WP1 – D1.2 Overall performance of proposed measures

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Name of KIC project the report results from that contributed to/ resulted in the deliverable	Green Light District
Name of report	WP1 – D1.2 Overall performance of proposed measures
Summary/brief description of report	This report presents the energy and carbon performance of combined measures for the Green Light District, as explored in the reports called Reduce, Reuse, and Produce.
Date of report	20-12-2020

Supporting Documents: attach in pdf format

WP1 – D1.2 RESEARCH REPORT

Overall performance of proposed interventions

KAVA: 2.2.18

Delft University of Technology

Climate-KIC is supported by the EIT, a body of the European Union

WP1 – D1.2 RESEARCH REPORT

Overall performance of proposed interventions

December 2021

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Content

List of Abbreviations

AE	All Electric
ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
COP	Coefficient Of Performance
DHN	District heat network
DHW	Domestic hot water
GJ	Gigajoules
GLD	Green Light District
GWh	Gigawatt hours
ha	Hectares
kWh	Kilowatt hours
LT	Low Temperature
MWh	Megawatt hours
PJ	Petajoule
PV	Photovoltaics
PVT	Photovoltaics thermal
SCOP	Seasonal Coefficient of Performance
VVE	Owners' associations
yr	Year

1 Introduction

1.1 Background

The project is about the transformation of the historical city centre, the 'Red Light District' into the 'Green Light District': a future proof, sustainable and prosperous area. The project follows a bottom-up approach by activating the community and with numerous co-creation projects.

The City of Amsterdam wants to be free of natural gas for energy use by 2040 and at the same time reduce their CO_2 emissions with 95 percent by 2050. This includes the historical city centre. Therefore, work package 1 analyses the potentials for a systemic renewable energy plan, following the New Stepped Strategy towards energy and carbon neutrality [Dobbelsteen 2008]:

0. Research
1. Reduce
2. Reuse
3. Produce

This research report is focused on task 1.6 of D1.2, which is related to all steps of the New Stepped Strategy. In the description of work it is defined as follows: "In this final task of WP1, the energy and carbon impact of all proposed measures will be assessed."

Research questions:

- What is the energy demand and renewable energy production with the implementation of all proposed strategies and solutions?
- What are the greenhouse gas emissions (translated to CO_2 equivalents) of the new plans?
- What are recommendations for further research or actions for further implementation?

1.2 Methodology

As was introduced in the Research report, the research executed by TU Delft is largely based on the methodology developed for the EU FP7 project called City-zen: 'The City-Zen Urban Energy Transition Methodology' [Dobbelsteen et al. 2018]: Reduce, Reuse and Produce. For the Green Light District, all of these aspects are studied to determine their potential. All the steps are elaborated in 2020 in 4 reports representing the steps for the Green Light District area:

- Reduce report (Task 1.2)
- Reuse report (Task 1.3)
- Produce report (Task 1.4)
- Combined strategies report (Task 1.5)

In the combined strategy report all steps are implemented in an order-1 historical building including the associated installation technical measures. Although it would be good to follow the steps of the New Stepped Strategy in time order from an energetic point of view, it seemed more practical to take the steps in reverse order. Insulating for example, which is the first step (reduce), fits best when the building has to be maintained, renovated or when renters move to another building. It takes too long to wait for this and then go to the next step. For that reason it was advised to take the steps in a reverse order to make implementation more practical. This means that we can start with step 3 and already have some reduction of CO_2 emission immediately by producing renewable energy (e.g.

electricity with PV panels. Then we can re-use energy for example with the help of a heat pump. Finally we can reduce the energy demand further, for example by insulating the building to reduce the heat demand end lower the heating temperature which will make the heat pump more efficient and so reduces the electricity demand for heating. The final goal for all buildings is to be disconnected from the gas grid (all electric) with the lowest CO_2 emission. For the CO_2 emission of electricity from the grid we use a CO_2 emission of 0.34 kg/kWh, according to the NTA 8800 [NEN, 2020). This value is policy determined and is based on the current electricity production of the Dutch network, including production with sustainable sources. Towards 2050, these CO_2 emissions must decrease towards zero.

1.3 Principles for the local grid

In the combined strategy report it was also advised to make use of a fifth-generation local thermal grid such as Kowanet[1]. A KoWaNet serves for the exchange and storage of heat and cold and can have various sources (figure 1). Such a network is the preferred alternative to natural gas:

- It can be applied locally and extended or linked over time;
- It can be used to heat and cool energy efficiently;
- In the long run, it has the lowest CO_2 emissions and consumption costs;
- It can be managed by local residents, societies of house owners or energy cooperatives.

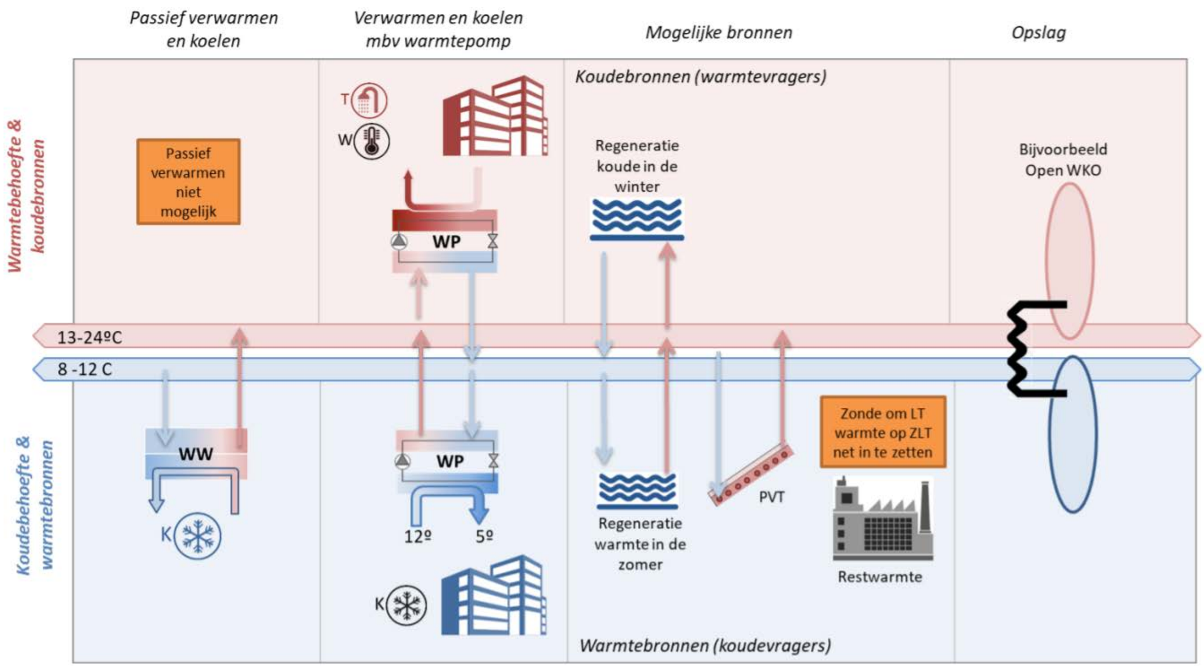

Figure 1: A 5th-generation thermal grid or KoWaNet [www.kowanet.nl]

However, there are some preconditions that determine whether such a network is promising and affordable for a neighbourhood:

- There must be a certain density of buildings;
- Residents must be willing to cooperate and think about suitable solutions;
- Homes must be able to be heated with temperatures of 65 degrees or less;
- There must be space for the heat pump and storage vessel for domestic hot water;
- There must be sustainable heat and/or cold sources in the area (ATES or BTES);

[1] Kowanet.nl

- Storage of heat and cold must be feasible locally;
- Pipes of the network must be relatively easy to lay.

Therefore, further local research should determine to what extent these conditions are present. For this all-electric future situation there will be extra electricity and power demand for the heat pumps and electric cooking. On the other hand electricity-production with PV-panels will also need a reinforced electricity grid. Because an all-electric energy supply will be the ultimate solution, a reinforcement of the electricity grid can be realised at the same time as the construction of a thermal network, which could reduce the construction costs.

It is advised that there will be a transition in time, from natural gas boilers to electric heat pumps, possibly in hybrid form, for the period up to 2040. As indicated with indicative calculations, even a hybrid system then is soon cheaper than a gas boiler. The municipality of Amsterdam can start with the preparation for this process by investing in a local source grid with heat and cold storage in an ATES, eventually combined with the reinforcement of the local electricity grid. Building owners can connect with heat pumps to this ATES-based source grid.

For making GLD natural gas free and carbon neutral, this network is the best energy solution for the heat supply (and possible cooling) of buildings in order to realise natural a gas-free GLD in time, with low energy consumption costs and without visible external units for (air) heat pumps.

1.4 Principles for the buildings and building services

The type of building is less important for the choice of strategy, because of the choice of heat pumps, we opt for heating with a maximum supply temperature of 65°C with the current heat pump technology. This means that all buildings must be ready for this by the year 2050, either by limiting heat losses (insulation of the roof, facade and floors, better insulating glass and frames, less ventilation losses and heat recovery), or by adjusting the heat output elements (LT air heating, LT radiators/convectors, wall or underfloor heating), or both.

Figure 2: Jaga Strada hybrid ventilator convector [Source: www.jaga.nl]

Heating should therefore be realised at the lowest possible temperature because then the efficiency of the heat pump is best. When energy losses are limited, low-temperature (LT) heating can be delivered through existing radiators. It is also possible to install LT release equipment. These can be enlarged radiators, underfloor or wall heating. Radiators, for example, can be replaced without much renovation, by a fan coil unit of the same dimensions (Figure 2). Such a convector gives off the same amount of heat at 55°C, compared to the radiator at 90°C supply temperature. If the heat losses are further limited, for example with insulation, the temperature can even be reduced to 35ºC, which means that the heat pump can heat even more efficiently. These low temperatures can also be delivered through LT radiators. Fan coil units and LT radiators have the advantage that they also are able to cool. There will be some noise produced by the small fans.

Figure 3: Installation of a hybrid heat pump system; gas boiler, heat pump and hot water storage. [Source: https://www.vakbladwarmtepompen.nl *]*

When using a heat pump in a building, there must be space for the heat pump itself and a storage tank for hot tap water, close to the current gas boiler where all connections are located. This requires at least 1.5 m^2 of floor space (figure 3). In the case of multi-storey buildings or in houses that are close to each other, you can create a separate collective boiler room outside the house and distribute the heat (up to 65ºC). However, this requires separate metering and administration of the heat supply.

2 The current energy demand

2.1 Heat and electricity demand

The current energy demand for the GLD has been calculated in report D1.1 Energy characteristics and challenges. The following table shows the final figures for heat and electricity demand in the year 2017 (table 1). We compare the three-stepped measures with the consumption in the year 2017. The heat demand has also been specified for space heating, domestic hot water (DHW) and cooking (not in D1.1). For electricity the total demand is shown and also what part of the electricity is used for cooling devices.

The demand is based on the use of gas and electricity on the meter in buildings in the year 2017 and conversion losses are excluded. This way, the potentials of different measures of energy reduction can be compared with these figures and next devices (e.g. a heat pump) can fill in the demand. The final demand can be compared with the energy demand of 2017.

Table 1: Energy demand per year for GLD situation 2017

ENERGY DEMAND GREEN LIGHT DISTRICT						
2017	Current Situation					
heat	(MWh/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	777,895	656,040	106,038	15,816	
	Residences	51,702	38,777	11,633	1,293	
	Small businesses	86,215	73,283	11,208	1,724	
	Large businesses	639,977	543,980	83,197	12,800	
Electricity	total	195,447	177,744			17,703
	Residences	12,006	12,006			-
	Small businesses	50,562	45,683			4,879
	Large businesses	132,879	120,055			12,824

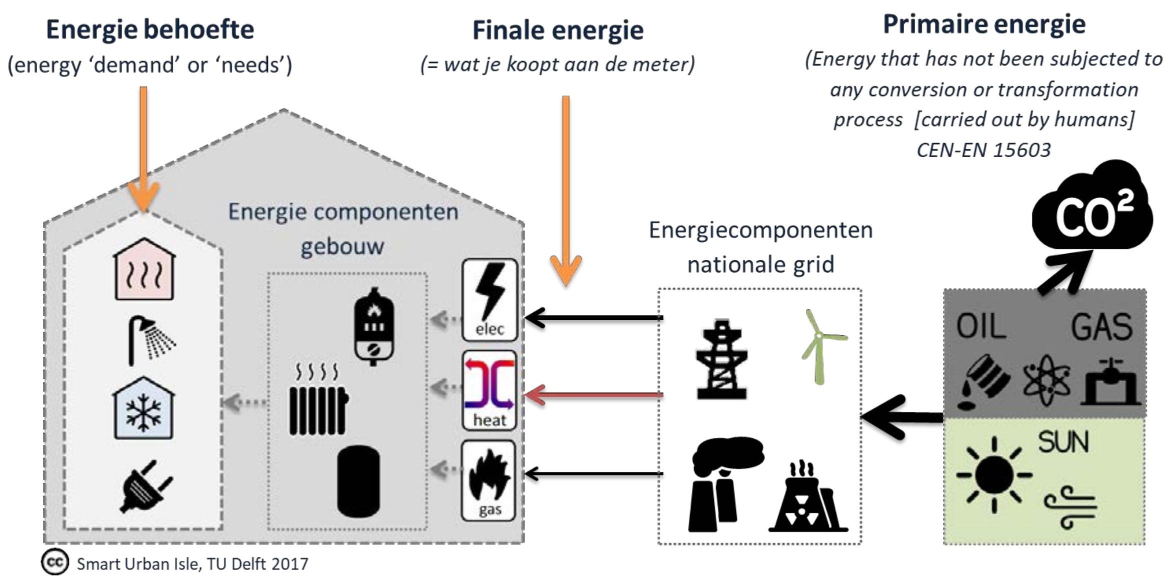

Figure 4: Diagram (in Dutch) showing the relation between primary energy (right), final energy consumption (what the user buys on the meter) and the energy demands (left) [Smart Urban Isle, TU Delft 2017].

Heat demand is not the amount of gas that you buy from your supplier (called: final energy consumption or consumption on-the-meter), but the energy needs, the amount heat that the building demands to be heated. This excludes the losses by the conversion of gas into heat by your boiler system and the gas used for cooking and domestic hot water. The final conversion to the heat demand is made by using a gas boiler efficiency of 80%.

The numbers for the energy demand are further explained in the reduce report and may need some extra attention: 84% of the heat is needed for space heating and 93% of the final heat demands is coming from the businesses (15 times as much as houses), while this research mostly focusses on housing. Because of the different use of heat in businesses it is recommended to be aware of this fact. Because there is no specific data available for the businesses, it is also recommended to investigate more precise what measures can be taken to reduce the heat-demand and the effect of these measures.

The electricity demand for businesses is even more than 16 times the amount of electricity for houses! Businesses also have a different use of electricity than houses (also no specific data available) and therefor it is also recommended to investigate more precise what measures can be taken to reduce the heat-demand and the effect of these measures. Part of the electricity demand for business is used for cooling. The residual heat from cooling (about 3 times as much as the electricity demand) can be used as a source for a heat pump for space heating and DHW.

2.2 The current carbon emission

The CO_2 emission caused by the combustion of natural gas is 1.89 kg per m^3. The amount of carbon emitted by the use of natural gas is the heat demand in kWh per year, divided by the efficiency of the heater (80%), divided by the energy content of 1 m^3 natural gas (which is 9.8 kWh) and multiplied by the CO_2 emission of a m^3 natural gas, which is 1.89 kg CO_2. This means that 1 kWh of heat, coming from combustion of natural gas, causes 0.24 kg CO_2.

Table 2: CO_2 emission in tonnes per year for GLD situation 2017

CO_2 emission GREEN LIGHT DISTRICT						
2017 Current situation						
heat	(tonnes of CO_2/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*186,695*	*157,450*	*25,449*	*3,796*	
	Residences	12,408	9,306	2,792	310	
	Small businesses	20,692	17,588	2,690	414	
	Large businesses	153,594	130,555	19,967	3,072	
Electricity	*total*	*66,452*	*60,433*			*6,019*
	Residences	4,082	4,082			-
	Small businesses	17,191	15,532			1,659
	Large businesses	45,179	40,819			4,360

As mentioned before, the CO_2 emission for the production of 1 kWh electricity from the grid is 0.34 kg/kWh. That is 42% more than with combustion of gas and will decrease when there is more sustainable electricity on the grid. Table 2 shows the CO_2 emission for heat and electricity demand.

Most of the CO_2 is emitted for space heating, so this takes most attention. The total CO_2 emission for the GLD is 253,147 tonnes of CO_2. This amount will be reduced in time with the New Stepped Strategy in reverse order. The suggested plan for GLD is to disconnect from the gas grid in time and to heat with heat pumps instead, as much as possible. Depending on the situation we can reach efficiencies of 200 till 600% with a heat pump which means that the CO_2 emissions will be 0.17 – 0,06 kg CO_2/kWh heat.

2.3 Steps in reverse order

In order to better fit the energy transition to all electric in time, the 3 steps are taken in reverse order, starting with the production of sustainable energy, as described in the Produce report. The next step is Re-use, which can be done on a building scale by recovering heat from ventilation air and/or shower drain water. On an urban scale this can be done by exchanging and storing (seasonal storage) heat and cold in the soil or in groundwater. For this, a local source network with heat-cold storage must be realized to which buildings with a heat pump can be connected. In this way heat and cold can be exchanged and stored. The Re-use report provides options for local sources of residual heat and cold.

The last step is to reduce the energy demand. The options for this are included in the Reduce report. This concerns the use of energy-efficient electrical appliances, insulation of the building, reduction of domestic hot water (DHW), etc. These measures can be taken when it best suits the time, for example during renovation, maintenance, sale of a building or a change of tenants.

The Combined Strategies report examined what these 3 steps mean for a 1st-order building in GLD, in terms of energy consumption, indicative costs and payback time. With regard to the costs of the measures, reference is therefore made to the combined strategies report. The following paragraphs of this report will indicate to what extent these steps can reduce CO2 emissions (as in 2017 according to the previous table) as a result of energy consumption.

3 Reduce, Reuse and Produce steps in reverse order

Based on the Reduce, Reuse and Produce reports, the energy demand, CO_2 emissions and reductions for Green Light District are calculated, starting with Produce potentials.

3.1 Produce potentials in the Green Light District

Table 3 below shows the potential of sustainable energy that can be produced in the 2012 area, according to the Producer report. Most of it is electricity or heat from solar. This amount of energy is based on rough assumptions. Heat and/or electricity from biomass (organic waste food) happens already outside the district and is not taken into account for the reduction of CO_2 in this calculation. Deep geothermal aquifers are considered unfavourable, as the aquifer is too thin here and/or the temperature of the aquifer is lower than 45°C. For that reason it is also not taken into account. Heat or cold from water is seen as reusing it and is part of the next step. Although there is some potential for smaller wind turbines, the placement is difficult, yield may be low and the payback time long. For that reason wind is also not taken into account.

Table 3: Potentials of sustainable energy sources in GLD

category	source/technology	electricity			heat			cold	
solar	roofs	8,999	MWh	OR	20,831	MWh			
wind	turbines	126	MWh						
biomass	waste (fermentation)	167	MWh	OR	251	MWh			
water	surface				31,680	MWh	OR	31,680	MWh
	sewage				2,055	MWh	OR	2,055	MWh
	drinking				1,370	MWh	OR	2,466	MWh
geothermal	deep				494	MWh			
	ultradeep	-			-	MWh			
	TOTAL	9,292	MWh		56,680	MWh		36,201	MWh

The highest yield for sustainable energy production comes from solar (on roofs). We can choose for solar surface for electricity or high temperature heat production but it is also possible to use this electricity for a heat pump(boiler) that gets its (low temperature) heat from exhausted ventilation-air, other low temperature waste heat sources or PV-Thermal panels. With the latter you can produce more heat with the same surface than using this space only for solar heat collectors, because the COP (coefficient of performance, i.e. the efficiency) of the heat pump will increase. This is calculated in the next step. The choice here is to use all the available space for PV-panels, producing electricity.

At this moment PV-panels pay themselves back within five years and financing is possible, so there is a good reason for building-owners to use the available roof-surface for PV-panels. Combining this with roof insulation or preparing the panels for a combination with thermal (PVT) is recommended. The electricity produced with PV panels in the GLD is 9 GWh per year and is equally distributed across the categories of residences, small and large businesses: 3 GWh each one of them (table 4). This brings the CO_2 emission from is 253,147 to 250,087 tonnes of CO_2 per year, a reduction of 1,2% for 116,322 m^2 of roof with PV-panels. This means there is just a small potential to produce sustainable energy within the district, relative to the energy demand.

Table 4: Energy demand in MWh and CO_2 emission in tons per year for GLD with PV panels

ENERGY DEMAND GREEN LIGHT DISTRICT						
Producing electricity with PV panels included						
heat	(MWh)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*777,895*	*656,040*	*106,038*	*15,816*	
	Residences	51,702	38,777	11,633	1,293	
	Small businesses	86,215	73,283	11,208	1,724	
	Large businesses	639,977	543,980	83,197	12,800	
Electricity	*total*	*186,447*	*168,744*			*17,703*
	Residences	9,006	9,006			-
	Small businesses	47,562	42,683			4,879
	Large businesses	129,879	117,055			12,824

CO2 emission GREEN LIGHT DISTRICT						
Producing electricity with PV panels included						
heat	(tonnes of CO_2/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*186,695*	*157,450*	*25,449*	*3,796*	
	Residences	12,408	9,306	2,792	310	
	Small businesses	20,692	17,588	2,690	414	
	Large businesses	153,594	130,555	19,967	3,072	
Electricity	*total*	*63,392*	*57,373*			*6,019*
	Residences	3,062	3,062			-
	Small businesses	16,171	14,512			1,659
	Large businesses	44,159	39,799			4,360
	total CO2-emeission:	**250,087**				

3.2 Reuse potentials in the Green Light District

On a building scale heat can be recovered and reused from the shower drainage or the exhaust air. On a district scale we can recover and use waste heat and cold by exchanging and storing it. Most of the waste heat on a district level in GLD has a low temperature and needs a heat pump to upgrade it to the desired temperature. The reuse-report describes the potentials of waste heat and cold in GLD. In the Green Light District, next to housing, multiple functions can be found with a heat potential:

- Shops (without product cooling)
- Supermarkets, shops and shopping malls (with product cooling)
- Hotel, restaurants, cafés
- Offices and other institutions
- Education (mainly university buildings)
- Health care (non-hospitals)
- Subway stations (ventilation shafts)
- Indoor car parking
- Webhosting and datacentre
- Sewage systems

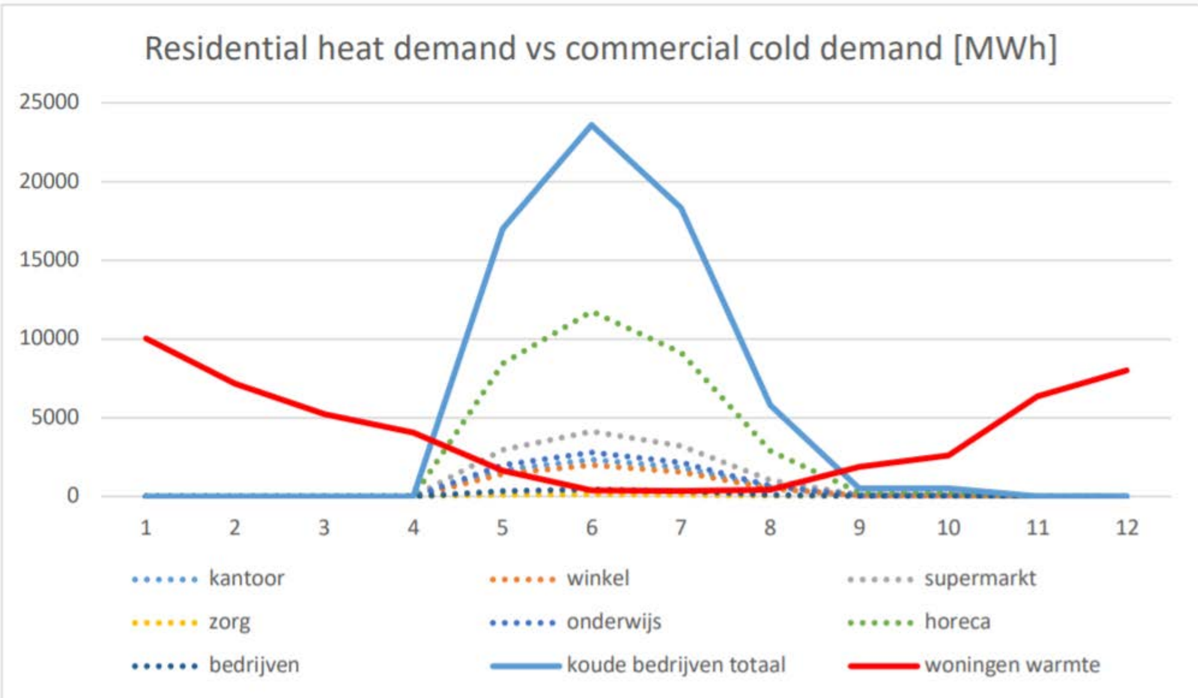

Figure 5: Heat demands of the residences over the year, plotted against the cooling demands of the businesses, showing the potential of exchanging energy when combined with seasonal energy storage.

At the same time, that heat is produced by a heat pump, on the other side waste cold is produced with the same electricity (demand). Dwellings mostly need heat and businesses mostly need cooling, so there can be a nice balance in GLD. Although most of the heat is needed in winter, and most of the cooling is needed in summer (figure 5). Therefor it is necessary that there is a low temperature distribution network to exchange heat and cold. This local network should be connected to a heat and cold storage (ATES) for seasonal storage.

The released condenser heat from cooling in GLD is estimated in the Reuse report at 83 GWh_{th}/yr. This is more than needed as a source for the heat pump to produce all the heat for the residential buildings. At this moment most of this residual heat is released in the outdoor air but in the future it can be released to the local grid and stored in the local ATES. On the other hand cold can be taken from the grid, which means a lower electricity demand for cooling (with or without heat pumps). This electricity reduction for cooling is not taken into account for the CO_2-emission calculation, because it is difficult to estimate. Around the area, multiple webhosting companies are found with residual heat potentials. Within the 1012 area, the main potential is the Schuberg Philis XS4ALL DC2 datacentre for which the waste heat potential is estimated at 103 GWh_{th}/yr, but further research needs to confirm this.

Next to waste heat from cooling, we can use heat or cold from other sources such as open water (31,680 MWh_{th}/yr), sewage systems (2,055 MWh_{th}/yr), drinking water (2,466 MWh_{th}/yr) and smaller sources like subway stations and indoor carparking. Solar thermal heat from PV-Thermal panels can be an additional heat source for heat pumps. When all the 116,322 m^2 PV panels from the last paragraph are provide with a thermal panel, an extra 70,000 MWh_{th}/yr can be used as a source for the heat pump.

Table 5: Energy demand in MWh and CO_2 emission in tons per year for GLD with heat pump and ATES

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reusing residual heat with heat pumps and ATES						
heat	(MWh)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*396,856*	*328,020*	*53,019*	*15,817*	
	Residences	26,498	19,389	5,817	1,293	
	Small businesses	43,970	36,642	5,604	1,724	
	Large businesses	326,389	271,990	41,599	12,800	
Electricity	*total*	*313,460*	*295,757*			*17,703*
	Residences	17,408	17,408			-
	Small businesses	61,644	56,765			4,879
	Large businesses	234,409	221,585			12,824

CO_2 emission GREEN LIGHT DISTRICT						
Reusing residual heat with heat pumps and ATES						
heat	(tonnes of CO_2/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*95,245*	*78,725*	*12,725*	*3,796*	
	Residences	6,360	4,653	1,396	310	
	Small businesses	10,553	8,794	1,345	414	
	Large businesses	78,333	65,278	9,984	3,072	
Electricity	*total*	*106,576*	*100,557*			*6,019*
	Residences	5,919	5,919			-
	Small businesses	20,959	19,300			1,659
	Large businesses	79,699	75,339			4,360
	total CO2-emission:	**201822**				

It is not necessary to insulate the building and choose for low-temperature heat release to make use of a heat pump. In the combined strategy report it was shown that approximately half of the heat demand can be produced with a hybrid heat pump when there is a distribution network with storage. The average SCOP (Seasonal Coefficient of Performance) for the heat pump will be around 3, depending on the temperature of the source. This means that for every 3 kWh of heat, 1 kWh of electricity is needed. 2 kWh is taken from the residual heat from the heat grid. When 50% of all the heat demand is produced with the heat pump, then there is 50% less heat needed. This costs 1/3 of the reduced heat demand in electricity. The other 2/3 has to come from low temperature residual heat. The total heat demand now is 777,895 MWh/yr and will be 396,856 MWh/yr when the rest is provided by heat pumps with an electricity demand of 132,285 MWh/yr. This brings the CO_2 emission from is 250,087 to 201,882 tons CO_2/yr, a reduction of 19% and 50% in natural gas demand.

To reach this goal, 264,570 MWh residual heat and an ATES is needed. The ATES is seen as a storage and not as a source, although some heat can be extracted from it because of groundwater flows. When there will be low- or mid-temperature district heating grids somewhere in the near future, the return flow of these networks can be used as a source for the source-network in GLD. The maximum temperature in the source network is 30°C and 25°C in the ATES. With this system it is also possible to cool passively (with source temperatures around 12°C) Or active with the heat pump for lower system temperatures.

There is more research needed to explore the precise local waste heat potentials and the possibilities and costs for a local distribution network with ATES. With hybrid heat pumps and a local source-network with ATES it is not necessary to insulate the building before using a heat pump. It is also not necessary to use an outside air-unit and the efficiency of this heat pump is higher than with an outside air driven heat pump. Unfortunately the investment costs are higher, mainly because of the distribution-network and ATES. The question is who will invest in this so-called 5^{th}-generation district heating system (kowanet) and who does the organisation, financing, exploitation and administration that is necessary for this heat-network. The Municipality can contribute as well as local energy cooperation's, building owners and users of the building. Further research on the possibilities is recommended.

3.3 Reduce potentials in the Green Light District

The Reduce report estimated the savings for the buildings of GLD. First the reduction of the heat demand by insulating the building envelop and using better insulating windows. The measures were chosen based on what is allowed or not for each order, as described in the decision insulation tool. The effect on the reduction of the cooling demand by insulating the building has not taken into account. The savings for space heating are calculated on the base of a standard renovation (30% savings) and an advanced renovation (61% savings). The principles of the reduce measures are described in the reduce report and lead to a total saving for space heating of 30% for a standard renovation and 61% for an advanced renovation (figure 5).

Next to these savings, buildings can be heated with lower temperatures what results in a higher efficiency of the heat pump and thus lower electricity demand. In case of a standard renovation we estimate a SCOP of 4, instead of 3 and for advanced renovation a SCOP of 5. This also means that the building can be heated with a heat pump only and no gas heater is needed for space heating. The reduction of all the measures including the reduction for space heating brings the CO_2 emission of GLD to 124,956 tonnes/yr for standard renovation and to 103,320 tonnes/yr for advanced renovation. This is a reduction of 51%, respectively 59% compared with the current situation (table 6).

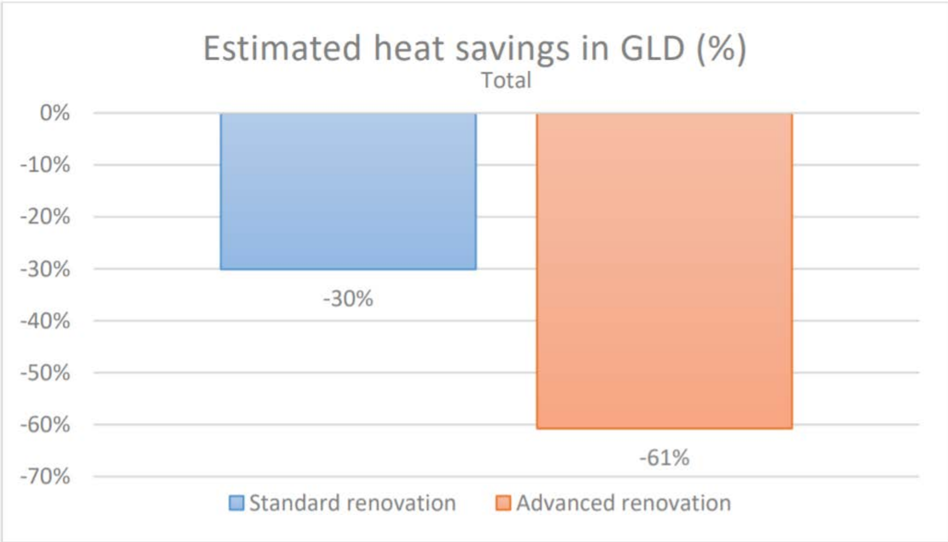

Figure 5: Graph of the estimated total savings for space heating

Table 6: Energy demand in MWh and CO_2 emission in tons per year for GLD with heat pump and ATES and advanced renovation (insulation)

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand space heating with heat pumps and ATES (advanced renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*68,836*	*0*	*53,019*	*15,817*	
	Residences	7,110		5,817	1,293	
	Small businesses	7,328		5,604	1,724	
	Large businesses	54,399		41,599	12,800	
Electricity	*total*	*255,291*		*237,588*		*17,703*
	Residences	13,969		13,969		-
	Small businesses	55,146		50,267		4,879
	Large businesses	186,176		173,352		12,824

CO_2 emission GREEN LIGHT DISTRICT						
Reduce demand space heating with heat pumps and ATES (advanced renovation)						
heat	(tonnes of CO_2/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*16,521*	*0*	*12,725*	*3,796*	
	Residences	1,706	0	1,396	310	
	Small businesses	1,759	0	1,345	414	
	Large businesses	13,056	0	9,984	3,072	
Electricity	*total*	*86,799*		*80,780*		*6,019*
	Residences	4,750		4,750		-
	Small businesses	18,750		17,091		1,659
	Large businesses	63,300		58,940		4,360
	total CO2-emission:	**103320**				

The Reduce report also estimates the energy savings for domestic hot water (DHW). The measures like a water-saving shower head, water tap with flow limiter and the use of a heat recovery system for shower drain water result in a 60% reduction of the thermal energy use for domestic hot water. To disconnect from the gas grid, this energy demand can be produced with the heat pump. Cooking has to be done then on electricity. For every MWh for cooking on gas, a MWh electricity is needed. Disconnecting from the gas grid means that buildings will have no fixed costs for the connection to the gas grid anymore.

Finally the Reduce report gives an estimation of the possible electricity reduction for appliances and lighting. Although this is an assumption and doesn't say much about future innovations, it is taken into account for the last CO_2 emission calculation. As shown in the Reduce report, large savings can be achieved in businesses when changing from artificial to LED light and by using more energy efficient ICT equipment. Therefore, the potential reduction of electricity consumption of businesses in the GLD is estimated at 37%. The reduction of the electricity consumption of residences in the GLD is estimated at 24%. Table 7 gives the final result of all reduce, reuse and produce measures. All the interim calculations can be found in the appendix.

Table 7: Energy demand in MWh and CO_2 emission in tons per year for GLD with heat pump and ATES, reducing DHW electric appliances, lighting and electric cooking for the advanced renovation (insulation) situation.

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand space heating and DHW heat pumps and ATES (advanced renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*0*	*0*	*0*	*0*	
	Residences	0				
	Small businesses	0				
	Large businesses	0				
Electricity	*total*	*208,439*	*190,736*			*17,703*
	Residences	10,700	10,700			-
	Small businesses	39,594	34,715			4,879
	Large businesses	158,145	145,321			12,824

CO_2 emission GREEN LIGHT DISTRICT						
Reduce demand space heating and DHW heat pumps and ATES (advanced renovation)						
heat	(tonnes of CO_2/yr)	total	of which for:			
			space heating	DHW	cooking	cooling
	total	*0*	*0*	*0*	*0*	
	Residences	0	0	0	0	
	Small businesses	0	0	0	0	
	Large businesses	0	0	0	0	
Electricity	*total*	*70,869*	*64,850*			*6,019*
	Residences	3,638	3,638			-
	Small businesses	13,462	11,803			1,659
	Large businesses	53,769	49,409			4,360
	total CO2-emission:	**70869**	with electric cooking and reduction appliances			

This is the final situation when all measures are taken and GLD can be disconnected from the gas grid. There is still a CO_2 emission of 70,869 tons because of the electricity demand, mainly from businesses, that cannot be produced within the GLD. Although the CO_2 emission has fallen by 72%, the buildings in GLD are not carbon neutral yet.

4 Conclusions and recommendations

4.1 Results of the CO_2 emission estimations

The graph of figure 6 shows the results of the different steps in reducing the demand, reusing residual energy and producing sustainable energy. There are not many possibilities in GLD to produce renewable energy. Putting PV panels on roofs is the only one effective measure to produce electricity. Using all the available and accepted roof area does not have much effect on the total demand: 1.2%. As mentioned before, in the current situation, carbon emissions are mainly determined by businesses: 93.5%.
Furthermore, we can see that most of the carbon emissions come from producing heat, mainly with natural gas: 74%. An adequate way to realise heat production more efficiently is by means of a heat pump. Because common heat pumps do not produce temperatures higher than 65°C, a hybrid system is initially chosen in which the heat pump supplies heat in addition to the gas boiler. As a result, 50% of the required heat can already be generated with the heat pump. The efficiency of a ground-sourced heat pump is better than an air-sourced heat pump and contributes more to lower carbon emissions.

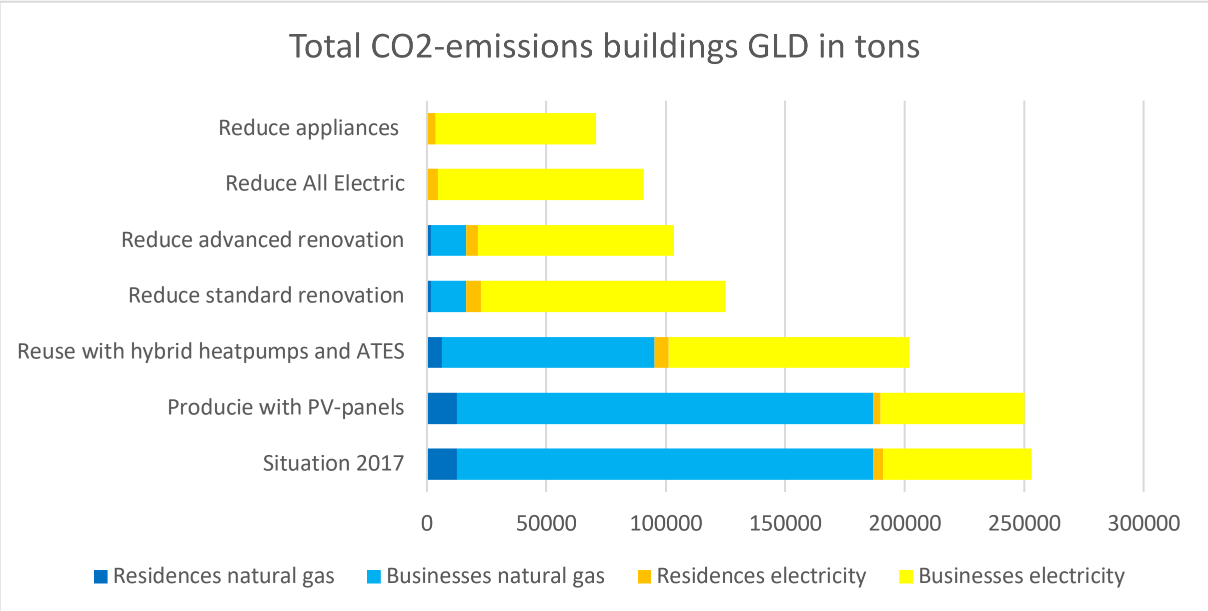

Figure 6: Graph of the estimated CO_2 emissions as a result of the different steps in reverse order.

Source network
In order to realise a system with a source network and ATES in the centre of Amsterdam, research will have to be done to find the space for it and to investigate if the underground is locally suitable for heat and cold storage. To limit the costs, the pipes in the streets can be installed during other street works such as quay, sewer or street renovations or combined with the laying of other pipes or heavier electricity lines. The municipality of Amsterdam could pay this network or contribute to it to

lower the costs for the building owner. They then only have to buy the heat pump and connect to the grid to have relatively cheap heat with low carbon emissions. Especially in the inner city, where building owners often have high maintenance costs for the historic buildings and where a number of energy-saving measures cannot be realised or are not allowed, such as insulation, PV panels or an outdoor unit for an air heat pump, it would be lenient to compensate them. Finally, these beautiful buildings provide a lot of income from tourism; they are the gems of the city centre. A source network with heat pumps has quite an effect on the CO_2 emission for domestic heating, especially for businesses, who have a high heat demand. Maybe therefore, they can contribute more to the network and also have the possibility of cheaper cooling.

Heat pump

To make the connection to the network (nearly) free of costs, building-owners are more likely to switch to a heat pump and will be more motivated to reduce the heat demand of the building by insulating. When using a heat pump, insulating has a double effect on the electricity demand. Firstly, it reduces the heat demand and secondly, they can heat with lower temperatures, which makes producing the heat with a heat pump more efficient, i.e. demanding less electricity. The next step then, reducing by insulating, has the biggest effect on the reduction of carbon emissions, especially when it concerns an advanced renovation.

Gradual renovation

When the building is energetic renovated, the gas heater can be removed and often the same heat pump that is left can take over the heating of the building because the total heat demand often is less than half the demand in case the building had not been renovated. The same applies to the source grid: in most cases, the demand from this grid is not more than it was before renovating, so it is not necessary to expand the grid in the future. Building-owners can plan their standard or advanced renovation so that energy costs are saved because in the future natural gas will rise in price more than electricity.

Disconnecting from the gas grid

Full heating with a heat pump and cooking on electric instead of natural gas enables an all-electric solution and disconnection from the gas grid. Residents and users of the building then do not have any costs for the connection to the natural gas grid anymore, which could be an incentive for an energetic renovation.

Big businesses

The possibility to further reduce the electricity consumption of equipment and lighting with more energy-efficient equipment can bring the total electricity consumption of residents down to the current level, even including the consumption for heating (previously with gas). This does not apply to companies that still have a high electricity consumption and therefore high CO2 emissions: more than 18 times as much as the residents. This can partly be explained by the fact that large-scale consumers pay considerably less for their electricity, which means that the payback period for measures is longer and therefore, there is less reason to take these measures. Probably there are extra savings to be made within these businesses. Further research into this is recommended and can be combined with research into the required cooling and residual heat that these companies can supply to a source network.

A smart combination of measures

It can be concluded that GLD can be disconnected from the gas network over time with the development of a source network with seasonal storage and heat pumps, possibly without much reinforcement of the electricity network. Although it is recommended to upgrade this electricity grid for new additional loads, such as charging electric cars. Despite the many savings, the reuse of residual heat and the production of electricity with PV panels, it is not possible to generate sufficient sustainable electricity within GLD to meet the demand entirely. If the remaining electricity demand from the grid is supplied by CO_2 neutral sources, carbon neutrality will be possible. Companies probably still have the greatest potential for limiting the electricity consumption. The behaviour of people and the development and application of better technologies can also speed up the road towards carbon neutrality in time.

4.2 Alternatives for heating the buildings in GLD

Of course there are other alternatives than a Kowanet for the centre of Amsterdam to disconnect from the natural gas network, but these all have other disadvantages that must also be taken into consideration. Because there is a lot of discussion about the alternatives, we briefly discuss them with their advantages and disadvantages.

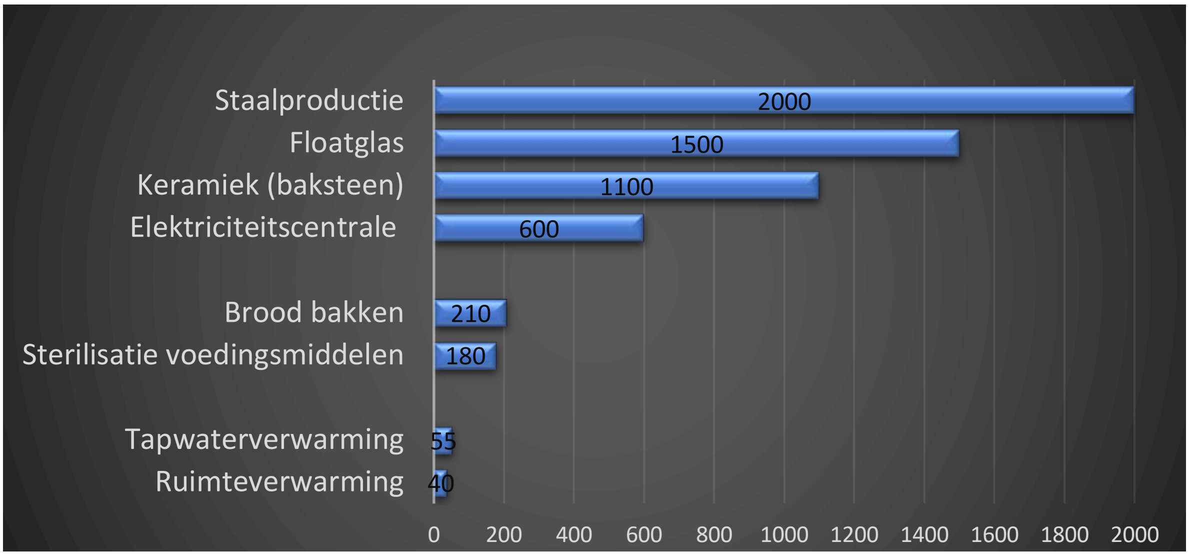

Figure 7: Temperatures required for production processes and industries, in °C [Gommans, TUDelft]

Green gases such as biogas or hydrogen gas is more often suggested as a sustainable alternative to natural gas, also for the city centre of Amsterdam. However, one must ask whether we should use such high-exergetic and therefore high-quality fuels for low-value applications such as space heating and warm tap water for buildings. The industry needs these fuels much more because they have fewer alternatives (Figure 7). Moreover, biogas is only available to a very limited extent and hydrogen gas would then have to be generated with sustainable electricity, with many losses (figure 8). Heat pumps are much more efficient in producing low-temperature heat (Figure 9), which means that a much smaller PV area or less wind turbines are needed to generate that heat.

ELEKTRICITEIT IN LUCHTWARMTEPOMP (NU)

Energieketen van opwek naar gebruik	**Opwek** Duurzame elektriciteit	**Transport elektronen** Per kabel naar land			**Transport elektronen**	**Gebruik in woning** met warmtepomp
Kenmerken	Idem	Idem				Uitgaand van een Seasonal performance factor van 2,7. Warmte wordt uit de buitenlucht gehaald
Efficiency (verlies)	100% (0%)	98% (-2%)			95% (-5%)	270% (+170%)
Cumulatief	**100%**	**98%**			**93%**	**263%**

Met dank aan Lennart van der Burg van TNO. Copyright Vakblad Warmtepompen

Figure 8: The overall efficiency of heating with an air-sourced heat pump [Van der Burg TNO, Vakblad Warmtepompen]

WATERSTOF IN HR-WATERSTOFKETEL (OPTIMISTISCH IN 2020)

Energieketen Van opwek naar gebruik	**Opwek** Duurzame elektriciteit	**Transport elektronen** Per kabel naar land	**Waterstof productie** Centraal, grootschalig middels water-elektrolyse aan land	**Comprimeren** Naar xx bar	**Transport H2 moleculen** Via bestaand hoge en middel druk gasnet	**Gebruik in woning** Met waterstof cv-ketel
Kenmerken/ aannames	• Wind park offshore met 4.700 vollasturen (54% van de tijd) en afstand <80 km van de kust • 1 turbine is 8 MW • Aanname geen curtailment (afschakeling turbine)	AC kabel Alternatieven: HV DC (3% verlies per 1.000 km) of H2-leiding	PEM-elektrolyse in 2020 bij 100% belasting	• Huidige gasnet van gasunie is 65 bar om zelfde hoeveelheid waterstof te transporteren is 3x hogere druk nodig dus circa 200 bar • Energie benodigd voor compressie is 2,5 kWh per kg waterstof.		Nieuw te ontwikkelen hr-ketel met waterstofbranders
Efficiency (verlies)	100% (0%)	98% (-2%)	73% (-27%)	93% (-7%)	95% (-2%)	85% (-15%)
Cumulatief	**100%**	**98%**	**71%**	**64%**	**62%**	**47%**

Figure 8: The overall efficiency of heating with hydrogen gas [Van der Burg TNO, Vakblad Warmtepompen].

	Prijs ex belasting	€ per kWh
Aardgas	10 ct / M3	0,010
Elektriciteit	5 ct kWh	0,050
Grijze waterstof	€ 1,50 – 2,50 / kg	0,045 – 0,075
Blauwe waterstof	€ 2,25 – 3,25 / kg	0,07 – 0,1
Groene waterstof	€ 3,00 – 6,00 / kg	0,09 – 0,18

Groothandelsprijs aardgas maart 2020
Groothandelsprijs elektriciteit indicatief 2020
DNV-GL "Technologiebeoordeling van groene waterstofproductie" november 2018, H_2 prijzen 2018, grootschalige productie De kostprijs voor waterstof is sterk afhankelijk van de elektriciteitsprijs, het aantal bedrijfsuren en de schaal van de SMR of elektrolyse installatie.

Figure 9: Indicative cost price without tax or transport costs of energy carriers (spring 2020) [source: https://opwegmetwaterstof.nl/kostenaspecten-van-waterstof/]

Biogas and hydrogen are expensive to produce (Figure 9) so that residents or building managers will be confronted with high energy costs for heating their buildings, also in the future when we can switch entirely to the production of green hydrogen (Figure 10). Moreover, combustion of hydrogen in a gas boiler is not an alternative for cooling; therefore, another alternative will have to be found for cooling that probably will run on (extra) electricity. The same applies to the alternative of high- or medium-temperature heat networks (district heating), which has already been installed in various places in Amsterdam and which is planned for many other neighbourhoods in Amsterdam [OverMorgen, 2020]. Other alternatives for energy-efficient cooling must also be found here.

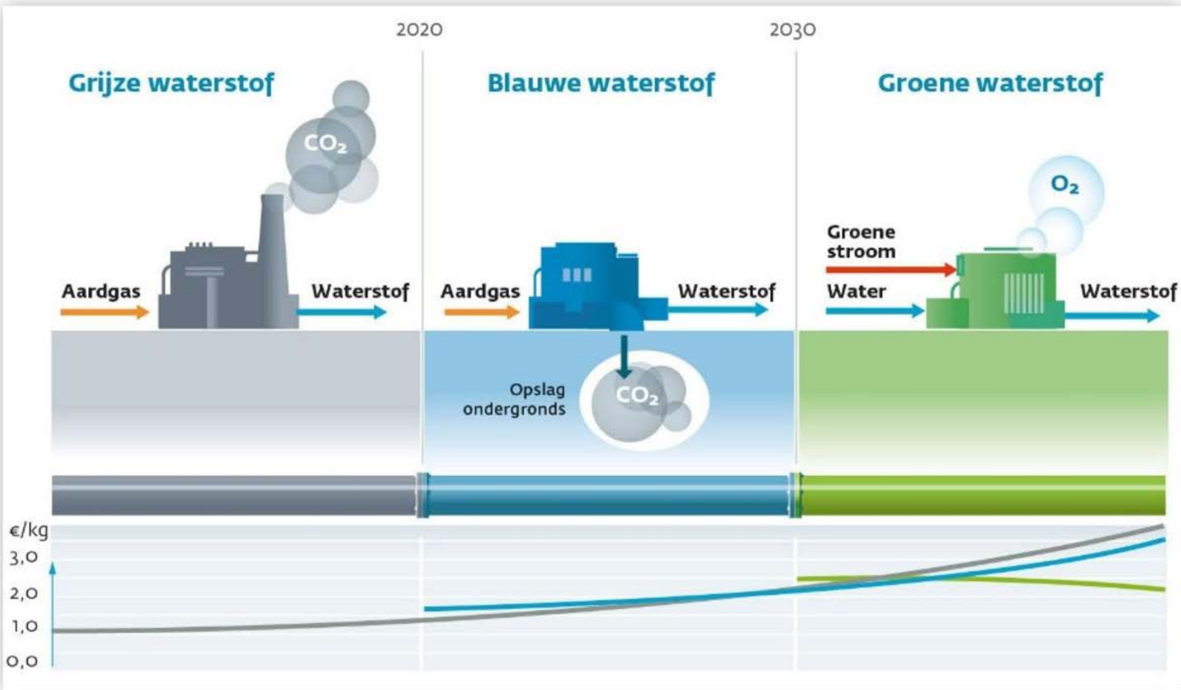

Figure 10: Hydrogen price development [Source: Gasunie pitch Elektriciteitstafel based on ECN 2017]

Figure 11: Heat transportation for district heating networks in Amsterdam [Municipality of Amsterdam]

District heating grids result in major spatial interventions because the heat from, mostly industrial, areas outside the city, must be transported to the centre in large pipelines (figure 11). Moreover, entire neighbourhoods have to be tackled at the same time, which does not always fit in the local planning for the neighbourhood. Local source networks, as proposed for GLD, can be constructed in phases and possibly linked to each other at a later date. Heat networks usually run on residual heat from fossil fuels and, moreover, a significant part of the heating is still done with natural gas.

4.3 Icon projects in GLD

An all-electric solution seems to be the most promising alternative towards a carbon-neutral future for GLD, disconnected from the natural gas grid. But of course there are different ways for all-electric heating and cooling and also some planned and realised examples. Here we will discuss some briefly.

A study was conducted for one of the oldest monuments in Amsterdam and its surroundings, the De Waag building, where the idea of a Kowanet was introduced for all the buildings around the Nieuwmarkt square [Dang, 2021]. The research focused on 3 main objectives:

- To develop an innovative and generic approach for energy retrofitting for historical buildings with conservation compatible energy retrofit packages, which allow buildings to be heated at a low temperature (<55°C), while preserving the historic values, improving indoor thermal comfort and minimising environmental impact;
- To investigate low-temperature heat sources (with a special focus on aquathermal energy from open water) and storage capacity that must be implemented to supply sufficient heat in the inner city;
- To develop an integrated vision of the gradual energy transition of the inner city starting with local heat and cold grids (clusters), which can later be linked to become an entire system.

The plan is that the source grid for the Nieuwmarkt is connected to all the buildings around the square to exchange heat and cold from the De Waag building, residences, companies, product cooling from the Albert Heijn supermarket, metro, local canal water and quay walls of the Geldersekade and an ATES to store heat and cold.

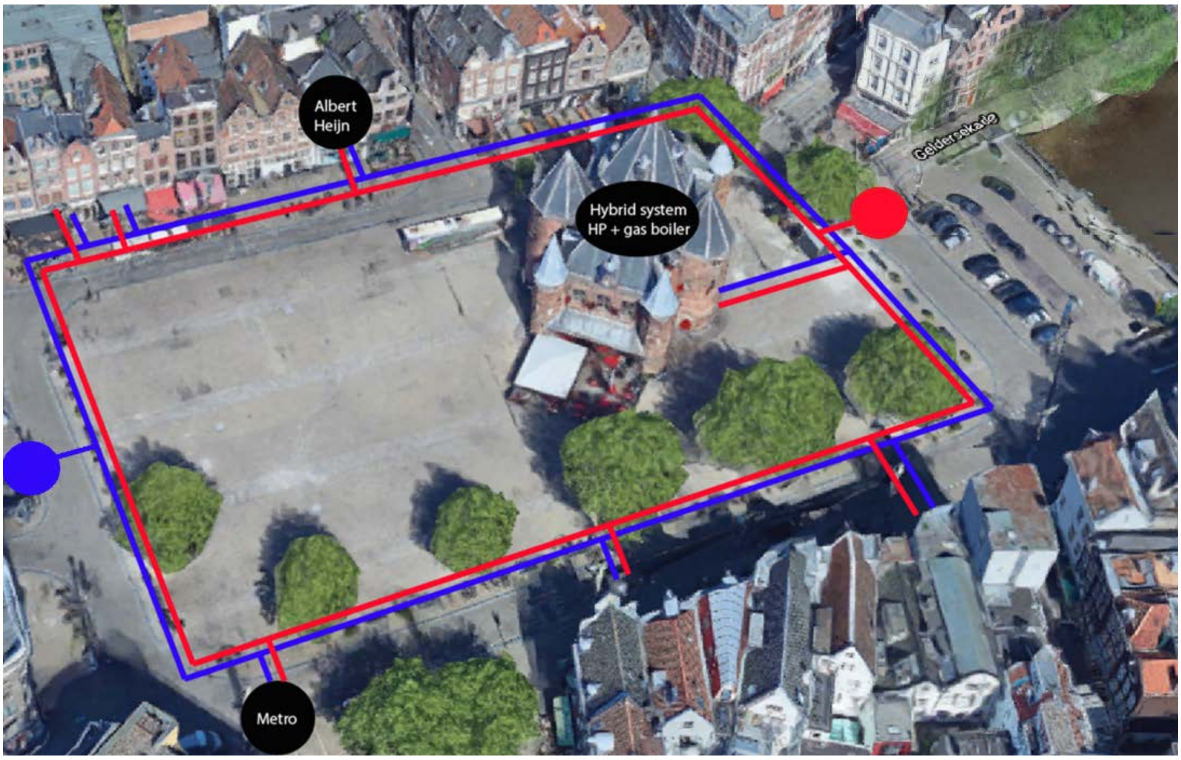

Figure 12: Concept of a low-temperature heat network on the Nieuwmarkt, connecting De Waag and other potential local heat sources [Source: AMS/TU Delft, Dang]

De Groene Grachten has equipped 2 different moderately insulated apartments in monumental buildings on the Zeedijk with various all-electric utilities to gain and share experiences. It concerns an upper floor apartment under the roof that is equipped with an air heat pump and an intermediate floor that is equipped with infrared panels on the ceiling (figure 13). Because it was a monumental building, the house on the mezzanine floor could not fit an outdoor unit of the heat pump to the facade. The house on the top floor had a small roof terrace where the outdoor unit could be installed (figure 14). Installing the infrared panels was done in a day. Placing the heat pump was quite difficult because the old radiators had to be replaced first by new (low-temperature) convectors and then the heat pump installation had to be installed again, which took a total of 5 days of work. Both homes had very low electricity consumption in the first year. The residents keep a blog that is freely accessible to everyone, about this and other experiences[2].

[2] https://greenlightdistrict.nu/blog/jill-en-jelle-wonen-een-jaar-aardgasvrij/

Figure 13: The apartment with Infrared panels on the ceiling [Foto: De Groene Grachten Amsterdam]

Figure 14: The outdoor unit of the heat pump on the terrace [Foto: De Groene Grachten Amsterdam]

Furthermore, a pilot project has started in one of the buildings of the University of Amsterdam at the collapsed quay at the Grimburgwal (figure 15) to experiment with the extraction of heat from the local canal to heat the building with the help of a heat pump. The plans have been published [De Groene Grachten, 2021] and TU Delft was part of the development team for the exploration phase.

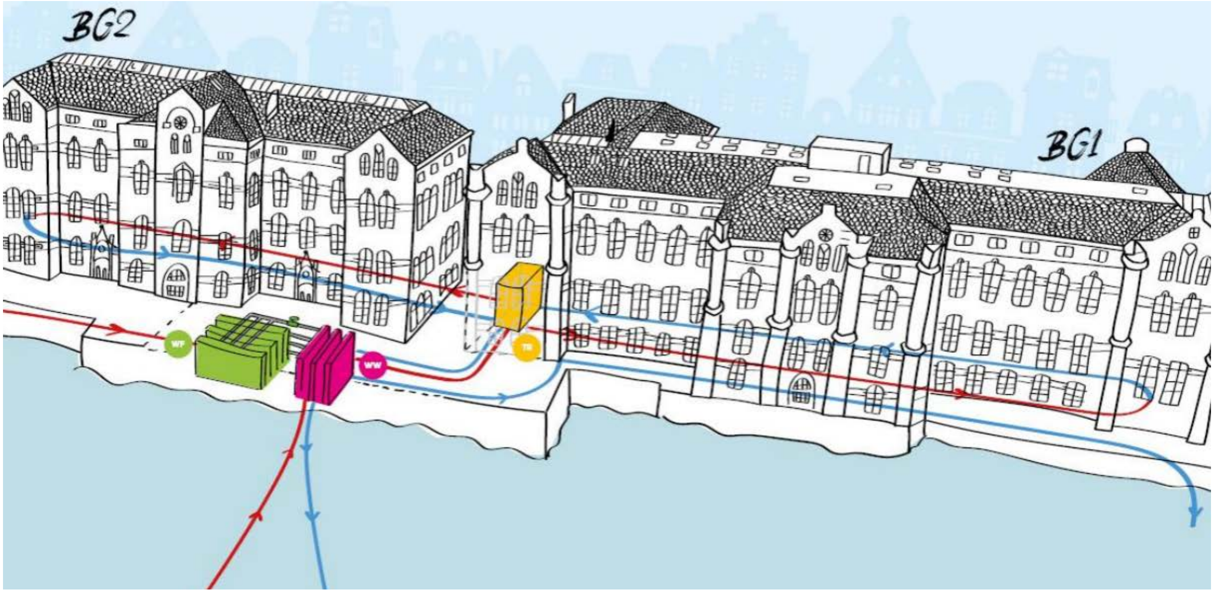

Figure 15: Pilot project with extraction of heat from canal for UvA at the Grimburgwal Amsterdam

From an energetic point of view a Kowanet (source grid that is able to exchange waste heat and cold) looks the most preferable system for GLD but local situations can sometimes not make this possible. In that case we can make a list of preferable all-electric solutions for the built environment, based on the SCOP (seasonal coefficient of performance) of the system and depending on the local opportunities [Gommans, 2021]:

1. Heat pump with residual heat and ATES in a local source network SCOP = 4.5
2. Heat pump with residual heat and BTES in a local source network SCOP = 4.0
3. Heat pump with ATES in a local source network SCOP = 4.0
4. Heat pump with PVT and individual BTES SCOP = 4.0
5. Heat pump with individual BTES SCOP = 3.5
6. Exhaust air heat pump boiler for tap water heating and air conditioner for space heating with outdoor air as source (with outside unit) SCOP = 3.3
7. Heat pump for space heating and DHW with outdoor air as source SCOP = 3.0
8. Infrared panel space heating and heat pump boiler for domestic hot water SCOP = 2.5
9. Infrared space heating and electric hot water boiler SCOP = 1.5
10. Electric resistance heating for space heating and DHW SCOP = 1.0

Finally, an order-1 building in GLD at the Dirk van Hasseltsteeg 49 (figure 16), was elaborated in the combined strategy report. Several measures are calculated and estimated for this building, such as CO_2 emissions, energy demand, energy label, energy costs, investment costs and payback time (figure 16). It gives an idea of the consequences of the reverse steps of the New Stepped Strategy for a historic building in GLD. A calculation like this could be made for the situation with a source grid for several buildings to give building owners and tenants an idea of the consequences of this energy system for their situation,

Front facade Back facade

Figure 16: Photos exterior facades of Dirk Van Hasseltssteeg 49 building [Source: Funda.nl].

	Natural gas demand [m3/year]	Heat demand [GJ/year]	Electricity demand [kWh/year]	Total energy costs [Euro/year]	CO_2-emissions [kg] building related	Energy-index [-]	Investments costs	Pay back time [year]	Energy label	natural gas demand [m^3] / m^2 floor area	electricity demand [kWh] / m^2 floor area	heat demand [MJ] per m^2 floor area
Existing situation gas heater	4.340	0	5.364	4.819	8.779	2,31			E	37,8	45,4	0
Existing situation air HP	2.159	0	9.912	3.988	7.572	1,87	9.500	11,4	B	18,3	84,0	0
Existing situation ground HP	2.143	0	8.370	3.620	6.674	1,66	17.500	14,6	C	18,2	70,9	0
Existing situation district heating	0	63	5.814	3.207	6.514	1,08	5.000	3,1	A	0,0	49,3	534
Insulated and district heating	0	24	2.945	1.537	2.996	0,53	5.000	16,1	A	0,0	25,0	203

Figure 17: Comparison of the existing situation with a gas boiler, with a hybrid air-, ground-sourced heat pump and with district heating.

4.4 Recommendations

From this study, which investigated the energy demand and renewable energy production with the implementation of all proposed strategies and solutions, as well as the greenhouse gas emissions (translated to CO_2 equivalents) of the new plans, we can give some recommendations:

- The suggested New Stepped Strategy in reverse order looks a promising way to move inhabitants, building owners and business people towards a carbon-neutral GLD without natural gas.
- Inhabitants, users and owners of the buildings have to organise to elaborate the suggested plans for the several local situations, together with and supported by the local government.
- More research has to be done on smaller scale for neighbourhoods that are interested in a local Kowanet: what is the local supply of waste energy, storage capacity in the underground, space for pipes and design of the public space in combination with future renovation of the electricity grid, quay walls, parking and electric charging stations, etc.
- The municipality can contribute to support the system in the public space with finances, organisation, advise and knowledge about the local situation and developments.

5 References

Dang M., Gommans L., Dobbelsteen A. van den, (2021) ‘Reduce, reuse and produce potentials for De Waag on Nieuwmarkt’, TUDelft & AMS Amsterdam

De Groene Grachten (2021), ‘Kansen voor duurzaam kadeherstel Green Light District’, Amsterdam

Dobbelsteen A. van den, Broersma S., Fremouw M., Blom T., Sturkenboom J. & Martin C.L. (2018). 'The City-zen Urban Energy Transition Methodology - The Amsterdam Roadmap towards a zero-carbon city', in: Proceedings SASBE2018 (1-12). UTS, Sydney

Dobbelsteen A. van den (2008). 'Towards closed cycles - New strategy steps inspired by the Cradle to Cradle approach', in: Proceedings PLEA 2008 – 25th Conference on Passive and Low Energy Architecture. UCD, Dublin

Gommans L., Weiers J. (2021) ‘Aardgasvrije transitie scenario’s voor de wijken en buurten van de gemeente Meerssen’ BOOM-Maastricht, 2021

OverMorgen (2020), ‘Transitievisie Warmte Amsterdam’

NEN (2020). NTA8800:2020+A1:220 nl; Energieprestatie van gebouwen – bepalingsmethode. NEN, Delft

6 Appendix with Interim calculations of CO_2 emissions GLD

ENERGY DEMAND GREEN LIGHT DISTRICT						
2017 Current situation						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*777895*	*656040*	*106038*	*15816*	
	Residences	51702	38777	11633	1293	
	Small businesses	86215	73283	11208	1724	
	Large businesses	639977	543980	83197	12800	
Electricity	*total*	*195447*	*177744*			*17703*
	Residences	12006	12006			-
	Small businesses	50562	45683			4879
	Large businesses	132879	120055			12824

CO2 emission GREEN LIGHT DISTRICT						
2017 Current situation						
heat	(tons CO2)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*186695*	*157450*	*25449*	*3796*	
	Residences	12408	9306	2792	310	
	Small businesses	20692	17588	2690	414	
	Large businesses	153594	130555	19967	3072	
Electricity	*total*	*66452*	*60433*			*6019*
	Residences	4082	4082			-
	Small businesses	17191	15532			1659
	Large businesses	45179	40819			4360
	total CO2-emission:	**253147**				

ENERGY DEMAND GREEN LIGHT DISTRICT						
Producing electricity with PV-panels included						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*777895*	*656040*	*106038*	*15816*	
	Residences	51702	38777	11633	1293	
	Small businesses	86215	73283	11208	1724	
	Large businesses	639977	543980	83197	12800	
Electricity	*total*	*186447*	*168744*			*17703*
	Residences	9006	9006			-
	Small businesses	47562	42683			4879
	Large businesses	129879	117055			12824

CO2 emission GREEN LIGHT DISTRICT						
Producing electricity with PV-panels included						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*186695*	*157450*	*25449*	*3796*	
	Residences	12408	9306	2792	310	
	Small businesses	20692	17588	2690	414	
	Large businesses	153594	130555	19967	3072	
Electricity	*total*	*63392*	*57373*			*6019*
	Residences	3062	3062			-
	Small businesses	16171	14512			1659
	Large businesses	44159	39799			4360
	total CO2-emission:	**250087**				

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reusing residual heat with hybrid heatpumps and ATES						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*396856*	*328020*	*53019*	*15817*	
	Residences	26498	19389	5817	1293	
	Small businesses	43970	36642	5604	1724	
	Large businesses	326389	271990	41599	12800	
Electricity	*total*	*313460*	*295757*			*17703*
	Residences	17408	17408			-
	Small businesses	61644	56765			4879
	Large businesses	234409	221585			12824

CO2 emission GREEN LIGHT DISTRICT						
Reusing residual heat with hybrid heatpumps and ATES						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*95245*	*78725*	*12725*	*3796*	
	Residences	6360	4653	1396	310	
	Small businesses	10553	8794	1345	414	
	Large businesses	78333	65278	9984	3072	
Electricity	*total*	*106576*	*100557*			*6019*
	Residences	5919	5919			-
	Small businesses	20959	19300			1659
	Large businesses	79699	75339			4360
	total CO2-emission:	**201822**				

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand spaceheating with heatpumps and ATES (standard renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*68836*	*0*	*53019*	*15817*	
	Residences	7110		5817	1293	
	Small businesses	7328		5604	1724	
	Large businesses	54399		41599	12800	
Electricity	*total*	*318927*	*301224*			*17703*
	Residences	17731	17731			-
	Small businesses	62255	57376			4879
	Large businesses	238942	226118			12824

CO_2 emission GREEN LIGHT DISTRICT						
Reduce demand spaceheating with heatpumps and ATES (standard renovation)						
heat	(tons CO_2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*16521*	*0*	*12725*	*3796*	
	Residences	1706	0	1396	310	
	Small businesses	1759	0	1345	414	
	Large businesses	13056	0	9984	3072	
Electricity	*total*	*108435*	*102416*			*6019*
	Residences	6028	6028			-
	Small businesses	21167	19508			1659
	Large businesses	81240	76880			4360
	total CO_2-emission:	**124956**				

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand spaceheating with heatpumps and ATES (advanced renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*68836*	*0*	*53019*	*15817*	
	Residences	7110		5817	1293	
	Small businesses	7328		5604	1724	
	Large businesses	54399		41599	12800	
Electricity	*total*	*255291*	*237588*			*17703*
	Residences	13969	13969			-
	Small businesses	55146	50267			4879
	Large businesses	186176	173352			12824

CO2 emission GREEN LIGHT DISTRICT						
Reduce demand spaceheating with heatpumps and ATES (advanced renovation)						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*16521*	*0*	*12725*	*3796*	
	Residences	1706	0	1396	310	
	Small businesses	1759	0	1345	414	
	Large businesses	13056	0	9984	3072	
Electricity	*total*	*86799*	*80780*			*6019*
	Residences	4750	4750			-
	Small businesses	18750	17091			1659
	Large businesses	63300	58940			4360
	total CO2-emission:	**103320**				

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*15817*	*0*	*0*	*15817*	
	Residences	1293			1293	
	Small businesses	1724			1724	
	Large businesses	12800			12800	
Electricity	*total*	*251757*	*234054*			*17703*
	Residences	13582	13582			-
	Small businesses	54772	49893			4879
	Large businesses	183402	170578			12824

CO2 emission GREEN LIGHT DISTRICT						
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*3796*	*0*	*0*	*3796*	
	Residences	310	0	0	310	
	Small businesses	414	0	0	414	
	Large businesses	3072	0	0	3072	
Electricity	*total*	*85597*	*79578*			*6019*
	Residences	4618	4618			-
	Small businesses	18623	16964			1659
	Large businesses	62357	57997			4360
	total CO2-emission:	**89393**				

ENERGY DEMAND GREEN LIGHT DISTRICT							
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)							
heat	(MWh)	total	of which for:				
			space heating	DHW	cook-ing	cool-ing	
	total	*0*	*0*	*0*	*0*		
	Residences	0					
	Small businesses	0					
	Large businesses	0					
Electricity	*total*	*266281*	*248578*			*17703*	
	Residences	13582	13582			-	
	Small businesses	56496	51617			4879	
	Large businesses	196202	183378			12824	

CO2 emission GREEN LIGHT DISTRICT						
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*0*	*0*	*0*	*0*	
	Residences	0	0	0	0	
	Small businesses	0	0	0	0	
	Large businesses	0	0	0	0	
Electricity	*total*	*90535*	*84516*			*6019*
	Residences	4618	4618			-
	Small businesses	19209	17550			1659
	Large businesses	66709	62349			4360
	total CO2-emission:	**90535**	with electric coocking			

ENERGY DEMAND GREEN LIGHT DISTRICT						
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)						
heat	(MWh)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*0*	*0*	*0*	*0*	
	Residences	0				
	Small businesses	0				
	Large businesses	0				
Electricity	*total*	*208439*	*190736*			*17703*
	Residences	10700	10700			-
	Small businesses	39594	34715			4879
	Large businesses	158145	145321			12824

CO2 emission GREEN LIGHT DISTRICT						
Reduce demand spaceheating and DHW heatpumps and ATES (advanced renovation)						
heat	(tons CO2/yr)	total	of which for:			
			space heating	DHW	cook-ing	cool-ing
	total	*0*	*0*	*0*	*0*	
	Residences	0	0	0	0	
	Small businesses	0	0	0	0	
	Large businesses	0	0	0	0	
Electricity	*total*	*70869*	*64850*			*6019*
	Residences	3638	3638			-
	Small businesses	13462	11803			1659
	Large businesses	53769	49409			4360
	total CO2-emission:	**70869**	with electric coocking and reduction appliances			