- The annual price increases for boiler or cogeneration fuels as well as electricity were assumed to be 0%/year, which favourably influences the net present value (NPV) and the internal rate of return (IRR). This is a favourable influence insofar as it is assumed that the price of fuels will increase and that the prices of electricity will remain more or less constant. Therefore, if we consider an increase in the fuel bill of cogeneration, this increase would be greater than that of the gain on heat, which would lead to a reduction in the net annual gain year after year, and therefore the NPV and IRR of the project.
- In the ‘Price stability’ scenario, it was decided to consider that energy prices for 2025 - 2030 remain equivalent to their 2018 values. Indeed, it seems logical to consider that the investment decisions of a company are often made taking into account the energy prices in force at the time the decision is taken. It must be noted that this realistic potential is calculated on an economic potential for which the project has a simple payback period (SPP) of less than 5 years.
- For the ‘electricity increase’ scenario, we have assumed that the price of electricity over the period considered is increased by 25% compared to its value in 2018 (elec price considered = elec price 2018 * 1.25). The price of fuels over the entire period considered is also increased by 15% compared to its 2018 value. Finally, the price of renewable fuels remained stable over the period considered.
- For the ‘increase in fuels’ scenario, we have assumed that the prices of electricity were fixed while the prices of both fossil and renewable fuels were increased by 25%, over the entire period considered.

In addition, it should be noted that the prices of natural gas and electricity decrease according to the quantity consumed. They are taken from the PWC study commissioned by CREG in 2020 ‘Comparison of electricity and natural gas prices observed in Belgium and in neighbouring countries in January 2020’, as illustrated below (CREG, 2020).



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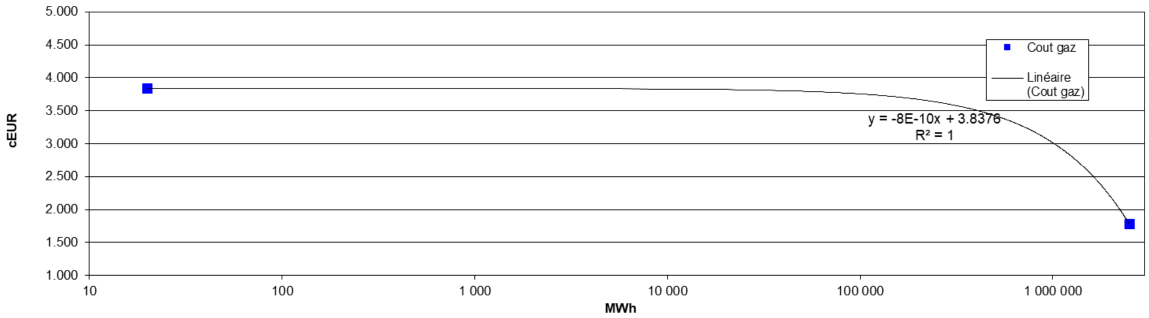
[40] This value was retained in agreement with BRUGEL.



	Cost (c €) elec
	Cost elec
	y = -1.129ln(x) + 30.102
	MWh
	20.00
	15.00
	10.00
	5 to 00
	0.00
	cEUR
	cEUR
	5.000
	4.500
	4.000
	3.500
	3.000
	2.500
	2.000
	1.500
	1.000
	MWh
	y = -8E-10x + 3.8376
	$R^2 = 1$
	Gas cost
	Linear (Gas cost)

Figure 10: Extrapolation of electricity and natural gas prices according to the MWh consumed, in 2018. Logarithmic scale. Source: CREG

In practice, given the Brussels establishments, only the price of €0.038/kWh is ultimately useful.

The price of renewable fuels and diesel is based on updated data (Valbiom: Biofuels price observatories and informazout.be), these are considered to be fixed, regardless of the quantities consumed.

Regarding synthetic methane[41] and biomethane (purified and concentrated biogas), these fuels, which will no doubt be developed, can be injected into the current gas network (the intrinsic characteristics of these fuels being equivalent to those of natural gas). Combustion technologies are therefore

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[41] By electrolysis of water, hydrogen can be produced. If we react this hydrogen with CO_2 in a methanation reaction, synthetic methane is obtained.

perfectly identical to those of gas today. The price of these fuels is not known precisely to date. In our estimates, we considered that the price of the energy component of gas (the *commodity*) would be 3 times higher than 'fossil' natural gas. By considering the breakdown of the cost of gas resulting from the PWC study, and by tripling the cost of energy, we obtain a cost per kWh of 7.6 c€.

Each fuel is associated with a CO weight$_2$, this determining the rate at which Gcs are granted for the installations.

Energy:

	CO_2 (kg CO_2/MWh)	**Price (€/kWh)**
Pure vegetable oil	65	0.075
Recycled vegetable oil	20	0.063
Biodiesels	80	0.08
Wood (gasification)	23	0.031
Locally produced biogas	20	0.031
Synthetic methane	20	0.076
Imported biomethane	20	0.076
Diesel engines	306	0.041

Table 24: Energy prices and CO weight$_2$ (source: BRUGEL)

5.2.5. The level of subsidies

We considered, at this stage, an absence of specific investment subsidy.

The tool that has been built also enables consideration of a subsidy rate that is differentiated between industry and the service sector.

5.2.6. The principles of the top-down approach: reminder

In contrast to the previous approach, we start from the overall consumption of the sector and we try to deduce a cogeneration potential. It should be noted that this approach is only applied to the service sector, 61% of which is covered by companies in the bottom-up approach, and to housing, where the share of establishments studied represents 30% of the sector concerned.

The results of the bottom up approach are used for extrapolation: drawing on these, we determine:

- Average thermal power, average efficiency, and average energy costs before and after installation of the equipment.
- We also calculate the share of Net Heat Needs (BNeC) that can be covered by cogeneration with a SPP of less than 5 years, using the bottom-up approach.

5.2.7. Installation of storage tanks

The heat storage tanks allow the cogeneration to operate longer and therefore increase the production of heat and electricity. We have allocated a flat-rate increase of 20% to 40% depending on the sector concerned (see profile sheet) if the choice is made, in the tool, to use the 'storage tanks' option. These values are based on ICEDD's experience in dimensioning cogeneration installations.

5.3. Key findings

This paragraph presents the main results of the analysis of cogeneration potential in the Brussels-Capital Region. It should be noted that additional results are also available in the calculation software, with all the details available there by sectors and sub-sectors. A detailed explanation of the software's functionalities is given in the appendix to this report.

5.3.1. Energy potential and economic potential.

In the bottom-up approach, 3 scenarios were studied. They are determined by different changes in energy prices (see previous paragraph); 'increase in electricity' scenario, 'increase in fuel' scenario and 'price stability' scenario.

The table below presents, by sector, the energy potential as well as the economic potential in the 3 scenarios considered (extrapolated bottom-up approach).

Thus, we observe that the heat production which can be cogenerated in the Brussels-Capital Region by only selecting energy considerations is 1 855 GWh (last column of the table). If we limit ourselves to cogeneration units with an SPP (simple payback period) of less than 5 years, we see that the production of cogenerable heat drops to 1 288 GWh in the 'fuel increase' scenario, 1 450 GWh in the 'price stability' scenario and 1 433 GWh in the 'electricity increase' scenario.

For each sector and each scenario, the table gives the electrical power of the cogeneration plants, their electrical production and the number of green certificates to which they will be entitled.

With heat storage	Electric power (MWe)	Electricity production (GWh)	Number of green certificates	Heat production (GWh)
Energy potential	**210.3**	**1 169.7**	**1 730 484**	**1 854.8**
- Commercial	67.4	332.9	208 932	495.1
- Industry	21.8	93.6	57 807	123.0
- Housing	121.2	743.1	1 463 745	1 236.8
Economic Potential - Scen: Stability	**154.6**	**900.2**	**1 546 687**	**1 450.3**
- Commercial	39.0	192.3	117 632	262.5
- Industry	1.8	9.8	6 276	16.0
- Housing	113.8	698.1	1 422 779	1 171.7
Economic Potential - Scen: rise in electricity	**153.2**	**881.2**	**1 516 930**	**1 433.0**
- Commercial	44.6	218.7	135 321	311.2
- Industry	2.9	14.5	9 111	22.7
- Housing	105.6	648.0	1 372 498	1 099.2
Economic Potential - Scen: increase in fuels	**135.8**	**790.3**	**1 441 414**	**1 287.7**
- Commercial	35.5	175.0	106 742	235.0
- Industry	1.2	0.076	4 883	12.6
- Housing	99.1	607.8	1 329 789	1 040.0

Table 25: Extrapolated bottom-up potential of cogeneration in the Brussels-Capital Region

If we look at these figures, we see that, although the increase in the cost of electricity should promote the profitability of cogeneration installations, this is not the case. There is little effect on the overall potential between the 'stability' and 'increase in electricity' scenarios. There is a simple explanation for this. As we can see, most of the potential is in multi-family housing. It must be noted that this sector is associated with some peculiarities:

Not much self-consumption of the electricity produced (only at the level of the municipalities). The influence of the greater increase in the price of electricity compared to that of fuels has no beneficial impact on the profitability of the installations. The slight increase in the fuel cost of this scenario (15% increase in fuel cost against 25% for the cost of electricity) has a negative effect. The profitability of installations in this sector is mainly due to the granting of additional GCs. This creates a certain distortion in the results obtained.

Further on, we will analyse the effect of removing the multiplicative coefficients for this sector on the estimate of the potential.

Table 26 compares the energy potential (figures in red) and the economic potential (in the 'price increase' scenario) according to the bottom up and top down methods in the case of the service sector and multi-family housing. Putting these two approaches into perspective allows us to 'validate' the results obtained.

	Bottom/up	**COMMERCIAL**	
	Sector share covered by individual data:	**60.7%**	
	energy potential	**Eco Potential - SPP**	**Top-down: Pot eco validation**
Fuel consumption (MWh)	**3 430 707.42**		**3 430 707.42**
Electricity consumption (MWh)	**3 060 488.86**		**3 060 488.86**
BNeC (MWh/an)	**1 159 160.79**	**541 389.15**	**670 296.11**
Total thermal power (kWth)	**99 343.85**	**52 632.84**	**64 430.14**
Total electrical power (kWe)	**67 377.33**	**39 049.58**	**30 407.71**
Cogenerated heat production MWh	**495 097.92**	**262 535.95**	**196 840.28**
Electricity production cog. MWh	**332 948.81**	**192 277.63**	**124 822.15**
Fuel cog consumption MWh	**946 538.18**	**523 670.50**	
Fuel overconsumption MWh	**337 336.86**	**200 628.84**	
Total number of GCs	**208 932.09**	**117 631.80**	
Total GC gains (€/year)	**19 426 873.68**	**10 939 757.22**	
Total CO2 avoided (tonnes/year)	**45 338.26**	**25 526.10**	
Total investment (k €/year)	**144 122.83**	**70 813.16**	
Electricity potential VAN MWh		**201 179.18**	

	Bottom/up	**MULTI-FAM. HOUSING**	
	Sector share:	**30.8%**	
	energy potential	**Eco Potential - SPP**	**Top-down: Eco scen validation**
Fuel consumption (MWh)	**3 896 143.82**		3 896 143.82
Electricity consumption (MWh)	**942 507.61**		942 507.61
BNeC (MWh/an)	**2 216 477.26**	**1 701 308.68**	1 701 308.68
Total thermal power (kWth)	**201 643.66**	**179 208.42**	179 208.42
Total electrical power (kWe)	**121 158.28**	**105 648.06**	93 449.38
Cogenerated heat production MWh	**1 236 761.22**	**1 099 156.91**	845 505.32
Electricity production cog. MWh	**743 112.22**	**647 981.82**	440 894.19
Fuel cog consumption MWh	**2 242 838.17**	**1 974 957/62**	
Fuel overconsumption MWh	**721 045.10**	**622 482.03**	
Total number of GCs	**1 463 745.04**	**1 372 497.64**	
Total GC gains (€/year)	**136 128 288.75**	**127 642 280.26**	
Total CO2 avoided (tonnes/year)	**317 632.67**	**297 831.99**	
Total investment (k €/year)	**317 814.88**	**286 502.50**	
Electricity potential VAN MWh		**3 347 332.55**	

Table 26: Comparison of bottom up and top down cogeneration potentials for the service sector and multi-family housing

It should be noted that cogeneration facilities supplied with synthetic methane, or purified biogas that is injected into the network, although they have equivalent energy potentials, have a higher economic potential of 164 MWel (of which 121 MWel, i.e. 73%, in the multi-family housing sector) for the 'increase in electricity' scenario. However, in contrast to this, they require 8 352 692 GCs granted under the current system. In the case of a 'synthetic methane' installation, the entire energy potential of multi-family housing is covered by the economic potential. Here again, we can see the effect of the multiplying coefficient linked to the granting of GCs.

With heat storage	Electric power (MWe)	Electricity production (GWh)	Number of green certificates
Energy potential	**210.3**	**1 169.7**	**9 047 610**
- Commercial	67.4	332.9	1 068 232
- Industry	21.8	93.6	283 864
- Housing	121.2	743.1	7 695 514
Economic Potential - Scen: rise in electricity	**164.1**	**956.0**	**8 352 692**
- Commercial	42.3	208.7	642 987
- Industry	0.6	4.2	14 191

- Housing	121.2	743.1	7 695 514

Table 27: Results of the 'engine powered by synthetic methane' potential

5.3.2. Effect of the GC grant rate (multi-family housing).

In the case of this first simulation we considered the current multiplier coefficients considered in apartment buildings. We can remove these and see the effect on the affected sector in the case of the 'electricity increase' scenario:

With heat storage	Electric power (MWe)	Electricity consumption (GWh)	Electricity production (GWh)	Number of green certificates	Consum. Combust (GWh)	BNeC (GWh)	Heat production (GWh)
Energy potential	**210.3**	**4 443.7**	**1 169.7**	**749 193**	**7 817.5**	**3 700.1**	**1 854.8**
- Commercial	67.4	3 060	332.9	208 932	3 430.7	1 159.2	495.1
- Industry	21.8	441	93.6	57 807	490.7	324.5	123.0
- Housing	121.2	943	743.1	482 454	3 896.1	2 216.5	1 236.8
Favourable potential at €93 / GC - gas engine	**97.6**	**4 443.7**	**549.5**	**1 117 698**	**7 817.5**	**1 579.0**	**924.5**
- Commercial	39.4	3 060	194.0	118 951	3 430.7	551.3	267.1
- Industry	2.1	441	11.0	7 027	490.7	38.0	18.0
- Housing	56.2	943	344.5	991 720	3 896.1	989.8	639.4

Table 28: Multi-family housing results with or without a multiplier

We can directly observe the significant influence of the multiplying factor in the deployment of cogeneration in the Brussels-Capital Region since without it, the potential in multi-family housing drops by 121 MW.$_{\text{electric}}$ at 56 MW$_{\text{electric}}$.

6. Solutions to meet heating and cooling needs

In this section, we present the various current and future technologies that can ensure the production of heating and cooling in the Brussels-Capital Region. For each of these, we provide an explanation of how the technology works as well as their technical and economic specificities.

Then we will estimate the value of *Levelised Cost of Heat* (LCOH) of each heat production technology to be able to compare them from the point of cost to the consumer.

The concept of LCOH is a special case of LCOE *(Levelised Cost of Energy),* voir par exemple (Hansen, 2019). It is calculated from the following equation:

$$LCOH = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

In which

- I_t = the investment costs (CAPEX) of the cogeneration, the back-up boiler, the network, the substations during year t
- M_t = operational and maintenance costs (OPEX) of cogeneration, network and substations during year t
- F_t = purchases of fuels consumed by cogeneration and the back-up boiler during year t
- E_t = the heat produced during year t
- r = the discount rate taken into account
- n = the service life (in years) of the installation

6.1. The different techniques that can be envisaged

Heat production:

The technologies considered for the production of heat (individual or collective) are as follows:

- **Individual technologies** of heat production:
    - Boilers (possibly condensing) powered by different possible fuels
    - Solar thermal panels
    - Heat pumps
    - Geothermal energy
    - Electric heating
    - Cogeneration

- **Collective technologies** production and distribution of heat include heat networks that can be supplied by:
    - 'Classic' boilers powered by different fuels
    - Cogeneration powered by different fuels
    - Riothermy (sewer heat)

  - Waste heat recovery
  - Renewable energy sources (biomass, solar thermal[42])

Production of cold:

As with heating production, cold can be produced by individual or collective installations:

- **Individual technologies** for cold production can be distinguished according to two main techniques:
  - Natural cooling
    - Natural cooling (including *free cooling*)
  - Active cooling (air conditioning)
    - Compression refrigeration machine and *free chilling*
    - System with variable refrigerant flow and energy recovery on water loop
    - Absorption and trigeneration refrigeration machine
- **Collective technologies** for cold production:
  - Refrigeration networks

Combined heat and cold production:

The combined production of heating and cooling can be done by a **collective installation**:

- Networks on temperate water loop

6.1.1. Heat generation technologies - Individual solutions

A. (Condensing) boilers

A.1. Operations

In a boiler, fuel is burned to produce heat which is then transmitted to a coolant (often water). Once heated, the fluid is transported to the heat emitters (e.g. radiators) via a central heating circuit (pipes and tubes). Domestic hot water can also be provided.

The particular feature of the condensing boiler is that an exchanger-condenser is placed at the boiler outlet. The water vapour present in the fumes is thus condensed and the latent heat of vaporisation of the water contained in the fumes is recovered. This reduces the need for fuel to generate heat and thus improves combustion efficiency.

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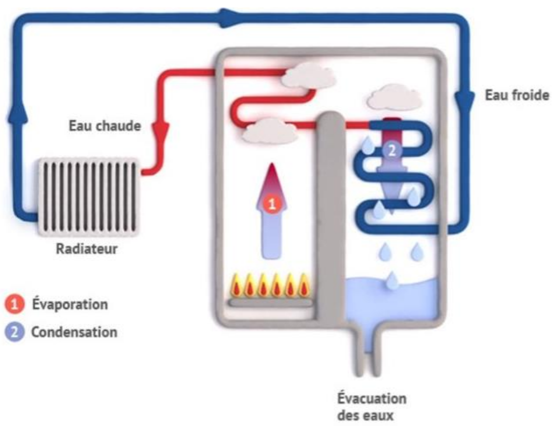
[42] http://solarheateurope.eu/2020/05/19/vojens-district-heating/



	Hot water
	Radiator
	Cold water
	Water discharge
	Evaporation
	Condensation

Figure 11: Condensing boiler

The performance of condensing boilers improves the lower the flue gas temperature is. It is therefore preferable to have a low coolant temperature at the outlet of the boiler. This is made possible by heat emitters (e.g. underfloor heating, radiators) working at low temperature. While a condensing boiler can perform well with radiators sized at 90 °/70 ° C, it will operate optimally at low temperature (return water temperature ≤ 50 ° C). This involves issuers conditioned to the following regimes: 70 °/50 ° C for radiators, 55 °/40 ° C for fan coil units, 40 °/30 ° C for underfloor heating, 70 °/40 ° C for domestic hot water.

The main difference between boilers is the fuel that is used. These can be natural gas, biomethane, fuel oil or biomass - i.e. logs, pellets or chips, and eventually hydrogen. In the case of hydrogen, a recent study has shown that it is possible to adapt natural gas boilers to run on hydrogen. (Gersen, Martinus, Van essen, Darmeveil, & Teerlingc, 2020). The authors highlight the good combustion performance of these adapted boilers as well as the clear reduction in NO_x emissions measured. However, adapting the network and the boilers will represent a significant cost despite the interest of this technology.

For the first three fuels mentioned, we consider condensing boilers while we are more focused on 'conventional' boilers for biomass. Although there are condensing boilers for biomass, this technology is much less common (Valbiom, 2015)[43].

In addition, boilers using pellets or chips share the technical feature that they can be automatically supplied with fuel by a feed or suction screw system. The benefit of these boilers lies in the fact that biomass is considered renewable, and is therefore neutral in terms of its carbon footprint. If the burnt biomass is replaced, the carbon emissions from combustion would be offset by the growth of new biomass. The sustainability of this sector is however called into question (see technical and financial specificities) and it presents disadvantages in terms of air quality. In addition, the Brussels authorities are currently considering the types of biomass combustion installations that should be prohibited on the territory of the Brussels-Capital Region in view of the air quality problems they raise (see Section

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[43] It is worthwhile specifying that the PCS efficiency (i.e. 'Energy released by the combustion of wood taking into account the recovery of the latent heat of the water vapour emitted during combustion') of the wood is 5.4 kWh/kg against 5.14 kWh/kg of lower calorific value (LCV) output (i.e. 'Energy produced by the combustion of a fuel without taking into account the latent heat contained in the water vapour produced') for anhydrous wood (which does not contain water). (Valbiom, 2015)

4.5.5).

A.2. Technical and financial specificities

In this section, we present the technical and financial specificities related to the technology under consideration. Although 'constraints' are mentioned, these also include the positives and negatives associated with the technology.

For condensing boilers, we distinguish here between the fuel-based boilers they use:

Natural gas and bio-methane

- Extended gas-distribution network

In the Brussels-Capital Region, the gas distribution network is widely extended and covers (practically) the entire territory. Biomethane, which consists of purified biogas and whose composition is close to 'classic' natural gas, can be injected directly into the distribution network without adapting the combustion means of the end consumer.

- No physical storage

These fuels do not require physical storage, so in effect, they require a smaller floor space.

- Low prices

Gas-fired condensing boilers are a relatively inexpensive and well-known technology.

- High efficiency

Among all the fuels presented, the natural gas boiler has the best efficiency, estimated at 104%, if it is calculated on the basis of the fuel LCV.

- Emissions

Greenhouse gas (GHG) emissions remain significant for these technologies even though the levels of CO_2 emissions vary depending on the fuel - natural gas is a lower emitter than fuel oil and solid fossil fuels. However, as a fossil fuel, natural gas does not fit into the long-term European and Brussels climate ambitions.

- Energy dependence

Natural gas is not a Belgian resource and results in energy dependence on third countries.

Diesel oil

- Known technology

Oil-fired boilers have been on the market for a long time. They therefore have the advantage of being a well-known technology.

- Independent solution

When buildings are not connected to the natural gas distribution network, oil-fired boilers are useful. Given the good coverage of this network, the scope of this advantage is however limited in the Brussels-Capital Region.

- Emissions

Fuel oil is a fossil fuel that emits more CO_2 than natural gas. As part of the Brussels climate objectives, the BCR's 2030 climate energy plan also plans to ban the installation of heating and/or domestic hot water production devices running on fuel oil from 2025 (see Section 4.5.5).

The combustion of fuel oil results in the emission of three other notable pollutants: NO_x, SO_x and dust. Natural gas emits only NO_x. Emission limit values for new installations are set by a European directive[44].

- Physical storage

This type of boiler requires a tank to store the fuel oil. In addition to the inconvenience of storage, this implies an additional cost (of the order of more than EUR 2 000) for the purchase and in the case of old underground tanks, risks of leaks and therefore of pollution of the ground by hydrocarbons.

- Energy dependence

Like natural gas, fuel oil is not a Belgian resource and results in energy dependence on other countries.

Logs, pellets and chips

- sustainability of biomass

The use of biomass as bioenergy is not necessarily sustainable. Article 29 of European Directive 2018/2001[45] moreover defines the criteria for the sustainability of biomass energy. A non-exhaustive list of criteria is presented briefly below:

- Operators or national authorities have management or monitoring plans in place to deal with the impact on soil quality and soil carbon content;
- Bioenergy is not produced from raw materials from biodiversity-rich lands such as primary forests and forests with high biodiversity;
- Bioenergy is not produced from raw materials from land with a large stock of carbon;
- Bioenergy is not produced from raw materials from land that used to be peatlands;
- Enforcement of national, sub-national or forest supply zone-level legislation that ensures:
    - the legality of harvesting operations;
    - forest regeneration of harvested areas;
    - that areas designated by international or national law or by the relevant competent authority for nature protection purposes, including in wetlands and peatlands, are protected;
    - that harvesting is carried out considering the maintenance of soil quality and biodiversity with the aim of minimising negative impacts;
    - that harvesting maintains or improves the long-term production capacity of the forest.
- Specific reduction levels of greenhouse gas emissions resulting from the use of bioenergy according to the year of commissioning of the installations for the production of biofuels, biogas or the production of heat and cold and electricity.

It is important to note that this framework applies regardless of the geographical origin of the biomass, but the resource must be of local origin (<50 km) so that the emissions linked to transport do not deteriorate its environmental performance (Filloux & Dastot, 2010).

In addition, several scientists have recently alerted the European Parliament against the potential indirect impacts of the directive[46]. Even though it sets sustainability criteria, the directive promotes the use of biomass as bioenergy which could have negative consequences:

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[44] Directive EU 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plants

[45] Directive of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[46] Letter from scientists to the European Parliament concerning forest biomass, 9 January 2018. https://www.canopee-asso.org/wp-content/uploads/2019/10/UPDATE-800-signatures_Scientist-Letter-on-EU-Forest-Biomass.pdf

  - Using trees specifically cut for use as bioenergy releases carbon that would otherwise remain stored in forests. It also risks shifting wood consumption to other forests for the production of wood products.
  - The efficiency of wood combustion is lower than the combustion of fossil fuels, which increases CO_2 emissions in the air.
  - Harvesting wood leaves biomass used for soil protection. This biomass breaks down and also emits CO_2.

The increase in CO_2 emissions$_2$ caused by the aforementioned reasons constitutes an obstacle in the fight against climate change.

- Air quality

For biomass boilers, the emission of other pollutants is a drawback. Although they emit less SO_2 than oil-fired boilers, they pollute more in terms of NO_x and dust. These boilers considerably deteriorate the quality of the air, particularly when wood combustion is not optimal (starting up, badly adjusted boiler, damp wood, etc.).

- Efficiency

Compared to natural gas or oil condensing boilers, these have lower efficiency. It can be estimated at between 60% and 97% depending on the fuel. These differences in efficiency are explained in particular by the quality of the resource (e.g. presence of resin in the bark), its humidity level, its energy density, the transformation processes (e.g. drying) undergone or the size of the solid fuel (the use of pellets can be more flexible than the use of logs to meet the same heat requirement).

- Physical storage

Storage is also a disadvantage of these boilers because they require, de facto, a larger floor space.

- Costs

Although biomass boilers cost more than natural gas boilers, they are still a relatively accessible technology.

- Cartage

Biomass would have to be transported to the BCR mainly by trucks. The increase in truck traffic in the region would cause additional inconvenience in terms of congestion, GHG emissions and atmospheric pollutants, as well as noise pollution.

A.3. Replicability in the Brussels Capital Region

In this section, we present the ease or difficulty with which the technology can be implemented in residential and service sector buildings in the BCR. As the presence of industries is limited in the region, it is not covered in its own right in this section.

- **Residential buildings**

Condensing boilers are one of the most widely used technologies for supplying residential dwellings with heat. They can either operate at the individual level (house, apartment) or at the level of a building (building to apartment). Natural gas boilers remain the easiest boilers to deploy because they are efficient and economical and the gas distribution network in the Brussels-Capital Region is particularly well developed. In addition, they are easily implemented in existing buildings. The only real constraint lies in the remaining GHG emissions associated with them and, ideally, the need to replace heat emitters with 'low temperature' emitters to maximise thermal efficiency. Given the climatic ambitions in force as well the air quality improvement objectives, oil-fired boilers are not recommended, especially as their advantage as a stand-alone solution is of little relevance in the Brussels-Capital Region due to the presence of an excellent natural gas network. Biomass boilers have several useful characteristics but they are not advisable for individual dwellings, given their significant impact on air quality. Biomass boilers could be of interest in the case of collective heating supplying a heating network (see Section 7) near a unit where the supply is consistent with the proximity of the resource. In addition, the use of biomass for heating buildings raises questions in terms of the sustainability of the resource, especially if it is imported from countries that do not comply with agro-environmental standards.

- Service sector buildings

For the same reasons as those mentioned for residential buildings, condensing boilers (natural gas) are a worthwhile technology for service sector buildings.

A.4. Assumptions for calculating LCOH

The technical and economic assumptions made for these technologies are grouped together in the summary table below. The ranges of values correspond to the values identified for households (low range) and for the service sector (high range), with the exception of fuel for which the reverse is the case when there is a difference. Since it is unlikely that a service sector building will be equipped with a log boiler, we have not taken this type of boiler into account for this sector.

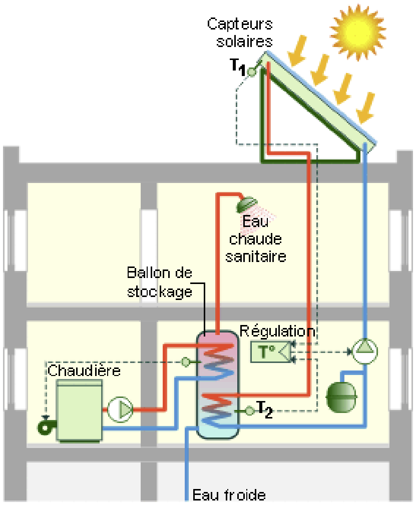
Technology	Sector	Power	Operating hours	Technical lifespan	Efficiency	Investments	Maintenance	Fuel
		kW	h/year	Year	%	kEUR	EUR/year	EURO/MWh
(Condensing) boilers	Biogas	[20 - 2 000]	[1 800 - 2 000]	20	102	[5.4 - 227.2]	[75 - 1 000]	[76 - 89]
	Natural gas	[20 - 2 000]	[1 800 - 2 000]	20	102	[5.4 - 227.2]	[75 - 1 000]	[34 - 40]
	Diesel oil	[20 - 2 000]	[1 800 - 2 000]	20	98	[7.7 - 368.2]	[142 - 6 600]	[47 - 49]
	Logs	20	1 800	20	85	5.8	150	47
	Pellets	[20 - 2 000]	[1 800 - 2 000]	20	95	[15 - 900]	[400 - 46 000]	58
	Wood chips	[20 - 2 000]	[1 800 - 2 000]	20	90	[15 - 1 080]	[150 - 54 000]	31

Table 29: Technical and economic assumptions for the boilers

B. Thermal solar panels

B.1. Operations

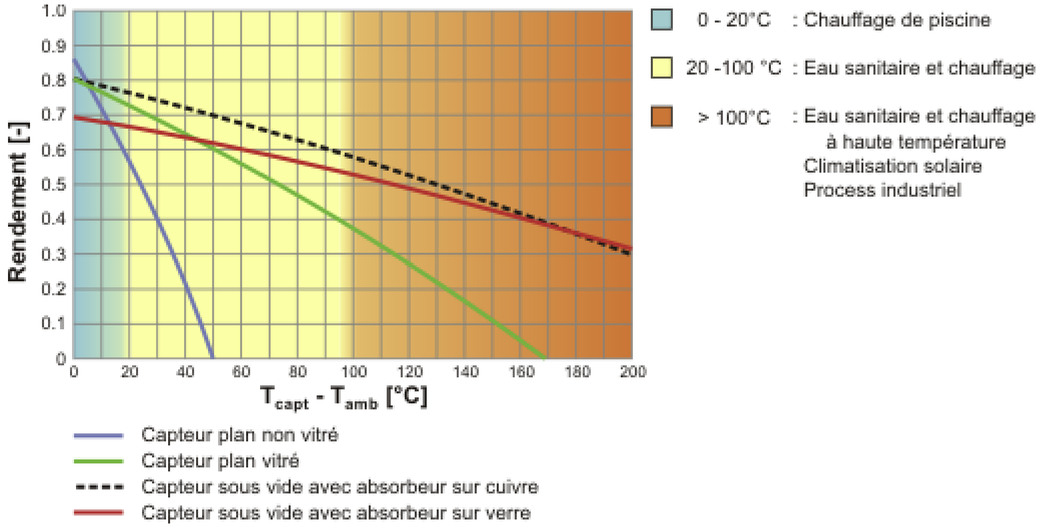
Placed on the roof of the building, the solar panels are equipped with sensors that collect direct and diffuse solar radiation in order to transform it into heat (unlike photovoltaic panels which produce electricity directly). The heat collected is transferred to a heat transfer fluid (e.g. glycol water) circulating in each of the collectors. The heat transfer fluid is routed to the hot water storage tank once a certain temperature difference is reached between the temperature encountered at the level of the sensors and that at the bottom of the storage tank.



	Solar collectors
	T1
	Storage tank
	Sanitary hot water
	Regulation
	Boiler
	T2
	Cold water

Solar thermal installations can be of two types: closed (indirect) or open (direct) solar loop. In **closed loop** installations, the heat transfer fluid heated in the collectors and that drawn from the storage tank are not the same. The coolant of the collectors indirectly heats the water consumed via an exchanger. In **open loop** installations, the water for consumption is the same as the water flowing through the collectors. In Belgium, this latest technology is used less because of the problems that can be caused by freezing. (EnergiePlus, 2020).

Depending on the type of sensor used, the efficiency varies. The collectors differ according to the quality of the absorber, the solar glass and the insulation of the collector. These three parameters determine the preferred temperature ranges per type of sensor and hence the preferred use for this:



	Efficiency [-]
	1.0
	0.9
	0.8
	0.7
	0.6
	0.5
	0.4
	0.3
	0.2
	0.1
	T_{capt} - T_{amb} [°C]
	0 - 20 °C: Pool heating
	20 - 100 °C: Domestic water and heating
	> 100 °C: Domestic water and high temperature heating Solar air conditioning Industrial process
	Non-glazed flat panel collector
	Flat glass collector
	Vacuum sensor with absorber on copper
	Vacuum sensor with absorber on glass

Figure 12: Preferred temperature range per sensor and preferred uses (EnergiePlus, 2020)

Depending on the performance and usage illustrated above, three categories of operating range can be included:

- Low temperature (0 to 20 °C): This particularly concerns swimming pools. The desired temperature is relatively low and heat losses have little influence. The efficiency of the collector will be essential, which is why flat collectors (glazed or not) are preferred.
- Medium temperature (20 to 100 °C): application for the production of domestic hot water and heating. The heat losses become more significant than the apparent efficiency. The sensors must be well thermally insulated. Vacuum collectors or glazed planes are thus preferable.
- High temperature (> 100 °C): application for industrial processes, solar air conditioning or high temperature heating. As thermal insulation is essential, only vacuum collectors can be considered.

As it is a function of solar radiation, the heat production is, of course, higher in summer than in winter. This explains why this technology is better suited for domestic hot water than for heating, since in the latter case, the need is highest in winter when the heat source is the lowest. Moreover, solar collectors are not always able to meet the entire heat requirement at all times (e.g. when there is no sun). It is therefore necessary to install a back-up system to ensure the desired temperature. This can be supplied with electricity, or via a conventional boiler.

The sensors have different apparent efficiencies depending on the technology (EnergiePlus, 2020):

- Non-glazed flat panel collector: 90 - 95%
- Flat glass collector: 75 - 85%
- Vacuum sensor with absorber on copper: 75 - 85%
- Vacuum sensor with absorber on glass: 50 - 70%

However, the efficiency of an installation does not depend solely on the optical efficiency of the sensors. It is estimated that a well-designed installation captures on average 300 to 400 kWh/m².year for 1000 kWh/m².year of irradiation on average in Belgium (EnergiePlus, 2020). This therefore corresponds to an average efficiency of 30 to 40%. An installation of this type has a lifespan of at least 25 years.

B.2. Technical and financial constraints

- Emissions

As it operates on renewable energy (solar), the solar panel does not emit GHGs during its operation, which ensures good environmental performance. For the sake of completeness, it should be noted that the production of panels emits GHGs but to a relatively low extent. In addition, the use of a back-up system will generate GHG emissions.

- Cost

When the solar panel relies solely on solar energy to operate, the 'fuel' cost is zero since the energy source is free. In addition, thermal solar panels require little maintenance, which reduces costs.

- Subsidies

In the Brussels-Capital Region, the installation of this type of panel for the production of hot water is currently subsidised.[47]. Provided that the implementation of a domestic hot water installation includes at least 2m² of optical panel surface and a domestic hot water tank, the work is eligible[48] for the subsidy (C7).

For a maximum of 50% of the eligible costs of the invoice, the amounts of the subsidy are distributed

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[47] https://environnement.brussels/thematiques/batiment-et-energie/primes-et-incitants/les-primes-energie-2021/primes-c-chaleur/chauffe, accessed 22 December 2020.

[48] A list of eligible work to determine the maximum amount of the subsidy or bonus for stopping the use of fuel oil or coal is specified by the energy subsidy form C7

as follows according to the category of the applicant[49]:

- A: €2 500 / up to 4 m² €200/m² over 4 m² (per housing unit if residential and per installation if service);
- B: €3 000 / up to 4 m² €200/m² over 4 m² (per housing unit);
- C: €3 500 / up to 4 m² €200/m² over 4 m² (per housing unit)

As of 2021, a bonus for the removal of fuel oil and coal is available for households and residential condominiums:

- A: €300 if an old oil boiler or €600 if an old oil or coal stove;
- B: €350 if an old oil boiler or €700 if an old oil or coal stove;
- C: €500 if old oil boiler or €1 000 if old oil or coal stove

- Intermittence

This technology is a function of solar radiation which is intermittent depending on weather conditions and also varies according to the seasons. A back-up system is therefore needed to meet the heat requirements.

- Solar potential

This technology also depends on the area and orientation of the roofs. The performance of the panels may therefore depend on the building on which the installation is planned because it may not be oriented at best or get a lot of shade due to the presence of taller buildings next to it, etc.

- Profitability

Despite low operating and maintenance costs, the investment cost remains substantial. This makes the technology dependent on the bonuses offered by Bruxelles Environnement in BCR.

- Unique DHW function

As explained previously, the constraints linked to this technology make it better suited to the production of domestic hot water than to heating. In addition, this technology achieves an economic optimum when it covers 50% to 70% of the annual hot water demand for individual dwellings and between 20% and 40% for larger installations such as apartment buildings. (PWC, 2015). The balance must be produced by conventional means (boilers, heat pumps, direct electric heating).

- Legionellosis

Bacteria can proliferate in the storage tank because the temperatures are favourable for it (30 to 40 ° C). This problem can nevertheless be managed by installing pumps (delamination) or tanks (transition). (EnergiePlus, 2020)

- PV competition

Solar panels intended for the production of DHW are installed on the roof like photovoltaic panels. This means that the two can potentially compete for roof area and choices may have to be made when the roof is unable to optimally reconcile the two technologies.

B.3. Replicability in the Brussels Capital Region

- **Residential buildings**

Solar heating is particularly suitable for domestic installations. The bonuses made available encourage

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[49] The categories of applicant depend on income and household composition. For single persons, the categories of applicants are based on income: category A if the income is > EUR 71 565.60, B if the income is between EUR 35 782.80 and EUR 71 565.60 and C if the income is < EUR 35 782.80. For cohabitants or couples: category A if the income is > EUR 86 565.60, B if the income is between EUR 50 782.80 and EUR 86 565.60 and C if the income is < EUR 50 782.80.

the installation of thermal solar panels. However, this technology can only cover part of the DHW production and must therefore be supplemented by another heat production system.

- **Service sector buildings**

In buildings with high demand for hot water, and especially in summer (e.g. swimming pools, hotels, etc.), solar heating is also an interesting technology, especially since it can benefit from subsidies. Again, this will have to be complemented by another method of heat production to ensure heating and the uncovered part of DHW.

B.4. Assumptions for calculating LCOH

The technical and economic assumptions of these technologies are grouped together in the table below. The ranges of values correspond to the values identified for households (low range) and for the service sector (high range):

Technology	Sector	Power	Operating hours	Technical lifespan	Efficiency	Investments	Maintenance	Fuel
		kW	h/year	Year	%	kEUR	EUR/year	EURO/MWh
Solar heating	Renewable .	[1.75 - 35][50]	800	25	35	[5.3 - 80]	[49 - 840]	-

Table 30: Technical and economic assumptions for thermal solar panels

C. Geothermal

C.1. Operations

Geothermal energy is based on the principle of extracting heat from the ground. Although the temperature of the ground varies according to the seasons under the first 10 metres of depth, beyond that it is relatively constant. In Belgium, it fluctuates between 10 and 14 ° C at a depth of 20-30m and then increases by 3 ° C per 100m on average.

Geothermal energy can therefore be distinguished according to the level of enthalpy[51]. Low enthalpy geothermal energy requires the use of equipment, such as a heat pump (HP), to raise the temperature of the heat captured in the ground for use while high enthalpy geothermal energy makes direct use of heat from the ground. In the case of the use of a heat pump, the ground serves as a cold source where heat is extracted in order to heat a warm source (the building). Conversely, the coolness of the ground can also be directly used to cool a heat transfer fluid which will then be used to cool a building (*geocooling).*

The enthalpy level is a direct function of the depth of the boreholes. Thus, two types of geothermal energy can be presented:

- **Shallow geothermal energy** (low enthalpy): these are the most frequently found installations in Brussels. Two cold sources can be used for shallow geothermal energy:
    - *Air (aerothermal)*: part of the hygienic air renewal in a home is provided by an air supply duct which is buried in the ground. In winter, this helps to preheat the fresh air

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[50] The thermal power was estimated on the basis of an area of the collectors of 5m² and 100m² for the residential and the service sector respectively.

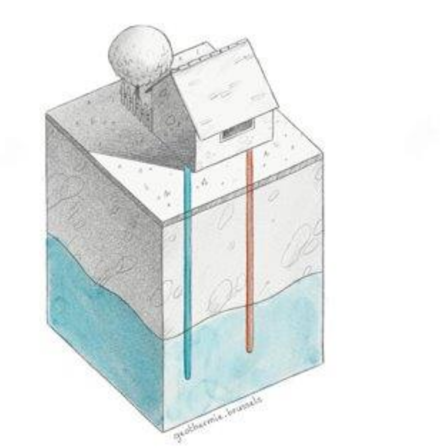
[51] Enthalpy is the total energy of a system. In other words, it is the sum of all the types of energy it contains at constant pressure. It is expressed in joules (J) or in kilojoules (kJ).

before it arrives at the house thanks to the higher temperature of the ground compared to the outside air. In summer, the cooler ground temperature will allow the natural cooling of the air entering the building. This is the Canadian well principle. However, the substantial investments, the risks of significant internal condensation, the additional pressure drops in the ventilation system and maintenance are all disadvantages that make it less of a priority technology (Energie Plus, 2020).

- ***Groundwater/glycol (hydrothermal)***: the heat extracted from the water or the ground is at low temperature (less than 30 ° C), which does not allow the direct transfer of heat by simple exchange. It is therefore necessary to add heat pumps to meet the heating needs of houses. Depending on the origin of the water used to heat the building, the geothermal system can be:
    - Open: underground water from a natural source is pumped from a water table, passes through an exchanger where its heat is captured for distribution to a building and is finally ejected, colder, in another point that is different from the pumping point.
    - Closed: a heat transfer fluid circulates in a closed circuit buried in the basement, and its heat will be used to heat the fluid. Once heated, the fluid will transmit its heat into the building. Closed geothermal systems capture heat from the ground via a piping system installed horizontally in the first few metres below the ground surface or vertically (up to several hundred metres). In Brussels, there are mostly closed systems.

Figure 13: Open geothermal system (geothermie.brussels)

Figure 14: Vertical closed geothermal system (geothermie.brussels)



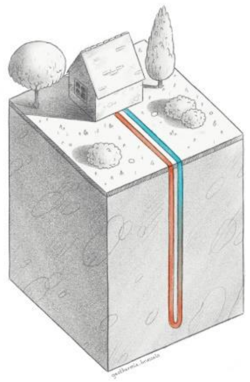
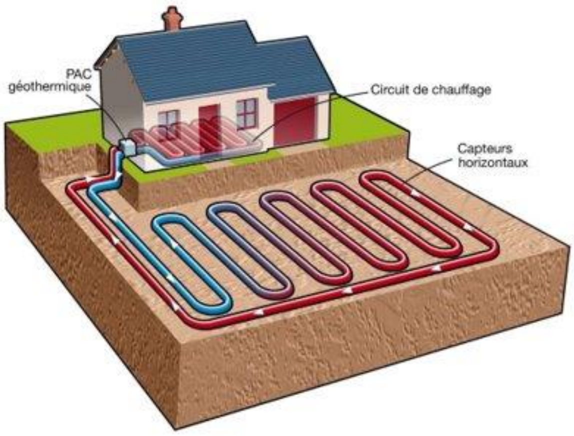


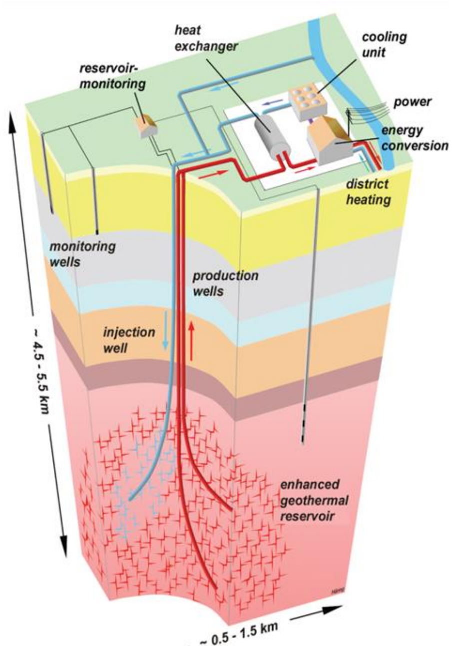
Figure 15: Horizontal closed geothermal system (geothermie.brussels)



	Geothermal heat pump
	Heating circuit
	Horizontal sensors

This type of geothermal energy is described in more depth in the section 'Geothermal heat pumps' and will not be elaborated on further here.

- **Deep geothermal energy** (high enthalpy): based on a principle similar to shallow geothermal energy in an open system, the thermal energy captured makes it possible to directly supply the buildings with heat thanks to the high temperatures extracted via deeper boreholes (> 1 000m). However, reaching these depths requires unconventional drilling techniques as well as rock stimulation (geothermie.brussels, 2020). This can therefore only be considered as a collective or industrial solution for large-scale projects and outside highly urbanised areas. In addition to the technical constraints, a specific geological context is necessary for these systems, as is the case with the Saint Ghislain site in the Mons region. For these reasons, deep geothermal energy does not appear to be a possible solution for Brussels. This is why we will not go into more detail on this technology.



© Geothermal Explorers Ltd, 2005

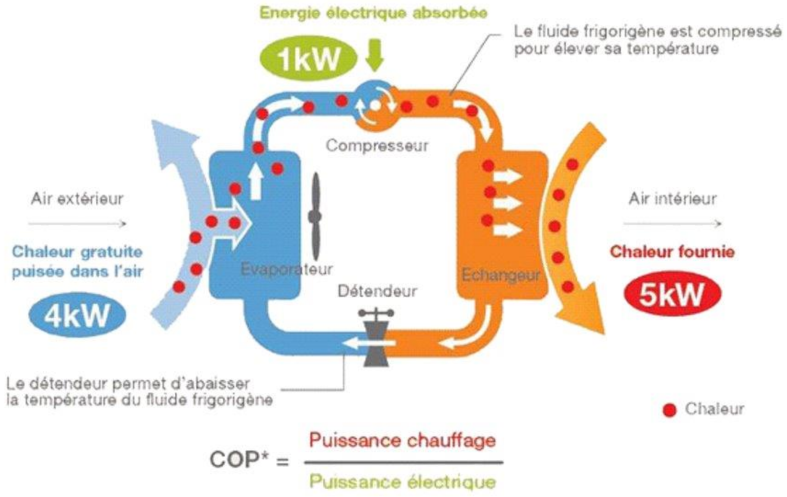
	reservoir-monitoring
	heat exchanger
	cooling unit

	power
	energy conversion
	district heating
	production wells
	injection well
	monitoring wells
	4.5 - 5.5 km
	enhanced geothermal reservoir
	~ 0.5 - 1.5 km
	© Geothermal Explorers Ltd, 2005

D. Heat pumps

D.1.Operations

The heat pump (HP) makes use of the free heat present in an external environment to restore it in a building. This heat is taken from a 'cold' source (e.g. groundwater, air, etc.) before being released into a 'hot' source (e.g. house, building). Through a compressor, the refrigerant present in the thermodynamic circuit is heated because its pressure increases, its temperature increases and the fluid evaporates. Then the fluid is placed in a condenser and it transfers its heat to the air which is diffused in the dwelling or the building via the emitters (e.g. radiators). The fluid condenses as it cools. At low temperature but at high pressure, the refrigerant passes through a pressure reducing valve where its pressure drops and it starts a new cycle. The figure below illustrates the operation of an air-to-air heat pump.



	Absorbed electrical energy
	Outside air
	Free heat drawn from the air
	4kW
	The expansion valve allows the temperature of the refrigerant to be lowered
	COP* =
	Heating power
	Electric power
	Heating
	Regulator

	Evaporator
	Exchanger
	Compressor
	The refrigerant is compressed to raise its temperature
	Indoor air
	Heat provided
	5kW

Figure 16: How an air-to-air heat pump works

Heat pumps have the advantage of being able to combine the production of heat and domestic hot water. In addition, they can be reversible which means that they can produce both heat and cold.

Heat pumps are an attractive system in that they can have excellent Coefficients of Performance (COP). Under the right conditions, 1 kWh of electrical energy can produce 2.5 to 3.5 kWh of thermal energy. If the electricity comes from a renewable source, the heat produced will be completely carbon-free. However, with the current Belgian energy mix, largely based on nuclear or fossil fuels, heat pumps are still the source of indirect non-negligible CO_2 emissions.

The heat transfer fluids in which the heat exchangers of the evaporator and condenser bathe distinguish heat pumps. In the context of this study, two types of HPs are presented:

- **Aerothermal heat pumps:**

Aerothermal heat pumps or ‘air-to-air’ and ‘air-to-water’ heat pumps are directly grafted to the building envelope and take heat from the outside air. After transfer as detailed previously, the heat is either expelled into the air in the building or used to heat the water in the heating pipes, which in turn will heat the air or the domestic hot water.

- **Geothermal heat pumps:**

Geothermal heat pumps or ‘water-to-water’ and ‘ground-to-water’ heat pumps draw heat from the ground or from groundwater to heat the water in the heating pipes. As introduced in Section 6.1.1.C, geothermal heat pumps can operate on the basis of open systems (extraction of heat from groundwater or surface water taken at one point and discharged at another point) or closed systems (piping system in which a heat transfer fluid circulates). In the case of closed systems, the installations can be horizontal or vertical. Depending on the mode chosen and the depth of the boreholes, geothermal heat pumps therefore require more or less infrastructure and space. Vertical installations use temperatures that are generally more constant than horizontal installations because the latter are located closer to the ground surface and are subject to climatic effects linked to the seasons. Ground temperatures are warmer in summer but can be negative in winter, which weakens the performance of heat pumps.

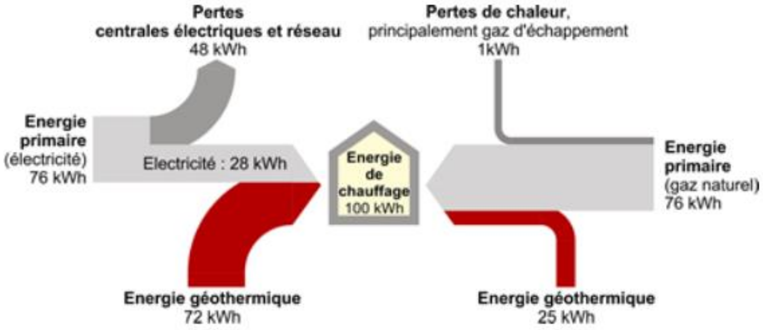
Not all HPs work the same either. Indeed, different operating modes exist and we list them below:

How it works	Heat producer	Working principle
Monovalent	HP only	The heat pump is the preferred heat producer and operates on its own. This operating mode is more particularly suitable for perfectly insulated buildings.
Monoenergetic	Electric back-up heat pump	The heat pump operates on its own until a specific point of equilibrium is reached below which an electrical resistance, integrated into the heat pump, provides additional heat to an accumulator (by radiators or fan coil units). It is a frequent solution for aerothermal heat pumps. When

		temperatures are low (typically < 0 ° C), the COP deteriorates. As the heat pumps cannot be oversized (i.e. the heat pump has to be the right size for it to function optimally at low temperatures), a back-up solution is needed to meet the heat needs at low temperatures .
Bivalent	Boiler + heat pump	A supplementary heating system (e.g. natural gas boiler) is installed, which allows operation in bivalent mode. This is useful when high operating temperatures (> 50 ° C) are required or when useful heating powers greater than the power available at the cold source are required. Bivalent operation is often found when installing heat pumps in renovated buildings. The old boiler (e.g. natural gas) is often retained and added to the heat pump to cover the heat needs during periods of low temperatures. In mid-season, the HP will nevertheless operate autonomously. 2 types exist: alternating bivalent and parallel bivalent. With the alternative bivalent type, the boiler operates on its own once the bivalence point (below a certain temperature) is reached. In the case of the parallel bivalent type, the boiler works in addition to the heat pump once the bivalence point (below a certain temperature) is reached.

Table 31: Typical operating modes of a heat pump (Bruxelles_Environnement_1, 2020)

In addition, there are two families of heat pumps: electric and gas. Currently, electric heat pumps are the most frequently encountered type. Although gas heat pumps are currently more marginal, they could nevertheless represent an interesting solution in the future. As illustrated in the graph below, the combination of a gas-fired heat pump with geothermal energy can be relevant due to the smaller size of the heat source required by the gas-fired heat pump.



	Power plant and network losses 48 kWh
	Primary energy
	(electricity) 76 kWh
	Electricity: 28 kWh
	Geothermal energy
	72 KWh
	Heating energy
	100 kWh
	Geothermal energy
	25 kWh
	Primary energy
	(natural gas) 76 kWh

	Heat losses, mainly exhaust gas 1kWh

Figure 17: Heat pumps (electricity and natural gas) and geothermal energy (Energie Plus, 2020)

D.2.Technical and financial specificities

- Efficiency

As already mentioned, the main advantage of heat pumps is the COP that they can potentially achieve. While aerothermal heat pumps can reach a COP of 2.5 to 3, geothermal heat pumps are potentially more efficient with a COP of 3.5 to 4. These levels are however reached under optimal conditions. These conditions deteriorate when the temperature difference between the cold source and the desired comfort temperature (that of the hot source) increases. This is why, to be efficient, the heat pump needs a cold source of sufficiently high temperature (to produce heat). Conversely, it requires a relatively low warm source (emitters) to reduce this difference (e.g. underfloor heating with 30/45 ° C regime). Heat pumps are therefore recommended in low-energy, passive buildings or with low heat requirements (e.g. new or thoroughly renovated in the service sector). Ideally, the emitters in the system should be chosen in line with these temperature levels. Thus, cold ceilings or radiating islands, active tiles or oversized convectors are recommended (EnergiePlus, 2020).

- Inexhaustible and local resources

Aerothermal heat pumps use air which is a continuously renewed resource. Theoretically, geothermal heat pumps also exploit a resource that is renewing itself. However, heat needs may require more heat than the soil or groundwater can naturally renew and therefore will tend to be depleted in the long run. Depending on the case, it is thus necessary to provide additional solutions such as a boiler to avoid drawing too much heat from the cold source or else to integrate soil regeneration techniques such as *free-cooling* (see Section 6.1.3.A) or *geocooling* as a possible complement to active cooling for the service sector or even for densely populated districts equipped with geothermal heat pumps.

- Reversibility

Heat pumps are systems that can always be made reversible, that is, they can produce heat and cold.

- Energy need

To operate, a heat pump needs energy which is in the vast majority of cases electricity which will produce indirect CO_2 emissions if it comes from fossil fuels. The source of electricity can however be renewable (photovoltaic panels or thermal solar panels). Heat pumps running on natural gas also exist, but CO_2 emissions arising from the combustion of gas remain a disadvantage.

- Surface and accessibility

Geothermal heat pumps induce larger installations than aerothermal heat pumps. For a single-family home, horizontal installations require a floor area equivalent to twice the living area. Housing thus needs land large enough to accommodate this type of infrastructure, which is difficult to achieve in densely urbanised districts. Although vertical installations do not require as much space, heavy and imposing machinery is nevertheless required to carry out the boreholes. Once again, it is hardly conceivable that this type of machine would have access to densely urbanised districts. In addition, it would only be possible to have vertical geothermal heat pumps for new constructions, given that it is no longer possible to have access to the ground under the building in the case of a city.

- Environmental / urban planning permit

Depending on the type of heat pump, different permits may be required for this system to be installed. In the context of aerothermal heat pumps, an environmental permit is necessary when the capacity of the heat pump exceeds 10 kW[52,53]. For geothermal heat pumps, an urban planning permit is requested given the necessary boreholes. In addition, a class 1B environmental permit is required. In the case of 'open' systems (i.e. with water withdrawal from groundwater), a catchment authorisation is required.[54]. These open systems also require a hydrogeological feasibility study (e.g. quantifying the productivity of the well, the hydrodynamic parameters of the aquifer, etc.) prior to their installation because they cannot be suitable everywhere. For these reasons, open systems are less suitable for small projects such as for a single family home.

- Costs

Geothermal heat pumps rely on boreholes (+/- EUR 50/m) to place probes at a greater or lesser depth. Given the infrastructure needs that this represents, geothermal heat pumps are expensive systems that are only intended for large projects or buildings. Given the need for electricity, the cost of use is also higher. In addition, the cost of permits and studies to be carried out increases the financial burden. In view of this, it can be difficult to generate profitability from a heat pump.

- Subsidies

In both residential and service sectors, a subsidy (C4) can be granted to Brussels for the installation of a heat pump exclusively intended for the production of heating or which ensures the combined production of heating and domestic hot water. The subsidies are distributed as follows:

- Residential (maximum 50% of the eligible costs of the invoice):
    - Category A[55]: €4 250 / housing unit;
    - Category B: €4 500 / housing unit;
    - Category C: €4 750 / housing unit.
- Commercial: maximum 25% of the eligible costs of the invoice

For the residential sector, a grant for stopping the use of fuel oil or coal is also available (see Section 'technical and economic specificities' of thermal solar panels). It is important to emphasise that reversible heat pumps are excluded from the subsidy for the residential sector.

In the case of the exclusive production of domestic hot water by a heat pump, the C5 subsidy covers a maximum of 50% of the eligible costs of the bill for a residential building. The subsidy amounts are between EUR 1 400 and EUR 1 600 per housing unit depending on the category of applicant. The bonus for stopping the use of fuel oil or coal can also be allocated.

- Noise and aesthetics

Aerothermal heat pumps are noisy systems because of the external fans and this can cause inconvenience, particularly in densely populated areas such as the Brussels-Capital Region. In addition, these systems are visible from the outside and their aesthetics can also cause problems for urban planning rules.

D.3.Replicability in the Brussels Capital Region

- **Residential buildings**

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[52] A priori does not concern individuals.

[53] https://environnement.brussels/thematiques/batiment-et-energie/quest-ce-que-lenergie-verte/produire-votre-propre-energie-verte-2#:~:text=Permis%20d'environnement%20%3A%20Les%20particuliers,ne%20d%C3%A9passe%20pas%2010%20kW.&text=La%20seule%20chose%20%C3%A0%20faire,de%20la%20pompe%20%C3%A0%20chaleur, accessed 22 December 2020.

[54] The Government decree of 8 November 2018 defines the operating conditions for open geothermal systems.

[55] The categories are explained in the 'technical and economic specificities' section of thermal solar panels.

Geothermal heat pumps offer better efficiency than aerothermal heat pumps. They should therefore be given preference if possible given that the environmental constraints (e.g. building possibilities, environmental permits, town planning permits, etc.) associated with the implementation of this type of project are significant. Geothermal heat pumps with vertical sensors are theoretically easier to install in urban areas given the floor space required to install heat pumps with horizontal collectors. However, the difficulties of access to the ground for the machines complicate the deployment of this technology for the residential sector in Brussels. In addition, the heat potential associated with the source depends on the nature of the soil or the water. It is thus not possible to have this kind of infrastructure everywhere and preliminary studies must be conducted on it. In addition, open systems are less suitable for small projects such as for a single family home even though they represent a lower investment for higher energy performance than closed systems. Geothermal heat pumps therefore seem more suitable for service (or industrial) sector buildings than for residential buildings.

Given the difficulty of geothermal heat pumps, aerothermal heat pumps can thus be worthwhile for the residential sector. However, it is important to pay attention to the aesthetic and acoustic inconvenience caused by these heat pumps.

- Service sector buildings

As mentioned above, geothermal heat pumps are more suitable for service sector buildings when environmental, technological and economic constraints can be minimised. A field of vertical probes is generally necessary to equip large buildings. It is therefore necessary to supplement the heat pumps with an auxiliary solution such as a boiler (natural gas) so as not to impoverish the soil by consuming too much heat compared to its regenerative capacity or to provide for the regeneration of the source by *geocooling* (plus possibly an active cooling unit) to guarantee the temperature balance of the ground.

D.4.Assumptions for calculating LCOH

The technical and economic assumptions of these technologies are grouped together in the table below. The ranges of values correspond to the values identified for households (low range) and for the service sector (high range), with the exception of fuel for which it is the reverse. It was decided not to consider an air-to-air heat pump for a service sector building given that it is less likely that this technology will be used for this type of building:

Technology	Sector	Power	Operating hours	Technical lifespan	COP[56]	Investments	Maintenance	Fuel
		kW	h/year	Year		kEUR	EUR/year	EURO/MWh
Air-air HP	Electricity	5	2 500	15	3.5	3 100	200	[167 - 215]
Air-water heat pump	Electricity	[5 - 400]	2 500	15	3.5	[5.8 - 80]	[175 - 6 000]	[167 - 215]
Water-water heat pump	Electricity	[5 - 400]	2 500	20	4	[10.15 - 120]	[138 - 8 000]	[167 - 215]
Ground-water heat pump	Electricity	[5 - 400]	2 500	20	4	[14.5 - 160]	[100 - 8 000]	[167 - 215]

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[56] A maximum COP has been selected to demonstrate the best possible performance achievable with the technology.

Table 32: Technical and economic assumptions for heat pumps

E. Electric heater

E.1. Operations

As they run on electricity still mainly produced in steam cycles with relatively low efficiency (55% for combined cycle gas turbine power plants, 33% for nuclear power plants), electric heaters are, even today, a source of indirect emissions.

There are two types of electric heating: direct and storage. Direct electric heating ensures the production and emission of heat where and when it is needed. Electric storage heating allows the heat produced in an accumulator to be stored during periods when the price per kWh is lower. It should be remembered that this was indeed the objective pursued by the 'peak hours / off-peak hours' or 'exclusive night' day tariffs which were put in place with the development of nuclear power generation.

E.2. Technical and financial specificities

- Efficiency

Electric heaters have a high efficiency between the quantity of electricity withdrawn from the network and the heat returned to the building because there are no local distribution losses and if there are transformation losses they are in the form of heat. Efficiency losses are, on the other hand, significant during the electricity production phase if this is done via 'steam' cycles as in combined cycle gas turbine power plants or nuclear power plants.

- Costs

Electric heaters require a relatively low investment to install although it is higher for storage heating (EnergiePlus, 2020).

Direct electric heating generates a high operating cost because it consumes mainly during the day and is generally activated during peak periods, when the price per kWh is currently the highest. In the case of electric storage heating, the operating cost can be reduced because the heat can be produced in off-peak hours if, at least, the consumers are equipped with dual-hour meters.

From this point of view, it should be noted that these conclusions are valid today, within the existing tariff framework. The situation could change with the development of renewable electricity production and the probable changes in the structure of electricity pricing in the Brussels-Capital Region. Indeed, it is likely that with the development of renewable production (including solar), production will be maximum around midday.

- Environmental impacts

This heating remains dependent on the efficiency of the means of producing electricity. As reported by Energie Plus (2020), the conversion factor is currently around 2.5 (i.e. 2.5 kWh of fuel is needed to produce 1 kWh of electricity) given the Belgian energy mix. However, this mix changes from year to year to include more renewable sources (21.1% of final electricity consumption in 2019 being from renewable sources.[57]) directly transforming solar flux or mechanical wind energy into electrical energy, which will improve the environmental performance of electric heating. Assuming a 2/3 renewable energy mix in 2050, this conversion factor could drop to 0.8, making the use of these systems potentially worthwhile in certain situations (EnergiePlus, 2020).

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[57] (APERe, 2020)

E.3. Replicability in the Brussels Capital Region

- **Residential buildings**

Electric heating does not currently appear to be a relevant solution for housing given its significant environmental impact. The expected change in the energy mix where renewable energies (excluding biomass combustion) would provide electricity production may nevertheless change the trend. However, even if the conversion efficiency at the point of consumption is close to 100%, this type of heating is much less efficient than heat pumps (see below), which can produce around 3 thermal kWh per electric kW consumed. Direct electric heating would remain relevant mainly as a back-up solution or possibly for certain very well insulated buildings whose residual thermal needs will be very low, in addition to a boiler for example, in view of its excellent efficiency and low investment costs and ease of installation.

- **Service sector buildings**

Given the high electricity consumption of this type of heating, it seems hardly credible that large service sector buildings would be heated exclusively by electric heating.

Electric heating only has a low potential in the BCR. We will therefore not investigate this technology further.

E.4. Assumptions for calculating LCOH

The technical and economic assumptions of these technologies are grouped together in the table below. In the context of this exercise, we are only focusing on direct electric heating because it is the most frequently encountered technology. The service sector is not considered because it is unlikely that a building will be heated exclusively by electric heating:

Technology	Sector	Power	Operating hours	Technical lifespan	Efficiency	Investments	Maintenance	Fuel
		kW	h/year	Year	%	EUR	EUR/year	EURO/MWh
Direct electric heating	Electricity	2.5	1 000	15	100	400	3	215

Table 33: Technical and economic assumptions for electric heaters

F. Cogeneration

F.1. Operations

Cogeneration is a technology that ensures the combined production of heat and electricity from a single primary energy source. The aim of this technology is to achieve higher overall energy efficiency than the separate production of thermal and electrical energy and thus to reduce CO_2 emissions.

Cogeneration is defined by European Directive 2012/27/EC[58] which determines that the electricity is considered as being cogenerated on condition that the total annual efficiency achieved is from 75% to 80% depending on the type of installation. This same directive specifies that cogeneration can be

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[58] On energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

considered 'high efficiency' if it allows primary energy savings of at least 10% compared to the separate production of electricity and heat.

Cogeneration can operate according to different technologies, listed according to the order of importance in which the technology is encountered:

- Individual cogeneration by internal combustion engine:

  These engines work on the same principle as the engines that equip cars or trucks. They are powered by a single fuel but which can be from different sources: fossil ones (fuel oil, natural gas) or renewable ones (biogas, biomass). The expected efficiency is of the order of 25 to 42% for electrical energy and 45 to 60% for thermal energy (Bruxelles_Environnement_2, 2020). This technology is particularly suitable for the service sector (e.g. hospitals, administrative centres, etc.).

- Gas turbine:

  In a gas turbine, a mixture of air and pressurised liquid or gaseous fuel is ignited in a combustion chamber. The hot gases expand to drive an alternator that will produce electricity, while the heat from the combustion fumes is recovered in a boiler. These turbines are essentially powered by natural gas and are particularly suitable for large ranges of electrical power (up to 100 MW). The electrical efficiencies of gas turbines are 20 to 25% against thermal efficiencies of 55 to 70% (EnergiePlus, 2020). They can be used in heating networks or in the service sector (e.g. hospitals). Although they are generally less able to adapt to a variable demand for heating, they are nevertheless useful for the production of steam for industrial use.

- Steam turbine:

  Steam is used to power a steam turbine. This steam could either be produced by a boiler (itself potentially supplied by a multitude of fuels) or recovered from an industrial process. They are more widely used by industry because they are particularly suitable for large electrical power installations (10 to 50 MW) (EnergiePlus, 2020).

- Individual cogeneration by fuel cells:

  The fuel cell is based on the conversion of chemical energy from combustion (oxidation-reduction reaction) into electrical energy, heat and water. In the cell, hydrogen is mixed with oxygen to produce the reaction. The residual heat released by the reaction is transferred to a tank through a heat exchanger, and is then used for domestic hot water or to heat the heating circuit. If the hydrogen used is produced in a carbon-free way (renewable or even nuclear), energy production will be neutral in GHG emissions. The efficiency of fuel cells is highly variable depending on the basic constituents of the cell. Thermal efficiencies are around 55% and electrical efficiencies are around 35%[59].

- External combustion engine - Stirling:

  Stirling engines or external combustion engines can be used for domestic micro-cogeneration. The thermal power of such installations, which are equipped with an electric power between 1 kW and 10 kW, generally oscillates between 5 and 25 kW. The efficiency of this type of motor is quite low in terms of electrical production, from 10 to 20%, but better for thermal production, from 80 to 90% (Bruxelles_Environnement_2, 2020). This technology is not very developed, among other things because of development difficulties and high maintenance costs, but it is mentioned as a reminder.

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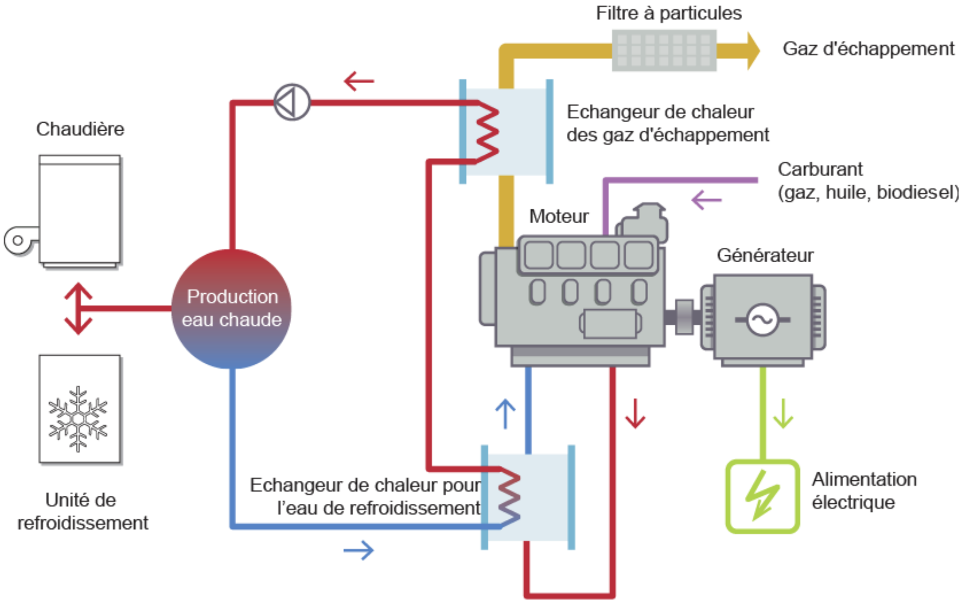
[59] https://cegibat.grdf.fr/reponse-expert/besoin-electrique-logement-choix-pile-a-combustible#:~:text= The following diagram illustrates the, reach 95% on LCV, accessed 22 December 2020.

Cogeneration works according to the following principle: engines and gas turbines drive the movement of an alternator which produces electrical energy. The heat dissipated in the exhaust gases and, if necessary, in the cooling water, is recovered and used. Steam turbines also drive an alternator. In this case, part of the steam produced can be used in the form of heat. Through an exchanger, this heat is extracted and transferred to a hydraulic circuit which ensures the production and distribution of domestic hot water or heating. In the case of the fuel cell, it produces electricity directly via a chemical oxidation-reduction reaction and the residual heat can be recovered by an end user.



	Boiler
	Hot water production
	Cooling unit
	Heat exchanger for cooling water
	Motor
	Exhaust gas heat exchanger
	Particle filter
	Exhaust gas
	Fuel
	(gas, oil, biodiesel)
	Generator
	Power supply

Figure 18: operation of a cogeneration installation with an internal combustion engine

F.2. Technical and financial specificities

- Emissions

Compared to the separate production of electricity and heat, cogeneration installations have the advantage of reducing primary energy consumption. If the cogeneration is supplied with biomass from renewable production, the cogeneration can also be considered as renewable. This also applies for trigeneration units.

- Efficiency

Cogeneration has good overall efficiency, around 85% for engines and gas turbines.

- Storing

If cogeneration is supplemented by heat storage capacities, this makes it possible to compensate for periods of low demand for heating and therefore to avoid cutting off the cogeneration or operating it at low power. In addition, the number of operating hours of the cogeneration can increase, which has a positive impact on its profitability.

- Costs

Cogeneration systems involve a significant investment cost. This changes depending on the fuel used, the technology and also the installed power. Motor cogeneration is more expensive compared to a conventional boiler. According to ADEME, it takes between EUR 6 600 and 10 000 / kWe of investment for installations in 215 and 1 150 kWe (ADEME, 2020) It takes EUR 10 000 for the biogas cogeneration. Motor-driven cogeneration plants also have significant maintenance costs. According to the same characteristics mentioned above, ADEME (2020) estimates these costs between EUR 89 and 196 / MWhe. As cogeneration via turbines is more focused on industry or large buildings, cogeneration projects will have a high cost.

To improve the profitability of projects, the cogeneration must be dimensioned in such a way as to maximise the self-consumption of electricity. Reinjection into the non-self-consumed electricity network is in fact done at very low rates.

Cogeneration installations can benefit from subsidies[60] and the sale of green certificates in the BCR, which contributes to better economic profitability.

- Limited lifespan

Internal combustion engines have only a limited lifespan estimated between 50 000 and 60 000 hours of operation. In general, it is estimated that to be profitable a cogeneration must be able to operate for a minimum of 3 500 hours per year.

- Back-up solution

In the Brussels-Capital Region, cogeneration systems are dimensioned primarily for the demand for heating but they cannot, at the risk of being oversized, cover all the thermal needs of the building where they are installed. It is therefore necessary to install a back-up boiler which will be able to cover the peaks in thermal power demand (mainly in winter).

- Environmental permits

It is a priori not necessary to apply for a permit for installations below 5 kWe. However, installations intended for collective housing, or the service or industrial sector and installations with nominal absorbed power greater than or equal to 20 kW will need an environmental permit[61] (Bruxelles_Environnement_2, 2020).

- Noise

Cogeneration, particularly by combustion engine, generates a lot of noise which can prove to be a nuisance in a dense urban environment such as the Brussels-Capital Region and which requires, in any case, investment in acoustic insulation.

F.3. Replicability in the Brussels Capital Region

In the Brussels-Capital Region, cogeneration projects have increased considerably in recent years. In 2020, Brugel lists 243 active cogenerations in the region, all with internal combustion except one steam turbine[62]. Of these units, 235 (96.7%) run on natural gas, 7 (2.9%) on rapeseed oil and 1 (0.4%)

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[60] Subsidy A1 (Energy audit) covering the feasibility study necessary for the installation of a cogeneration system.

[61] https://environnement.brussels/thematiques/batiment-et-energie/energie-verte/produire-votre-propre-energie-verte/cogeneration, accessed 22 December 2020.

[62] https://www.brugel.brussels/documents/statistics/rechercher, accessed 28 December 2020.

by waste incineration. All of these units have a nominal electrical power of 90 MW against a thermal power of 54 MW. 41 MWel if only conventional cogenerations are considered, excluding incinerators.

- Residential buildings

At the individual level, cogeneration is not a credible solution because of its costs and its technical complexity. However, cogeneration is relevant for collective projects for the production of heat and electricity. From a residential point of view, apartment buildings with a large number of households, which create a significant and stable demand for heat, constitute a target audience for cogeneration. By connecting several buildings via a heating network, the potential of cogeneration would be all the more worthwhile because the unit could operate more optimally thanks to an increase in demand for heating and to the stabilisation of the demand profile of heat. The urban density of the BCR can facilitate the implementation of this type of project.

- Service sector buildings

The increase in projects and the type of possible installations confirm the benefit of cogeneration in the Brussels context. Large service sector buildings with high and relatively stable demand for heating, such as hospitals, nursing and care homes or swimming pools, are particularly relevant for this technology.

F.4. Assumptions for calculating LCOH

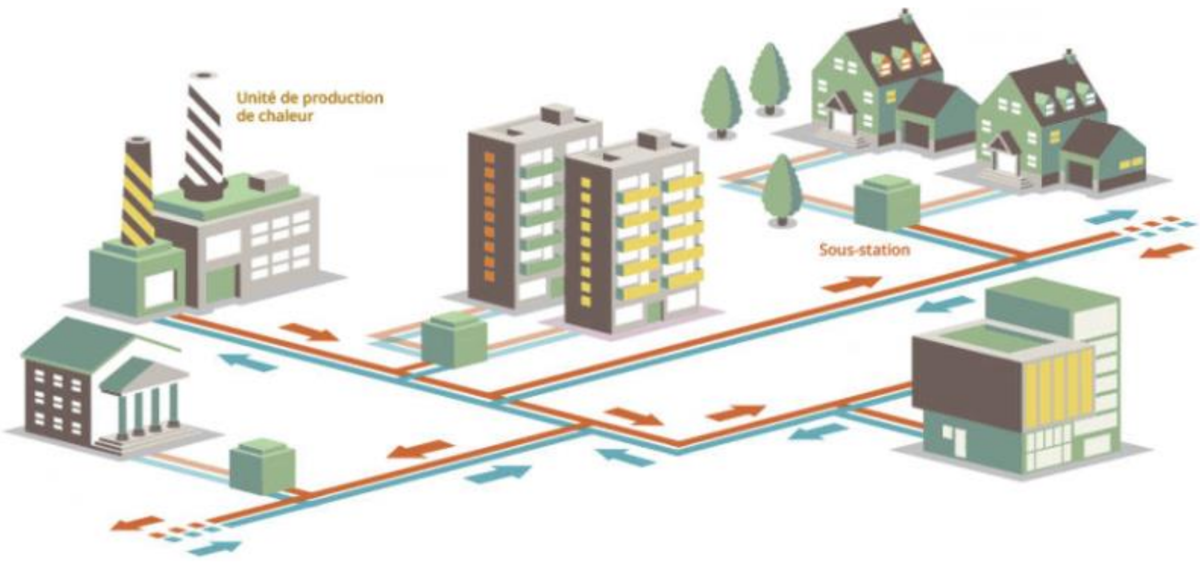
The assumptions made for this technology can be found in the following section where cogeneration is the subject of an in-depth technical and economic analysis.

6.1.2. Heat production technologies - Collective solutions

A. District heating

A.1. Operations

Collective heat production technologies bring together district heating networks. Also called ‘district heating systems’, they function as a central heating system on a district or city scale. From one (or more) production unit(s), the heat is transported, through an underground pipe network (primary network), by a heat transfer fluid (generally liquid water but it can be water vapour) to sub-stations that ensure distribution to places of consumption. Heat exchangers (in substations) capture heat from the primary network to transfer it to the secondary network (e.g. home) which ensure distribution to final emitters (e.g. radiators). The buildings of a district or a city are thus supplied, in the form of water or steam, with heating, domestic hot water or for other specific uses (e.g. industrial processes, swimming pool heating, etc.). Once the heat transfer fluid is cooled after having transferred its heat to the exchangers, it is re-routed to the production unit in order to be heated again.



	Heat production unit
	Substation

Figure 19: How a heating network works (ADEME, Les réseaux de chaleur, 2020)

Heating networks make it possible to develop different energy sources thanks to different technologies that can be combined on the same network:

- From 'classic' **boilers** powered by different fuels**:**

  Information relating to the boilers can be found in Section 6.1.1.A. These remain relevant insofar as the application of individual solutions to heating networks can be envisaged by adapting their size and dimensioning to meet the needs of networks rather than a home.

- From **cogeneration** powered by different fuels:

  See Section 6.1.1.F.

- **Riothermy** (sewer heat):

  Riothermy consists of extracting residual heat or cold from sewage water to heat or cool buildings. The water discharged by homes is at a relatively constant temperature (between 10 ° and 14 ° C) throughout the year. By placing an exchanger in the drainage network, the thermal energy contained in the water is extracted before its temperature is raised via a heat pump to the required level.

  However, caution is required in order to avoid extracting too much heat from this water, otherwise the purification process will be weakened. As a large and fairly constant flow is needed, the zone potentially supplied by riothermal energy will be quite small in the Brussels region. In addition, the fouling of exchangers by sewage can also be a problem.

  The technology patented by Vivaqua is currently in its infancy. Besides a pilot project in Molenbeek, only one municipal administration building in Uccle is in the process of being equipped with this system. Although it may be beneficial in the BCR, there are currently numerous uncertainties as to its real potential, given the technical constraints and the sparse information available about its profitability. Although it might become useful in the future, the speed of deployment does not seem very fast in the long run.

- **Waste heat recovery**:
  - ***Industrial processes***: Waste heat recovery, which is mainly used in industry, consists of recovering the excess heat produced by various industrial processes after optimising them. Waste heat recovery can thus be used when a furnace produces substantial

excess heat, as in the case of an incinerator. This waste heat can be recovered in two ways: by internal or external recovery. In internal recovery, the company's own needs (beyond the needs of the industrial process itself) are covered thanks to the recovery of waste heat. In particular, this concerns the heating of company buildings while for external recovery, other companies or a territory (composed of residential and service sector buildings) can benefit from the heat recovered via a heating network through a thermal exchange. In some cases, heat pumps can be installed at end users to raise the temperature of the coolant.

The heat recovered from industrial processes can be used to supply the heat needs of buildings by transferring it to the network via a heat exchanger. Several limits exist to this type of network: firstly, the distance between the area of demand for heating and production is potentially high given that industries are generally located far from urban centres. Secondly, the amount of heat recovered is not necessarily in line with the needs requested. A back-up boiler may be necessary to fill this gap. Thirdly, the network implies a long-term commitment whereas it is not guaranteed that the production of heat will be ensured over the same time interval. In the particular case of the Brussels-Capital Region, which has a relatively sparse industrial sector, this solution is mentioned for informational purposes.

  - ***Waste incineration:*** in Europe, 10% of district heating networks are supplied by installations for the recovery of energy from household waste. With a quantity of household waste estimated at 500 000 tonnes per year, a real energy potential exists in the Brussels-Capital Region. (Bruxelles Environnement, 2016). In Brussels, excess heat is recovered by the waste incinerator in the Neder-Over-Heembeek unit. In particular, it supplies energy to the Docks Brussel shopping centre. However, the phasing out of the incinerator (Gouvernement bruxellois, 2019) will prevent the long-term development of a more extensive heating network around this industrial installation.

- **Renewable energy sources**:
  - **Solar heating**: Solar heating is being tested to supply low-temperature networks that store thermal energy collected in summer in gigantic underground reservoirs. These installations cannot cover all the thermal needs of consumers connected to the network. They must therefore be supplemented by additional centralised back-up boilers (or cogeneration). Likewise, due to the low temperatures of the water circulating in the network, a temperature increase via heat pumps may be necessary for each individual consumer. For example, the Vojens project in Denmark illustrates the potential of this type of installation[63]. The installation, which is equipped with 70 000 m² of sensors and an underground thermal storage capacity of 200 000 m³, produces 28 000 MWh annually for a peak power of 49 MW. The installation provides almost half of the annual heat needs of the network, the rest being provided by three gas engines, a 10 MW electric boiler and several gas boilers as well as a heat pump.
  - ***Geothermal***: at high temperature of the water or the water vapour that is transported, the heat distribution can be direct (as in the case of the Saint Ghislain installation near Mons). A decentralised heat pump system can also be installed in homes if the network operates at too low a temperature.

While the use of renewable or recovered resources is preferred, heating networks running on natural gas remain a credible alternative. However, this option would be called into question if the ban on the installation of cooking, heating and domestic hot water production appliances from natural gas or

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[63] http://arcon-sunmark.com/cases/vojens-district-heating, accessed 1 February 2021.

butane/propane from 2030, currently being studied by the Brussels authorities also extended to collective installations.

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At present, the emergence of 4th generation district heating networks offers new perspectives. These operate at lower temperature ranges (45 ° to 55 ° C), which allows the integration of renewable energy sources such as geothermal energy and waste heat recovery. These networks improve the energy efficiency of the system thanks to the low temperatures which reduce heat loss and therefore energy consumption. Low energy density districts and energy efficient buildings are particularly well suited (even essential) to these networks. In addition, this type of network offers more flexibility in the context of a ‘thermal smart grid’ thanks to heat storage (i.e. underground storage of hot water over a long period in reservoirs, boreholes or aquifers) which makes it possible to reduce the intermittency constraint of renewable energies. Finally, they pave the way for the simultaneous production of cold on the same network as detailed in Section 6.1.5.A. It may therefore be beneficial for the Brussels region depending on the needs and the types of buildings concerned.

A.2. Technical and financial specificities

- Economies of scale

The establishment of a network makes it possible to reduce the consumption of resources but can pose a problem in a densely populated region whose underground is crisscrossed in all directions with cables and pipes of all kinds.

- Control of nuisances

Nuisances (e.g. air quality, noise) are better controlled thanks to centralised operations in the heating system but also by the application of stricter standards on production units due to their size.

- Energy efficiency

The production unit has an industrial size and its energy efficiency can be continuously improved because the heating system is managed and maintained by professionals. On the other hand, these advantages can be lost, at least in part, because of the inevitable thermal losses of the network. It must also be maintained on a regular basis to avoid an increase in these thermal losses.

- Ease of switching

The energy source used to supply the network can be easily changed without having to operate in the buildings (e.g. to replace boilers).

- Diversity of sources

Many sources of energy can be used. Among these, renewable sources that are difficult to exploit at the household level, such as deep geothermal energy or waste heat recovery, can be used to supply households. Balance between heat requirements and waste heat recovery.

- Emissions

Provided that renewable energies are used, GHG emissions linked to energy production can be low or zero. For example, reuse of wastewater does not result in direct GHG emissions. Only the energy necessary for the operation of the heat pump can have an environmental impact.

- Energy density

The heating network can only be present in densely urbanised areas. The investment costs linked to the construction of the network, namely the heating system and the distribution circuit, are high. The quantity of energy supplied per km must therefore be sufficient for the network to be economically viable. This therefore represents the quantity of energy consumed (in MWh) by users per metre of network over a year. ADEME has set a threshold of 1.5 MWh/metre.year to authorise the allocation of aid from the Heat Fund for the creation or extension of district heating networks (ADEME, 2019). Based on the figures proposed by a study by Capgemini Consulting in 2010 carried out on behalf of the Public Service of Wallonia, PwC estimates this threshold at 2 MWh/metre. (PWC, 2015). For the BCR, these density thresholds are achievable insofar as the region has a dense and continuous urban environment (see Section 7)

- Investment

The initial cost of a heating network is significant in particular because of the construction of the heating system and an underground pipe network to convey the heat (or cold). This significant investment represents uncertainty about the profitability of the network regardless of how it is supplied.

- Time frame

This type of project can take a long time to see the light of day, given the feasibility and sizing studies that are necessary before its implementation and which typically take a long time. In addition, a network is built for the long term, which implies a long-term commitment.

- Stakeholders

This type of system requires the involvement of a large number of players, which can tend to complicate the decision-making process and the setting up of the project.

- Future energy renovation

The buildings in the network will certainly have to undergo energy renovation to improve their insulation. This will lower the thermal needs of the renovated buildings and may jeopardise the profitability of the networks in the long term.

A.3. Replicability in the Brussels Capital Region

- **Residential buildings**

Heating networks are a credible solution in the future for the Brussels-Capital Region. While it is obvious that the project will have to accommodate many of the constraints mentioned above to suit an urban context (e.g. energy density, construction of infrastructure, investments, etc.), these are high-potential systems. For residential buildings to benefit, it will be necessary to form networks encompassing several buildings in order to guarantee energy density. Heating networks will be all the more efficient if they use production units based on renewable energies and if they are capable of ensuring the production of cold as well (see Section 6.1.4.A and 6.1.5.A).

- **Service sector buildings**

The emergence of various district heating network projects in the BCR suggests that this is a promising technology that is particularly suitable for service sector buildings. Several projects today cover the needs of hospitals and university sites (ULB Solbosch, ULB & VUB Plaine, UCL Saint-Luc, Hôpital Brugmann site Horta, AZ-VUB Laarbeek), districts (Bervoets à Forest), a shopping centre (Docks) and soon the Royal Domain of Laeken.

A.4. Assumptions for calculating LCOH

The LCOH calculation presented in the next section is based on individual solutions only. Nevertheless, Section 7 studies the technical and economic potential of heating networks supplied by cogeneration according to different types of districts. The main assumptions related to these types of heating networks can be found in Section 7.

6.1.3. Cooling technologies - Individual solutions

Two building needs must be distinguished:

- Ventilation, or rather hygienic ventilation, is a means of ensuring respiratory comfort by injecting external air into the building to dilute pollutants and particularly CO_2 and VOCs[64];
- Cooling is, as its name suggests, a technique for lowering the temperature of a building or a room.

The cooling of a building is often provided by the external air directly or indirectly. The cooling air flows are, in most cases, much greater than the hygienic ventilation flows. When these two flow rates are close like in clean rooms or operating theatres, they are combined using the same equipment.

Natural cooling

A. Natural cooling (including *free cooling*)

A.1.Operations

There are several possible techniques for the natural cooling of buildings, which are differentiated according to the (in)direct use of outdoor air and the ventilation method (natural or mechanical). We identify three techniques that we present below:

1. Natural direct cooling (*free cooling)*
2. Mechanical direct cooling
3. Natural indirect cooling

Natural direct cooling (*free cooling*)

Free cooling is a natural cooling technique (unlike an active technique such as air conditioning) which aims to cool a building by making use of free outside air. It is based on intensive natural ventilation made possible by the use of an elaborate system of transverse free cooling, one-sided free cooling as well as chimney effect, etc. It is therefore organised to facilitate air flows, which makes it more complex to implement in the case of renovations. Natural ventilation involves air circulating naturally in a building because of the differences in pressure and density of the air between two facades. Natural ventilation therefore does not rely on any fans and therefore there is no electricity consumption. Although it is indispensable, it is however difficult to control and the quality of the air is not guaranteed everywhere. Natural cooling by intensive ventilation is often different from hygienic ventilation because the air flows are greater. For example, type C hygienic ventilation uses an air inlet grille in the window frames and extraction in the sanitary facilities with a mechanical extractor.

Figure 20: Transversal natural free cooling

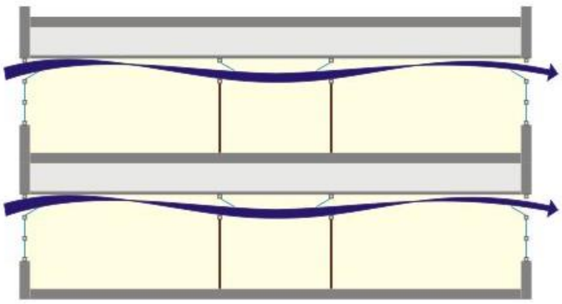
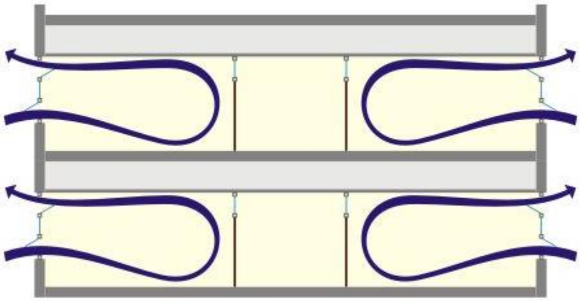


Figure 21: Unilateral natural free cooling



Source: CSTC

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[64] Volatile organic compound

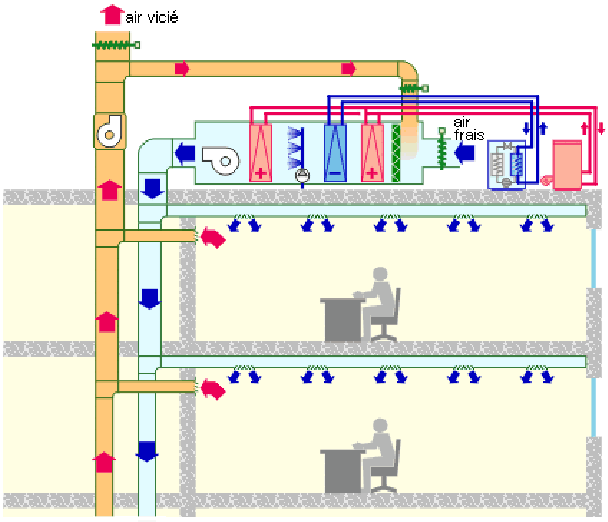
The principle of natural direct cooling involves using it when the temperature outside the building is lower than the inside temperature. Daytime *free cooling* cools the indoor air of the building by ventilating cooler outdoor air during the day. At night, nocturnal *free cooling* consists of renewing the indoor air of a building with cooler outdoor air, and thus discharging the heat accumulated during the day.

Another technique of *free cooling* for air consists of taking external air and passing it through a buried duct. This is referred to as a ‘Provençal’ well. Indeed, the temperature of the earth remains relatively constant around 10 ° C. The ‘Provencal’ well is in fact a ‘Canadian’ well used in summer to cool the air.

One last technique of *free cooling*, but with water, is the use of geothermal energy in mid-season (when the needs are less) without using the associated refrigeration machine and this, by simply circulating the cooling water in the ground. This is referred to as natural *geo-cooling*. This technique is only used if a geothermal system operates in winter to heat the building via a reversible geothermal heat pump (HP). Indeed, in winter, the heat pump draws heat from the ground to heat the building and, consequently, cools the ground by constituting a reserve of cold which can be used in summer. Conversely, in summer, the cold is pumped from the ground by the heat pump in reversible mode to cool the building resulting in the reconstitution of a heat reserve for the following winter. This technique makes it possible to perpetuate geothermal energy /*geo-cooling* in the long term for large service sector buildings which must maintain a balance between cold and heat needs so as not to impoverish the soil. It should be noted that to be considered a ‘passive’ standard, a service or industrial sector building must have a net cooling requirement less than or equal to 15 kWh/(m^2.year); the same applies for heating[65].

Mechanical direct cooling

Direct mechanical air cooling is carried out through an air handling unit. The unit treats (cooling, humidifying, heating, etc.) the air before sending it to the building and its premises through a network of ducts. This type of cooling is considered to be mechanical *free cooling* as long as it does not require a cooling coil supplied by a chiller, for example. At night, the air handling unit can operate on its own to cool the building. Ventilation is said to be mechanical because it consists in bringing (by supplying) fresh air and/or extracting stale air via a fan requiring electricity.



	Stale air

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[65] https://www.guidebatimentdurable.brussels/fr/batiment-passif.html?IDC=1521&IDD=23407, accessed 18 January 2021.

Figure 22: Mechanical direct cooling (Energie Plus)

Natural indirect cooling

Indirect mechanical natural cooling by air makes use of the external air to cool the internal environment via a more water-based system (*slab cooling*, *free chilling* by air cooler or a cooling tower on chilled water without the use of a group of cold production system such as a cooling unit or trigeneration, etc.). For example, the *slab cooling* (illustrated below) consists of the laying of a slab containing a pipe with cold water circulating in it. The water in the slab is cooled by the outside air through an exchanger placed on the roof or a cooling tower.

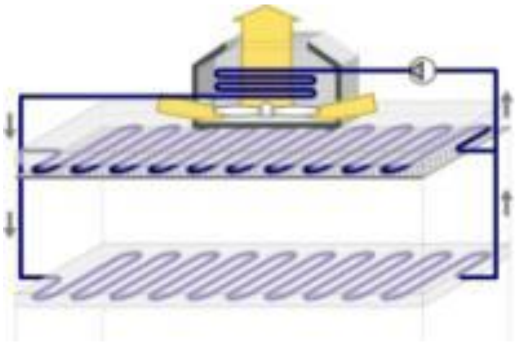

Figure 23: Natural indirect cooling - slab cooling

A.2. Technical and financial specificities

- **Limited cooling power**

Free-cooling cannot always replace active cooling mechanisms - particularly in service and industrial sector buildings - because it is not powerful enough. Its effectiveness will depend on the characteristics of the buildings where it is located and the season. Indeed, free-cooling for air and water can be very effective in mid-season and especially in winter if cooling is needed.

- **Adapted building design**

In the case of direct mechanical free-cooling, few renovations are to be expected because it only requires ventilation ducts (PWC, 2015). The situation is more complex for natural or hybrid free-cooling or even night-cooling because they require an adapted design of the building (thermal inertia, internal air transfers to the building, etc.) or a thorough renovation of buildings in the service and industrial sectors. A potential analysis for each building must therefore be carried out upstream. This is because work such as the installation of adequate air ducts, the construction of ventilation stacks, etc., is required. This involves significant costs for relatively limited efficiency.

Geo-cooling can only be conceived from a financial point of view in the context of geothermal energy.

- **Energy consumption**

Free-cooling manages to make use of the free cold air coming from the ground and from the air. It therefore saves energy although the transport of cold still has a certain energy cost. Free-cooling is worthwhile when it complements active cooling systems. For example, Energie Plus illustrates that a 3 000 m² building equipped with an air conditioning system reduced its energy consumption by 21% to 44% (depending on the level of thermal inertia of the building) thanks to the nocturnal free-cooling with automatic opening[66]. However, this example should be taken with caution because many

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[66] https://energieplus-lesite.be/ameliorer/climatisation/limiter-les-besoins/organiser-le-rafraichissement-par-free-cooling/, accessed 23 December 2020.

parameters come into play to determine the achievable gain: building structure, ventilation mode, size of openings, outside temperature, etc.

In the event that free-cooling is based on intensive mechanical ventilation, the electrical consumption is potentially considerable (PWC, 2015). While this mechanism can reduce the energy consumption of active solutions, it is a rebound effect that must be taken into account.

In all cases, the installation of a free-cooling system must be the subject of a potential analysis and be part of a strategy for reducing cooling needs that have been previously established.

- Passive buildings

Due to their excellent thermal insulation, passive buildings are sensitive to overheating. It is essential to be able to supply them with cold in order to discharge this heat from them. As the cooling season is lengthened in passive buildings, the cooling needs are felt quite early and therefore at times when the outside air is sufficiently cold. Given the passive design of the building, free-cooling is particularly appropriate.

In this respect, controlled mechanical ventilation offers the possibility of installing by-passes which no longer make it possible to preheat the incoming air in summer. The air therefore no longer passes through an exchanger - it is no longer heated by the hot stale air extracted from the building - and is sent directly into the building, which can take advantage of the coolness at night. In this way, the hygienic ventilation can provide a limited cooling function.

- Air quality and noise pollution

When the system is mechanical, it can generate significant noises which represent an inconvenience. This is especially important in an urban setting such as the BCR. Conversely, noise pollution can also come from outside through the cooling system. In a highly regulated area where high demands are made, preference must be given to mechanical ventilation using silencers.

- Nocturnal potential for air

Free-cooling is a function of the outside temperatures which must be low enough for the cooling to be efficient. This is why it may be less efficient in mid-season or during the day during the summer. In a context of warming average temperatures, the optimal cooling windows will potentially be smaller in the future. Night therefore offers greater potential.

Bruxelles Environnement illustrates this with the following example[67]: for a room in a service sector building heated to 26 ° C with a thermal load of 60 W/m² and an outside temperature of 20 ° C. The air should be renewed 10 times per hour, which leads to technical and comfort-related issues. With mechanical ventilation, the power consumption of the fans would be multiplied by 2.5. On the other hand, if the outside temperature is only 16 ° C, an air renewal would be necessary 6 times per hour. The potential is therefore greater at night.

- Seasonal potential with water

Natural *geo-cooling* is a function of the soil temperature depending on the season. The ‘height’ of the cold storage that has been created in winter will determine the availability of power and energy for cooling in summer.

- Subsidies

Controlled mechanical ventilation has been the subject of subsidies (B5) in the BCR for buildings of at least 10 years for both residential and service sectors. The subsidies are set as follows[68]:

- Residential (maximum 50% of the eligible costs of the invoice):
    - Centralised system with heat recovery and regulation (supply and extraction):

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[67] https://www.guidebatimentdurable.brussels/fr/applicabilite.html?IDC=7806, accessed 24 December 2020.

[68] https://environnement.brussels/sites/default/files/primes-premies/GIDS_B5_FR_2021.pdf, accessed 3 February 2020.

        - Category A[69]: EUR 2 500 / housing unit
        - Category B: EUR 3 000 / housing unit
        - Category C: EUR 3 500 / housing unit
    - Centralised system on demand with regulation (extraction only):
        - Category A: EUR 1 250 / housing unit
        - Category B: EUR 1 500 / housing unit
        - Category C: EUR 1 750 / housing unit
- Service: maximum 25% of the eligible costs of the invoice for a centralised system with heat recovery and regulation (supply and extraction) with an exchanger efficiency of at least 80%.

If the work carried out under the subsidy is combined with at least two other subsidies of a different type, a bonus for carrying out more than one kind of work may be granted. The subsidy is thus increased by 10% for applicants in category A and B, and by 20% for applicants in category C.

A.3. Replicability in the Brussels Capital Region

With 10% of the power consumption of the BCR being dedicated to cooling (Bruxelles_Environnement_3, 2020), the use of passive techniques is advisable. In cases where free-cooling is not sufficient, it is still useful to use it in addition to active techniques to reduce the energy consumption of the latter.

- Residential buildings

In the BCR, the PEB specifies that the temperature can only exceed 25 ° C inside a building for a maximum of 5% of a year[70], which corresponds to a maximum superheat index of 6 500 kWh. Insofar as it makes it possible to achieve this objective for new constructions, free-cooling should be considered. For renovation projects, it is generally necessary to install air and transfer ducts. This is not difficult.

In addition to other measures such as roof insulation, natural free-cooling may be sufficient to ensure cooling of residential buildings. Its ease of implementation is also an additional advantage to its use. Night-cooling will however be given preference due to its greater efficiency. It is nevertheless important to specify that the priority is above all to combat sunlight, which constitutes the main overheating factors of low-energy or even passive type buildings, by ad hoc protections (e.g. awnings, shutters, shutters, etc. etc.) and openings (e.g. to the north where there is no direct sunlight) in the building.

Natural *geo-cooling* like the Provençal well or that intrinsic to geothermal energy if the heat pump is reversible, is relatively limited in the BCR, given that space and easy access to the ground are required. In the case of residential buildings, if the building is well insulated, the heat pump can work at low temperatures. The ground is therefore not depleted; natural sunlight is sufficient to regenerate the ground.

- Service sector buildings

In the context of small service sector buildings, the same observation as for residential buildings can be drawn. For large service sector buildings, a comprehensive consideration of the natural cooling strategy is required. The building must in fact be designed specifically (e.g. building depth, wind orientation, etc.) to ensure optimal free-cooling operation. For example, mechanical free-cooling requires high air flow rates and therefore large air ducts which are not always possible to integrate

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[69] The categories are explained in the 'technical and economic specificities' section of thermal solar panels.

[70] https://www.guidebatimentdurable.brussels/fr/vademecum2017-2-exigence-surchauffemax.html?IDC=10875, accessed 24 December.

into renovation projects.

If the building is located in an area with poor air quality or significant noise pollution, it will be worthwhile considering mechanical ventilation.

As with residential buildings, accessibility to the ground for *geo-cooling* in an urban environment is relatively limited for service sector buildings which require large natural or active cooling capacities and, consequently, large floor areas. However, when this technology is used, it is essential to balance the needs for cold and heat so as not to deplete the ground and to ensure the sustainability of the geothermal installation.

A.4. Assumptions for calculating LCOH

Cooling technologies are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions.

Active cooling (air conditioning)

B. Compression refrigeration machine and *free-chilling*

B.1. Operations

As a cooling mechanism, the refrigeration machine removes excess heat from the building (cold source) to the outside environment (hot source). This technology is based on a closed refrigeration circuit containing a refrigerant. The refrigeration cycle is ensured by a classic four-step process: compression, condensation, expansion, evaporation.

Machines or refrigeration units are distinguished by the energy source they use: air, water or the ground.

Refrigeration unit - air

Classic refrigeration unit rejecting the heat from the condenser into the outside air. The use of outside air results in limited efficiency with an EER potentially reaching an *energy efficiency ratio* of 3 (PWC, 2015). Nevertheless, it is easily installed on the majority of buildings.

Refrigeration unit - ground

Also referred to as active *geocooling*, this technology is based on the transfer of excess heat into the ground by geothermal storage (in groundwater) for example. Since the soil temperature is generally lower than that of the air, the ground performs better. In this case, the EER oscillates between 4 and 5 (PWC, 2015).

Refrigeration unit - water

This time, the excess heat will be transferred to surface water like a lake. As water generally has a lower temperature than air, it performs better.

The air and water refrigeration units can be coupled with the *free-chilling*, which consists of cooling the chilled water in the refrigeration installation by ‘contact’ with the outside air (via a cooling tower or a dry cooler) when the air temperature is sufficiently low (from 8 or 10 ° C). This mechanism makes it possible to shut down the refrigeration unit when these temperatures are reached. The higher the cooling needs in winter are, the more potential this technology has.

B.2. Technical and financial specificities

Depending on the energy source used, several technical constraints can be identified.

- **Refrigeration units using air**

Refrigeration units using air as an energy source (often referred to as 'chillers') provide lower efficiency than other variants of this technology. They require room on the roof to place a condenser and are prone to the problem where the chilled water freezes in the cooling tower.

- **Refrigeration units using the ground**

For refrigeration units using the ground, space is also an issue given that vertical boreholes in the ground are required. These boreholes are also expensive, drive up the investment cost of the technology and are complex to carry out in urban areas (e.g. density, presence of obstacles, environmental and urban planning permits). In order not to disturb the thermal balance of the basement, this type of installation nevertheless requires a balance between the heat input into the ground and the heat absorbed over a period of five years.

- **Refrigeration units using water**

Finally, refrigeration units using water are limited in terms of the distance between the building and the water source. Substantial financial costs are to be expected to build the transport facilities to the water source (e.g. pipes, pumps, etc.).

- ***Free-chilling***

For an installation to be suitable for *free-chilling*, it has to work in winter. In addition, the presence of 'high' temperature terminals (e.g. cold ceilings, oversized fan coils, etc.) will make it more worthwhile (Energie Plus, 2020). It will be easier to adapt an installation to the *free-chilling* if it is already equipped with a water condenser because the cooling tower can be used to cool the chilled water with the outside air. As mentioned for solutions using air, *free-chilling* is prone to freezing problems. One solution is to add glycol, but the latter is expensive and reduces the efficiency of the refrigeration exchange. In addition, various technical constraints may appear when it is necessary to adapt the installations to *free-chilling:* loss of power of a fan-coil exchanger having to go from a 7 ° C / 12 ° C to 12 ° C / 15 ° C regime, a 300 kW tower weighs between 3 and 4T against 9 to 12T for 1 000 kW, etc. (Energie Plus, 2020)

B.3. Replicability in the Brussels Capital Region

- **Residential buildings**

As the refrigeration units making use of water and the ground are not solutions available for capacities lower than 35 kW, it is not possible to consider them for residential buildings other than apartment buildings. (Bruxelles_Environnement_4, 2020). Even if there are solutions using air with a lower capacity such as 3 kW, their lower efficiency make them less attractive solutions.

- **Service sector buildings**

Both the service and industrial sectors could be equipped with refrigeration units using air as a source. Ideally, *free-chilling* should be expected to improve efficiency. Indeed, it suffices to have the space on the surface to place a condenser there. With the geothermal potential and access to the water source being more difficult in the BCR, the other solutions remain a potential alternative but are more complex to set up.

B.4. Assumptions for calculating LCOH

Cooling technologies are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions.

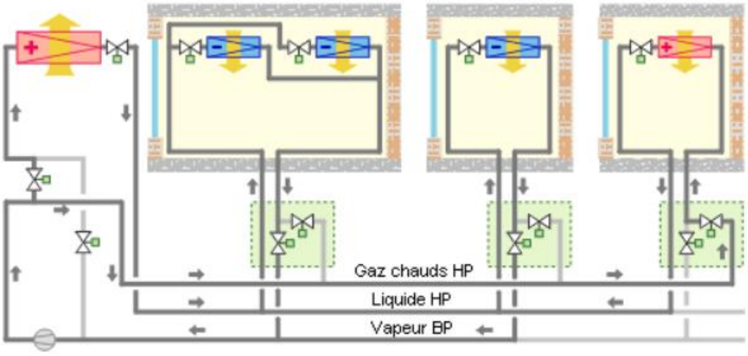
C. Variable refrigerant flow (VRF) system and water loop energy recovery

C.1. Operations

Energy recovery from a water loop can be carried out through several technologies. However, these systems all operate on the same principles as heat pumps.

VRF system

The VRF system (*Variable Refrigerant Flow)* - also referred to as 'VRV' (*Variable Refrigerant Volume*) operates on the principle of a direct expansion air-to-air heat pump. A network of tubes in which a refrigerant circulates connects internal units and an external unit. The indoor units are composed of an evaporator and an electronic expansion valve while the outdoor unit is commonly referred to as a 'condenser group' and is composed of a condenser and a compressor. In this configuration, both the condenser group and the internal units are reversible. The internal units are installed in the rooms to be air-conditioned, while the external unit acts as an 'exchanger' with the outside environment by discharging the excess heat or refrigeration contained in the refrigerant.



	HP hot gases
	HP liquid
	LP steam

Figure 24: Operating principle of the VRF system in bulk cooling (Energie Plus)

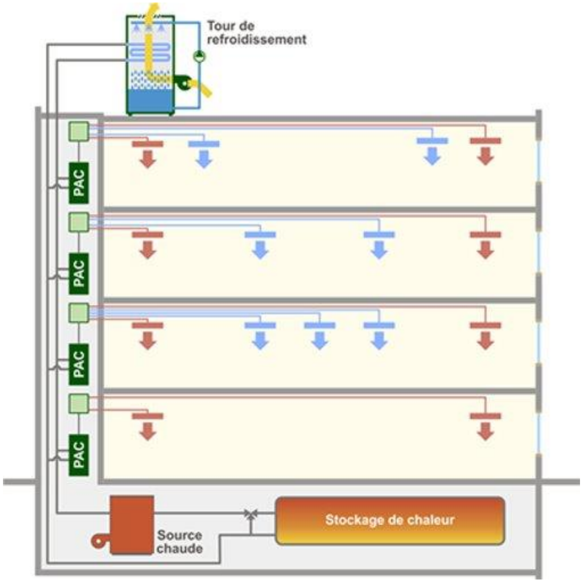
This system is useful insofar as it can be reversible thanks to a cycle reversal valve placed at each room; these can be fitted with one or more internal units. For a computer room in need of cooling, the internal unit operates as an evaporator. Conversely, for a room requiring heating, the indoor unit works as a condenser. As far as the external unit is concerned, it can operate as an evaporator as well as a condenser, depending on whether the air-conditioned premises require heat discharge (predominantly data centres) or 'external heat pumping' (office type premises in winter). The great advantage of this 3-pipe system is that it can directly transfer heat/cooling from an area with a need for cooling/heating to another area with a need for heating/cooling, without going through the external unit. This is the case when the cooling needs are the same as the heating needs.

Energy recovery from the water loop

This system works on the same principle as the VRF with the difference that the outdoor unit exchanging via air becomes an indoor unit hydraulically connected to a temperature-controlled water loop (or temperature-controlled water heating network for large complexes). A large number of units can be connected to the water loop. Just like the VRF, each of these units, on the secondary side, can be connected to a group of units which, in this case, are referred to as terminal units or 'subunits'.

This system allows a dual recovery of heat/cooling:

- Between sub-units or terminal units such as a conventional 3-pipe VRF (see above);
- Between indoor units via the water loop.



	Cooling tower
	HP
	Heat source
	Heat storage

Figure 25: Operating principle of energy recovery on a water loop

In the winter season, the system operates as a heat pump whose 'cold' source (heated by a boiler placed in series on the water loop) is the water circuit. In summer, the system operates as a refrigeration machine with cooling of the condenser by the water loop, itself cooled by a cooling tower placed on the roof. This system is particularly effective in mid-season when heat transfers can be carried out, thanks to this loop, between rooms with simultaneous cold and heat needs.

If the temperature-controlled water loop is interfaced with geothermal energy, it will be necessary to ensure that the annual heating and cooling needs are balanced to heat the ground in the summer period and cool it in the wintertime period. If this is not the case, production of heat or cold will be necessary for the balancing.

C.2. Technical and financial specificities

This section details in particular the constraints related to the VRF system given that explanations have already been provided for the air-to-water and ground-to-water heat pump type systems in their respective sections.

- Flexible system

The VRF system offers the possibility of easily adapting to cooling and/or heating demands as needed. By means of its reversibility or via energy recovery, the system can effectively switch quickly from one to the other. In addition, the system can be adapted according to the number of rooms to be covered. On a circuit, up to 64 indoor units can be connected.

Depending on the situation, a particular type of technology for the system may be preferred:

- For well-insulated buildings with low thermal inertia, it represents a worthwhile opportunity. This type of building often faces thin walls because they are modular but they are highly sensitive to temperature variations. The flexibility of this system makes it easy to respond to these situations.

- When it is possible to predict a simultaneous demand for heating and cooling, the 'energy recovery' method is ideal. Indeed, this variant is relevant both in mid-season and when significant internal contributions are expected. For example, the heat emitted by specific rooms (e.g. computer room, industrial process) can be transferred to other rooms in need of heat. Another situation, such as the production of domestic hot water by collecting the heat from the premises in summer, lends itself well to this type of technology.
- Efficiency

According to the producers, the VRF system can allow an improvement in efficiency of up to 28% compared to a conventional reversible heat pump (ICEDD, 2019) when optimal operating conditions are met. The energy benefit will be even greater if energy recovery is possible.

With regard to water loop systems, there is a deterioration in efficiency during the winter period when heating must be provided because of the greater temperature gradient between the outside air and the required temperature. Nevertheless, this type of application is useful in mid-season when performance is good. The excellent efficiency is obtained when the system operates at partial load, with some producers announcing an EER[71] of more than 7 (at 25 ° C outside temperature) and a COP of 5.5 (at 9 ° C outside temperature).

- High price

As a relatively new technology, the investment cost of a VRF system is high. However, it should be kept in mind that this investment is made for a period of 20 years and that it must be put into perspective with a comparable technology such as a 4-pipe fan coil installation.

- Presence of a refrigerant network throughout the building

Given the length of the network for the VRF system, the risks of leakage exist and leaks not easy to detect. In addition, refrigerants are subject to European regulations according to their toxicity and flammability. Although they are not directly harmful to humans, their environmental impact is potentially disastrous because some, such as the R410a fluid, the most common for this type of installation, have a heating power 2 000 times greater than CO_2 (Bruxelles_Environnement_5, 2020). Although there are no regulations in the BCR prohibiting this technique, Luxembourg applies a power limit (50 kW) to installations of this type (Energie Plus, 2020).

C.3. Replicability in the Brussels Capital Region

- Residential buildings

Given the cost associated with this type of technology, it is not possible to equip residential buildings with it. They are therefore not possible except possibly for apartment buildings.

- Service sector buildings

The VRF can be relevant in the context of small new service sector buildings (< 5 000 m²), particularly when the heating and cooling needs are simultaneous. In the context of larger projects, this technology may be worthwhile but within the limit of its cooling capacity (max 150 kW) (Bruxelles_Environnement_5, 2020). In addition, it must be taken into account that a maximum height difference of 90m can be achieved in the outdoor and indoor unit with 1 000m of piping at most. Beyond these constraints, 'water loop energy recovery' systems should be given preference. It is essential to give preference to energy recovery, even if the prices are higher, because the associated performances are superior and allow to combine the production of cold and heat.

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[71] *Energy Efficiency Ratio:* coefficient of cooling efficiency. It represents the energy performance of the heat pump operating in cooling mode. It is calculated as the ratio between the useful energy or heat absorbed at the evaporator over the energy supplied to the compressor.

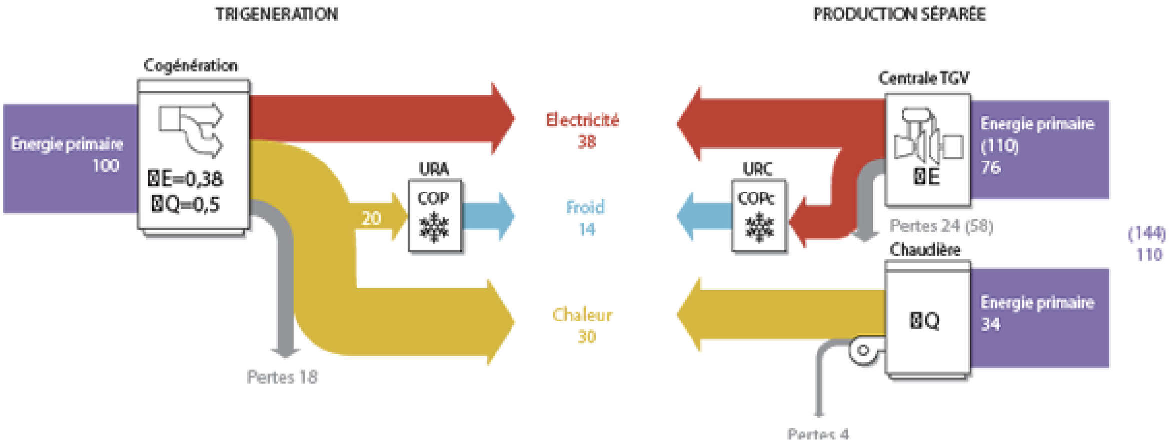
C.4. Assumptions for calculating LCOH

Cooling technologies are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions.

D. Absorption and trigeneration refrigeration machine

D.1. Operations

Trigeneration works on the same principle as cogeneration with the difference that a unit for the production of cold by absorption has been added to it. By making use of the heat produced by the engine or the turbine, particularly in summer when the needs are less, cold can be produced for the air conditioning or refrigeration of buildings. Again, this system aims to save the amount of primary energy used by combining the production of three energies: electricity, heat and cold.

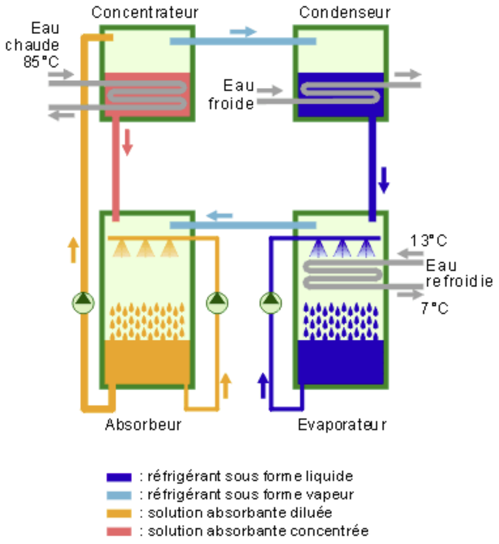


	TRIGENERATION
	Cogeneration
	Primary energy
	URA
	COP
	Losses
	Electricity
	Cooling
	Heating
	SEPARATE PRODUCTION
	Combined cycle gas turbine power plant
	URC
	COPc
	Losses 4
	Losses 24 (58)
	Boiler
	Primary energy
	Primary energy

Figure 26: comparison of primary energy consumption between trigeneration and separate production (Energie Plus)

Trigeneration allows the production of cold thanks to an absorption machine. This machine is equipped with four main components:

- *Evaporator*: a refrigerant (e.g. water) is sprayed into it at very low pressure. The refrigerant evaporates there by capturing the heat of the water which circulates in the evaporator through a circuit. This water cools.
- *Absorber*: the water vapour contained in the evaporator is conveyed to the absorber where an absorbent solution (lithium bromide) is continuously pumped so that it can be sprayed again. In this way, the absorbent solution absorbs the water vapour from the evaporator while maintaining the low pressure essential for the evaporation of the refrigerant there. Eventually the solution becomes saturated and dilutes.
- *Concentrator:* the diluted solution is warmed (to 85 ° C) in a concentrator where it is concentrated before being returned to the absorber. On heating, some of the water evaporates.
- *Condenser:* the water vapour coming from the concentrator is cooled by circulating cold water in the condenser before being returned to the evaporator.



	Hot water 85 °C
	Concentrator
	Condenser
	Cold water
	Chilled water
	Evaporator
	Absorption bottles
	Refrigerant in liquid form
	Vapour refrigerant
	Diluted absorbent solution
	Concentrated absorbent solution

Figure 27: Working principle of absorption machine (Energie Plus)

The additional feature of trigeneration, compared to a conventional absorption machine, is that the concentrator is fed by the waste heat recovered from the cogeneration installation. The application of trigeneration is particularly relevant in places where cold and heat are consumed (e.g. slaughterhouses, pharmaceutical, chemical and agro-food industries, office buildings and some housing estates).

D.2.Technical and financial specificities

Trigeneration presents the same constraints as cogeneration. In this section we only look at the differentiating or additional elements compared to cogeneration.

- Efficiency

Usually, the low temperature heat (30-40 ° C) discharged from the condenser is sent to a cooling tower; this constitutes a significant energy loss. The efficiency of the absorption machine is affected and is around 70%. In this case, it can be complicated to evaluate green certificates. If this waste heat is recovered, for instance for heating the water in swimming pool basins, the efficiency of the absorption machine goes from 70% to 120%.

- Costs

Trigeneration requires even higher initial investments than for cogeneration. While the energy efficiency is better, it is generally not sufficient to compensate for the low economic efficiency of this technology.

- Not very flexible

To function optimally, stable and balanced heating and cooling requirements are recommended in relation to the guaranteed production. This limits applications to specific buildings such as hospitals or industries.

- Waste heat

Trigeneration works on the basis of waste heat recovery. Again, the applications of this technology are limited, particularly in the BCR where there is little industry. In addition, the temperature of the recovered heat should be in the range of 80-95 ° C to allow absorption cooling.

D.3.Replicability in the Brussels Capital Region

- **Residential buildings**

For residential dwellings, this technology would possibly be useful if it were coupled with a cooling network (see respective section).

- **Service sector buildings**

As for residential buildings, it would require the presence of a cooling network where the central production unit (heat and cold) would be equipped with trigeneration.

For optimal efficiency, this technology should preferably be associated with the recovery of waste heat in industry. In view of the few possibilities in the BCR, this solution is of little interest.

D.4.Assumptions for calculating LCOH

Cooling technologies are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions.

6.1.4. Cooling production: technologies - collective solutions

A. Refrigeration networks

A.1.Operations

Cooling networks, operating on the opposite principle to heating networks, are used to cool buildings by collecting the heat in them in order to evacuate it to a discharge point (e.g. river). The system consists of one (or more) production unit(s), a piping system, in which a heat transfer fluid, commonly called chilled water, circulates at 1 ° to 12 ° C on the flow and 10 ° to 20 ° C on return (an operating current value: 12/7 ° C), and substations for heat collection.

Currently, the first technique uses refrigeration units which discharge heat into the air or into the water. However, energy recovery techniques (e.g. waste heat from waste incineration) can also be deployed once complemented by absorption machines to produce cold. *Free-chilling* is also a solution and allows the direct use of air or water as a source of cold. Overall, cooling networks have better energy and economic efficiency when they distribute chilled water at high temperature (13/18 °C operation for example) with the objective of maximising their cooling by renewable energies (*free chilling,* natural *geocooling*, etc.).

A.2. Technical and financial specificities

The constraints are very similar to those presented for heating networks. We only briefly go over some of them in this section.

- **Cost**

Due to the infrastructure required for the installation of a cooling network, the investment costs are substantial. The project will only be relevant if energy and economic returns can offset these costs, particularly in the long term.

- **Dense urban areas**

As mentioned for heating networks, the outputs of a network will be all the more efficient when they cover a densely urbanised area. The cooling needs must therefore be high enough for connected buildings. At this level, service sector buildings have more cooling needs than residential ones.

A.3. Replicability in the Brussels Capital Region

- **Residential buildings**

The demand for cooling appears relatively limited in residential buildings. If large apartment buildings can nevertheless be connected to a network, this technology becomes more worthwhile. This type of network could nevertheless become more useful with passive buildings which need more cooling.

- **Service sector buildings**

Only service sector buildings are of more interest in the BCR, given the low level of industry in the region. Buildings such as shops, hospitals, offices, etc. may have greater potential for this type of infrastructure. The cooling network could be worthwhile if coupled with heat production. The potential nevertheless probably remains limited and certainly needs to be assessed before launching this type of project.

A.4. Assumptions for calculating LCOH

Cooling technologies are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions. However, the information provided for district heating networks is similar to that of cooling networks, given their proximity.

6.1.5. Combined heating and cooling production technologies - Collective solutions

A. Networks on temperate water loop

A.1. Operations

The presentation of heating and cooling networks led to the same conclusion: to be economically profitable, the network needs to cover major needs (for heating or cooling). Climate change has the effect of causing an increase in average temperatures, resulting in de facto greater cooling needs (particularly in summer). Conversely, the energy transition encourages the reduction of energy consumption. Heating networks are better insulated and experience less heat loss, while buildings will be passive in the future and will have low energy consumption. This runs counter to the economic profitability of a network. At a time in particular of the development of sustainable districts, mixing the residential (more in need of heating) with the service sector (more in need of heating and cooling) on the same network could be a solution in the long term.

These networks operate in a similar way to an energy recovery system on a water loop (refer to 6.1.3.C) where each building has a reversible water-to-water heat pump connected to the network. The water circulates in a primary water loop with temperature-controlled water (between 10 ° and 35 ° C) before being distributed to the substations of the connected buildings. The heat pumps are installed in these substations and, thanks to their reversibility, ensure both the production of hot water for heat and domestic hot water needs and the production of cold/chilled water for cooling. Heat and cold are transmitted to the terminal units (e.g. fan coil units) via a secondary water loop

Temperature-controlled water networks are part of an approach involving 4th generation heating networks that integrate renewable energies, allow storage and reinforce the flexibility of the network (‘thermal *smart grid*’). Several sources of renewable energy and thermal recovery can be used to supply the temperature-controlled water loop:

- Geothermal energy (water tables, lakes, canals, sea, etc.)
- Riothermy (wastewater networks)
- Waste heat recovery
- Possible cold process

A.2. Technical and financial specificities

Once again, the technical and financial specificities are similar to those presented in the case of heating networks (refer to 6.1.2.A). Specifically for temperature-controlled water networks, it is nevertheless important to highlight the following specificities:

- **Pooling of heating and cooling needs**

As mentioned elsewhere, the heating and cooling needs must be balanced to avoid thermal depletion (the source becomes too hot or too cold depending on the case) of the renewable energy source (e.g. groundwater). The pooling of needs should allow this annual thermal balancing (heating in summer and cooling in winter of the renewable source). This is also facilitated by the fact that the calories released into the network by the production of cold can be directly reused for the production of heat. In addition, the network operates at low temperature, de facto relieving the pressure on the energy source.

- **Energy-efficient buildings**

Given the low temperatures, these installations are better suited for energy-efficient buildings with low temperature emitters. This is why it fits better with new or renovation projects.

- **Integration of renewable energies**

Provided that the heating and cooling needs are balanced to avoid thermally drying up the renewable energy source, the temperature-controlled water networks can be supplied by renewable energy sources and thus be part of an energy transition approach.

- **Modularity of needs**

If production is decentralised, this also means that each building can adapt its production to its needs. Thus, buildings can give off different water temperatures according to their needs. The systems are modularised at the reversible terminal heat pumps, allowing the choice of the terminal temperature level without affecting the temperature of the temperature-controlled water network. Only the performance of one reversible heat pump with respect to another is modified according to the temperatures requested on the secondary loop. With centralised production, the water loop is roughly the same temperature everywhere.

- **Limitation of thermal losses**

Even if the current heating networks are much better insulated than in the past, the water circulating in the network at low temperature makes it possible to avoid further heat loss. The network does not need to be insulated, which reduces investment expenses.

A.3. Replicability in the Brussels Capital Region

- **Residential and service sector buildings**

As mentioned, districts combining residential and service sector buildings offer worthwhile opportunities for accommodating temperature-controlled water networks. Combining the response to the needs for cooling (mainly in the service sector) and heating (in the service and residential sectors) while increasing volumes by connecting these buildings to a single network boosts the possibility of making the construction of a network profitable. This kind of district can be found in Brussels. Low-energy-density districts are also relevant for the use of these networks.

The possibility of developing these networks should be considered on a case-by-case basis. For the region, the problem lies with the geothermal installation which cannot take place anywhere (refer to 6.1.1.C and 6.1.1.D). However, the example of the Bruxelles Environnement building which is equipped with a geothermal installation drawing from the water table illustrates that this is possible.

A.4. Assumptions for calculating LCOH

The temperature-controlled water networks are not the subject of an additional analysis. We are therefore not providing technical and economic assumptions. However, the information provided for heating networks can give an indication given their similarity although in this case it must be taken care that two needs are met.

6.2. Summary table - LCOH

Based on the technical and economic assumptions presented in their respective sections, we calculated the *Levelised Cost of Heating* (LCOH) specific to certain individual heat production technologies. The table below summarises the results obtained for the calculation of the LCOH:

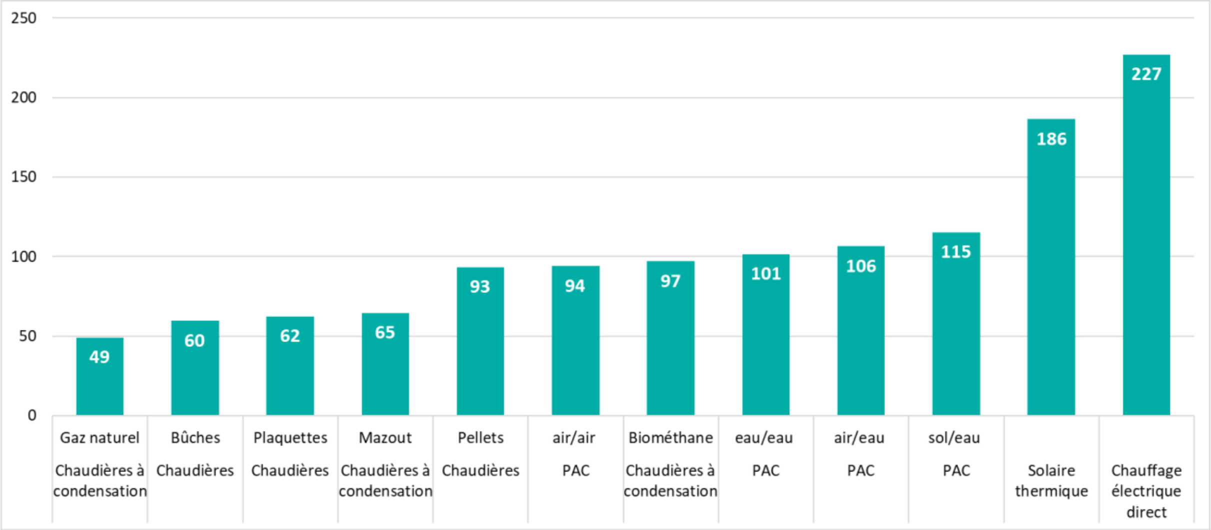
Technology		Sector	LCOH (EUR/MWh)	
			Residential	Service
Condensing boilers		Biogas	97	78
		Natural gas	49	37
		Diesel oil	65	54
Boilers		Logs	60	/
		Pellets	93	84
		Wood chips	62	61
Direct electric heating		Electricity	227	/
Heat pumps	Air-to-air	Electricity	94	/
	Air-to-water	Electricity	106	59
	Water-to-water	Electricity	101	54
	Ground-to-water	Electricity	115	55
Solar thermal (only DHW)		Renewable.	186	144

Table 34: Comparison of LCOHs of different heating solutions

The following table establishes a ranking in ascending order of individual heat production technologies for the residential sector. The boilers occupy the five most economically worthwhile positions, with natural gas in particular as the most economical solution (49 euro/MWh). As biomass boilers pose a lot of air quality problems and oil-fired boilers will eventually be banned in the Brussels-Capital Region, air-to-air heat pumps and biomethane boilers are the cheapest solutions after natural gas condensing boilers.

Conversely, in view of the small quantity of energy produced compared to its cost over its lifetime, solar thermal energy does not constitute an economically efficient solution.

From the point of view of LCOH, direct electric heating is the worst of the solutions presented in this report. The high cost of electricity, not to mention the amount of primary energy required, explains this poor result.

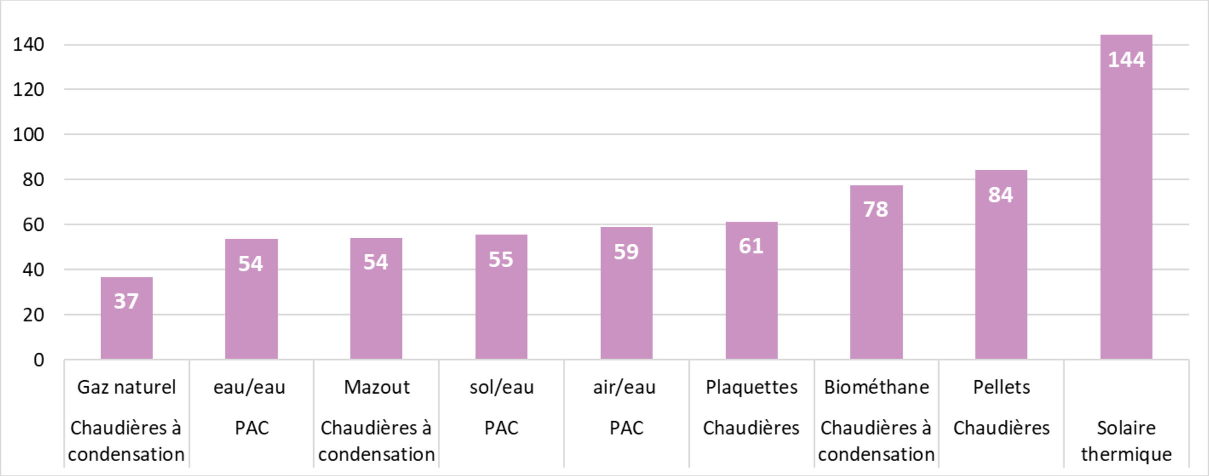


	Natural gas
	Condensing boilers
	Logs
	Boilers
	Wood chips
	Boilers
	Diesel oil
	Condensing boilers
	Pellets
	Boilers
	air-to-air
	HP
	Biogas
	Condensing boilers
	water-to-water
	HP
	air-to-water
	HP
	ground-to-water
	HP
	Solar heating
	Direct electric heating

Table 35: LCOH of individual heat production solutions for the residential sector (EUR/MWh)

At the service level, natural gas boilers once again demonstrate the best results. Water-to-water, ground-to-water heat pumps and fuel oil boilers (or even air-to-water heat pumps) obtain practically identical performance, which illustrates the profit potential of geothermal energy, in particular.

As the sale of fuel oil boilers will be banned with effect from installation by 2025, geothermal heat pumps are certainly of interest to the service sector when possible. Considering that biomass boilers are not a preferred solution for the region because of the impact on air quality and that solar thermal is not economically efficient, boilers burning biomethane are still worthwhile as an additional solution. The existence of the distribution network is moreover a significant argument for this sector.



	Natural gas
	Condensing boilers
	water-to-water
	HP
	Diesel oil
	Condensing boilers
	ground-to-water
	HP
	air-to-water
	HP
	Wood chips
	Boilers
	Biogas
	Condensing boilers
	Pellets
	Boilers
	Solar heating

Table 36: LCOH of individual heat production solutions for the service sector (EUR/MWh)

7. Comparison of solutions for meeting heating and cooling needs

7.1. Principle of the analysis

Paragraph 3 of article 14 of Directive 2012/27/EC requires that a cost-benefit analysis be carried out of the various possibilities for producing heat and cold. The text of the Directive also explains that this analysis is capable of facilitating the identification of the most resource-and cost-efficient solutions for meeting heating and cooling needs.

To meet this demand in the Directive, it was decided to model different types of districts in which central heating solutions can be considered. In each case, an effort will be made to examine the cost per MWh of heat consumed by customers connected to the grid. In a second step, this cost can then be compared with individual solutions for the production of heat.

The objective of this analysis is to try to define in which cases a district heating solution is preferable to an individual solution.

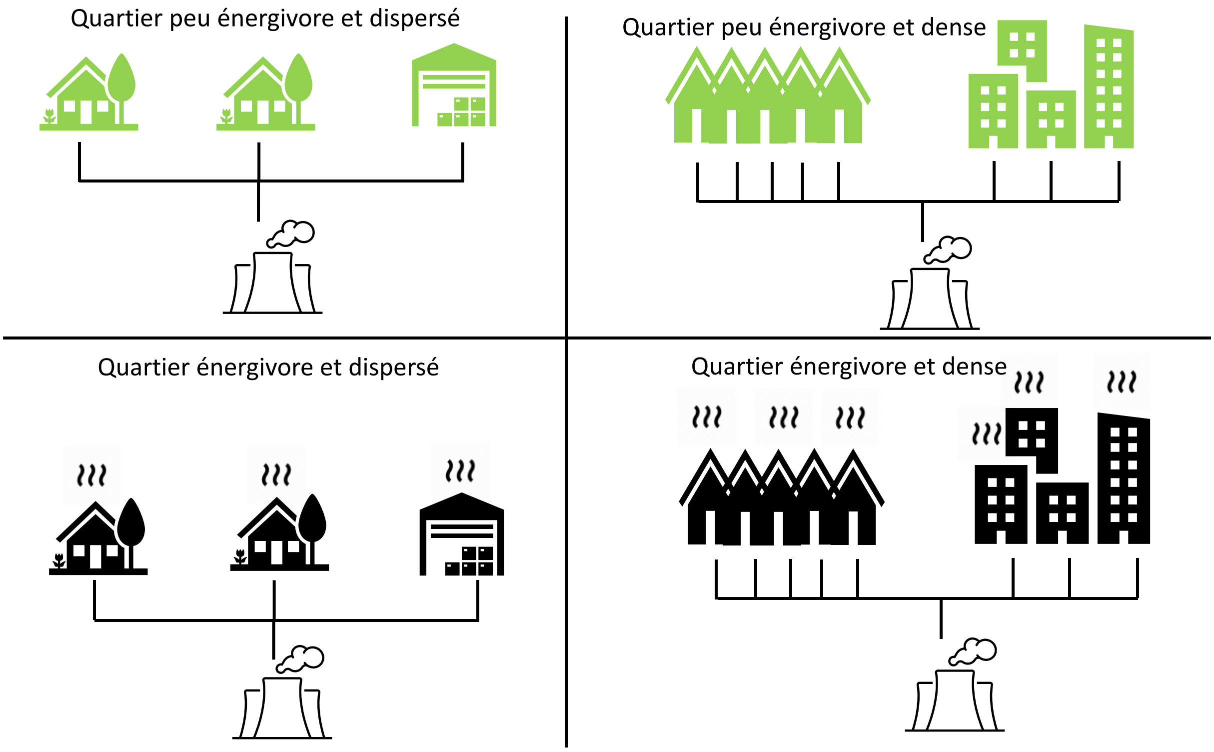
As a first step, it was decided to define four different types of districts which can schematically represent four urban or peri-urban development situations (see figure below). These different districts are supposed to be made up of housing as well as service establishments. The four types of districts that were selected are as follows:

- Energy efficient and dispersed district
- Energy efficient and dense district
- Energy-intensive and dispersed district
- Energy-intensive and dense district

Initially, the districts considered consist of 1 000 housing units (houses and apartments) and 20 000 m² of service sector buildings.

The following main hypotheses were used to define these different districts:

- In dense districts, the distance between houses is assumed to be 6 metres.
- In scattered districts the distance between houses is assumed to be 20 metres.
- Apartment buildings and service sector buildings are assumed to be 100 metres apart.
- In energy-intensive districts:
  - the consumption of residential dwellings is equal to that observed on average in the Brussels energy balance sheets at present;
  - the consumption of service sector buildings is that which can be observed on average in Brussels energy balance sheets at present.
- In low-energy districts:
  - the consumption of residential dwellings is equal to the objectives of the renovation strategy by 20;50, i.e. (15 kWh/m²/year for heating, with DHW unchanged)
  - the consumption of service sector buildings is calculated on the basis of the PEB criteria for current new buildings.



	Energy efficient and dispersed district
	Energy-intensive and dispersed district
	Energy efficient and dense district
	Energy-intensive and dense district

Figure 28: Schematic representation of 4 types of heating networks

7.2. Determination of the technical characteristics of heating networks

In each typical district, the heat consumption profiles are aggregated into a single heating demand curve. A calculation similar to that presented in Section 5 of this report was produced to determine the characteristics of a cogeneration unit that could supply this district with heat. For this cogeneration, the following elements will therefore be determined:

- Thermal and electrical power
- Thermal and electrical efficiency
- Time period for operation
- Thermal and electrical production
- CO savings$_2$ achieved
- Investment costs related to cogeneration
- Purchase of fuels of this cogeneration unit
- The number of green certificates granted
- Simple payback time, net present value, internal rate of return

Once the cogeneration unit has been sized, it is necessary to route the heat produced via a network to the end consumers.

The following parameters were taken into account:

- Investments in a heating network (€500 / running network metre)
- Investments in a substation that provides the interface between the heat network and the end consumer (generally it is a heat exchanger)
    - €3 000 / substation in the case of residential buildings
    - In the case of the service sector and apartment buildings, the cost is determined on the basis of a technical-economic curve of specific costs depending on the power demand
- The need to invest in additional heat which makes it possible to meet peak thermal needs based on the application of a technical-economic curve which gives the cost according to the power of the back-up boiler
- Maintenance costs of this heating network (4% of CAPEX/year)

7.3. Analysis of heat production costs

Once the technical and economic characteristics of the cogeneration and the heating network have been determined, it is necessary to estimate the production cost of the heat delivered to each consumer connected to the network. For this and as in Section 6, we used the concept of LCOH *(Levelised Cost of Energy),* voir par exemple (Hansen, 2019).

The objective of this analysis is to compare the cost of heat delivered to end consumers connected to a heating network with the cost of heat for an individual solution (typically an individual boiler).

Energy price assumption: energy cost based on a CREG study (CREG, 2020)

7.3.1. How do we calculate the LCOH in the case of cogeneration?

In the case of an installation which produces only one form of energy (electricity or heat), the calculation is relatively simple and does not cause any specific methodological problem.

On the other hand, if the heating network is supplied by cogeneration which produces two forms of energy (electricity and heat), it is necessary to be able to determine what is the share of the costs (CAPEX, OPEX and fuels) that it must be attributed to the production of heat.

The first solution would be to consider that all the costs are to be attributed to the production of heat. However, this cost allocation rule cannot be justified since cogeneration also produces electricity. Various proposals have already been formulated, including that of distributing costs in proportion to energy production. (Nian, Qie, Zhanyu, & Hailong, 2016). The distribution of costs (CAPEX, OPEX, fuel) would be based on the electrical and thermal efficiency of the cogeneration.

By following this approach and assuming a cogeneration with an electrical efficiency of 30% and a thermal efficiency of 50%, it should be considered that 62.5% of the costs of the cogeneration (50 / (30 50)) are to be attributed to the production of heat. However, this way of doing things, based on energy efficiency, does not seem satisfactory to us insofar as heat and electricity are two forms of energy of very different quality, which is reflected in their very different selling prices.

Therefore, rather than working in proportion to efficiency, it was decided to base the calculation on the economic cost of the two forms of energy produced by cogeneration by placing ourselves in the position of the end consumer. For simplicity of reasoning, we have assumed that all users of the district heating network are residential customers.

To achieve this distribution in proportion to the economic value of the electricity and the heat supplied by the cogeneration, it is necessary to quantify their economic value. Here, too, there are no hard and fast rules. However and insofar as we place ourselves in the perspective of the end (residential) customer, we have chosen to adopt the prices paid by this customer to buy their electricity and heat.

For electricity, this does not pose a major problem. We know the selling prices of electricity to residential customers. Even if these can fluctuate, we have adopted a standard value of €0.025/kWh (including tax). On the other hand, there is no equivalent value for heat and we cannot refer to the price paid by the final consumer to buy their MWh of natural gas since a combustion installation is necessary to transform this fuel into useful heat for the occupants of the accommodation.

However, this value can be determined by estimating the LCOH of the heat produced by an individual reference boiler fired with natural gas. As specified in paragraph 6.2, we have selected a value of €49/MWh.

Therefore, cogeneration with an electrical efficiency of 30% and thermal efficiency of 50% will produce 30 kWh of electricity and 50 kWh of heat. By multiplying the electric and thermal kWh by the price paid by the residential customer for these forms of energy, we deduce that the combustion of 100 kWh of natural gas in the cogeneration unit can be valued at an amount of €9.95 for a residential customer. The calculation is as follows:

30 kWh * €0.25/kWh 50 kWh * €0.049/kWh = €9.95

Therefore, we can estimate that the share of costs (CAPEX, OPEX, fuel) of cogeneration that should be attributed to heat production alone is 24.6%. The calculation is as follows:

Share of costs for thermal generation

50 kWh * €0.049/kWh / €9.95 = 0.246

This value close to 25% appears to be more appropriate than that obtained by the energy approach (62.5% in our reference) since the electricity produced has a value much higher than the heat. The use of this economic metric to distribute the thermal production costs of cogeneration is, conceptually, quite close to an exergetic approach, which would take into account the quality of the forms of energy produced.

Concretely, this reasoning implies that, in the LCOH formula, only 24.6% of the costs caused by cogeneration (CAPEX, OPEX, fuel) will be taken into account. It should be noted that this rule of proportionality only applies to cogeneration, and the costs of other equipment which is only used for the production of heat (back-up boiler, heat distribution network, substation) will be 100% attributed to heat production.

7.4. Analysis of results

By applying this methodology to the case of the 4 predetermined typical networks, we find the LCOH values of the heat supplied to the end customer in the four types of predetermined networks and in different scenarios. The first scenario is that of a network supplying 1 000 homes and 20 000 m^2 of service activities from a centralised heating system made up of cogeneration and a back-up boiler powered by natural gas. This is currently a benchmark situation even though the regional authorities are currently reflecting on the future place of fossil fuels in the Brussels energy mix (see Section 4.5.5).

Unsurprisingly, we observe that the cost of MWh is lowest in the case of dense and inefficient districts from an energy point of view (more precisely, they have performance comparable to the average for the Brussels situation in 2018). It stands at €66/MWh. On the other hand, in the case of a dispersed and efficient district from an energy point of view, the costs of the heat delivered via a district heating network soar to €320/MWh.

This difference in the cost of heat delivered via networks is a good illustration of a difficulty with which the Brussels authorities will be confronted. Heating networks are all the more justified when they supply densely populated and energy-hungry districts. A future network that would be sized to supply such a district will see its profitability decrease as the renovation of housing in this district progresses, since its consumption will decrease.

Main assumptions	District type	LCOH [€/MWh]
1000 housing units, 20 000 m² of service sector, Network supplied by an auxiliary boiler + cogeneration, Natural gas.	Energy-intensive, dense	66
	Energy-intensive, dispersed	96
	Energy efficient, dense	149
	Energy efficient, dispersed	320

Table 37: Comparison of LCOHs for central heating (1000 homes, natural gas cogeneration)

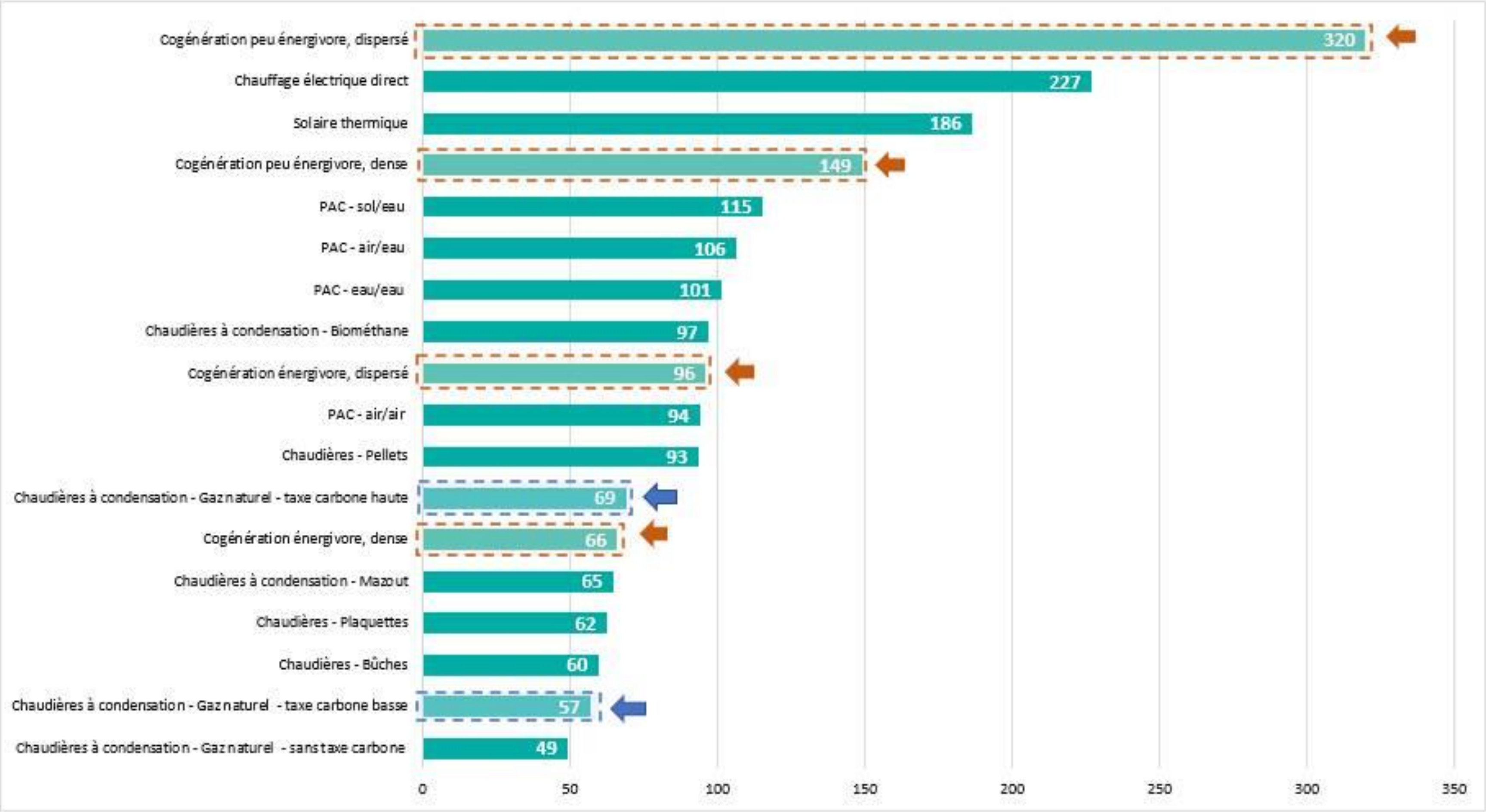
The results of this analysis can also be compared with the LCOH of the individual solutions studied in Section 6 (refer to Figure 29). We see in this figure that, in the case of a network of 1 000 dense and energy-intensive homes, the LCOH of the distributed heat is relatively similar to that of individual oil or biomass boilers (chips and logs), all technical solutions which are or will eventually be banned in the Brussels-Capital Region (see Section 4.5.5).

The LCOH of this network solution remains higher than individual natural gas heating but is significantly lower than all other forms of heat production (pellet boiler, heat pump, solar thermal). The LCOH of the other types of network is much less attractive when compared to individual solutions.

In this same figure, we have indicated the LCOH of the heat distributed by individual condensing boilers supplied with natural gas in two scenarios for the change in a possible carbon tax.

- Low change: from 10 to 100 euro / MWh between 2020 and 2050
- High change: from 10 to 300 euro / MWh between 2020 and 2050

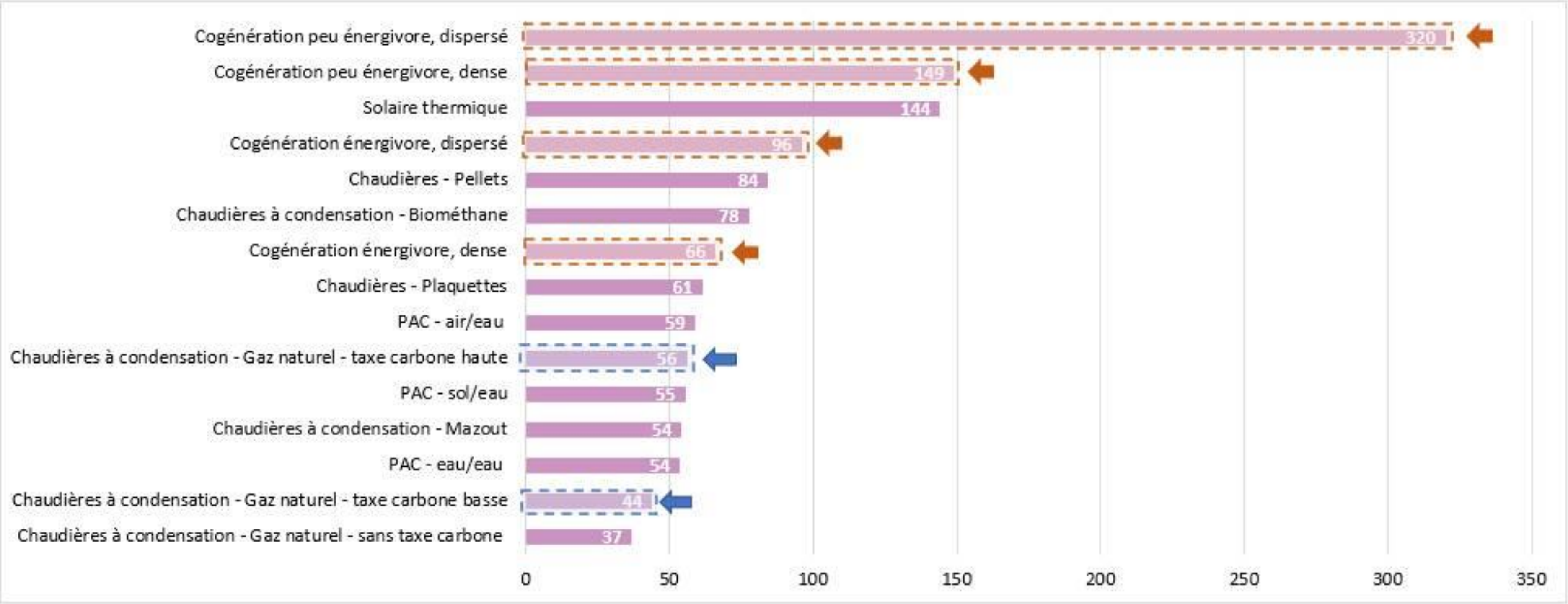
A similar exercise is performed for the service sector (refer to Figure 30)



	Energy efficient, dispersed cogeneration
	Direct electric heating
	Solar heating
	Energy-efficient, dense cogeneration
	HP - ground-to-water
	HP - air-to-water

	HP - water-to-water
	Condensing boilers - Biomethane
	Energy-intensive, dispersed cogeneration
	HP - air-to-air
	Boilers - Pellets
	Condensing boilers - Natural gas - high carbon tax
	Energy-intensive, dense cogeneration
	Condensing boilers - Fuel oil
	Boilers - Wood chips
	Boilers - Logs
	Condensing boilers - Natural gas - low carbon tax
	Condensing boilers - Natural gas - without carbon tax

Figure 29 : Comparison of LCOHs of individual heat production and cogeneration solutions in the residential sector (EUR/MWh)



	Energy efficient, dispersed cogeneration
	Energy-efficient, dense cogeneration
	Solar heating
	Energy-intensive, dispersed cogeneration
	Boilers - Pellets
	Condensing boilers - Biomethane
	Energy-intensive, dense cogeneration
	Boilers - Wood chips
	HP - air-to-water
	Condensing boilers - Natural gas - high carbon tax
	HP - ground-to-water
	Condensing boilers - Fuel oil

	HP - water-to-water
	Condensing boilers - Natural gas - low carbon tax
	Condensing boilers - Natural gas - without carbon tax

Figure 30 : Comparison of LCOHs of individual heat production and cogeneration solutions in the service sector (EUR/MWh)

A similar calculation of LCOH can be performed for other district configurations and other technical solutions for the heating system. First, we tested the cost of delivering heat in the case of a network supplying 4 types of districts containing only 100 homes but 20 000 m² of service activities.

The central heating unit is unchanged. It is still cogeneration and a back-up boiler fuelled by natural gas. We note that the LCOH of the dense energy-intensive network is close to the situation of the reference network (€61/MWh against €66/MWh). On the other hand, the increase in LCOH is less marked for less dense and/or less energy consuming networks. This result is explained by a lower investment requirement in the case of this much smaller network.

In the rest of the reasoning and as the cost of heat distributed in a network supplying 100 homes is reduced, only a district of this size will still be considered.

Main assumptions	District type	LCOH [€/MWh]
100 housing units, 20 000 m² of service sector, Network supplied by an auxiliary boiler + cogeneration, Natural gas.	Energy-intensive, dense	61
	Energy-intensive, dispersed	77
	Energy efficient, dense	94
	Energy efficient, dispersed	148

Table 38: Comparison of LCOHs for central heating (100 homes, natural gas cogeneration)

With a view to the complete decarbonisation of heat in the Brussels-Capital Region by 2050, it will be necessary to opt for networks supplied by carbon-free energy sources.

Initially, we considered that this district of 100 housing units could be supplied by cogeneration burning uncleaned biogas, containing around 50% of methane, and by a back-up boiler burning biomethane. In fact, current profitability calculations show that the local biogas plant should be sized to cover the needs of cogeneration. The back-up boiler is supplied with fossil fuels. In the present case, we considered that this additional fuel would be biomethane imported from other regions or countries.

Main assumptions	District type	LCOH [€/MWh]
100 housing units, 20 000 m² of service sector, Network supplied by an auxiliary boiler + cogeneration, Local biogas for cogeneration, Imported biomethane for the boiler.	Energy-intensive, dense	115
	Energy-intensive, dispersed	131
	Energy efficient, dense	149
	Energy efficient, dispersed	203

Table 39: Comparison of LCOHs for central heating (100 homes, local biogas cogeneration - biomethane boiler)

It is also possible to supply the same network and an equivalent heating plant by purchasing biomethane (and in the future syngas) produced in other regions or countries. Under these conditions, the cost of the heat delivered to the various end customers is given in the table below.

Main assumptions	District type	LCOH [€/MWh]
100 housing units, 20 000 m² of service sector, Network supplied by an auxiliary boiler + cogeneration, Imported biomethane.	Energy-intensive, dense	89
	Energy-intensive, dispersed	105
	Energy efficient, dense	131
	Energy efficient, dispersed	185

Table 40: Comparison of LCOHs for central heating (100 homes, biomethane cogeneration)

If the heating plant is equipped with boilers only, without back-up cogeneration, the heat production costs are a little higher since there is no benefit from the contribution of the sale of electricity produced by the cogeneration (modelled as explained in paragraph 7.3.1). Under these conditions and in the case of a dense and energy-intensive network, the LCOH amounts to €105/MWh.

Main assumptions	District type	LCOH [€/MWh]
100 housing units, 20 000 m² of service sector, Network supplied by a boiler, Biomethane.	Energy-intensive, dense	105
	Energy-intensive, dispersed	121
	Energy efficient, dense	135
	Energy efficient, dispersed	189

Table 41: Comparison of LCOHs for central heating (100 homes, biomethane boiler)

In order to protect air quality, the Brussels-Capital Region is currently reflecting on the place that wood will have in the Brussels energy mix with regard to the air quality problems that its combustion generates. We have however simulated the LCOH of the heat distributed in the 4 predetermined types of districts by assuming that the central heating is equipped with boilers (without cogeneration) which burn wood.

The centralised combustion of wood, even if it is not free from problematic emissions such as fine particles, makes it possible, in fact, to better control the quality of the smoke leaving the chimney than in the case of individual wood heating systems.

In this configuration, the LCOH of the heat distributed is very close to that which is calculated in the case of a network supplied by cogeneration supplied with natural gas. In addition, if we introduce a carbon tax that goes from 10 to 300 euro / tonne of CO_2 between 2020 and 2050, the heat supplied by the network supplied by a wood-fired boiler becomes more economically advantageous than that supplied by a natural gas condensing boiler.

Main assumptions	District type	LCOH [€/MWh]
100 housing units, 20 000 m² of service sector, Network supplied by a boiler, Timber.	Energy-intensive, dense	64
	Energy-intensive, dispersed	80
	Energy efficient, dense	96
	Energy efficient, dispersed	150

Table 42: Comparison of LCOHs for central heating (100 homes, wood boiler)

Finally, we tested the possibility of building a 4th generation heating network (at low temperature) to supply a dense and energy-intensive district of 100 housing units which would be located on the edge of the canal. This would be the cold source of a heat pump which would supply the entire network with heat at low temperature. If the electricity consumed by the heat pump of the heating plant comes from carbon-free energy sources, this also results in centralised and carbon-free heat production which also has the advantage of being completely free from atmospheric emissions. The LCOH of this heat production solution is however high, since even in the case of a dense and energy-intensive network, it amounts to €130/MWh.

8. Heat and cold production decarbonisation strategy

8.1. SWOT analysis

The purpose of this report is to take stock of production of heat and cold in the Brussels Region. The analysis intends to go further by proposing recommendations for the successful decarbonisation of heat and cold production by 2050. First, on the basis of a SWOT analysis, we recall the technical and legal context in which the Brussels-Capital Region finds itself and we try to identify the levers and obstacles to decarbonisation. Secondly, we identify the ways in which this can be achieved.

8.1.1. Identification of the strengths, weaknesses, opportunities and threats of the decarbonisation of heat and cold production in the Brussels-Capital Region

For the purpose of the SWOT analysis, it is useful to recall the theoretical framework of this type of analysis. A SWOT analysis aims to identify the strengths, weaknesses, opportunities and threats which we explain below:

- Strengths: **internal factors** to the Brussels-Capital Region promoting the decarbonisation of heat and cold production in Brussels;
- Weaknesses: **internal factors** to the Brussels-Capital Region, hindering the decarbonisation of heat and cold production in Brussels;
- Opportunities: **external factors** to the Brussels-Capital Region, which can promote the decarbonisation of heat and cold production in Brussels;
- Threats: **external factors** to the Brussels-Capital Region which could harm the decarbonisation of heat and cold production in Brussels.

The SWOT analysis can be found below:

Factors internal to the Brussels-Capital Region

Strengths	• **Utilisation of the dense and widely extended gas distribution network**: the network is strategic because it covers almost the entire region. Although it currently distributes natural gas, it could be converted in the future to distribute new energy carriers such as biomethane or even, in the longer term, syngas. • **Capitalising on the city's urban structure:** ○ **(1)** With an active client every 7 metres[72] on the network, Brussels has a high urban density. Proximity to consumers concentrates heating and cooling needs and should make it possible to achieve economies of scale, particularly in terms of infrastructure. Urban density is an important profitability criterion for heating networks, in particular because major investments can be shared. The mapping of needs in Section 3 of this report can help the decision-maker to identify the most promising areas to guarantee a certain density.

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[72] Brugel, Annual report 2013, https://www.brugel.brussels/publication/document/rapports/2014/fr/rapport-19-rapport-annuel-2013.pdf.

	○ **(2)** Brussels contains mixed districts. The presence of districts combining residential housing and service sector buildings diversifies the needs for heat and cold. Pooling these reinforces needs and therefore potential economies of scale. Again, Section 3 of this report looks at areas of greatest need in the region. • **Leveraging ambitious local political will**: launched as a flagship measure within the framework of the PNEC, the Brussels renovation strategy aims to significantly reduce the energy consumption of buildings. The primary energy consumption target of 100 kWh/m²/year on average for residential buildings by 2050 must be achieved through renovation and the deployment of renewable energies. • **Maintaining the 'energy' subsidy mechanism:** In addition to the incentive to move towards more efficient technologies and/or making use of energy of renewable origin, these make it possible to extend the use of existing infrastructures. For example, biomethane or syngas could circulate through the gas distribution network and serve as fuel for condensing boilers subsidised by subsidies. It is economically attractive insofar as only the cost of the *commodity* would change and not the costs of distribution and transport. • **Exploiting the proximity of the canal:** ○ **(1)** The canal could represent a preferential transport route for raw materials such as biomass. A large quantity can thus be imported into the city at low cost while avoiding the inconvenience associated with transport (traffic, emissions and noise). ○ **(2)** The canal can also serve as a cold source for the (de)centralised production of heat and cold, for instance for geothermal energy. Given the low flow rates of the canal, however, it is necessary to avoid the multiplication of sampling points at the risk of drying up the resource of its heat. Section 3 of this report analyses the areas with the greatest heat needs in the vicinity (1km) of the canal. • **Taking green certificates into account:** this mechanism provides significant financial support for the development of cogeneration, all the more so as they benefit from multiplier coefficients which overvalue production. However, this does not apply to collective dwellings because the electricity produced cannot be self-consumed by the inhabitants of the building, except possibly in the case of energy communities (see 'opportunities').
Weaknesses	• **Poverty in the Brussels-Capital Region (low wage level):** with a risk of poverty rate[73] by 31.4% in 2019, the population of the Brussels-Capital Region is economically less advantaged than that of the other regions of the country (18.3% in the Walloon Region and 9.8% in the Flemish Region). This potentially translates into less purchasing power and less ability to make individual investments to decarbonise domestic heat and cold production facilities.

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[73] Statbel defines the at-risk-of-poverty rate as 'the share of people with an equivalent disposable income (after social transfers) below the poverty line'. https://statbel.fgov.be/fr/themes/menages/pauvrete-et-conditions-de-vie/plus

- **A high tenant rate which reinforces the phenomenon of *split incentive:*** the concept of *split incentive* is defined as 'a circumstance in which the flow of investments and profits is not optimally distributed among the parties to a transaction, thus skewing investment decisions' (Meyer & Maréchal, 2016). In light of these circumstances, we note that the high tenant rate encountered by the Brussels Region reinforces the 'tenant-owner' dilemma. Given that the burden of the investments rests on the owner but that this party will not benefit from the repercussions of the investment (greater energy comfort, reduction of the bill), the owner is not very inclined to invest in energy renovation. Conversely, the tenant has few incentives to adopt energy-saving behaviour in the event that their rent includes charges for energy bills.

- **The high proportion of condominiums hinders the renovation process:** co-owners face the difficulty of reconciling several opinions of different co-owners. At the same time, the *split incentive* also exists in the case of 'condominiums and residents' organisations'. The residents' organisations can be reluctant to start large-scale work because they can generate tensions between the co-owners and the occupants of the building. This is the reason why residents' organisations will tend to opt for easy and unambitious repairs. The Brussels Region is probably particularly prone to this phenomenon given the high rate of condominiums in the region.

- **Urban density limits the potential of renewable energies:**
    - **(1) The space that can be devoted to production and storage** of energy from renewable sources is limited because the population density is high. The lack of access to the ground makes work difficult and restricts the deployment of geothermal heat pumps. Likewise, the small size of the territory makes large-scale solar thermal projects very difficult (if not impossible) as in Vojens in Denmark (refer to 6.1.2.A.1).
    - **(2) Intensive use of the same resource by several consumers can lead to a risk of depletion** of the resource. A scenario with too many residents of the same district equipped with a geothermal probe could prevent a renewal of the energy source.
- **Increased risk of overheating**: under the influence of climate change, the heat islands created by the mineralisation of urban space are getting stronger. The demand for cold is therefore likely to increase in the future. This phenomenon could be reinforced with the renovation strategy which pushes for well insulated buildings but which may experience difficulties in discharging the excess heat once it has entered the building.
- **Urban structure not very conducive to the transport of biomass**: the inconveniences (noise, traffic, pollution) linked to the transport of biomass are particularly harmful in dense urban areas.
- **The weak presence of industries** reduces the attractiveness of certain technologies such as waste heat recovery.
- **The phasing out of the Neder-Over-Heembeek incinerator** prevents the leveraging of the potential additional source of the Brussels incinerator to serve as a centralised network unit.
- **Some environmental standards reduce the scope of possibilities for**

	decarbonisation of the production of heat and cold although they are justified to guarantee a certain quality of life in an urban context: ○ **(1) Air quality standards**, set by a decree of 31 May 2018, limit the development of biomass boilers in Brussels; ○ **(2) Environmental standards and conditions for obtaining environmental permits**, set by a decree of 8 November 2018, force the deployment of geothermal energy in Brussels; ○ **(3) Acoustic standards**, set by a decree of 21 November 2002, restrict the installation of noisy systems such as air-to-air heat pumps in Brussels. • **Old heating networks have a bad image** in Belgium given the shutdowns of historic networks such as Verviers or Seraing.

Factors external to the Brussels-Capital Region

Opportunities	• **Making the renovation strategy part of the 'momentum' created by the national recovery plan**: Having inherited an amount of EUR 395 million to revive the Brussels economy, the region has placed energy renovation at the centre of the measures to be taken. This budget should make it possible to promote the implementation of the strategy. • **Boosting job creation** thanks to the amount of work required for the renovation of buildings and the installation of carbon-free solutions: the skills necessary for this work will require a wide variety of profiles (low-skilled workers, experts, design offices, lawyers, etc.), ensuring that everyone is included to a high degree. • **Fostering the development of energy communities**: Directive 2019/944 of the European Union set the legal framework for the introduction of this new type of player in the energy market. By forming an 'energy community', members of the same community can exchange energy with each other. In this context, cogeneration becomes more attractive because the excess electricity produced can be used when it would have been reinjected, without financial compensation, into the network otherwise. • **Optimising the decision criteria to think about renovation collectively rather than individually**: through the renovation strategy, the region has set itself a high ambition for energy renovation. It is important to establish objective criteria to carry out trade-offs when a collective renovation is more attractive than an individual renovation. For example, it could be relevant to study the possibility on a district scale of implementing a heating network supplied by a biomass plant. In this case, less energy renovation of buildings should be considered and there would be less air pollution than with an individual solution - not to mention that emissions control is also easier on larger installations. • **Considering heating and cooling production networks**: 4th generation district heating networks allow the integration of renewable energies, offer storage possibilities and operate at lower temperature ranges. By pooling the demand for heat and cooling on the same network, which is particularly suitable for mixed residential/service areas in Brussels, the temperature-controlled water networks increase their profitability. Section 3 of this study analyses the potentially relevant areas for accommodating networks on the

	basis of their heat energy density. In addition, as heat loss is directly related to the temperature difference between the inside of the pipe and the environment, a low-temperature network reduces these losses proportionally. They therefore have definite advantages from an energy point of view in the context of decarbonisation. Section 7 nevertheless illustrates the economic difficulty encountered by these networks. Unless the area is dense and energy intensive, the estimated LCOHs are high and make networks an uneconomic solution at present.
Threats	• **Evaluating the possible contradiction between the profitability of heating/cooling networks and the energy renovation of buildings**: given the significant investments in terms of infrastructure and maintenance, the networks must be able to count on a significant and stable demand for heating and/or cooling in order to be economically profitable. However, the energy renovation of buildings aims to reduce their energy consumption. • **Anticipating contract difficulties for heating networks**: in addition to stable demand, the heat supply must also be guaranteed for the user. The contract between the two parties must therefore provide for the complications caused by the cessation of production or consumption: o *Producer*: the network needs a stable network of consumers. Consumers must have confidence in this network and not experience too frequent breakdowns, as this could lead them to resort to individual solutions. This explains the high recurring maintenance costs and the high costs of these networks. In the case of consumption ensured by a limited number of players such as a company, the producer must be able to contractually anticipate the cessation of the activity of this company. o *User*: a network risks being handicapped by the shutdown of production (e.g. due to bankruptcy). In this case, work will be necessary to re-equip a user with an individual solution. This can be accompanied by significant costs or even financial difficulties for a company that has based its business model on the use of energy from a network. • **Objectively considering the sustainability of biomass:** when used as bioenergy, the sustainability of biomass is sometimes questioned given the emissions associated with transport and CO_2 emissions otherwise stored if this biomass had not been used. • **Evaluating the availability of biomass**

8.2. Priorities to be pursued to decarbonise heat and cold in the BCR

This section of the report aims to identify, based on all the elements that were analysed during this study, the strategy that should be implemented to allow the decarbonisation of the heat and cooling demand of buildings in the Brussels-Capital Region by 2050.

To achieve this goal, different avenues can be activated. First of all, heating and cooling needs should be reduced either by modifying consumer behaviour or by improving the energy performance of heating buildings (envelope and heating system).
Next, the residual needs for heating and cooling must be met without using carbon. The heat requirement estimated at 5.8 TWh in an accelerated renovation scenario (see Section 2), will call for the full attention of the Brussels authorities. Electricity, whether through heat pumps or even sometimes direct electric heating, could play this role if its production is also carbon-free, which is not the case today but will increasingly be, as the share of renewables in the production mix increases. Biomass could also be part of the solution for decarbonising heating needs, but it can only be deployed by taking into account its negative impacts in terms of emissions into the air (PM, etc.) and the constraints on the sustainability of the resource. Finally, in the longer term, synthetic fuels produced from carbon-free energy sources could complete the energy mix of the demand for heating and cooling if their environmental and economic cost of production is sharply reduced.
The paragraphs set out a list of measures to be taken from technical, legal, economic and financial points of view to enable the decarbonisation of heating and cooling production in the Brussels-Capital Region. Each of these measures is briefly described and then its economic (including employment) and legal implications are cited. Finally, an indicated implementation time is proposed. Three time horizons are envisaged: the short term (i.e. during this legislature), the medium term (i.e. before 2030) the long term (i.e. between 2030 and 2050).

8.2.1. Technical paths

- Setting up a strategy to activate the potential for collective renovation of buildings. In Section 7.4 we have shown that the LCOH of heat distributed via a network is three times higher for a low-energy district (2050 standard) than for a district whose consumption is similar to the average consumption observed today. Under these conditions, if we want to develop heating networks in Brussels, it will be necessary to determine in which districts collective renovation, rather than individual renovations, should be undertaken by directly integrating the profitability of a heating network over the long term. This means that here the renovation can potentially be taken less far than with individual renovations. In these cases, it is always a question of leaving the party responsible for collective renovation to determine the best balance between the level of renovation and the supply of carbon-free heat. The objective of this collective renovation must be carbon neutrality by 2050. This discussion will be fully integrated into the implementation of the Alliance Emploi Rénovation desired by the Brussels Government.
    - Economic implications: Very low (the cost of the study).
    - Implications in terms of jobs: None.
    - Legal and legislative implications: potentially high. This would require reviewing the renovation strategy to incorporate this notion of collective renovation.
    - Implementation deadline: Short-term:
- Developing pilot projects for low-carbon heating networks. Once it has been determined exactly which districts are best served by providing decarbonised heat (or cooling) via a

heating network, it will be appropriate to experiment with the deployment of this type of solution on a 'real scale'. This could be done through a call for tenders for the collective renovation of a district which could be financed through public private partnerships. As it will be a question of building carbon-free heating networks, the simplest solution would be to supply them with biomass. We know that the combustion of biomass is subject to strong environmental requirements in the Brussels-Capital Region. However this centralised solution should make it possible to greatly reduce the nuisances of biomass in terms of atmospheric pollutant emissions (excluding CO_2). It will also be necessary to ensure that the biomass used is produced in a sustainable manner.

  - Economic implications: potentially significant for the regional budget. Everything will depend on the method of financing the project and the involvement of private partners.
  - Implications in terms of jobs: significant job creation for the construction of networks and the heating plant.
  - Legal and legislative implications: could require certain exemptions in terms of individual renovation obligations if the Brussels framework is not adapted.
  - Implementation deadline: Medium term.

- <u>Studying the feasibility of 4th generation networks.</u> Alongside a heating network supplied by biomass, it would also be advisable to study the feasibility of developing 4th generation low-temperature heating (or cooling) networks of that could use the canal as a source of cold for a heating plant. However, many questions, both technical and economic, remain open (real potential of the canal without overexploitation of the thermal deposit, economic benefit, etc.) which will have to be analysed in a specific study.
  - Economic implications: none (the cost of the study)
  - Implications in terms of jobs: None.
  - Legal and legislative implications: None.
  - Implementation deadline: Short-term:
- <u>Adapting the legislative framework to allow the injection of biomethane into the Brussels network and its use.</u> The SWOT analysis shows that the extent of the natural gas network in the Brussels-Capital Region is one of the strengths that the Brussels authorities can use to decarbonise the production of heat and cold. Indeed, it could very easily convey the biomethane produced on or outside the regional territory to provide part of the residual heat needs. The use of biomethane will not require any adaptation of the network or major modifications to the combustion installations at the end consumers. The traceability of biomethane could be ensured via a system of Guarantee of Origin Label (LGO) (BRUGEL, 2017). However, we must be aware of the fact that the potential of biomethane produced in Belgium will remain limited in relation to total consumption. A recent study (VALBIOM, 2019) indicates that the potential for the production of injectable biomethane into the network amounts to 15.6 TWh while the gross domestic consumption of Belgium, in 2019, is 193 TWh (FEBEG, 2019). In addition, the biomethane production capacity on the territory of Brussels will necessarily be low compared to regional energy needs.
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  - Economic implications: Biomethane is still a more expensive fuel than natural gas. However, the situation could change favourably if a progressive carbon price is put in place.
  - Implications in terms of jobs: None
  - Legal and legislative implications: Real but certainly not major

  - Implementation deadline: Short term

- <u>Defining a low-carbon coverage strategy for residential needs after renovation</u>

  After the implementation of the Renovation Strategy, the heat requirement of the Brussels-Capital Region will still amount to 5.8 TWh, which will have to be covered by carbon-free forms of energy (see Section 2). At best, biomethane can only represent a fraction of this supply because of its actual availability. The combustion of solid biomass will come up against very strict atmospheric emission standards which should only allow a few centralised heating network solutions. Likewise, the use of solid biomass will also be limited to its sustainable exploitation potential. Under these conditions, it will be necessary for the Brussels-Capital Region to analyse precisely how the residual heat (and cooling) needs could be covered by 2050. At first glance, it appears that most of these needs will have to be covered by electric heating systems such as heat pumps, direct electric heating or even 4th generation networks powered by centralised heat pumps. Note that this heating electrification solution will only have climatic significance if electricity production is carbon-free, which should be the case by 2050.

  - Economic implications: Very low (the cost of the study).
  - Implications in terms of jobs: None.
  - Legal and legislative implications: None.
  - Implementation deadline: Short-term:

- <u>Adapting the legislative framework to allow the injection of synthesis gas into the Brussels network and its use.</u> The potential for biomethane will remain limited, as will the availability of biomass in general. On the other hand, the production potential of synthesis gas is a priori much greater if we consider imports from third countries. Although these solutions remain very unprofitable at present, the situation could change in the future due to the fall in production costs but also to the gradual introduction of carbon pricing on a Belgian and European scale. These synthesis gases can be produced from excess carbon-free electricity produced in Belgium or abroad. Hydrogen injection is possible in the existing natural gas network in limited proportions (around 10%) even if this option will have to prove its technical and economic relevance. Beyond that, it will be possible to use synthetic methane which will not require adaptation of the network or of the combustion installations.

  - Economic implications: The production costs of syngas is currently very high compared to fossil solutions. Nevertheless the *spread* between synthesis gas and natural gas should evolve favourably with the improvement of technological solutions (lower production costs of synthesis gas) and with the introduction of progressive carbon pricing (progressive increase in the price of fossil natural gas).
  - Implications in terms of jobs: None
  - Legal and legislative implications: Real but certainly not major
  - Implementation deadline: Long term

8.2.2. <u>Legal avenues:</u>

- <u>Adapting the legislative framework of energy communities to promote cogeneration for each building and heating by heat pumps.</u> The transposition of Directives 2018/2001 and 2019/944 will establish the concept of renewable, local and citizen energy communities and collective self-consumption of electricity in Brussels law. To promote the development of cogeneration within apartment buildings, the legislative framework should be adapted in such a way as to facilitate the self-consumption of the electricity production of cogeneration installations within the same building. This kind of adaptation will improve the profitability of cogeneration projects, which could negate the significance of the multiplier factor for the granting of GCs for apartment buildings. However, it should be noted that the best cogenerations are supplied with natural gas. Therefore, future investors will have to be assured that by 2050, their new facilities can be supplied with biomethane or synthetic gas, otherwise they will give up engaging in such projects. Finally, it should be noted that the incentives for collective self-consumption within the same building or an energy community could promote the electrification of heating via heat pumps.

  - Economic implications: A priori, public finances should not be impacted by these adaptations but they could be economically attractive for consumers.
  - Implications in terms of jobs: greater development of cogeneration in apartment buildings and heat pump heating solutions will certainly generate jobs.
  - Legal and legislative implications: Real but certainly not major
  - Implementation deadline: Short term

8.2.3. Economic avenues:

- Maintaining a system of subsidies and loans for the most relevant carbon-free solutions. To support each player, whether residential or professional, public support remains relevant both in terms of financial assistance for the installation of decarbonised heating or cooling solutions and in terms of guidance on the technologies recommended by public authorities. The necessary level of intervention of the public authorities could, where applicable, be based on a calculation of LCOH as we used it in Section 6. As the natural gas network could be one of the key elements of the decarbonisation strategy of the Brussels-Capital Region (thanks to biomethane and in the longer term to synthesis gas), the subsidies for the installation of natural gas boilers condensation remain relevant. However, they should only be granted after an in-depth renovation of the home to ensure that they are not oversized and only cover the residual (and irreducible) needs of the building in question. Therefore, aid for renovation remains, of course, the first priority. This is what will reduce the energy needs for heating and cooling.
  - Economic implications: The cost to the public authorities will depend on the level of support decided.
  - Implications in terms of jobs: the energy transition will be a major source of job creation in the future.
  - Legal and legislative implications: None
  - Implementation deadline: Short term
- Establishing favourable electricity pricing for heating by heat pumps and storage of renewable electricity in the form of heat. One of the ways to decarbonise the residual demand for heat and cold is to electrify it. Under these conditions, it seems relevant to use the levers available to the Region (in compliance with the regulator's tariff competences) to promote heating by heat pumps but also the storage of electricity in the form of heat. In this respect, it is worth recalling that this is an option that was implemented in Belgium at the beginning of the nuclear power programme with the bi-hourly tariff (for DHW heating) and the exclusive night tariff (for storage heating). They both aimed to store excess electricity produced by nuclear power plants as heat overnight.
  - Economic implications: A priori, public finances should not be impacted by these adaptations but they could be economically attractive for consumers.
  - Implications in terms of jobs: heat pump heating solutions should generate jobs.

  - Legal and legislative implications: Actual
  - Implementation deadline: Short term (for the new tariff period)

- Promoting public-private partnerships and third-party investment in the development of carbon-free heating networks. Currently, there are forms of third-party investments which relate solely to improving the energy performance of more or less large groups of buildings. A collective renovation strategy, including the implementation of carbon-free heating networks where this is justified, should allow the emergence of public-private partnerships whose objective is no longer improving energy performance but carbon neutrality. at a determined time horizon (at the latest in 2050) for a given district or set of housing units.
  - Economic implications: potentially significant for the regional budget. Everything will depend on the method of financing the project and the involvement of private partners.
  - Implications in terms of jobs: significant job creation for the construction of networks and the heating plant.
  - Legal and legislative implications: could require certain exemptions in terms of individual renovation obligations if the Brussels framework is not adapted.
  - Implementation deadline: Medium term

- Implementing carbon pricing. In the opinion of many economists, the implementation of carbon pricing is an essential condition for the success of the energy transition[74]. As it is difficult to envisage it within the framework of the competences of the Brussels-Capital Region, it should be supported by the Brussels authorities at the federal level. However, it should be noted that carbon pricing could, despite everything, be implemented in Brussels without waiting for the other federated entities if this pricing is part of the arsenal of environmental taxation in Brussels.
  - Economic implications: potentially significant and positive for the regional budget. A carbon tax could help finance the energy transition in Brussels and could allow redistributive effects to the households that need it most.
  - Implications in terms of jobs: The net impact in terms of job creation of a carbon tax is difficult to estimate and is outside the scope of this study.
  - Legal and legislative implications: significant; federal (and/or regional) legislation should be adapted. In addition, the implementation of carbon pricing is politically very delicate.
  - Implementation deadline: Medium term

8.2.4. Financial avenues:

- Setting up a guarantee fund for 4th generation district heating networks. The canal could potentially serve as a cold source for a 4th generation heating network which works at low temperature. Nevertheless, there are still many uncertainties as to the profitability and the technical difficulties that this type of installation will pose in practice. To reassure potential investors, the Region could set up a guarantee fund that would be used to secure investments

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[74] See, for example, the interview with the Governor of the National Bank on 12 February 2021. https://www.lecho.be/economie-politique/belgique/general/la-banque-nationale-plaide-pour-une-taxe-co2/10283893.html

in these innovative networks.

  - Economic implications: potentially significant and this will have a negative impact on the debt ratio of the Brussels-Capital Region but, in principle, these funds can be recovered at the end of a determined period.
  - Implications in terms of jobs: if this fund makes it possible to promote the creation of 4th generation district heating networks, the impact in terms of jobs will be linked to their construction and maintenance.
  - Legal and legislative implications: Weak or nil.
  - Implementation deadline: Medium term

8.2.5. Other avenues:

- Communicating on the importance of the transition and the associated Brussels policy. Communication and information on the policies put in place to ensure the energy transition in Brussels will remain fundamental. These are important to ensure that the population adheres to measures which may appear restrictive (obligations to increase housing insulation standards, etc.).
  - Economic implications: Low, linked to the budgets allocated to communication campaigns.
  - Implications in terms of jobs: None
  - Legal and legislative implications: None.
  - Implementation deadline: Short term

- Training professionals from all relevant sectors. The energy transition will require unwavering support from all of society and will mobilise considerable human, technical and economic resources. Faced with this challenge, we must be able to count on competent professionals who will carry out the energy renovation of Brussels' buildings to the highest standard and at the lowest cost. The Alliance Emploi Rénovation specifically includes a training component for stakeholders. In addition, this mobilisation of professionals will generate jobs, some of them local.
  - Economic implications: depending on the training budgets that will be provided for in the Alliance Emploi Rénovation.
  - Implications in terms of jobs: Importantly, the renovation of buildings creates many jobs, both skilled and unskilled.
  - Legal and legislative implications: Weak or nil.
  - Implementation deadline: Short term

8.3. By way of conclusions

The energy transition in the Brussels-Capital Region has started and is supported by numerous policies and strategic orientations (see Section 4). From a long-term perspective, all heating and cooling needs will have to be carbon-free. To achieve this, it will of course be necessary to further improve the energy performance of buildings in Brussels, as is moreover provided for in the renovation strategy.

Residual heat and cooling needs must be covered by carbon-free energy sources. Some of these can be electrified. While the electricity generation fleet will temporarily emit more CO_2 with the closure of nuclear power plants, it will become less and less CO_2 emitting as the renewable part of the generation mix increases. Individual heat pumps are therefore needed to meet an increasing share of the heating and cooling needs. To a lesser extent, direct electric heating could help cover the demand for heating.

In certain particular configurations (see Section 7), the heating networks will be able to cover part of Brussels’ needs but they must imperatively be supplied by carbon-free energy sources so as not to compromise the overall objective of decarbonisation in Brussels. As the potential for waste heat recovery is very low or even non-existent in the long term (phasing out of the Neder-Over-Heembeek incinerator), the Brussels-Capital Region could develop district heating networks that burn renewable fuels that it needs. This is locally produced biogas or even wood if air quality standards allow it. The Brussels-Capital Region could also test the feasibility of 4th generation district heating networks along the canal or elsewhere.

Beyond the electrification of heating needs and collective solutions, the Brussels-Capital Region could use its particularly extensive and dense natural gas network. While it is currently used to distribute a fossil gas emitting CO_2, it may, in the future, be converted, in principle free of charge, to deliver carbon-neutral gas to the various residential and professional users. Initially, it may be biomethane that has been produced in the Brussels-Capital Region or in other regions or countries. In the longer term, we could inject synthesis gas, possibly imported. Beyond covering heating and cooling needs, the current Brussels gas network could also participate in the decarbonisation of mobility in Brussels by supplying service stations selling carbon neutral CNG.

Despite its very urban character, the Brussels-Capital Region therefore has significant assets to decarbonise its heat and cooling needs by 2050. To achieve this, however, it is important to guide the investment choices of all players, whether residential, professional or institutional, in a long-term perspective. From now on, we must think *‘future proof’*.

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