Beyond gas

Prospects for two new concepts: Low-Temperature Geothermal and the 'Minewater' smart thermal grid

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Delft, CE Delft, June 2019

Publication code: 19.3K61.096

Natural gas / Use / Households / Reduction / Innovation / Renewable energy / Geothermal heat / Waste heat / Mining

This report was commissioned by the Netherlands Enterprise Energy (RVO) and TKI Urban Energy

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Preface

Across the Netherlands, major efforts are underway to reduce the carbon footprint of heating systems in the built environment. Climate agreements, sustainability programmes and earth quakes in the Groningen gas fields are driving a major acceleration of endeavours to move beyond natural gas as the option of choice for space heating. There are a range of alternatives available: heat pumps, district heating, 'green gas' and biomass. Many of these are already mature and have been in use for many years, albeit on a modest scale.
There are also new options, though: innovations developed here in the Netherlands that can potentially make a major contribution to the envisaged heat transition. This study considers two such innovations, both of them variants on the theme of low-temperature heat grids: low-temperature geothermal heat (LTG) and the 'Minewater' smart thermal grid.

Knowledge on these two innovations is still limited and the Netherlands Enterprise Agency (RVO) and TKI Urban Energy commissioned CE Delft and IF Technology to improve understanding of the characteristics and potential of these low-temperature options in the Netherlands. Each option is currently being implemented by a single party at one location and the obvious question is whether they can be rolled out elsewhere in the Netherlands. What are the prospects and what are the barriers?

This study is the first in this country to look more closely at the two concepts, individually and together. One of the results is that for the first time a quantitative estimate has been made of the (substantial) promise of each option – and the added value of the synergy between them.

It would have been very hard to undertake this project without collaborating with the parties currently engaged with the two technologies: Visser & Smit Hanab (LTG) and Mijnwater B.V. (Minewater) and particularly without the cooperation of and input from Kees van der Zalm (Visser & Smit Hanab) and Louis Hiddes and Herman Eijdems (Mijnwater B.V.). On behalf of the two project principals and ourselves they are extended a great deal of thanks for their indispensable contribution.

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Summary

At the request of the Netherlands Enterprise Agency (RVO) and TKI Urban Energy, CE Delft and IF Technology have carried out a study on the potential in the Netherlands of two new space-heating concepts: low-temperature geothermal heat (LTG) and the 'Minewater' smart thermal grid with underground buffering, as rolled out by Mijnwater B.V. in the former mining town of Heerlen. Both concepts are collective variants of low-temperature (LT) heat grids. LTG uses geothermal heat produced from a depth of 250-1,250 metres.
The Minewater concept is an LT heat exchange system involving exchange of both heat and cold between LT sources (including LTG) and the demand side, using buffering to optimize the system.

Highlights

This study describes and explores two collective heat technology concepts about which little knowledge was available in the Netherlands. It yielded the following key results:
- Low-temperature geothermal heat (LTG) is a viable option at many locations in the Netherlands, even where conventional geothermal is not (yet) feasible.
- The Minewater concept can be applied very widely throughout the country, employing either surface or underground thermal buffering.
- Combining LTG and Minewater has synergy benefits: a good LT heat source in combination with minimal above-ground wastage due to efficient exchange of heat and cold.
- Both concepts can be implemented on a smaller scale level than is usual for high-temperature heat grids (HT grids).
- The technical concepts can be further elaborated and implemented, though it is desirable that policy support be facilitated, as legislative barriers and funding options are still a limiting factor.
- There appears to be a viable growth model for both concepts, starting with either LTG or Minewater, with further growth certainly feasible, either independently or together.

Conclusions and observations

The study allows the following conclusions and observations:

General conclusions

- There are just a few parties in the Netherlands that are knowledgeable on the Minewater and LTG concepts. This report is the first (publicly available) analysis of these concepts, individually and combined, as technologies relevant for the heat transition in The Netherlands.
- There is very little experience with either technology: both have been rolled out at only a very small number of sites.
- Both concepts can potentially make a promising contribution to the heat transition in the Netherlands.
- Minewater and LTG are concrete examples of LT heat grids. The variants elaborated (LTheat supply and 70/40 grids) may potentially be the next steps in 'greening' current HT heat grids and the entire heat supply in the Dutch urban environment.

Conclusions on LTG

As yet, virtually no use has been made of low-temperature geothermal heat in the Netherlands, and in discussions on greening the country's heating systems it is a topic that is consistently undervalued. As the analyses in this report show, however, this is misguided, for LTG can make a substantial contribution to a successful heat transition. In terms of technical potential and constraints, it can be implemented at numerous locations. Financially, too, it has interesting prospects, which can only improve as use of natural gas becomes increasingly discouraged in the Netherlands. LTG has a number of variants, of which horizontal directional drilling is the one presently being developed and rolled out in our country. In the near future the first practical results will be coming in.

The technical potential of LTG in the Netherlands amounts to 229 PJ per annum, sufficient to cover 37% of present heat demand in the Dutch built environment. In the heavily urbanized environment (where heat grids are most likely to be rolled out) even 70% or more of heat demand could be met by LTG.

Conclusions on the Minewater concept

While the Minewater concept started out as the first LTG project in the built environment, today it can best be described as a smart thermal grid supplemented by large-scale thermal buffering. What were originally LTG sources have now become buffers and the core of theconcept has shifted from underground to above ground. It is now primarily a low-temperature, buffered heat exchange system. Now the subsurface is no longer seen as a source but as a buffer, this opens the way to thinking about the concept's potential outside the mining area where it was originally implemented. The present analysis shows the Minewater concept could meet a very substantial percentage of heat demand in the Dutch built environment, potentially serving 2.0 to 3.6 million homes. This figure could be even higher, if new, sustainable LT heat production is also added in the form of solar thermal and/or surface-water heat. The option of combining LTG and Minewater would also boost the contribution, putting the number of homes up to around 3.5-4.5 million.

If utility buildings in such areas are also supplied, in the Netherlands as a whole Minewater-type systems could potentially supply 85.7-159.5 PJ heat and 2.4-4.3 PJ cold, thus delivering climate-neutral heat and cold to around 2.0-3.6 million buildings.

Study methodology

Very few if any studies have yet been carried out on the potential of these two heating technologies. This means that in carrying out this study we have made use of the practical knowledge built up by two firms in the Netherlands. For LTG this is Visser & Smit Hanab, who in the past few years have developed the horizontal directional-drilling variant of LTG and rolled it out in Zevenbergen. Over a similar period the Minewater concept has been developed and implemented by Mijnwater B.V. in Heerlen. Both concepts are still very much under development. Based on interviews with these parties, combined with our knowhow on related heat technologies, for both concepts may key aspects have been analysed in some depth: technology, finance, technical potential. A specific analysis has also been made of the additional benefits of combining the two concepts in a single solution for providing heat and cold supply to the built environment and greenhouse horticulture.

Low-temperature geothermal (LTG)

The concept of low-temperature geothermal (LTG) involves production of geothermal heat from shallow geological formations. This heat ranges in temperature from about 20 to 55°C. In practice the depth of LTG lies between that of Aquifer Thermal Energy Storage (ATES, heat/cold storage in water-bearing layers) and conventional, deep geothermal. There is no fixed maximum depth for LTG recovery; this is essentially given by the maximum depths achievable with standard groundwater drilling or simplified oil and gas drilling, i.e. down to around 1,500 metres. An upper limit of 250 metres is generally taken, as shallower layers are often used for ATES or other purposes like drinking water abstraction. Nonetheless, LTG at depths less than 250 metres is not out of the question, as long as other (local) interests are taken into due account.

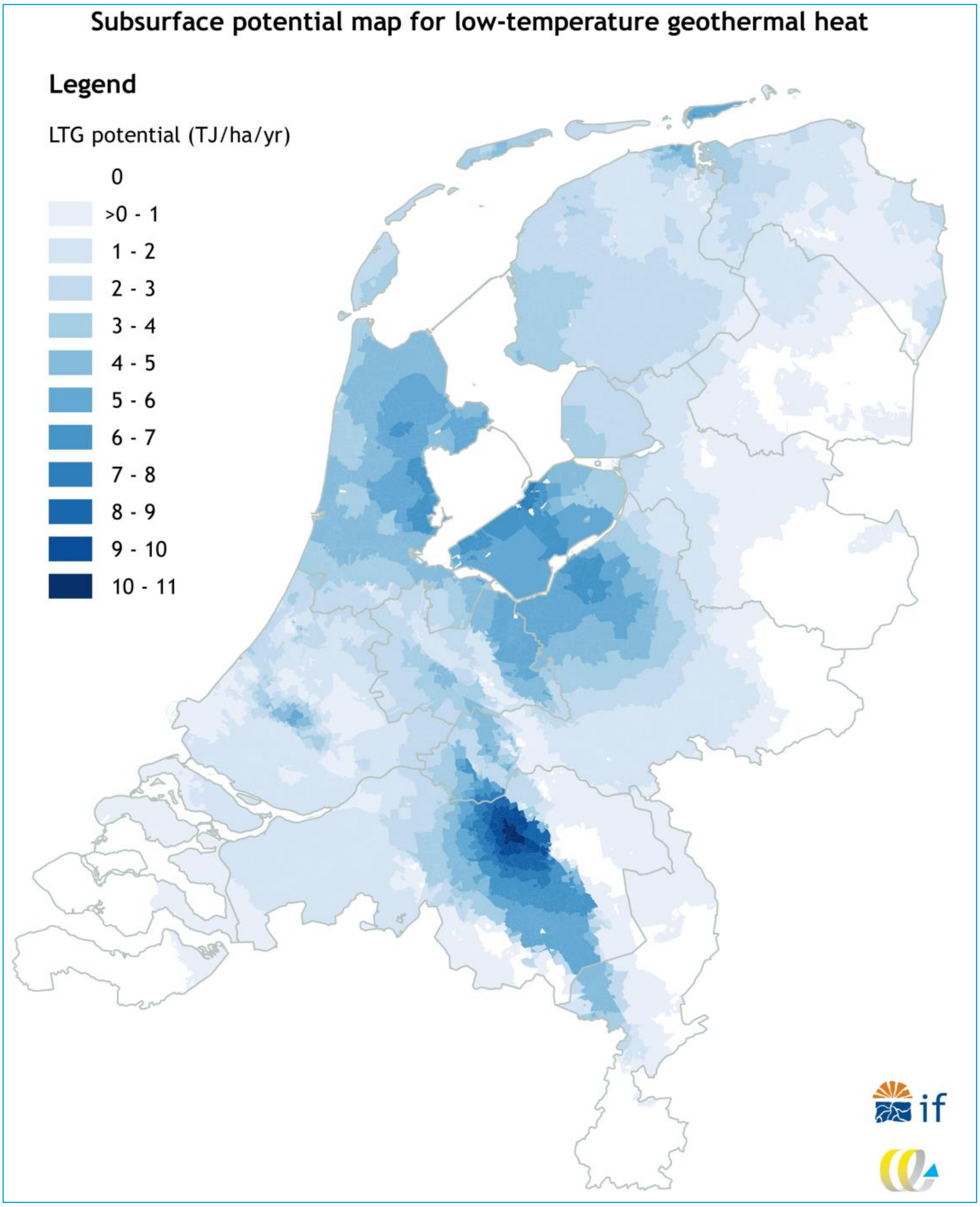
There are two ways LTG can be used in combination with a heat grid in the built environment and greenhouse horticulture: direct supply of heat and indirectly, via a central heat pump. In the former case the heat is supplied directly to end users, under the proviso that the facilities or buildings are properly equipped for LT heating (well-insulated homes with underfloor heating, for example). Under current regulations tap water must have a temperature of 55°C, implying a need for a booster heat pump or other solution. Similarly, if higher-temperature space heating is required, a heat pump for the individual home or larger building would also be needed. In that case the sub-surface heat would need to be upgraded to around 50-70°C using a heat pump before being supplied to users. This would require buildings to be insulated modestly to well, with little if any changes to the heat delivery system needed. The LTG wells can be drilled either in the traditional, vertical manner or horizontally. In the latter variant, currently employed by Visser & Smit Hanab, a horizontal screen is installed underground. This option has several advantages over vertical boreholes, in particular increased capacity in the case of thin geological formations and limited above-ground impact during drilling operations, as the hot and cold well (‘doublet’) can be sunk from a single location.

Suitability of the subsurface for LTG varies across the Netherlands: there is a wide range of geological formations and not all locations are equally suitable. Nonetheless, LTG appears to be a viable technical proposition across most of the country. A provisional evaluation by combining above-ground heat demand and subsurface potential indicates that LTG has a likely technical potential of 229 PJ per annum. This is 37% of current heat demand in the built environment and greenhouse horticulture areas of the Netherlands. In the heavily urbanized environment (where heat grids are most likely to be rolled out) 70% or more of heat demand could even be met by LTG.

Current legislation does not stand in the way of further development and large-scale roll-out of LTG. There are indirect barriers, though, and due attention will need to be given to the boundary between the terms of the Water Act and Mining Act at 500 metres depth. LTG holds out innovation potential for the Netherlands, particularly when it comes to heat pumps, heat generation, thermal buffering and heat infrastructure.

For implementing LTG in existing homes, cost-effective exploitation is feasible with a connection fee of 2,000 to 4,000 euro per dwelling. It should be noted, though, that there are considerable uncertainties in the business case, making it is as yet impossible to provide a robust picture.

Figure 1 - National subsurface potential map for low-temperature geothermal heat



Minewater (smart thermal grid)

In its present design, the Minewater concept can best be described as a smart thermal grid with geothermal buffering, or as a low-temperature heat exchange system with storage of both heat and cold. It is a demand-driven concept that allows supply and demand of heat and cold to be matched in a smart and efficient manner using an LT grid. Buffering allows the system to be optimized and permits intelligent use of the available supply as it varies over time. It is a staggered system: first there is exchange between clustered buildings, then exchange among clusters and finally exchange with the buffers. This is enabled through sophisticated control of heat and cold flows in the infrastructure via fast internet connections, creating a ‘smart thermal grid’. The low temperature of the core infrastructure means the system can be hooked up to numerous heat sources (consumers of cold), including data centres, cold-storage/freezing warehouses and ice rinks, where a considerable amount of waste heat is generated but which are not of interest for HT heat grids.

The Minewater concept has major scope for implementation in the built environment. As temperatures can be regulated at either an individual or a cluster level, a wide range of users can be connected. With housing, for instance, two adjacent dwellings, one insulated modestly, the other very well, can be connected to the same infrastructure. With a block of flats or other large building, the specific heat demand of individual homes can be catered for. For optimal operation it is best to be able to exchange a large number of thermal flows (i.e. both heat and cold), but this is not absolutely essential. Even in situations involving mainly demand for heat, the concept has great potential because there is a large amount of low temperature renewable heat available, e.g. in the form of LTG, warm surface water and solar heat. The Minewater concept has major parallels with the ‘district’ form of Aquatic Thermal Energy Storage (DATES) implemented at several sites with large buildings requiring both heat and cold, like Uithof Utrecht, Eindhoven University of Technology and Overhoeks Amsterdam. There, too, a smart thermal grid is combined with a geothermal buffer.

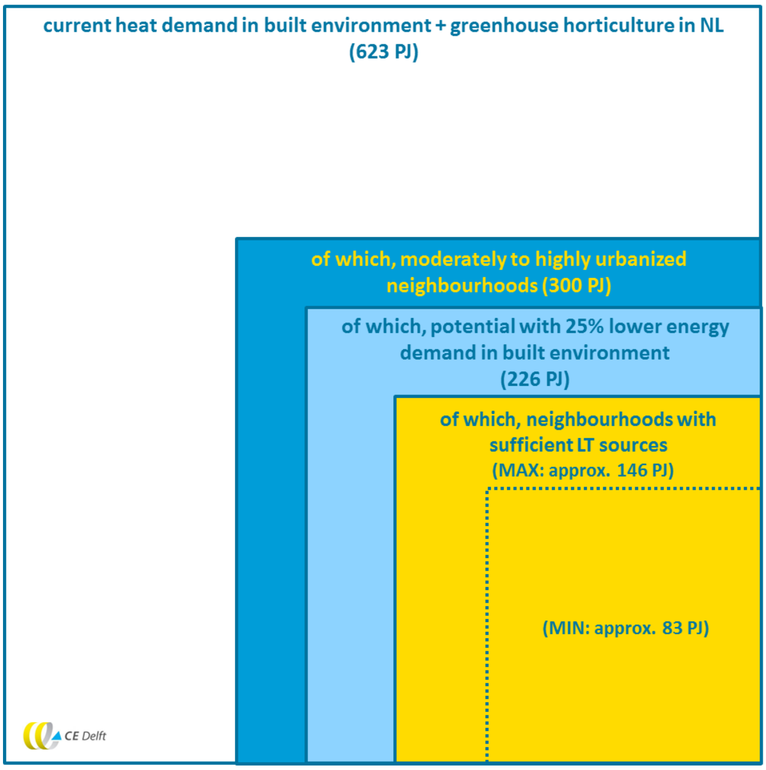
Originally, the Minewater concept was developed as an LTG system, but the specific capacity of the water in the abandoned coal mines below Heerlen proved insufficient for extended, long-term exploitation. This led to the concept being developed further. Now, the minewater is used solely as a heat and cold buffer for the above-ground smart thermal grid. In assessing the technical potential of the concept elsewhere in the Netherlands, we looked for locations with scope for heat/cold exchange among multiple suppliers and consumers. As the concept employs a thermal grid, our search area consisted primarily of urbanized districts. This pointed to a technical potential of approximately 160 PJ per annum heat and 4 PJ cold. For the Netherlands as a whole between 2.0 and 3.6 million dwellings could thus potentially be served by a Minewater-type system.

Besides its use of low-temperature heat sources and reciprocal thermal exchange, heat and cold storage is also a key part of the Minewater concept. The two main options for this purpose are a underground buffer tank and open-loop aquifer storage (ATES). The latter is currently cheaper.

Besides sophisticated control of thermal flows, the Minewater business model has a second ‘smart’, innovative feature. At the moment this is relevant only for large-scale consumers, though. This is because small-scale consumers are subject to the terms of the Heating Supply Act, and specifically to its provisions regarding maximum price (as explained in the text box in Subsection 3.6.3). This means they cannot act as ‘prosumers’, i.e. as both producers and consumers, which is a prerequisite for intelligent matching of supply and demand.

At the moment there is a viable business case for connecting individual large-scale consumers in Heerlen grid operated by Mijnwater B.V.. To roll out the system to existing homes requires a shift in scale, so the costs of the core infrastructure (the backbone) can be spread out over a greater number of connections. If the concept is implemented elsewhere, this can initially be phased in smaller-scale clusters, with these being connected to a backbone at a later date.

Figure 2 - Schematic representation of the approach adopted for future heat demand

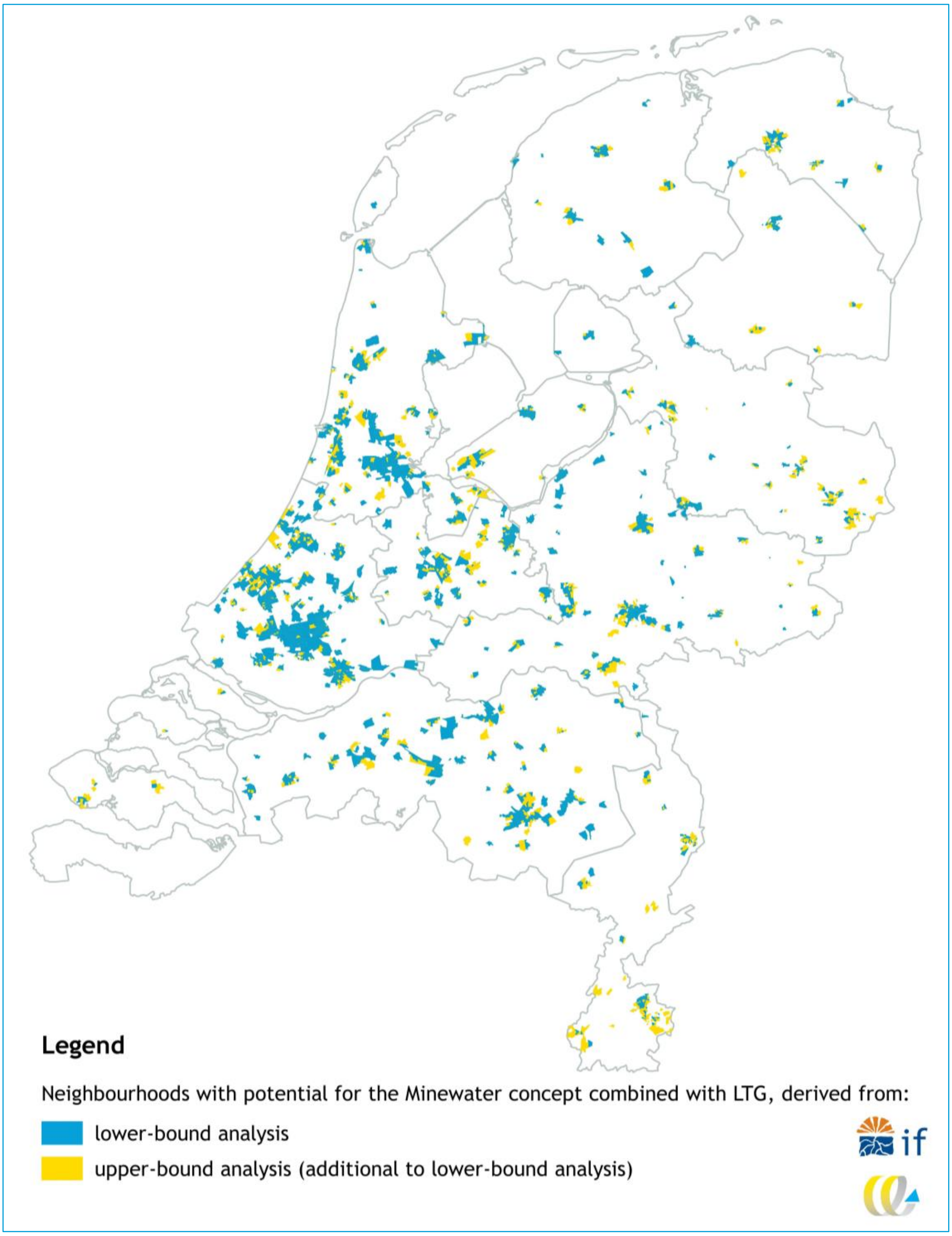


Synthesis

Besides the scope for individual application of the LTG and Minewater concepts, there are also major benefits to be gained from combining them. For Minewater, dovetailing with LTG brings in a major additional source of low-temperature heat. For LTG, combination with Minewater means less demand for underground heat because initial exchange is above-ground, while the subsurface LTG source can also be used for storage, giving it a considerably longer lifetime. While this does not necessarily imply an increase in LTG potential, it does improve long-term security of supply. Combining the Minewater concept with LTG boosts its potential enormously, as it substantially increases the number of areas where optimal heat/cold exchange can be achieved. The technical potential of combined application is around 227 PJ per annum for heat and 6 PJ per annum for cold. This means the current heating requirements of 3.5 to 4.5 million Dutch homes can be met, i.e. over half Dutch homes.

It is important to note that other renewable heat sources like solar thermal or surface-water heat can also be fed into the system, whether or not in combination with LTG. The potential ramifications of this kind of expanded system have not been investigated in the present study.

Figure 3 – Map of the Netherlands showing neighbourhoods with potential for the Minewater concept combined with LTG, current situation



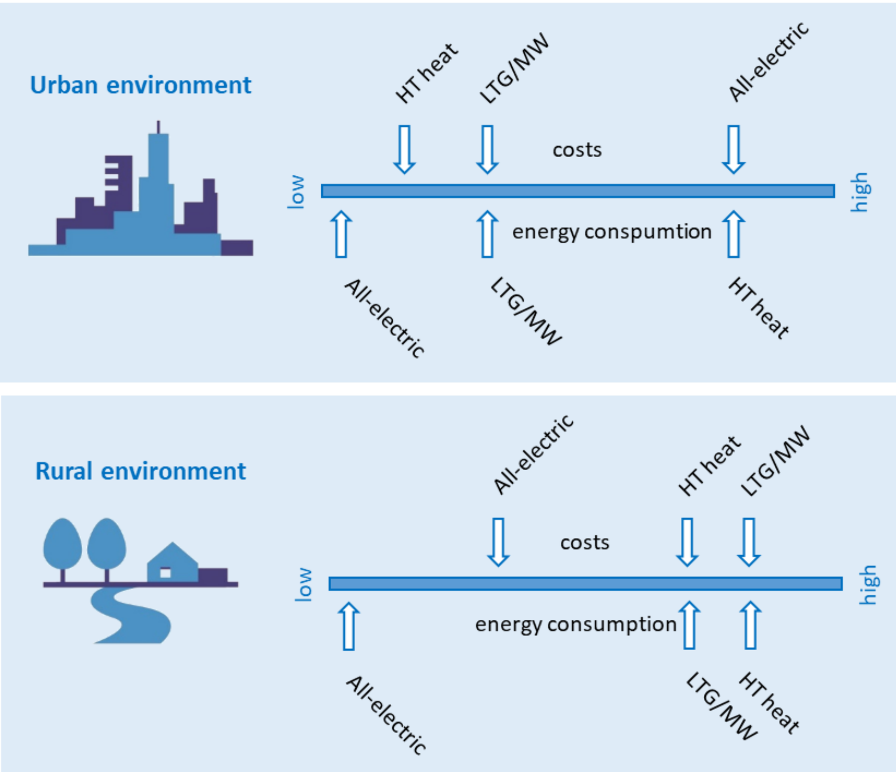
LTG and Minewater among a palette of possibilities

Besides LTG and Minewater there are a range of other heating technologies that can contribute to climate-neutral or zero-gas heating. The options available in the Netherlands differ in terms of their potential, area of application, temperature level, scale, availability and so on. To build up a picture of where each might best be deployed and arrive at sound choices among them requires additional study. However, a first-pass comparison allows the following initial conclusions to be drawn:

- Compared with traditional HT heat grids employing waste heat or deep geothermal heat, an LT system based on LTG and/or Minewater can be deployed at many more locations, because there are vastly more LT heat sources and they are distributed throughout the country. In energy terms LT systems are more efficient than HT systems, with less distribution losses, limited need for building-envelope improvements and higher-efficiency conversion for space heating and tap water. LT systems are more expensive, though. Although the grid itself costs slightly less than an HT grid, LT systems also require heat pumps as well as limited modifications to buildings.
- There is less geographical scope for rolling out LT grids than there is for all-electric solutions, i.e. heating methods that require no heating infrastructure at all, which means they can be deployed in thinly populated areas, too. At the system level there is very little difference in energetic efficiency between the two approaches. Per dwelling the LT infrastructure costs less, because of the required expenditure on building alterations for all-electric.

Figure 4 provides a *rough indication* of the relative appeal of the various options.
In practice this will need to be determined district-by-district and neighbourhood-by-neighbourhood.

Figure 4 - Rough indication of relative appeal of zero-gas heating technologies



Recommendations

Based on the results of the present study the following recommendations are made:

General recommendations

- Bring LTG and Minewater to the attention of potential end-users and intermediaries via relevant media and have these options included in the various publically available databases. Inclusion in the RVO Heat Atlas is a possible starting point to this end.
- With both options there is a 'chicken-and-egg problem': what comes first, connecting homes or developing resources? A strategic choice needs to be made on this issue. The small-scale nature of the two concepts is of advantage in this context.
- Make a detailed comparison of the costs of LT and HT heat *infrastructure*.
- Conduct additional research on how existing buildings can be primed for LT heating (heat delivery systems, envelope improvement, hot tap-water provision, etc.). This aspect applies to all 'green' heating systems and is not specific to the LTG or Minewater concept.
- For a 100% sustainable heating system it is very important that peak heat demand is not much higher than average winter demand. Among other things, this means the share of the back-up/peak-load system (generally gas-fired) in the total supply is minimized, with maximum heat being derived from the main, sustainable source. The technical means of achieving this cost-effectively is an issue that needs researching and then demonstrating. Potential options include distributed storage and temporarily stopping night-time temperature reduction.

Recommendations on LTG

- In this study the potential of LTG has been calculated based on the thickness and temperature of sandy sediments. For the economics, though, the sediments' permeability is also of key importance, so this parameter needs to be better mapped.
- A national-scale map does not suffice for establishing local potential. It is therefore recommended (for decision-making at municipal level, for example) to map LTG potential (including permeability) in greater detail in a number of areas on a regional/municipal scale, prioritizing areas where there is a demand for heat but few alternative heat sources like deep geothermal or waste heat.
- Given the status of LTG technical development, it is recommended to set up more demonstration projects in a variety of surface and subsurface situations.
- There is substantial LTG potential between ground level and 500 m deep, depths having the great advantage that cheaper drilling methods can be used and smaller-scale projects are feasible. The downside, though, is that these depths rule out eligibility for subsidies under the SDE+ scheme. We therefore recommend extending the scope of this scheme to include shallower depths, preferably up to and including grade level, but if this is unfeasible in connection with the present ATES market, then from a depth of around 250 m (below which there is virtually no ATES).

Recommendations on the Minewater concept

- Roll out of the Minewater concept on a wider scale requires a better understanding of the potential of low-temperature heat sources in the Netherlands: number, location, volume, capacity, profile, etc. There are still many gaps in the picture that need to be filled in.
- At present, the terms of the Heating Supply Act mean the innovative Minewater business case can only be implemented for large-scale users. It is therefore recommended that

this legislation be revised so this innovative business case can also be used for small-scale consumers.

- For a thorough analysis of the match between thermal demand and LT heat supply and implied buffering requirements, it is essential to build up a detailed picture of the demand profiles of heat and cold consumers (both homes and utility buildings). Only when this has been done can it be assessed how many sources and how much buffering are needed to meet heat and cold demand.
- Besides the example of Minewater in Heerlen, in the Netherlands there are only a very limited number of other demonstration projects involving higher-temperature buffering in the deeper subsurface environment. Our knowledge about these issues therefore also needs to be improved, whether by further analysis of the limited number of existing systems or by establishing new demonstration projects.
- The scope for combining large-scale solar-thermal and/or aquathermal systems with LTG and/or Minewater needs to be investigated, on the one hand as a heat source for Minewater-type projects, on the other for regeneration of LTG.

1 Introduction

1.1 Background

In the Netherlands geothermal energy is undergoing rapid development as a renewable heat source for heating horticultural greenhouses and buildings. Currently operational geothermal projects extract their heat from deep reservoirs at depths of 1,500 to 3,500 m that are also exploited for oil and gas recovery. This contrasts with heat production at shallower depths, known in English as ‘shallow geothermal’ and in German as ‘*oberflachennahe geothermie*’. In the Netherlands the terms of current legislation and subsidies have created a *de facto* transition at a depth of 500 m. Virtually all the ‘shallow’ geothermal projects in the Netherlands operate at a level above 250 m, however, with all the ‘deep’ geothermal projects below 1,250 m. The intervening region from 250 to 1,250 m is currently being investigated by a number of parties at several sites in the Netherlands. As yet, though, its potential in this country is still unclear, as are the conditions under which this form of renewable heat holds promise.

In the Netherlands two different technologies are currently being developed to exploit shallow underground heat as a sustainable source. Visser & Smit Hanab are developing Horizontal Directional Drilling (HDD) as a variant of shallow, low-temperature geothermal heat (LTG), while Mijnwater B.V. have developed and rolled out the Minewater concept in Heerlen, making use of the thermal capacity of the abandoned coal mines to drive a sustainable heat grid and combining this with a ‘smart’ thermal grid through which buildings exchange both heat and cold. This project has been awarded several prizes. Although the Netherlands has only a handful of mines that might be used in a similar fashion, the Minewater concept can be rolled out in other variants and at other locations, for example for Aquifer Thermal Energy Storage (ATES) or other large-scale forms of thermal storage. The question, as with LTG, is what potential this concept has for ‘greening’ heating systems in the Netherlands, and under what conditions it will be most promising.

The LTG and Minewater concepts both operate at temperatures different from what is currently standard for most Dutch buildings. To gain an idea of the prospects of each, potential heat demand at such temperatures therefore needs to be assessed, both in the current situation and in a future in which a range of demand-side measures have been implemented, particularly to improve the energy performance of buildings.

In light of the new possibilities opened up by low-temperature geothermal (via HDD) and the Minewater concept, the Netherlands Enterprise Agency (RVO) and TKI Urban Energy commissioned the present study, the chief aim of which is to assess the approximate potential of the two options in the Netherlands. More specifically, the aim is to establish what role they can play in the ‘heat transition’ envisaged for Dutch greenhouse horticulture and the built environment. Given that both concepts are still undergoing intense development, a secondary goal is to assess the scope for improvement in terms of further innovation (technological, organizational, financial and policy-wise).

1.2 Methodology

The study was carried out in three phases:

1. **Description and exploration**
   Description of the low-temperature geothermal heat (LTG) and Minewater concepts. This was done by means of a desk study and interviews with staff at Visser & Smit Hanab and Mijnwater B.V. In a parallel desk study, descriptions of alternative heating options were drawn up.
2. **Analysis of opportunities and barriers**
   Qualitative and quantitative analysis of the potential of each concept. For LTG, subsurface potential maps were prepared and compared with above-ground heat demand. For Minewater, above-ground exchange potential was inventoried and then linked to the scope for thermal storage in underground aquifers or artificial tanks.
   In addition, rough-and-ready business cases were established for each concept, estimating relevant costs and revenues, and identifying barriers and opportunities with respect to policy and legislation.
3. **Synthesis**
   The two concepts can be developed separately or in combination. In this synthesis step the added value of rolling them out together was assessed.

In the course of this study the project principals as well as staff at Mijnwater B.V. and Visser & Smit Hanab were engaged with for input and as a sounding board for our analyses and reporting.

1.3 Report structure

This report starts out by first examining the two concepts in detail: low-temperature geothermal in Chapter 2, the Minewater concept in Chapter 3. These chapters cover all the aspects cited under the first two phases of the project, summarized above. The third phase, synthesis of the two concepts, is the subject of Chapter 4. In Chapter 5 we present our conclusions and recommendations. Additional information is provided in several appendices, including (Appendix D) a comparison with three alternative heating options potentially competitive with or supplementary to Minewater and LTG.

2 Low-temperature geothermal heat

This chapter provides a detailed technical review of the use of low-temperature geothermal heat (LTG).

2.1 Core features

LTG has the following core features:
- Production of geothermal heat from shallow sediments down to a depth of around 1,500 metres.
- Production temperature between 15 and 40°C.
- Direct low-temperature (LT) heat delivery or indirect heat delivery combined with heat pumps.
- In the built environment the most interesting market is (existing) dwellings, characterized mainly by heat (rather than cold) demand. Other potential large-scale consumers of LT heat (approx. 40-70°C) include the greenhouse horticulture sector.
- Compared with gas-fired heating systems, LTG systems reduce primary energy consumption and thus CO_2 emissions. The overall attainable energy performance depends mainly on how heat pumps are used and, above all, on source-heat temperature. Using the current (projected for 2017) emission factor for power generation, LTG combined with heat pumps can reduce carbon emissions by around 50%, assuming the heat pumps boost the temperature to 50°C. Even greater emission cuts will be achieved as the share of renewables in the Dutch electricity mix rises.
- The national heat potential of LT heat in urban areas is 229 PJ per annum, 37% of current heat demand in the Dutch built environment.
- Capital expenditure on thermal wells depends on production depth and attainable capacity and ranges from 1,200 to 2,000 €/kW_{th}.
- For LTG combined with heat pumps, the cost price of heat production varies between 15 and 18 €/GJ (excl. subsidies and tax schemes), depending on drilling depth.
- LTG is eligible for subsidy under the SDE+ scheme provided the heat is sourced deeper than 500 metres. The SDE+ scheme makes the technology an attractive proposition.

2.2 Concept description

LTG is here defined to mean recovery of heat from shallow sediments, which in practice means an production depth somewhere between ATES (Aquifer Thermal Energy Storage) and conventional (deep) geothermal. There is no precise limit for LTG recovery depths, though, this being determined more by the maximum depths achievable with conventional groundwater drilling or simplified oil and gas drilling. A depth of 250 metres is generally taken as an upper limit, because shallower sediments are often used for Aquifer Thermal Energy Storage (ATES) or other activities like drinking-water abstraction. Nonetheless, LTG at depths less than 250 metres are not out of the question, but simply imply making proper allowance for other (local) interests.

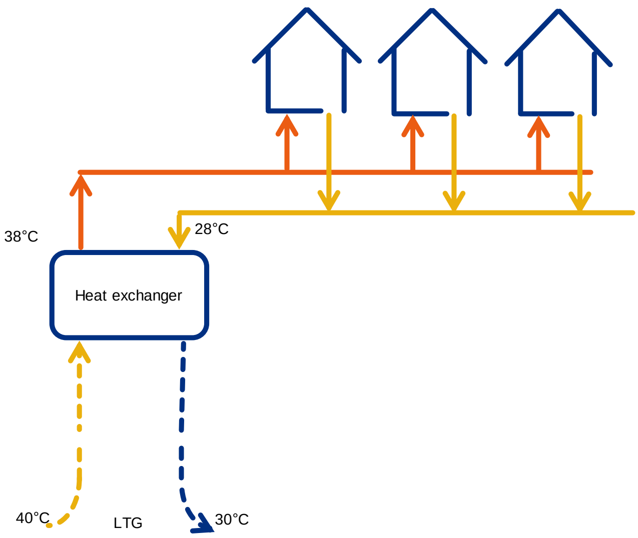
Table 1 - Operating depth of subsurface energy systems with their conventional applications

Technology	Depth (m)	Conventional application
ATES	0-250	Heat and cold storage
Low-temperature geothermal, LTG	250-1,500	Heat recovery/production (combined with heat pump)
Conventional geothermal	1,500-3,500	Heat recovery/production (direct use)
Ultra-deep geothermal	> 3,500	Steam generation/electricity production

In the case of LTG, geothermal energy is recovered from shallow sediments. Depending on depth, the water produced has a temperature between 15 and 45°C. If the temperature is sufficiently high, the heat can be used directly for heating purposes. In many cases this will not be the case, though, and heat pumps will have to be used to efficiently upgrade the heat. The options can be summarized as follows:

– **Direct heat delivery (Figure 5)**
  If sufficiently high-temperature heat (> 30°C) can be produced, it can be used directly for space heating. To use this relatively low-temperature heat directly, buildings need to be very well insulated and fitted out with LT heat-delivery systems like concrete core activation or underfloor heating. For hot tap water an additional heat boost will be needed, using a heat pump boiler, for example.

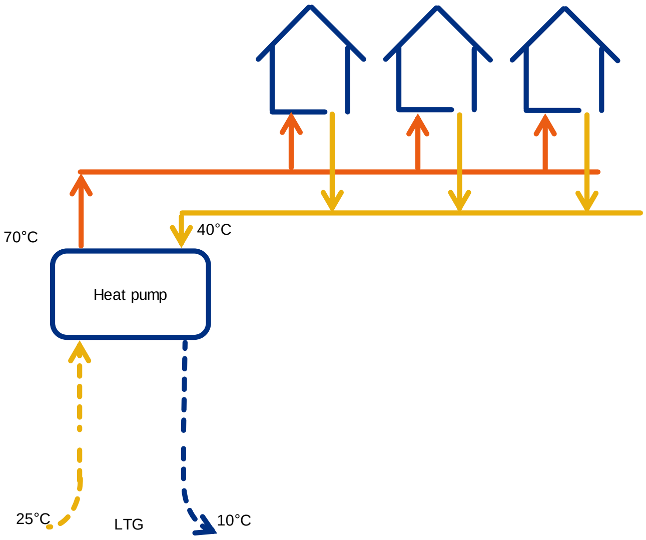
Figure 5 - Direct LTG heat supply



– **LTG with centralized heat generation (Figure 6)**
  In this case the low-grade LTG heat is upgraded to the desired temperature using a centrally installed heat pump, possibly supplemented by some kind of collective peak-load/back-up provision. The heat is delivered to end users via an insulated distribution grid, with connection sets for individual customers.

  The maximum temperature attainable with traditional heat pumps is 55°C, which is sufficient for buildings with a high-quality envelope and LT heat-delivery systems in place (e.g. underfloor heating, heating batteries in air handling units, fan coil units). Hot tap water will have to be provided locally, i.e. within individual homes, using an electric boiler, heat pump boiler or some such means to boost the temperature.

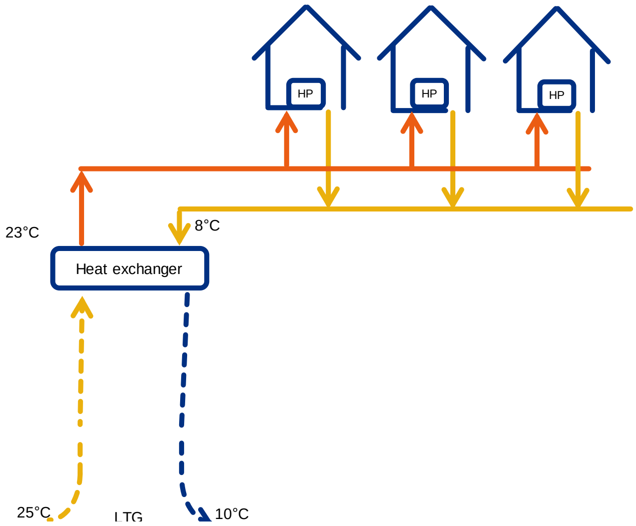
Figure 6 - LTG with central HT heat pump



With a high-temperature heat pump even higher temperatures can be attained: 70°C, for example. This enables temperatures similar to today's district heating systems, sufficient for both space heating and hot tap water. With this relatively high temperature, a wide range of buildings can be connected. Older, less well-insulated homes can often be rendered suitable for heating with a supply temperature of 70°C by relatively simple means (double glazing, limited ancillary insulation and draught-proofing, etc.). If more rigorous steps are taken (additional ancillary insulation, high-efficiency double glazing, comprehensive draught-proofing, etc.), older homes can be heated with 50°C heat. Such improvements reduce heat leakage, allowing existing heat-delivery systems (radiators) to give off enough heat to warm the house. If need be, there is also the option of enlarging existing radiators (from double to triple convector plate, for instance) to this end. An alternative is to install a central gas-fired or electrically-heated back-up system alongside the central heat pumps, allowing the heat grid temperature to be temporarily increased in periods when 70°C is insufficient, on the basis of a heating curve. This will generally only be necessary for a limited number of hours per year, when outside temperatures are very low.

– **LTG with distributed heat pump(s) (Figure 7)**
  In this variant the low-grade LTG heat is piped to consumers at its original temperature via a supply/return grid. Depending on the temperature, uninsulated plastic piping can often be used, making the grid both relatively cheap and easy to install. The heat pumps are decentralized, at either end-point (home, office, etc.) or block level (block of flats, row of houses, etc.). If traditional heat pumps are used, these will set certain demands on end-point heat delivery, such as LT delivery systems and (electric) auxiliary heating for wam tap water.

Figure 7 - LTG with distributed heat pumps



Difference with conventional geothermal

Although less energy will be saved with LTG plus heat pump compared with conventional geothermal, LTG has a number of advantages:

- LTG requires lower investments, making the investment threshold considerably lower.
- The drilling depths can be achieved using cheaper, more compact drilling methods.
- Because of the lower temperature, cheaper materials and components can be used.
- Because of the limited cooling of the water as well as the water quality at the depths concerned, there is less chance of precipitation reactions and scaling.
- The lower energy levels involved permit roll-out at smaller scale.
- LTG can be applied alongside other forms of geothermal, or at locations where these are not technically feasible, permitting optimal, possibly multiple, utilization of subsurface potential.
- Combinations with direct cold supply are possible in situations where heat pumps are used that cool down the available heat to sufficiently low return temperatures (< 18˚C); the cold can then be stored in a short- or long-term buffer and used for cooling.

2.3 Technical aspects

2.3.1 Drilling and safety concerns

With LTG, subsurface heat is recovered from relatively shallow sediments down to a maximum depth of about 1,250 m BGS (below ground surface). In the Netherlands heat production below 500 m as well as exploration at such depths must comply with the terms of the Mining Act, requiring a licence from the ministry of Economic Affairs, issued by the State Supervision of Mines (SodM), the government body charged with enforcing mining legislation. Shallower drilling is covered by the Water Act, for which the provincial executive is the competent authority. Drilling beyond 500 m must meet the stringent safety requirements of the Mining Act, as potential hazards increase with drilling depth.
These hazards are associated mainly with the presence of oil and gas in sediments, in combination with high pressures. Drilling below 500 m is thus subject to an array of safety regulations, with strict requirements set on drilling management and operation.
The detection of gas and oil as a by-product of several Dutch geothermal projects has led

to a tightening of safety and other regulations for geothermal drilling, making them now virtually equivalent to procedures for regular oil and gas drilling.

The need for compliance with all the procedures and safety requirements for conventional oil and gas drilling has had a major impact on drilling costs. In the Netherlands areas can be identified where oil and gas are almost or entirely absent down to a depth of 1,000 m and in such areas drilling involves significantly less safety risks.

Developing cheaper technologies for LTG will therefore also depend on reliable identification of safety risks. If it can be unequivocally established that there can be no oil or gas in the sediments being drilled through and safety is thus guaranteed, consideration might be given to adopting a more limited set of requirements (using only a diverter rather than a blowout preventer, for example).

Depending on the risks identified, available mitigating measures and practical experience, it may be possible to develop a mix of oil/gas, water and HDD drilling techniques suitable for working in 'LTG sediments' that better match the smaller-scale operations in terms of investments.

2.3.2 Developments and innovations

Until now, mainly vertical drilling has been used for LTG, i.e. the relatively cheap technique used for water abstraction, which means sinking two wells by means of straight flush rotary or reverse rotary drilling. To avoid premature thermal breakthrough later on, the geothermal wells need to be sufficiently far apart. Distances between 1,000 and 1,500 m are the rule here, but may be lower if a slight temperature drop is acceptable after fifteen years or so.

Figure 8 shows an example of a typical reverse rotary drilling rig. At the surface the required area is limited to a mobile unit, several settling tanks and somewhere to put the soil: approximately 30 x 30 m.

The maximum drilling depth theoretically attainable with current reverse rotary drilling is about 1,000 m BGS (below ground surface). At present, Dutch market leaders in this field have drilling rig that can reach a maximum depth of 500-750 m. To go deeper, firms will have to modify their equipment or invest in new, heavier-duty rigs. Their willingness to do so will depend on market demand.

An important issue here is that current water drilling firms have little experience with the technical, organizational and legal aspects associated with the Mining Act that is in place for drilling depths beyond 500 m BGS. This entails the technical challenge of having to ensure drilling methods and technologies comply with the provisions of this Act. This also holds for organizational aspects such as the additional safety measures, mandatory certificates, procedures and site organization in force for deeper drilling.

Figure 8 – Example of a reverse rotary drilling rig

Horizontal Directional Drilling

Figure 9 – Geothermal directional drilling rig

One innovation in the field of LTG is the combination of existing HDD (Horizontal Directional Drilling) technologies with oil/gas drilling technologies, permitting drilling to a maximum depth of around 1,250 m BGS using a relatively light, compact drilling platform.

Visser & Smit Hanab are currently developing this technology and setting up one of the first demonstration projects at Zevenbergen. They have named it Geothermal Directional Drilling (GDD).
As in traditional geothermal projects, GGD drills down from a single drilling site to the geological formation of interest, then proceeding horizontally and installing horizontal screens. This is in contrast to traditional drilling for water, which uses vertical wells. See figures 10 and 11.

Figure 10 - Traditional vertical wells

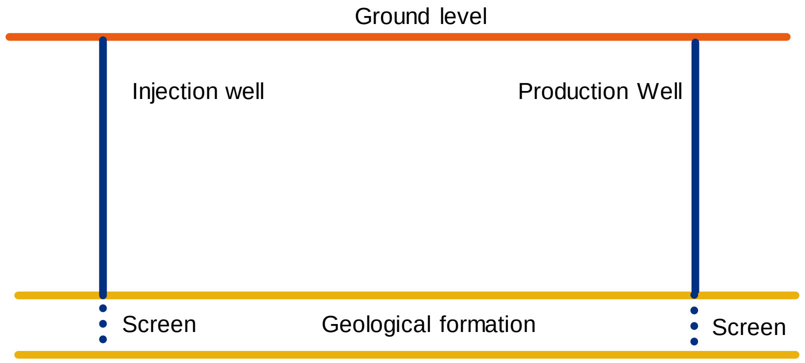
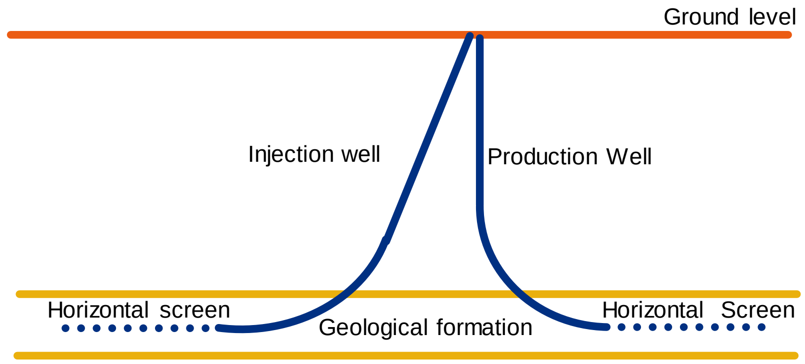


Figure 11 - LTG with horizontal filters



The main advantages of LTG with horizontal screens are:
- The horizontal screens can boost the capacity from thin sediments; poor permeability can thus be compensated for by creating a longer screen path.
- Since drilling can take place from a single site, this limits the search for a suitable location.
- One drilling site means less transport of equipment, a short lead time and limited drilling nuisance.
- There is no need for a separate transport line between the production and injection well.
- The drilling site later becomes the geothermal exchange point and can be chosen close to the area being supplied.

2.3.3 Heat recovery, distribution and end-point delivery

The temperature of LTG heat is generally too low to be used directly for space heating. Direct heat supply sets high demands on the LTG source (a suitable formation at the right depth, temperature and capacity) and the buildings to be heated ((very) low-temperature heat-delivery systems combined with an excellent thermal envelope). These conditions are rarely met, implying very little potential for direct use of shallow geothermal heat. By using heat pumps, though, the low-grade LTG heat can be upgraded, reducing dependence on LTG recovery temperature and enhancing scope for useful application.

Heat pumps can be deployed on either a centralized or distributed basis. Centrally installed heat pumps can serve an entire neighbourhood or housing estate; distributed heat pumps either individual homes (individual heating) or blocks of flats or other large buildings (block heating). For illustrations see Figure 12.

The use of central or distributed heat pumps has a range of consequences; see Table 2.

Table 2 - Comparison of central and distributed heat pumps

Aspect	Central heat pump	Distributed heat pumps
Distribution temperature level	Mid-temperature heat: supply 70°C, return 40°C. Or low-temperature heat: supply 50°C, return 40°C.	Low-grade (source) heat: supply 15-40°C, return 8-15°C. Distributed upgrading (dwelling/block level) to required temperature (50-65°C).
Distribution grid	Insulated piping, generally steel with PUR sheathing.	Plastic piping with little or no insulation.
Space requirements in home	With mid-temperature heat, limited space requirements: delivery set. With LT heat, relatively high: booster heat pump with boiler unit for hot tap water.	Relatively high: heat pump with boiler unit.
Collective space requirements	Energy plant with central heat pumps and possibly back-up system and buffering capacity.	Limited: only heat exchange between LTG and distribution grid.
Hot tap water	With mid-temperature heat, directly via heat exchanger in delivery set. With LT heat, auxiliary heating with booster heat pump.	With individual combi-heat pumps, integrated in heat pump, possibly combined with electric heating element. With heat pumps at block level, auxiliary heating with booster heat pump.
Maintenance and control	Simpler, because of major input from centrally installed equipment.	More complex, because of mainly distributed equipment.

Figure 12 – Examples of central and distributed heat pumps (dwelling and block level) and connection set

2.3.4 Conceptual system integration

Like other kinds of subsurface energy systems, LTG is capital-intensive. For economically viable implementation the following conceptual issues are therefore relevant:

- **Maximimizing equivalent full-load hours**
  The per-kW investment costs of LTG are high compared with conventional technologies, but operating costs are lower. From a financial perspective it is therefore attractive to supply heat a maximum number of hours a year at relatively low thermal power levels. There are a number of strategies to this end: peak shaving via buffering, limited night-time temperature reduction, bivalent heat generation, etc.
- **Maximizing heat recovery**
  Maximizing the amount of geothermal heat produced means making optimum use of the thermal energy available per m^3 pumped-up water. Although use of a heat pump reduces the system's overall Seasonal Performance Factor (SPF; see 2.4), energy output is increased because of the greater temperature difference, i.e. more heat is generated. As long as there is enough demand for this heat, on balance its cost price will fall, the more energy is produced. The SPF of heat production itself does decline, though, an issue discussed in the next section.

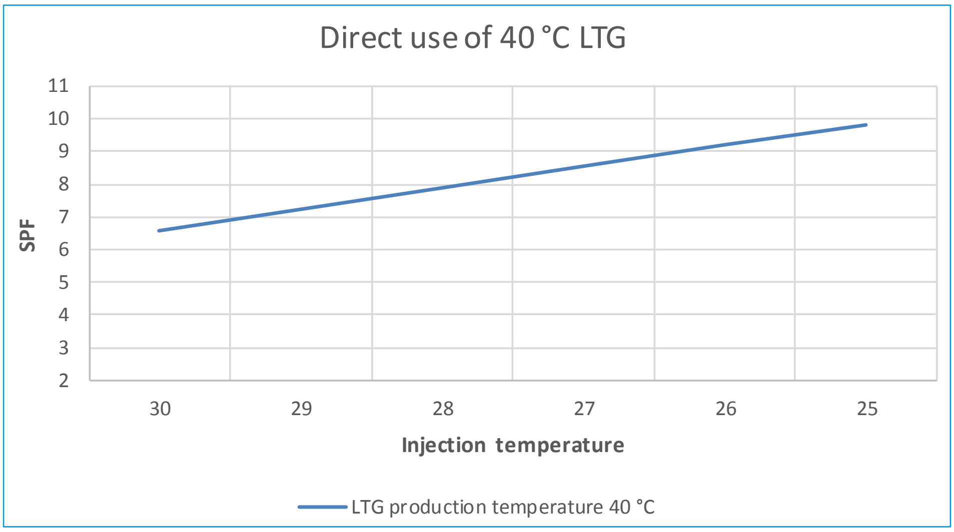
2.4 Energy performance

The energy performance of LTG can be expressed as the Seasonal Performance Factor (SPF): the ratio between electrical energy input and thermal energy output (Coefficient of Performance, COP), averaged over the entire heating season. The SPF of heat production in an LTG system is not fixed, but determined mainly by the SPF of LTG recovery itself plus that of the heat pump. These depend on several factors, including:

- productioen and injection temperature;
- formation resistance and pump capacity;
- relative contribution of heat pump;
- heat-pump condenser and evaporator capacity.

The highest SPF is achieved with direct LTG heat delivery without a heat pump. Direct delivery of 40°C heat has an SPF of between 6 and 10, depending on the return temperature; see Figure 13.

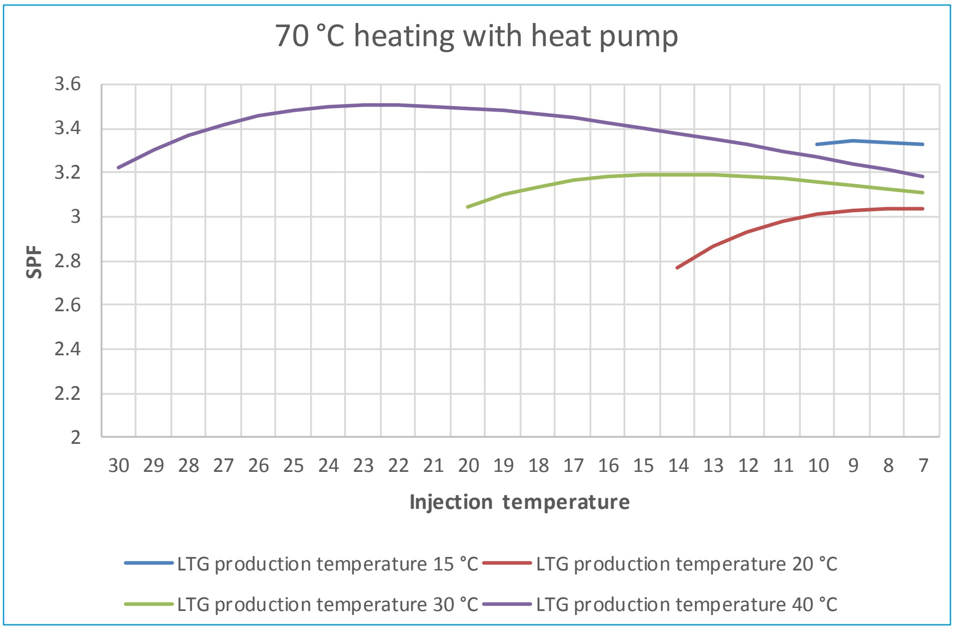
Figure 13 - SPF of direct use of 40°C LTG



In today's built environment there is fairly limited scope for direct use of shallow LTG. Direct use makes high demands on buildings' thermal envelope and heat-delivery systems, while at the same time also setting requirements on local geology: for direct use of 40°C heat there obviously needs to be a suitable formation at hand from which such heat can be recovered. The need for a combination of suitable building stock on the surface and suitable sediments below means direct use of LTG heat in the Dutch built environment does not look particularly promising. In contrast, though, there is plenty of scope for utilizing 70°C heat, which can generally be usefully applied to heat both existing homes and newbuild after only relatively simple architectural changes, if such are needed at all.

One major drawback, however, is that the SPF drops substantially at a production temperature of 70°C, falling to between 2.8 and 3.5; see Figure 14. This is solely for heat production (LTG doublet and heat pump) and excludes distribution and end-user delivery.

Figure 14 - SPF of 70°C LTG with heat pump



Because of the relatively low SPF of 70°C input, the extent to which buildings can be heated using lower-temperature heat is an an issue requiring further investigation.
One strategy might be to vary the temperature of the heat supply depending on the ambient temperature, using a generic heating curve. For most of the year, the great bulk of today's buildings can be heated using lower-temperature heat (approximately 50°C), with hotter input only being needed during particularly cold snaps (heavy frost) or if buildings need to be heated quickly. This can then be resolved by:

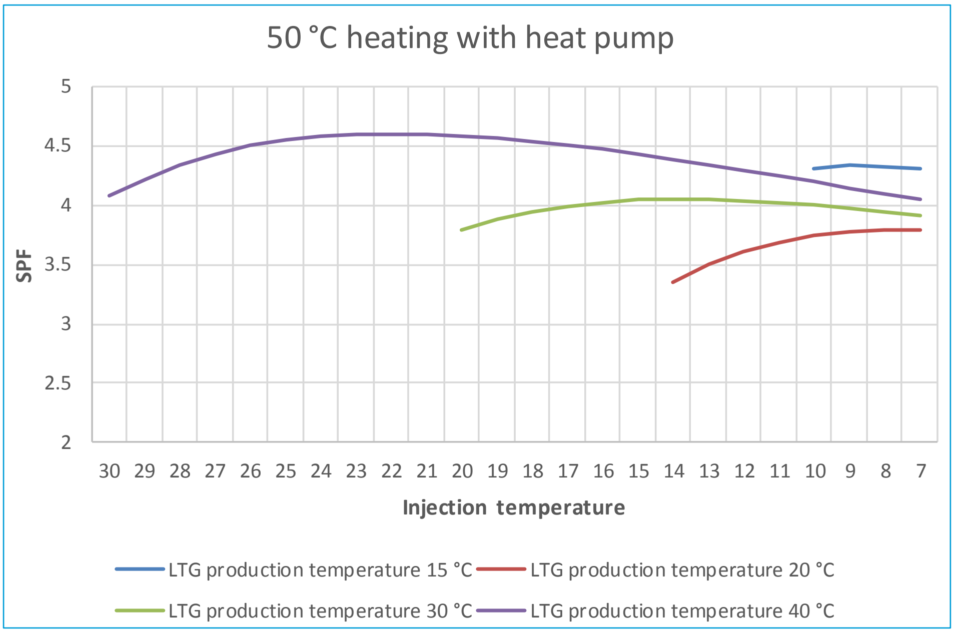
- installing a local back-up system for a brief surge of higher-temperature heat; and
- less night-time temperature reduction in buildings.

A lower heating temperature (lower than 70°C) means a higher SPF of heat production, due mainly to improved heat-pump efficiency at lower ouput temperatures. See figure 15.
The average SPF of 50°C heat production is between 3.0 and 4.2 (instead of between 2.8 and 3.5 for 70°C ouput).

It is not only the heat production temperature that affects the SPF, but also the source temperature. As this rises (with increasing sediment depth), so too does the SPF attainable with the heat pump, boosting overall SPF. This effect can also be seen in the above figures, though it is damped by the fact that deeper sediments have greater resistance, depressing the SPF of the LTG resource. Because of the low resistance of shallow sediments (aquifers down to around 250 m BGS) LTG with production temperatures of about 15°C yields a relatively high overall SPF, despite the relatively low SPF of the heat pump.

Compared with heat production using a natural gas boiler, LTG heat generation means lower CO_2 emissions. The precise emission reduction will depend on specific LTG parameters (production temperature, production temperature, formation resistance, etc.) and on the CO_2 emission factor of electricity production.

Figure 15 - SPF of 50°C LTG with heat pump



As the share of renewables in the Dutch electricity mix rises in the years ahead, so too will the carbon emission reduction attainable with LTG. Table 3 reports projected reductions based on forecast emission factors for power generation ('integrated method') from the Dutch National Energy Outlook (NEV 2015). Emission reduction depends on the precise SPF of LTG heat production.

Table 3 - Feasible CO_2 emission cuts of LTG relative to natural gas

Jaar	70°C with heat pump	50°C with heat pump	40°C direct
2017	35-38%	49-52%	71-80%
2020	47-50%	58-61%	76-84%
2030	61-63%	69-72%	83-88%

LTG heat production has a similar SPF compared to individual ground-source heat pumps (GSHP), implying feasible CO_2 emission cuts of the same order. Although with LTG the SPF of the heat pump on its own is potentially higher than with individual GSHP, because of the heat pump's higher evaporation temperature, the LTG well pumps consume more energy than individual GSHP, making the overall emission reduction roughly the same on balance.

2.5 National potential of LTG

To assess the potential for low-temperature geothermal in the Netherlands, we mapped suitable geological reservoirs . This led to identification of the following six reservoirs at depths of between 250 and 1,250 metres BGS:
— Oosterhout Formation;
— Rijnland Group;
— Maassluis Formation;
— Breda Formation;

- Brussels Sand Member;
- Delfland Group.

Two sources were used for this mapping: '*Kansen voor lagetemperatuuraardwarmte voor de glastuinbouw*', published by KEMA, DLV glas en energie and IF Technology in 2012 (ref.: 74100973-CES/IPT 12-3178) and '*Potentieel geothermie Zuid-Holland*', published by IF Technology in 2016 (ref.: 66141/SB/20161129).

The maps showing the individual potential of the six formations (in TJ/hectare/yr) are included in Annex B.

We estimated the potential by dividing the geological reservoir into hectare (100 x 100 m) units and calculating the potential of each, as follows:

Potential per hectare = $((H \times (T_{res} - T_{ret}) \times C) \times Q_{ex})/T$ [MJ/hectare/yr],

where:
H reservoir thickness [m]
T_{res} production temperature from reservoir [°C]
T_{ret} return temperature to reservoir [°C]
C total heat capacity of reservoir [MJ/m^3°C]
Q_{ex} fraction of extractable heat, 30-50% of total heat present
T period during which heat production occurs [yr].

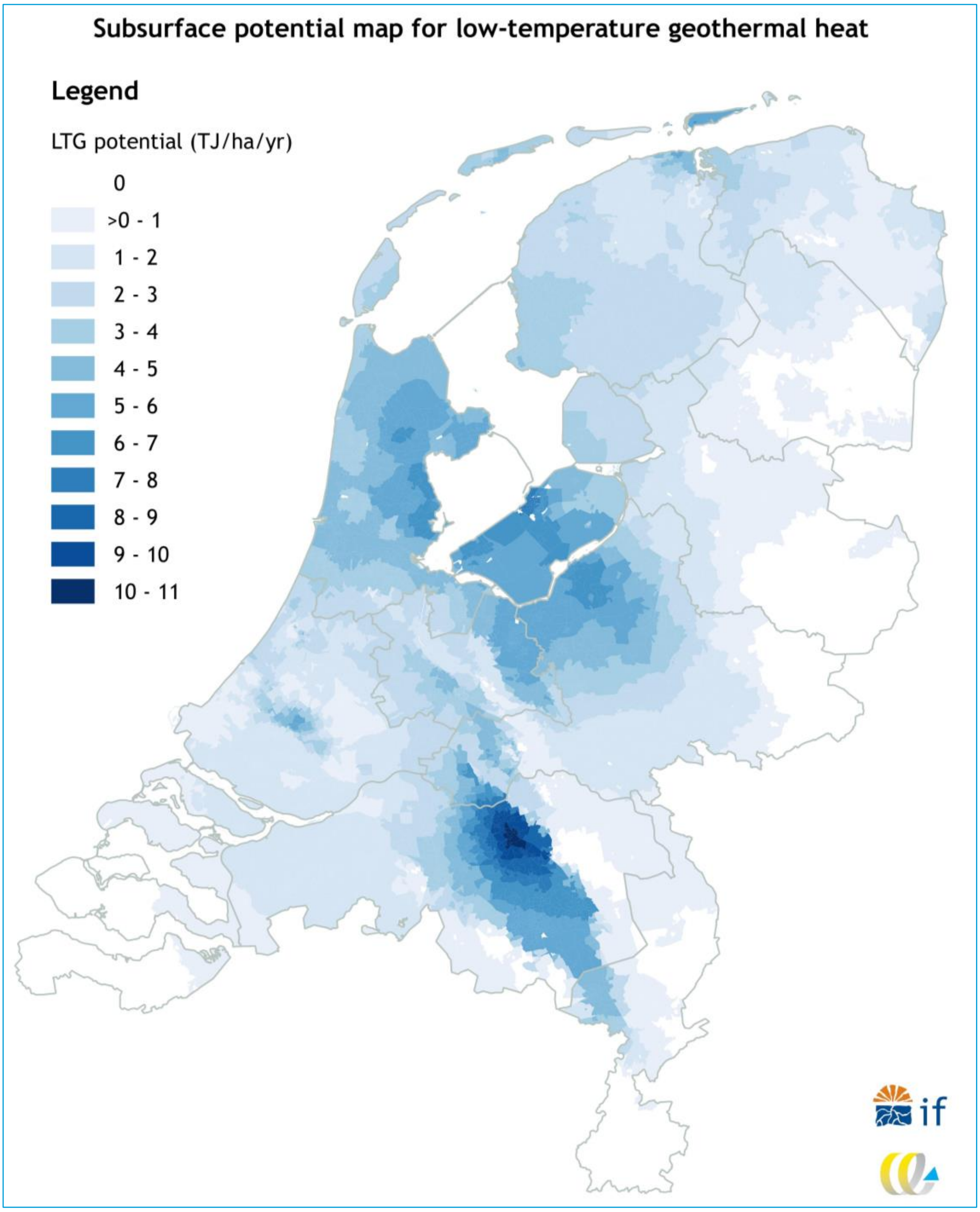
The parameter Q_{ex} was employed because in practice not all the available heat can be recovered, owing to the presence of underground cold pockets and the need to space individual systems. It is a theoretical artefact to capture the extractable heat relative to the total amount present.

A return temperature of 7°C was assumed and an production period of 30 years. This is the return temperature yielding maximum capacity utilization. Our financial analysis also shows the economic optimum occurs at maximum energy recovery from the LTG water, despite the COP/SPF of the heat pump falling as this rises. The relationship between cost price and SPF is discussed in Section 2.6.2. The values of the other parameters depend on the reservoir characteristics in the hectare concerned.

In Figure 16, below, the potential of the six suitable formations has been amalgamated into a single map by summing the potential of each. The unit is TJ/ha/yr. In the legend, '> 0 – 1' has a cut-off of 0.5 TJ/ha/yr, below which economic recovery becomes unviable. This map is thus the **national subsurface potential map for low-temperature geothermal**. It gives no consideration to whether or not the above-ground area is built-up, looking solely at the suitability of sediments (one or more).

The total Dutch subsurface potential represented in this map amounts to 6,931 PJ per annum.

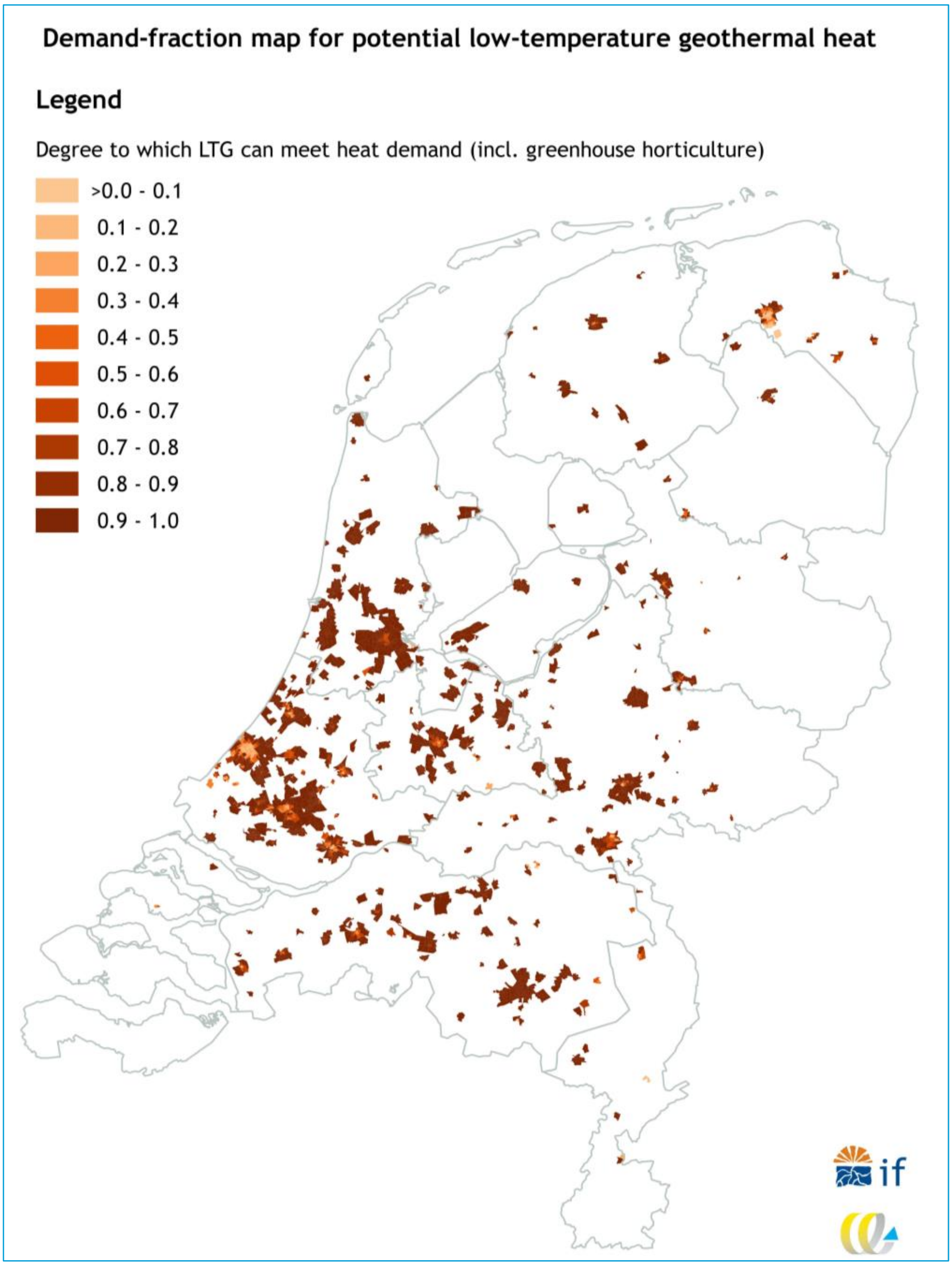
Figure 16 – National subsurface potential map for low-temperature geothermal



Next, potential utilization was calculated with reference to the heat demand per ‘CBS district’, as defined by Statistics Netherlands (CBS), taking only built-up districts with an urbanization index (STED) of 1, 2 or 3, thus ignoring 4 (‘barely urbanized’) and 5 (‘non-urbanized’). The heat demand of the greenhouse horticultural sector was also factored in.

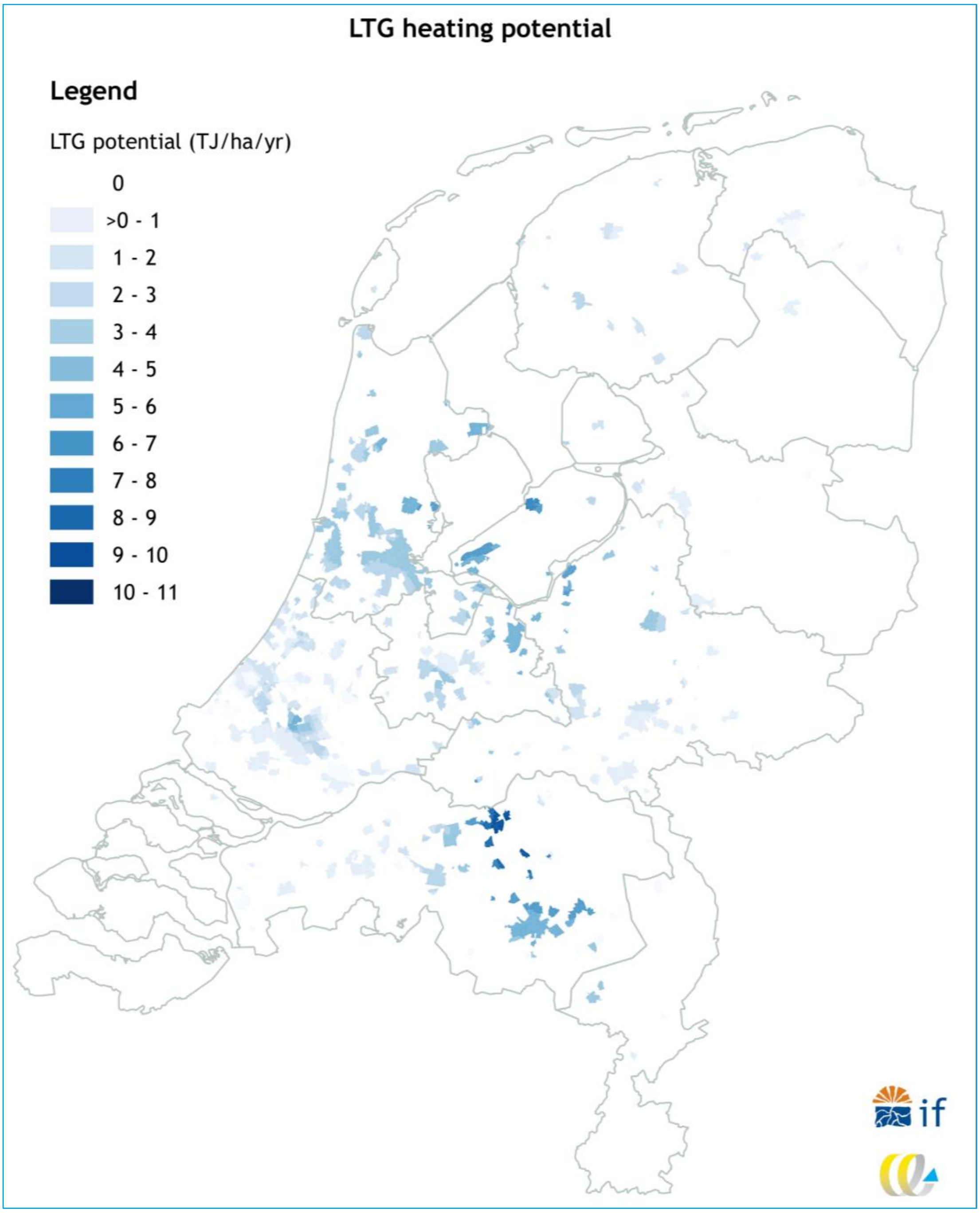
On this basis a so-called **'demand-fraction map'** was created, showing the percentage fraction of heat demand that can potentially be covered by low-temperature geothermal heat in the most built-up CBS districts and greenhouse horticultural areas. This map is shown in Figure 17.

Figure 17 – Demand-fraction map for potential low-temperature geothermal



By combining the two previous maps a **national LTG heating potential map** was derived (Figure 18).

Figure 18 – National LTG heating potential map



To determine national potential, for each CBS district and greenhouse horticultural area the heat demand was assessed relative to the available LTG resource. If heat demand exceeded available LTG, the latter was taken as the potential; if it was less, the former was taken. On this basis the national LTG heating potential was calculated as 229 PJ per annum, or 37% of current heat demand in the Dutch built environment and greenhouse horticultural areas.

Sustainability of LTG heating potential

The 30-year time frame adopted assumes the LTG production temperature remains constant for 30 years, after which the production temperature will be affected by the return of cooler water, a process known as thermal breakthrough. As a result, after this period the production temperature will gradually start to decline, which means the heat capacity of the LTG doublet will also start falling at the same rate. This process is called thermal depletion. This temperature decline is a gradual process that starts slowly (several degrees a year at most), speeding up over time as the sediments around the production point continue to cool. During that period there comes a time when LTG potential becomes insufficient to deliver the required amount of heat. At that point a new production well can be drilled far enough away from the cold pocket created in the sediment, permitting further heat production. This pocket will slowly rewarm, through geothermal conductivity, a natural regeneration process that may take several centuries.

If the LTG reservoir is used not only as a heat source but also as a buffer for seasonal storage of (waste) heat, thermal depletion can be postponed or even avoided altogether (if heat input and output are in equilibrium). This means the LTG concept can be very effectively combined with the Minewater concept, as discussed further on.

2.6 Financial aspects

An LTG system in a built-up area comprises the following main elements:
- LTG source system (LTG wells through to heat exchangers);
- central or distributed heat generation (heat pumps, possibly a back-up system);
- distribution to end points;
- end-point delivery;
- other provisions (control systems, architectural provisions, mechanical & electrical components).

Besides the elements of the LTG system itself, modifications may also be required in the connected buildings, including:
- improved insulation for LT heating;
- modifications to heat-delivery systems.

The required modifications to buildings depend very much on the type of building (year of construction, envelope quality, heat-delivery systems installed) and the temperature of the incoming heat.

2.6.1 LTG source system

Of the elements cited above, it is above all the LTG source system that is characterized by uncertainty when it comes to investments and operating costs, given the limited practical experience with this kind of wells. While there is plenty of experience with realizing wells for water (down to 250 m BGS) and wells deeper then 1,500 m (mainly for the oil and gas industry), the depths in between that are relevant for LTG are still relatively uncharted territory.

Capital expenditure

Investment outlay (capital expenditure, CAPEX) in LTG wells strongly depends on the drilling method adopted and on the measures that need to be implemented under current regulations to meet (safety) requirements and procedures.

There is little detailed information available on the cost of drilling horizontal wells. The technique is currently being developed by Visser & Smit Hanab, with the first pilot project being rolled out in Zevenbergen. In consultation with the firm, estimates have been made of the anticipated CAPEX for an LTG doublet using Geothermal Directional Drilling (GDD), based on the following assumptions:

- production rate: 300 m^3/h;
- return temperature: 8°C;
- length of horizontal screen path: 500 m per well;
- inter-screen spacing: 1,000 m underground.

Estimated investments for a range of LTG systems is reported in Table 4. The figures for each of the main constituent elements are detailed in Appendix C. These data were drawn up using input from Visser & Smit Hanab. It should be noted that the data represent average investments, with exact figures depending on local circumstances and sediment characteristics.

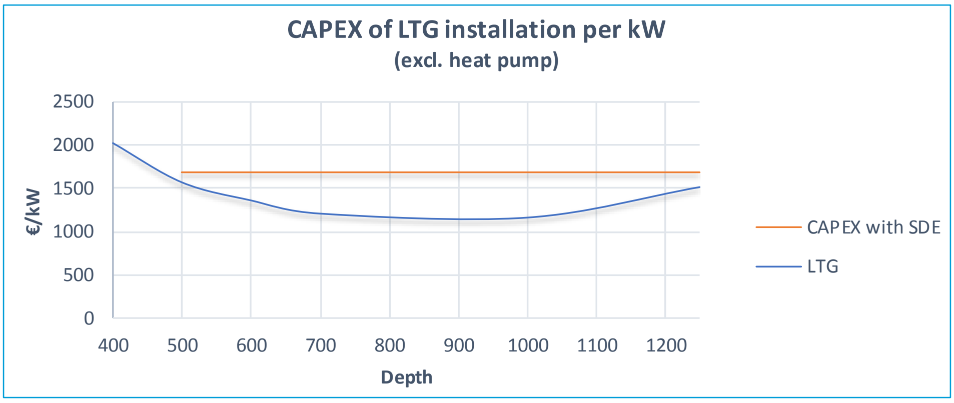
The cited figures are for the underground portion of the LTG system, including submersible pumps, piping and fittings up to the heat exchanger. Costs relating to heat pumps, buffers, distribution grid, process-control building and zoning plan are thus excluded (for these, see below).

Table 4 - Investments for an LTG system (excl. VAT, accuracy +/- 10%)

Depth (m BGS)	Temperature (°C)	Capacity (MW)	Investment (€)	€/kW
400	19	3.8	7,740,000	2,020
500	23	5.2	8,210,000	1,575
600	26	6.3	8,560,000	1,365
700	31	8.0	9,730,000	1,215
1,000	40	11.1	13,030,000	1,170
1,250	49	14.3	17,550,000	1,230

Figure 19 shows CAPEX per kW as a function of depth of the horizontal screen paths.

Figure 19 - CAPEX per kW as a function of depth



As the graph above shows, capital expenditure on LT geothermal heat production from vertical wells depends on depth and attainable capacity and varies between 1,200 and 2,000 €/kW_{th}. For comparison, the graph also shows CAPEX for conventional geothermal as subsidized under the SDE+ 2017 scheme ('CAPEX with SDE'). While LTG requires less investment per kW, given the overall CAPEX and electricity costs for the heat pump, there are grounds for reviewing the SDE+ subsidy for LTG.

It should be noted that the CAPEX figures above are based on reference data from a demonstration project. Actual values may deviate with differing geological conditions and/or assumptions.

Operation and maintenance

Besides capital expenditure there are also the costs of operation and maintenance (O&M), estimates for which are reported in Table 5. These figures are explained in Annex C and were calculated using input from Visser & Smit Hanab. It should again be noted that these represent average costs, with precise figures depending on local circumstances and sediment characteristics.

Table 5 - O&M costs for LTG doublet (excl. VAT, accuracy: +/- 20%)

Depth (m BGS)	O&M costs (€/year)
400	170,000
500	170,000
600	170,000
700	185,000
1,000	250,000
1,250	300,000

2.6.2 Cost price of heat

The cost price of the LTG heat is expressed in €/GJ and is made up of the following main elements:
- CAPEX;
- annual O&M costs;
- electricity costs.

The cost price calculated makes no allowance for subsidies or tax schemes.

Equivalent full-load hours

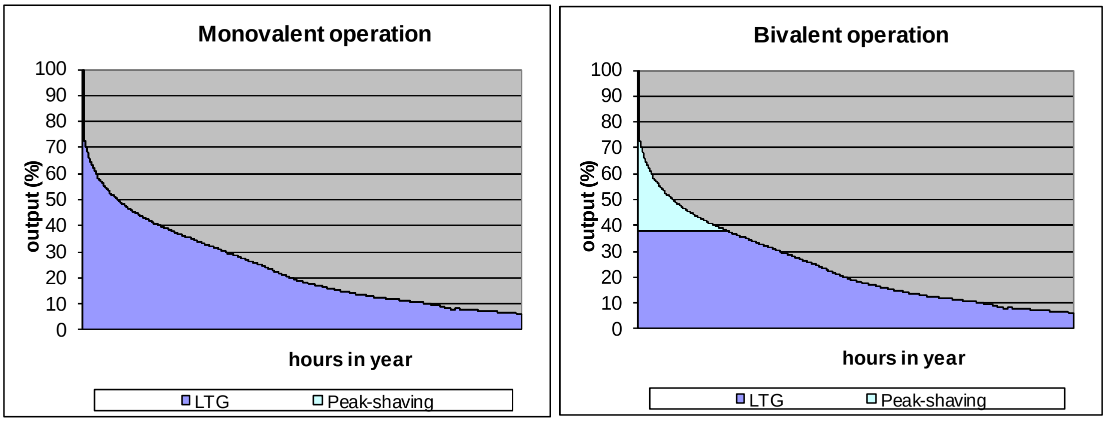
A key factor determining heat cost price are the number of equivalent full-load hours that LTG is available. The more there are, the more heat is utilized and the lower the cost price per GJ.

If LTG can supply the full heat output and thus cover the entire heat demand (monovalent operation), the number of equivalent full-load hours will be limited (around 1,000-1,500 hours). If peak heat demand can be reduced (peak-shaving), LTG can be used for more full-load hours.

Peak shaving can be achieved in two ways:
1. By employing an auxiliary back-up system (bivalent operation). And/or
2. By buffering heat in buildings, with additional local buffers in clusters and buildings.

Figure 20 illustrates insertion of LTG into an annual load-time curve for a conventional district heating system in a built-up area.

Figure 20 - Typical insertion of LTG into an annual load-time curve for a conventional district heating system



In the case of bivalent operation with LTG in the baseload, LTG supplies around 38% of the required peak output and consequently around 90% of heat demand, the remaining 10% being delivered by a back-up system. LTG then has around 4,000 equivalent full-load hours.

Direct heat supply or via heat pump

discussed, LTG heat can only be utilized directly, without a heat pump, if the buildings served have very-low-temperature heat-delivery systems like concrete core activation. Heat pumps can be used for two purposes: to increase enery recovery from the geothermal heat, and/ or to raise its temperature. Use of a heat pump almost always has a positive effect on heat cost price, because more energy recovery boosts the amount of effective heat delivered. On balance, and ignoring SDE subsidy input, this reduces heat cost price, despite the heat pump's additional CAPEX and OPEX. SDE reinforces this effect even further, as shown in Figure 22.

The cost-price calculation assumes the heat produced can be effectively used, which depends on the heat-delivery systems in place.

In Figure 20, below, the calculated heat cost price is shown for both direct heat supply and supply via a heat pump. This is solely the cost of heat production (geothermal resource and central heat pump), and does not include the costs of distribution and end-point delivery. In Section 2.7 a rough business case is calculated for LTG, including distribution and end-point delivery.

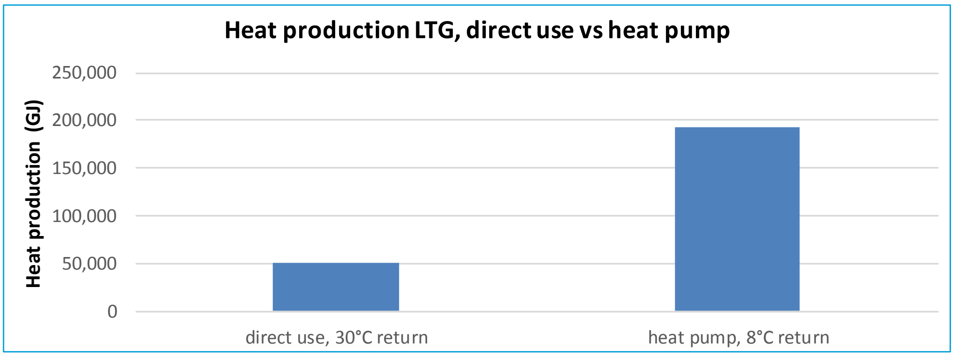
Heat cost-price calculation was based on the assumptions in Table 6.

Table 6 – Assumptions for calculating LTG heat cost price

Parameter	Value	Unit
Production depth	1,000	m BGS
Production/production temperature	40	°C
Injection temperature with direct use	30	°C
Injection temperature with heat pump	8	°C
Production rate	300	m^3/h
Full-load hours	4,000	h
Average electricity price	0.075	€/kWh
Heat pump SPF	6.0	-
Interest	6%	%/yr
CAPEX, doublet	13,000,000	€
CAPEX, central heat pump	3,300,000	€
Depreciation, LTG wells	30	yr
Depreciation, heat pump	15	yr
O&M, doublet	250,000	€/yr
O&M, heat pump	100,000	€/yr

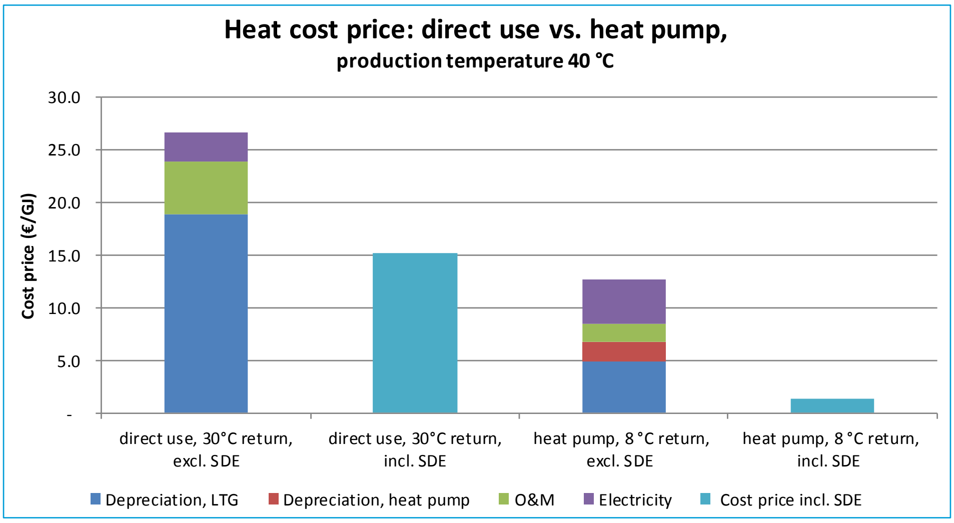
With direct supply of 40°C heat and a return temperature of 30°C, heat output is around 3.5 MW. With 4,000 full-load hours this means 50,000 GJ of heat is produced annually. If a heat pump is used, the geothermal heat is cooled down to 8°C, increasing the heat output from the source to 11.1 MW, with the heat pump ultimately supplying 13.4 MW of 40°C heat. Taking the same number of full-load hours a year, this means delivery of 193,000 GJ heat annually, or almost four times as much as in the case of direct use; see Figure 21.

Figure 21 - Heat output: direct delivery vs. heat pump



The heat cost price with and without a heat pump is shown in Figure 22.

Figure 22 - Heat cost price: direct delivery vs. heat pump



As Figure 22 shows, the power consumption of the heat pump is a significant fraction of the total cost price, which is therefore more sensitive to the electricity price in this variant.

Heat production and deployment

A cost-price-optimized LTG system produces a lot of heat and to use it effectively requires large-scale deployment. Depending on the depth, degree of energy recovery, attainable capacity and percentage input from LTG, the required scale is 1,000-2,500 dwelling equivalents. While this is 2-3 times less than for conventional geothermal, the minimum scale for LTG is still relatively high. This is due mainly to the fact that LTG with horizontal screens is optimized for a relatively high production rate.

Smaller-scale deployment is possible if implementation is via simple, comparatively cheap vertical wells down to 200-500 m BGS. In that case the required scale of deployment is somewhere between 300 and 800 homes. Without SDE subsidy, this boils down to a similar heat price of between 12 and 15 €/GJ. Given the depth cut-off of around 500 m, however, this variant is not eligible for such a subsidy, making it less appealing in financial terms.

Energy recovery by heat pump

The extent to which the heat pump cools down the LTG water, i.e. the amount of energy recovered, is of major influence on the cost price of the heat produced. Generally speaking, the more energy recovered, the lower the cost price. Figure 22 shows the calculated cost price for heat produced at various temperatures depending on the degree of energy recovery, assuming centralized heat production (source and collective heat pump). The price reported does not include subsidy or tax schemes. Besides the influence on heat cost price, the influence on the SPF of heat production has also been calculated. Cost-price calculation was based on the assumptions in Table 7.

Table 7 – Assumptions for cost-price caclulation at various energy recovery levels

Parameter	Value	Unit
Production depth	700	m BGS
Production temperature	31	°C
Production temperature	50	°C
Production rate	300	m^3/h
Full-load hours	4,000	h
Average electricity price	0.075	€/kWh
Interest	6%	%/yr
CAPEX, source system	9,729,000	€
CAPEX, heat pump	250	€/kW
Depreciation, LTG wells	30	yr
Depreciation, heat pump	15	yr
O&M, doublet	185,000	€/a
O&M, heat pump	3% of heat pump CAPEX	%/yr

The results of the calculations are reported in Figure 23.

Figure 23 - Cost price and SPF as a function of energy recovery

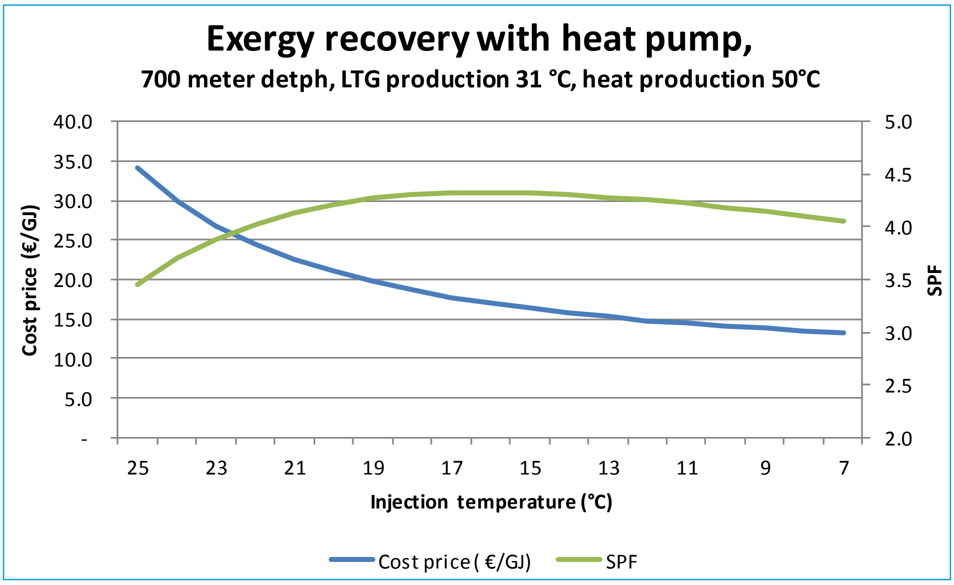


Figure 23 confirms the picture that the more energy is recovered (and therefore the lower the injecton temperature), the lower the heat cost price. This is because increased energy recovery increases production capacity and therefore final heat output. In financial terms, the increased heat production more than compensates for the higher electricity costs due to the loss of heat pump SPF.

The more energy is produced from the geothermal heat, the further the heat pump SPF falls. This effect is partly compensated by the SPF of the LTG wells rising, because of the greater temperature difference. On balance, the overall SPF of heat production does decline slightly the more energy is recovered. With 50°C heat production and cooling down to 7°C an overall SPF of 4 is calculated for heat production. This is comparable with the energy performance of an individual ground-source heat pump and higher than the SPF of around 3.5 for an individual air/water-source heat pump. Depending on the application, an optimum will need to be found that balances cost price and energy performance.

Cost price of produced heat as a function of sediment depth

Provided suitable sediments are present, LTG can be rolled out at a range of depths. Since sediment thickness, depth, permeability and temperature may vary considerably locally, it is impossible to calculate a single, unambiguous cost price for LTG heat production. For an indication of the influence of sediment depth on cost price, a series of calculations were therefore made under assumptions regarding sediment parameters, based on estimated underground potential. These assumptions are reported in Table 8. The cost price estimates do not include subsidy or tax schemes.

Table 8 -Assumptions for calculating heat cost price as a function of sediment depth

Parameter	Value	Unit
Production temperature	50	°C
Full-load hours	4,000	h
Production rate	300	m^3/h
Return temperature	8	°C
Average electricity price	0.075	€/kWh
Interest	6%	%/yr
Depreciation, LTG wells	30	yr
Depreciation, heat pump	15	yr

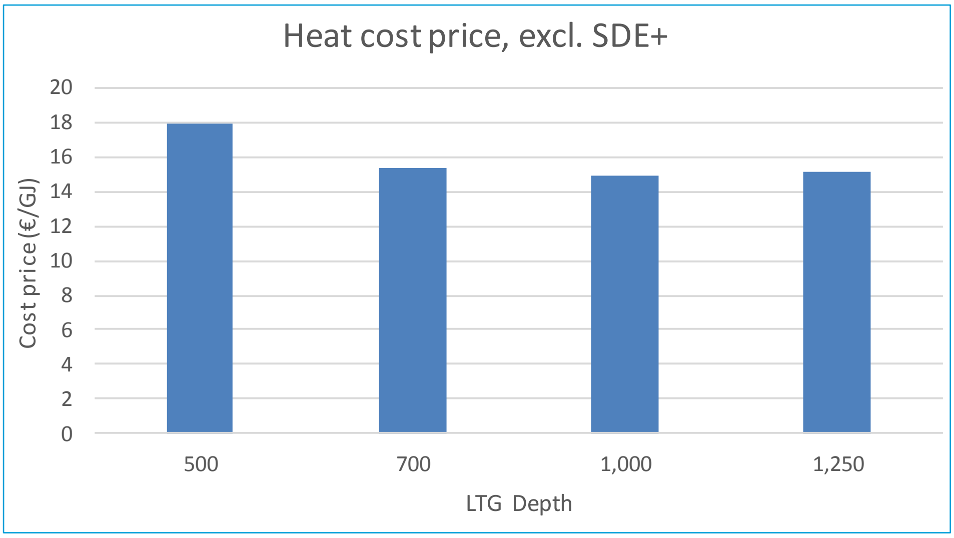
The results of the cost-price calculations are reported in Table 9.

Table 9 – Results of heat cost-price calculations

Drilling depth (m)	500	700	1,000	1,250
ESP well head (bar)	20	25	30	35
Production temperature (°C)	23	31	40	49
SPF, heat pump (70% Carnot)	4.8	4.8	4.8	4.8
COP, LTG	17.2	21.1	24.5	26.9
Heat pump capacity (kW)	6,577	10,084	14,030	17,976
Heat output (MWh)	26,306	40,336	56,120	71,904
CAPEX, doublet (€)	8,209,000	9,729,000	13,027,000	18,059,000
CAPEX, heat pump (€)	1,644,148	2,521,028	3,507,517	4,494,006
CAPEX, total (€)	9,853,148	12,250,028	16,534,517	22,553,006
Capital costs (€/yr)	765,661	966,373	1,307,541	1,774,682
Power consumption, LTG (kWh)	1,212,121	1,515,152	1,818,182	2,121,212
Power consumption, heat pump (kWh)	5,426,375	8,320,442	11,576,268	14,832,093
Energy costs (€/yr)	497,887	737,670	1,004,584	1,271,498
O&M (€/yr)	219,324	260,631	355,226	434,820
Cost price, without SDE (€/GJ)	**18.0**	**15.3**	**15.0**	**15.1**

Depending on drilling depth, the cost price of 50°C heat production using LTG combined with heat pumps is between 15 and 18 €/GJ, translating to a cost price of 54-65 €/MWh.

Figure 24 - Cost price of 50°C heat, including heat pump, excluding SDE+



SDE+

The SDE+ subsidy scheme is an operating grant that incentivizes renewable energy production by industry and (non-profit) institutions, see https://www.ecn.nl/collaboration/sde/. The 2018 scheme opened on 7 March 2018 with an annual budget of 6 billion euro.

The SDE+ scheme distinguishes the following categories of geothermal heat production:
- below at least 500 m BGS;
- below at least 3,500 m BGS;
- below at least 500 m BGS, where one or both wells of the doublet is an existing oil or gas well;
- with the production unit expanded with at least one additional well at least 500 m BGS.

The SDE+ scheme reimburses the so-called 'unprofitable component': the difference in cost price between geothermal and a reference, which in 2017 meant a subsidy of about 11.40 €/GJ heat output. The subsidy is fixed for fifteen years, with the annual sum paid out corrected for changes in energy prices.

Under the terms of the SDE+ scheme, LTG is only eligible for subsidy if it is sourced below 500 m BGS. This 500 m transition point is therefore something that needs to be reviewed when it comes to LTG, as there may well be locations where shallower geothermal heat production is feasible. In addition, the current SDE+ scheme takes greenhouse horticulture as its primary reference point. It is recommended to reconsider both the 500 m transition point and application specifically in the built environment.

2.7 Approximate business case

It is hard to make a solid pronouncement on the financial viability of LTG, as this depends on multiple factors like energy prices, system concept, sediment suitability and depth, deployment area, required temperature levels and so on. Certainly with the current building stock, viability also hinges strongly on the costs of measures that need to be taken in homes and other buildings prior to heat-grid connection, as well as the architectural measures needed for a lower-temperature heating regime.

To gain a rough indication of the financial viability of LTG, calculations were made for a simplified business case for existing building stock, to identify the main contours of the energy and monetary flows involved and gain a rough impression of the economic viability of LTG in the urban environment. The calculations are based on approximate indices and input parameters, with results likely accurate to +/- 30%. As no allowance was made for site-specific parameters, actual costs may in reality turn out higher or lower.

The energy concept was defined as follows:
- LTG doublet: 300 m^3/h capacity, 600 m depth;
- primary heat distribution grid: insulated plastic piping from LTG source to central heat pumps;
- distributed heat pump units at building/neighbourhood level;
- LT heat output: max. 55°C;
- secondary heat grid from heat pump units to in-house delivery sets;
- in-house delivery sets in tandem with booster heat pumps for hot tap water production;
- zero-gas energy concept: no gas-fired back-up system.

The business case was designed as follows:
1. The deployment area (number of homes connected) was set by matching the collective heating rating of these homes to the available capacity of a single LTG doublet, with due allowance for synchronization factors and possible additional peak-shaving measures.
2. Energy demand was based on the number of homes connected and consumption indices, with due allowance for heat pump performance and distribution losses.
3. Capital expenditure on energy-system components (LTG doublet, heat pumps, back-up system, distribution grid, connection sets, etc.) was estimated using standard indices.
4. The operating costs of the energy supply (electricity, O&M) were estimated.
5. Annual revenue from annual SDE+ subsidies (if applicable) was included as per the 2017 scheme for geothermal.
6. Annual revenue from avoided fixed and variable costs (reference costs) was included as per the maximum tariffs laid down in the 2017 Heating Supply Act (as explained in the text box in Subection 3.6.3).
7. A one-off connection fee was taken equal to that for a standard district-heating connection.
8. Finally, the initial rate of return (IRR) achievable with the zero-gas energy system was calculated.

Table 10 - Assumptions for business case

Homes		
Average heat demand, space heating	30	GJ
Average heat demand, tap water	7.5	GJ
Heating rating, average dwelling	8	kW_{th}
Synchronicity, centralized heat generation	60%	
LTG doublet		
Depth, LTG doublet	600	m
Maximum flow, LTG doublet	300	m^3/h
Production temperature	27	°C
Injection temperature	8	°C
Pump capacity, LTG doublet	333	kW_e
Distribution		
Transport losses, primary distribution grid	20%	
Transport losses, secondary heat grid	8%	
Heat pumps		
COP, central heat pump	4.5	
COP, booster heat pump	4.5	
Financial assumptions		
Electricity tariff, incl. distribution costs	75	$€/MWh_e$
One-off connection fee	4,500	€/home
Annual index, variable gas/heat price	5%	
Annual index, other costs and revenues	2%	

Under the above assumptions, the results are as follows:
- with the capacity of a single LTG doublet and synchronicity duly factored in, 1,770 homes can be connected;
- allowing for heat-pump conversion efficiencies and grid heat losses, around 67,000 GJ LT geothermal heat can be produced annually for delivery to homes;
- LTA doublet operation provides over 2,800 equivalent full-load hours per annum.

The capital expenditure figures assumed for the main components are reported in Table 11.

Table 11 - Capital exdpenditure on main components

Component	CAPEX
LTA doublet	€ 8,559,000
Central heat pumps	€ 4,250,000
Distributed booster heat pumps	€ 5,568,000
Delivery sets	€ 2,125,000
Distribution (primary and secondary)	€ 7,084,000
Design and consultancy	€ 1,148,000
Contingencies	€ 2,883,000
Subtotal CAPEX	€ 31,617,000
Tax revenues (EIA) and ISDE subsidy, booster heat pumps	€ -/- 2,125,000
Net CAPEX	€ 29,492,000
Connection fees	€ -/- 7,970,000

The cost of getting an LTG system up and running, including distribution and heat pumps through to connection sets in individual homes, is estimated at over € 18,000 per home, exclusive of connection fees, subsidies and tax schemes (Investment Subsidy for Renewable Energy, ISDE, and Energy Investment Allowance (EIA)).

Estimated annual operating costs are reported in Table 12.

Table 12 - Annual operating costs

Item		Cost
Electricity costs, LTG doublet	€	70,000
Electricity costs, distribution	€	14,000
Electricity costs, central heat pumps	€	320,000
Electricity costs, booster heat pumps	€	61,000
O&M, LTA doublet	€	170,000
O&M, central heat pump units	€	128,000
O&M, delivery sets and booster heat pumps	€	96,000
O&M, distribution	€	35,000
Administration & project management	€	89,000
Total annual operating costs	**€**	**983,000**

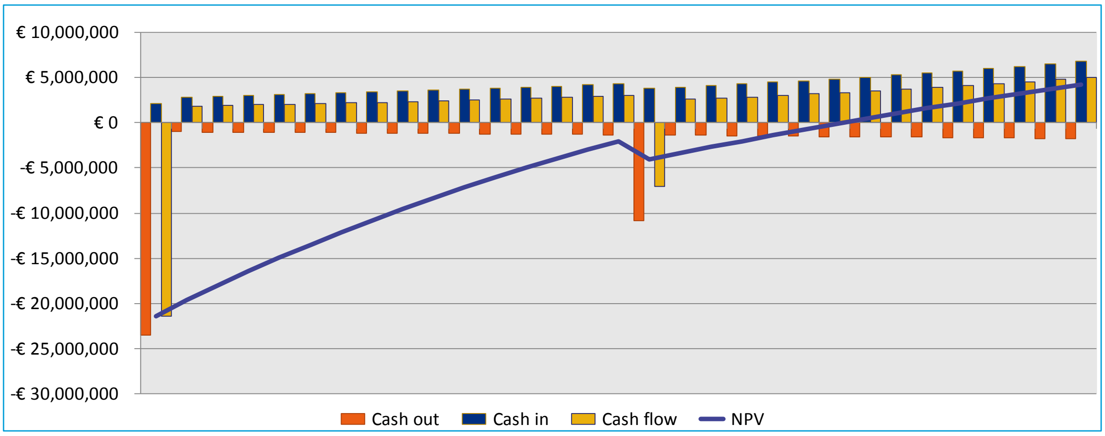
In calculating the business case, allowance was made for the following subsidies and tax schemes:
- SDE+ subsidy based on the current scheme and 2,820 full-load hours per annum;
- ISDE subsidy on the booster heat pumps (€ 1,200 per pump);
- Energy Investment Allowance (EIA) on the collective heat pumps (13.5% over max. 200 €/kW).

Annual revenues were taken in accordance with the terms laid down in the Heating Supply Act (according to the 'NMTO principle'; see text box in Subsection 3.6.3) and included as follows:

Table 13 - Annual revenues from heat supply

Items		Revenue
Standing charge for heat (incl. revenue from delivery set and metering costs)	€	787,000
Variable income from heat supply (18.75 €/GJ)	€	1,245,000
Income from SDE+ subsidy	€	764,000
Total annual revenue	**€**	**2,796,000**

Figure 25 - Cash flow and Net Present Value



A Net Present Value (NPV) calculation gives an IRR of 9.8%.

The following points should be noted:

- *The business case does not include the costs of architectural modifications required for installing LT heating plant in buildings; these depend on the specific situation and extent of the modifications and cannot be generically estimated.*
- *Nor does the business case include the costs of any modifications to domestic heat-delivery systems or insulation required for space heating with LT heat.*
- *Installing heat infrastructure in an existing neighbourhood or estate can be a very complex process. In the business case a figure of € 4,000 per home was assumed for the (primary and secondary) heat infrastructure. In practice these costs may prove higher or lower, depending on local circumstances.*
- *There is scope for further improvement of the business case by adding a low-cost back-up system (at the moment this is a gas-fired boiler), or applying additional peak-shaving measures like thermal buffering combined with smart demand management, for instance. This is an issue requiring further study.*
- *Because the price of heat is indexed to that of gas (according to the 'not-more-than-otherwise principle' (NMTO); see text box in Subsection 3.6.3), a higher gas price means increased financial returns. In the business case an annual price rise of 5% was assumed. This is 3% higher than the figure taken for inflation correction. This is a reasonable assumption because, based on CBS data for 1996-2017, the long-term average historical trend in the consumer price for natural gas works out at 5.1% in the Netherlands. This assumption may well even be conservative, given the pledge in the coalition agreement for 2017-2021 to incrementally increase the energy tax on natural gas each year. On the other hand, though, there is debate on decoupling the heat and gas price at some stage, as the NMTO principle is ultimately untenable. For this reason the gas price trend and thus also the heat tariff have been set fairly conservatively.*

2.8 Opportunities and barriers

2.8.1 Suitable sectors

The LTG concept can be rolled out in existing buildings and new build, where the main demand is for heat. In the built environment it is private homes that constitute the main market of interest. Among large-scale users of relatively low-temperature heat (< 70°C) there are potentially other customers too, including greenhouse horticulture.

If there is demand not only for heat but for cold, too — in the commercial building sector, for instance — alternative concepts like ATES or Minewater may be more appropriate, given their explicit linkage of heat and cold. (The Minewater concept is the subject of Chapter 3.)

2.8.2 SWOT analysis

To gain a better understanding of the potential role of LTG in the energy transition a SWOT analysis was carried out to assess its strengths and weaknesses. These are mainly factors intrinsically relevant to the technology's application, but consideration was also given to its potential market performance, governed principally by external factors over which there is little influence. The results of this SWOT analysis are shown below, with the most important aspects in bold letters:

Strengths	Weaknesses
– **Very suitable for LT heating** – **Major potential** – **Can be rolled out at numerous locations** – **No competition with other subsurface use** – **Smaller-scale than deep geothermal & industrial waste heat** – **Simple to develop above 500 m BGS** – Availability of techniques to mitigate geological uncertainties (GDD) – Requires less space for drilling rig, simpler implementation in urban environment – Fewer risks than with conventional geothermal (drilling depth, presence of gas, water parameters, etc.) – Hook-up to local renewable electricity possible (Energy performance standard for district-level provisions) – Combined with heat pumps, high temperatures feasible, permitting application in large fraction of existing buildings – No NIMBY problems	– **Large scale required (greater than e.g. all-electric), 1,000-2,500 dwelling-equivalents if deeper than 500 m BGS** – **Uncertainty about geology (little known about 250-1,250 m region)** – **Limited implementation capacity (firms with practical know-how and experience)** – Heat pump required, giving lower Equivalent Generating Efficiency (EOR) – Less suitable for utilities because of cold demand – Safety risks at greater depths lead to higher costs – Little administration/spatial planning for subsurface – Little practical experience with heat/water recovery at depths involved – Not yet demonstrated below 250 m BGS – Not feasible at building level for most buildings – Depletion of geothermal reservoir
Opportunities	**Threats**
– **'Beyond gas' movement, Paris climate agreement, Energy Agenda, etc. are creating a market for zero-gas heat** – **In the future, old gas grids will no longer be replaced** – Export opportunities for know-how/expertise – Major demand for local sources of renewable heat	– **Competition with individual solutions (air/water-source and ground-source heat pumps)** – **Organizationally complex (multiple parties involved)** – **Possible rise in electricity price (relevant for heat pump)** – No SDE+ shallower than 500 m BGS

– SDE+ for geothermal and RNES guarantee make business case appealing below 500 m BGS – BENG standards make LTG interesting as distric-level measure – Falling cost and growing efficiency of heat pumps due to technological advances	– Public opinion on colective grid – Two permit regimes (Water Act/Mining Act) at transition depth – Heating Supply Act may form an impediment (interruptions, fixed/variable)

2.8.3 Influence of financial instruments and legislation

Current financial instruments form an important factor determining whether or not market development of LTG and the Minewater concept will be successful.

SDE+ for geothermal and the 500 m transition point

Geothermal projects deeper than 500 m below ground surface (BGS) are currently eligible for support under the SDE+ subsidy scheme. This puts sediments between 0 and 500 m BGS at an unfair disadvantage as a renewable heat source. The Dutch organizations BodemenergieNL and IF recently provided the following input to energy research centre ECN for inclusion in recommendations to the Dutch ministry of Economic Affairs in connection with the terms of SDE+ for 2018:

- *The transition point of 500 m BGS is undesirable. To the extent that it is practically feasible this should be raised, preferably to ground level.*
- *Heat recovery and storage are crucial for improving the sustainability of buildings and heat grids and for utilizing waste heat and renewable heat sources. In the Netherlands there are numerous sediments above 500 m that are suitable for heat (storage and re-)recovery.*
- *Conventional subsurface energy storage systems provide capacity for both heat and cold and are currently viable in high-capacity applications without SDE+ since cold supply to utility buildings is financially rewarding. In smaller utility buildings and homes there is relatively little, if any, demand for cold, however, making such systems financially untenable if 'NMTO tariffs' are applied. There is therefore a need for financial support so that smaller utility buildings and homes can also be cost-effectively 'greened'.*
- *Shallower drilling requires far less space, making this geothermal concept much easier to roll out in the (existing) built environment.*
- *Despite its lower temperature, heat supplied from sediments shallower than 500 m BGS has a cost price roughly in the same range as heat from greater depths, because wells can be drilled at lower cost and groundwater production capacity per well is high, while risks are low.*
- *Heat storage requirements can vary in scale according to the project. Accessing shallow sediments simplifies market introduction considerably, particularly in the built environment.*
- *Heat pumps for individual dwellings are now incentivized via the ISDE subsidy scheme. Slightly larger projects supplying renewable heat from sediments < 500 m BGS currently fall between two stools, being eligible for neither ISDE nor SDE+, and the same holds for high-rise dwellings: precisely the largest category of buildings, with the greatest savings potential (Agterberg, 2016).*
- *Potential drawbacks and mitigation thereof:*
  - *Subsurface interaction between heat recovery projects and geothermal. This can be resolved at the provincial/municipal level; in technical terms there appears to be no reason why the transition point should not be shifted to grade level. There are*

already regulations in place for interaction between geothermal systems; these could be extended to include heat storage/production projects.

- *The legal framework: above 500 m BGS the Water Act, Environmental Control Act and General Provisions for Environmental Law Act (Wabo) apply rather than the Mining Act, which applies to mining activities. The Water Act allows thermal disequilibrium, as long as this involves subsurface cooling (net heat production). In legal terms, then, this would not necessarily appear to be a showstopper.*

— *Potential: with the temperature lower, the recoverable potential per m aquifer thickness is less than in the case of deeper geothermal. While in the long term the recoverable heat potential is consequently relatively limited, for kick-starting local renewable heat projects it can play a major role. The system can also be used for heat storage as more waste heat and/or solar heat and/or surface-water heat become available. Phased investment in a gradually expanding core grid is highly desirable and can be elaborated in this manner.*

The above recommendations to ECN are emphatically underscored by the conclusions to be drawn from the present study. Sediments between 0 and 500 m BGS have considerable heat potential; the cost price of heat recovered from them may be able to compete with ‘conventional’ geothermal; and heat recovery from these shallower depths has numerous advantages, such as being smaller-scale, involving less risk and requiring less space for drilling in urban settings.

ISDE subsidy for collective heat pumps

Besides SDE+ subsidies, the ISDE scheme is also relevant (see also the recommendations to ECN above). ISDE incentivizes small-scale, distributed heat pumps to the detriment of larger, centralized units. LTG projects shallower than 500 m BGS (as well as Minewater-type projects), using large-scale, central heat pumps, now fall outside structural subsidy schemes. Given the potential and relatively low cost price of the heat delivered by such systems, it is desirable to close the gap between ISDE and SDE+.

Water Act and Mining Act in relation to safety

Down to a depth of 500 m BGS, subsurface heat recovery projects fall under the Water Act; beyond that point, the Mining Act applies. There are major differences in safety requirements and procedures between the two regimes and it is recommended that these be closely examined to see if more harmonization can be achieved while guaranteeing that potential safety risks are adequately addressed.

3 Minewater - Smart Thermal Grid

This chapter goes into the details of the Minewater concept as it has evolved since its original inception. In its present version it can best be described as a smart thermal grid in tandem with geothermal buffering and the main focus of the chapter is on the physical properties of the grid and the role of buffering in 'Minewater 2.0'. At the time of writing, the 'smart' side of the system — 'Minewater 3.0' — is still very much in development, making it premature to provide an adequate description here.

3.1 Core features

The Minewater concept has the following core features:
- exchange of heat and cold via a low-temperature heat grid; the connected buildings can be both producers and consumers, i.e. prosumers;
- a demand-driven system;
- various temperature regimes;
- combination with subsurface or artificial buffering;
- useful application of low-grade waste heat and/or cold from industry;
- available waste heat/cold sources have major potential;
- major scope for feed-in of renewable heat/cold sources.

3.2 Concept description

The Minewater concept is based on the energy grid developed by the firm Mijnwater B.V., headquartered in Heerlen, in the south of the Netherlands. Although in describing the concept we frequently refer to the this firm's main project, the concept has validity and potential in its own right.

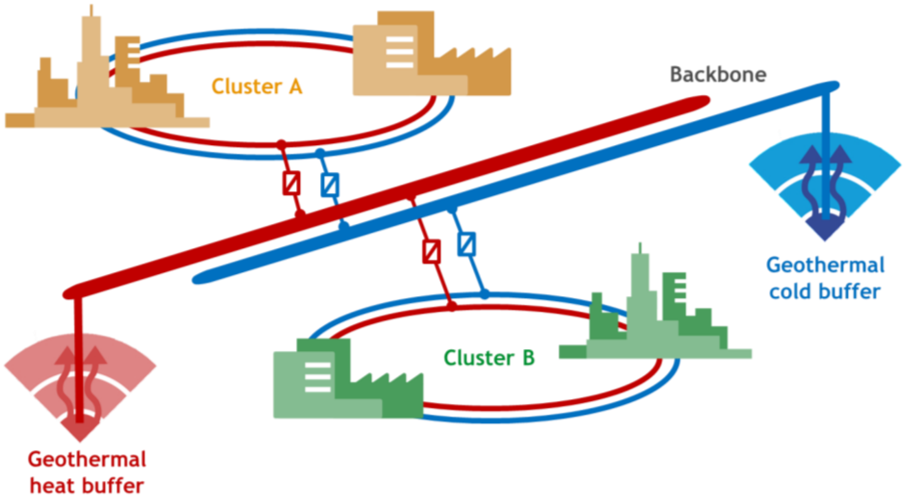
In 2003 Mijnwater B.V. began work on development and implementation of an innovative concept for recovery, exchange and distribution of renewable, low-temperature (LT) heat (28-30°C) and sustainable, high-temperature cold (16-18°C) via a thermal energy grid. This grid comprises multiple levels and clusters and forms the basis for heat and cold supply at a very wide range of temperatures. In rolling out the Minewater concept in Heerlen the abandoned Oranje-Nassau coal mines were re-engineered as a geothermal buffer, giving the Minewater concept its name. The concept can also be implemented elsewhere, however, using other types of buffer. Figure 26 provides a schematic picture, in this case with geothermal buffers, as applied in Heerlen.

In the Minewater concept thermal energy is distributed at low temperature. This energy can then be utilized by customers as heat and/or cold in three different ways:
- Low-temperature (~30°C): the heat from the backbone/clusters is applied more or less directly for space heating of buildings. These need to be well-insulated, i.e. newbuild or renovated to an A label or better, with underfloor heating or other LT heat-delivery systems. A separate provision for hot tap water is required. Cooling can also be supplied by the Minewater infrastructure.
- Mid-temperature (~60°C): the heat from the backbone/clusters is upgraded to the desired temperature by means of distributed, individual heat pumps. Many existing homes where energy-conservation measures have been implemented (up to a C or B label, for example) can be adequately heated with 60°C heat using current delivery

systems (radiators). The temperature level of the heat pump means it can also provide hot top water. Cooling can also be supplied by the Minewater infrastructure.

– High-temperature (~90°C): the *baseload* heat demand of poorly or partly insulated buildings can be met by a mid-temperature heat pump, which needs to be in constant use to deliver sufficient heat. In cases where this provides insufficient capacity or comfort a supplementary system can be installed using, say, natural gas (conventional central-heating boiler) or possibly an electric boiler. If a gas-fired boiler is used for peak-time heating, a connection to the gas grid is still therefore required. In the transition phase this set-up can be applied in existing housing stock, switching to the mid-temperature variant as the homes become better insulated. In certain buildings it will be possible to improve air quality (and humidity conditions) by tweaking the ventilation system, cutting heat losses considerably and thus a permitting lower-temperature heat delivery system.

Figure 26 – Simplified schematic representation of the Minewater concept as implemented in Heerlen with geothermal buffering



Note: In reality the Heerlen Minewater energy grid is more complex and also has four clusters rather than two. The water from the clusters is separated by heat exchangers from the water in the backbone.

Development of the Minewater concept

Minewater 1.0

Between 2006 and 2008 five wells were sunk into abandoned coal mines under Heerlen to recover heat and cold for supply to end-users. This original design had a number of limitations that hampered long-term development of this Minewater concept, including: thermal depletion of the resources[1], limited resource capacity, no exchange among end-users and a supply-driven customer proposition.

[1] In concrete terms this means that in the specific Heerlen setting long-term application of LTG was out of the question. This does not hold for the options analysed in Chapter 2, however.

Minewater 2.0 – Smart Thermal Grid

To get around the problems of Minewater 1.0, a version 2.0 was developed. Rather than being supply-driven, this now revolved around a demand-driven customer proposition. In practice this meant that Minewater no longer supplied end-users 'merely' with energy (heat and cold), but also enabled inter-customer exchange, with the mine water no longer being used only as a source but also as a thermal buffer. To this end, connections were grouped geographically in clusters, with each connection acting as a thermal energy 'prosumer'. These clusters are hooked up to a backbone, which in turn connects the geothermal buffers.

Minewater 3.0 – Smart Thermal Grid

Work is currently underway on a Minewater version 3.0, a follow-up to 2.0 characterized by sophisticated control of the grid's thermal flows in terms of timing and buffering. This 'smart thermal grid' will make detailed allowance for the energy requirements of the various consumers and their scheduling, on the one hand, and recognize demand patterns combined with weather forecasts, on the other. In this way version 3.0 of the system should be considerably more efficient than version 2.0.

Difference from alternatives

Compared with a conventional district heating grid, the Minewater grid is distinguished by being demand-driven, with heat/cold only being pumped if there is demand. In addition, all the available waste energy flows are utilized and heat/cold stored in buffers when supply outstrips demand. This makes the concept far more energy-efficient and means it is not a classical source-based grid, as connected buildings also serve as suppliers, i.e. as prosumers rather than merely consumers. The Minewater concept is thus a more innovative design than traditional heat grids, while at the same scarcely more complex in terms of hardware, using existing technologies, but reconfigured.

A Minewater-type LT energy grid also provides far greater scope for connecting a wide range of sources of waste heat and cold. In a conventional district heating grid the waste heat needs to have a high minimum temperature of 90-120°C, limiting the number of suitable sources. With LT distribution (in the case of heat) this minimum drops to 28-30°C, vastly widening the scope to feed in sources like data centres, cold-storage/freezing warehouses, greenhouses and ice rinks. An added advantage is that the energy losses associated with heat transport are far lower than with HT heat grids. At the same time, higher-temperature feed can still be fed into the system if so desired, boosting the grid's capacity.

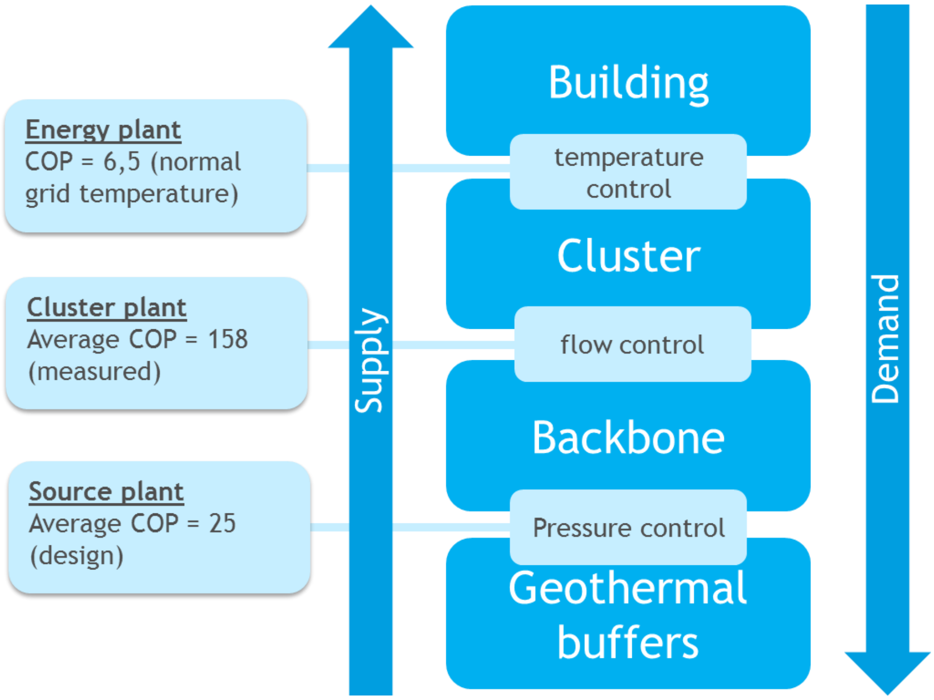
The Minewater concept is very similar to the so-called District Aquifer Thermal Energy Storage (DATES) concept already applied at several sites with multiple large buildings with demand for both heat and cold (e.g. Eindhoven Technological University, Uithof Utrecht, Overhoeks Amsterdam). Here, too, a smart thermal grid is combined with a geothermal buffer.

3.3 Technical aspects

Minewater aims to achieve optimum energy utilization with minimum loss of energy, through:
- use of both waste heat and cold;
- a minimum number of conversion steps in the process;
- use of heat/cold as close to source as possible;
- smart and efficient design of plant and equipment;
- own administration and process control of energy plant;
- demand-driven operation.

All the plant and equipment between the various elements of the Minewater infrastructure (buildings, clusters, sources) is fitted out with advanced process-control systems that can operate autonomously, driven by end-user demand. The infrastructure, automation and associated systems with their coefficient of performance (COP) are shown schematically in Figure 27.

Figure 27 - Demand-driven plant and equipment in the Minewater system applied in Heerlen



Source: Based on Verhoeven et al., 2014; plant data from (Verhoeven & Eijdems, 2016).

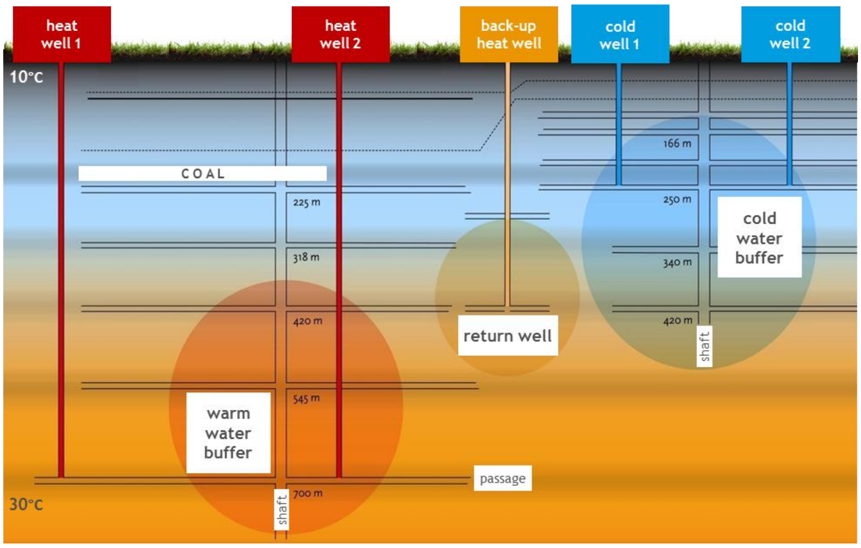
3.3.1 Heat resource to delivery system

As discussed in the previous section, a wide range of heat and cold resources can be fed into the Minewater system. In the Heerlen example, sources include the following:
- heat/cold from geothermal buffers (partly stored, partly recovered geothermal heat/cold);
- waste heat from a data centre, a supermarket, office buildings and an apartment complex via heat exchange.

Over the course of time the disused mine shafts in Heerlen have filled up with groundwater warmed up by the earth. The deeper into the mine, the hotter the water. To retrieve this warm water, two wells were sunk to a depth of 700 m, where the water has a temperature of about 28°C. Several kilometres away two other wells were sunk to a depth of 250 m, as a source of cold with a temperature of 16°C. Besides heat, cold can thus also be supplied and buffered for the cooling of buildings. Figure 28 provides a schematic picture of the subsurface situation at Heerlen.

In the latest Minewater concept developed by Mijnwater B.V. the underground mine sources are not used primarily as a source of heat and cold, but as a buffer for storage and reuse of (waste) heat and cold. In addition, the wells are to be made bidirectional in the future (both retrieval and injection of water) for back-up and capacity expansion, with the focus on energy exchange and buffering rather than one-way energy production. This will also do away with the risk of depleting the geothermal resource, which will then essentially be a geothermal buffer connected to the system backbone.

Figure 28 – Schematic picture of the subsurface Minewater system



NB: In the latest Minewater concept the return well has been taken off-line, now serving only as a back-up.

The backbone is physically separated by a heat exchanger from the cluster grids, i.e. the closed grids supplying building clusters with heat/cold. In a cluster grid, flows of waste heat/cold are exchanged between buildings, thus minimizing reliance on the backbone. The cluster grids are mutually separated and can operate independently at different temperatures. If so desired, the various clusters draw in heat/cold from the backbone via heat exchangers and can exchange it via the backbone.

In the Minewater concept residual heat/cold is buffered as far as possible at its own temperature to keep energy losses to a minimum. This means there is buffering everywhere in the energy grid where there is a temperature difference, as follows:

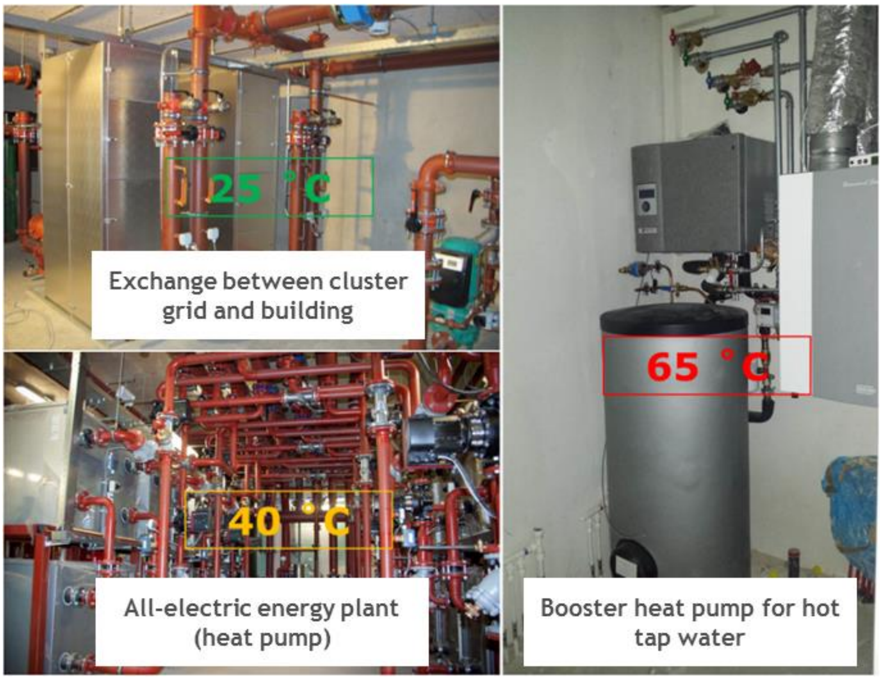
Backbone: geothermal buffers
Cluster grids: e.g. an artificial buffer (not yet applied in Heerlen)
Energy plant: distributed buffer vessels in homes and utility buildings, or solutions like concrete core activation.

Figure 27 reports the COPs of all the elements of the Minewater energy grid as applied in Heerlen.

3.3.2 In-building supply and delivery systems

In the Minewater concept a small ‘energy plant’ is installed on end-user premises as an interface between the thermal grid and the building’s own heat-delivery system. It has two main elements: a heat exchanger and an all-electric heat pump (in Figure 29 upper and lower left, respectively). The electric heat pump ensures the heat/cold supplied by the grid is given the appropriate temperature to heat or cool the building. Given the varying temperature of the incoming water from the grid, the heat pump does not always need to be used. The energy plant settings are adjusted to ensure automatic adoption of the most energy-efficient method, i.e. passive heating with no heat pump use whenever feasible. For the supply of hot tap water an additional booster heat pump is installed (right-hand photo in Figure 29).

Figure 29 – Elements of the energy plant in a large (utility) building



NB: The cited temperatures indicate the temperature level of the process shown.

Where feasible, heat/cold buffers are also installed in the building. These can be used to store the cold produced on spring and autumn mornings when the heat pumps are warming up the building, for example. When the sun breaks through later in the day, this cold can then be used for cooling. The remainder of the net heat or cold demand is met by the cluster grid.

The energy plant must also ensure the return water meets the temperature requirements of the cluster grid and backbone, in part to avoid depletion of the (geothermal) buffers and sub-optimal heat-pump operation. For maximum efficiency, Mijnwater B.V. retain ownership of the energy plant and handles process control. This means they can influence the demand side — through in-building heat storage to avoid peak demand, for example.

The 'end product' they supply is therefore not so much heat/cold supply, but a comfortable indoor climate.

The COPs of the energy plant depend on the difference between the input and output temperature of the heat pump and how it is controlled. This temperature difference is not constant but can vary. The following situations can be distinguished (Verhoeven, 2016):
- Normal cluster temperature: heat pump must raise the temperature from 26°C to 40°C; COP = 6.5.
- At a higher cluster temperature, above the exit temperature from the building (30°C), (partial) use can be made of passive heating, raising the COP considerably (COP = 8.0 with 20% passive, COP = 11.7 with 47% passive).
- If the cluster temperature exceeds the heating temperature of the building, 100% passive heating is feasible. If at the same time the cluster temperature also exceeds the backbone temperature, all that is needed is electricity for the cluster pumps, and the COP can jump to over 60.

3.4 Energy performance

To give an idea of the energy and environmental performance of the Minewater concept, let us consider its impact on energy-saving, sustainability and ultimate CO_2 emissions reduction. If unambiguous conclusions are to be drawn, though, we must first clearly define the situations in which performance is being assessed, as it makes a great deal of difference whether application is being considered in existing buildings or newbuild, in homes or utility buildings. The same holds for what aspects are being assessed — in particular, building modifications. In the following sections we briefly discuss energy and environmental performance for four situations:
- existing housing stock;
- newbuild homes;
- existing utility buildings;
- newbuild utility buildings.

Existing housing stock

In existing homes the Minewater concept can provide a range of possible solutions for various temperature levels, each with its own **energy savings**:
- c. 30°C heating: very well insulated homes (A label or better) connected 'directly' to the Minewater infrastructure (though with a heat pump to give maximum flexibility for smart control of heat supply). In this situation energy savings are high. In summer (comfort) cooling is needed, which can be provided by the heat pump, which can also supply hot tap water.
- c. 60°C heating: reasonably well insulated homes (C or D label) connected to the Minewater infrastructure via a heat pump. Energy savings are average. The need for comfort cooling is location-specific. Hot tap water can be supplied by the heat pump.
- c. 90°C heating: minimally insulated homes (E label or worse) connected to the Minewater infrastructure via a heat pump (baseload) and (natural) gas-fired HE boiler (peak load)[2]. The role of the HE boiler can also be fulfilled by an electric heat pump, but this will then have a (very) low efficiency. This will only be for a small part of the year, though. As the building envelope remains unchanged, there are no savings on heat

[2] This corresponds more or less with current hybrid heat pumps marketed the past few years to replace traditional HE boilers.

demand. Comfort cooling is unnecessary and hot tap water is supplied by the HE boiler or heat pump.

The **sustainability** of the heating system is highly dependent on the source of the heat fed into the infrastructure. Because of the low basic temperature, though, there is plenty of scope for using renewable sources. If the feed to the Minewater infrastructure is 100% renewable, it depends on the precise mode of implementation whether the system has short- or long- term sustainability. As time progresses and the grid supply becomes fully renewable, the ‘low’ and ‘medium’ variants at 30 and 60°C, respectively, can be made sustainable. The ‘high’ variant at 90°C must/can also be based on green or renewable gas.

CO_2 emissions reduction depends on the scope. In all situations local emissions will be very substantially reduced, as natural gas use will be drastically cut, possibly to zero. As the system still uses electricity to pump round the water and power the heat pumps, CO_2 reduction is not yet 100%, but somewhere between 50% and 75%. Only when the Dutch/European electricity mix is completely climate-neutral will the Minewater concept be so, too. It may be added that this holds for **all** heat concepts involving electrically-powered elements.

Newbuild homes

Newbuild homes fitted out with an LT heat-delivery system can be connected to Minewater infrastructure either ‘directly’ or via a heat pump. Although the former option is best in terms of energy consumption in the home itself, inclusion of a heat pump means greater flexibility for the grid as a whole. At the moment a substantial percentage of newbuild homes come with a gas connection and HE boiler. Compared with such dwellings, Minewater means considerably better energy and environmental performance. In the coming years, standards for newbuild homes will be becoming ever more stringent and as of 2021 all newbuild must meet the Near-Zero-Energy Building (BENG) standard. A newbuild home connected to a Minewater-type system is one of the options for meeting this standard. In that situation all BENG-compliant dwellings score more or less the same when it comes to energy and environmental footprint.

Existing utility buildings

As with existing dwellings, the energy and environmental benefits of implementing the Minewater concept in existing utility buildings depend very much on how precisely it is implemented and to what purpose. The scope is broad — from heating an office building or school, for example, to cooling a data centre. If the concept is applied for *space heating or cooling* the same kind of results in terms of **energy savings**, **CO_2 emissions reduction** and **sustainability** can be achieved as with existing housing stock. If the Minewater concept is used for *process heat or cooling*, as with cooling a data centre or products (with the heat being ‘harvested’ to feed the heat grid), benefits will be very dependent on the current or reference technology, which will differ according to the situation.

At the level of the individual building, the energy and environmental performance of the Minewater concept may well be better than opting for an individual, all-electric solution. This is because of the relatively high temperature of the heat grid (compared with the outside air or soil), which means the heat pumps used achieve a higher efficiency in heating the buildings.

The overall system efficiency, i.e. including the energy consumption of the collective heat grid, depends on grid scale and the amount of heat/cold being transported. Given the emphasis of the current Minewater concept on optimizing these flows, it is to be anticipated that system efficiency will be better than if building-specific solutions are implemented.

Newbuild utility buildings

As of 2021, newbuild utility buildings must meet the same standards as dwellings, i.e. they must be ‘near-zero-energy’, or BENG. This can be achieved using the Minewater concept as well as by other means, and which alternative scores best will hinge very much on the source of the electricity used. If this is 100% renewable/zero-carbon there will be no difference on that aspect. It is anticipated that the Minewater system will use less energy for space heating, because of the temperature of the heat grid and the higher efficiency of the heat pumps used.

3.5 National potential of the Minewater concept

To gain an idea of the potential of the Minewater concept for the Netherlands as a whole, an analysis was made of potentially suitable locations for applying the concept of a smart thermal grid combined with thermal buffering. To this end we first consider potential heat resources, then potential supply areas, combining these to estimate the total potential contribution to the Dutch heat transition.

3.5.1 Scope of application and suitable markets

The Minewater concept can be applied in newbuild and existing buildings, both homes and utility. Use of Minewater heat and cold in industrial processes is feasible, but only n a limited scale. In the Netherlands the bulk of industrial heat/cold demand is for far higher (> 200°C) or far lower (< 0°C) temperatures than Minewater can supply. This is not to say that there are insufficient processes of interest, as supplier or consumer of thermal energy, but there is at present too little information available on such processes to undertake an analysis. Table 14 provides an overview of the industrial processes that could in principle serve as a source or consumer of heat for the Minewater concept.

For optimum energy inter-building exchange it is best that there is as much variety as possible in the buildings in the area. The heat released by an old G-label dwelling with a high temperature level can then be used for heating a modern A-label home that can suffice with LT heat. The cold generated in heating these homes can then be used to cool a data centre, supermarket or other utility building. Conversely, the heat arising in cooling the latter can be used to heat homes. The more complementary thermal sources, in whatever shape or form, the more potential for energy exchange and a Minewater-type system.

In the following section we consider in more detail the areas in the Netherlands that are suitable for application of the Minewater concept.

Table 14 - Industrial processes that can potentially serve as heat suppliers or consumers

Industrial Sector	Unit operation	Temperature range (°C)
Food	Drying	30-90
	Washing	60-90
	Pasteurising	60-80
	Boiling	95-105
	Sterilising	110-120
	Heat Treatment	40-60
Beverages	Washing	60-80
	Sterilising	60-90
	Pasteurising	60-70
Paper Industry	Cooking and Drying	60-80
	Boiler feed water	60-90
	Bleaching	130-150
Metal Surface Treatment	Treatment, electro-plating, etc.	30-80
Bricks and Blocks	Curing	60-140
Textile Industry	Bleaching	60-100
	Dyeing	70-90
	Drying, De-greasing	100-130
	Washing	40-80
	Fixing	160-180
	Pressing	80-100
Chemical Industry	Soaps	200-260
	Synthetic rubber	150-200
	Processing heat	120-180
	Pre-heating water	60-90
Plastic Industry	Preparation	120-140
	Distillation	140-150
	Separation	200-220
	Extension	140-160
	Drying	180-200
	Blending	120-140
Flour By-products	Sterilising	60-90
All Industrial Sectors	Pre-heating of boiler feed water	30-100
	Industrial solar cooling	55-180
	Heating of factory buildings	30-80

Source: (IEA-ETSAP and IRENA, 2015).

3.5.2 Suitable sites for application in the Netherlands

The scope for implementing the overall Minewater concept depends very much on the supply and demand of (LT) heat and (HT) cold in the direct vicinity. Certain elements of the concept such as demand-driven, anticipatory control can also be applied in other heat grids and consequently in more areas. In our analysis of suitable sites for application in the Netherlands we have explicitly opted to exclude HT heat sources, as we consider these should be reserved for HT heat grids; they require more effective insulation of piping, moreover. Such sources can always be hooked up to a Minewater system, however, although the strength of the concept lies in the utilization of low-grade waste heat.

As noted in the previous section, a wide variety of building types (both dwellings and utility) creates optimum scope for energy exchange. For viable implementation of a heat grid the area should be sufficiently built-up, moreover, with limited transport distances[3]; in our analysis we proceeded from CBS urbanization classes of 3 or higher[4]. This means densely developed areas in villages, towns and cities (modest to high urbanization). For the transport distance between source and demand area we took a maximum of 500 metres.

Besides inter-building energy exchange, the presence of a thermal energy source (for both heat and cold) is obviously also important. Table 15 lists the heat sources taken for identifying suitable locations for a Minewater-type system. There are obviously more thermal sources conceivable (like solar-panel farms), but to gain an initial impression of scope only the listed sources were used.

Table 15 – Heat and cold sources adopted for analysis of potential sites

Source	Type	Assumption
Medium-sized industry	Heat supply Cold demand	Industrial park with a max. environmental zoning category of 3 or higher[5] (lower bound) or 2 or higher (upper bound)
Sewage treatment plants	Heat supply	At all Dutch sewage treatment plants there is potential for heat recovery from effluent water
Cold-storage/freezing warehouses	Heat supply Cold demand	Cold-storage warehouses affiliated with Nekovri
Abattoirs	Heat supply Cold demand	Abattoir locations according to Netherlands Enterprise Agency (RVO)
Data centres	Heat supply Cold demand	Dutch locations listed in Data Centre Handbook and from NLIX
Ice rinks	Heat supply Cold demand	Known Dutch locations
Supermarkets	Heat supply Cold demand	Neighbourhoods with large supermarkets (> 250 m^2 floor space) according to CBS (within 1 km); heat supply included if at least 1 large supermarket within 1 km radius
Horticultural greenhouses	Heat supply	Greenhouse horticulture areas according to RVO with a minimum area of 7 ha
Industrial bakeries	Heat supply	Members of Dutch Association of Bakeries (NVB)
Industrial laundries	Heat supply	List based on Certex-certified companies

3 See '*Afwegingskader Locaties*' (RVO, 2013), which states that a collective heat supply needs a minimum heat density of 500-600 GJ/ha, translating approximately to areas in CBS urbanization classes 1, 2 or 3.

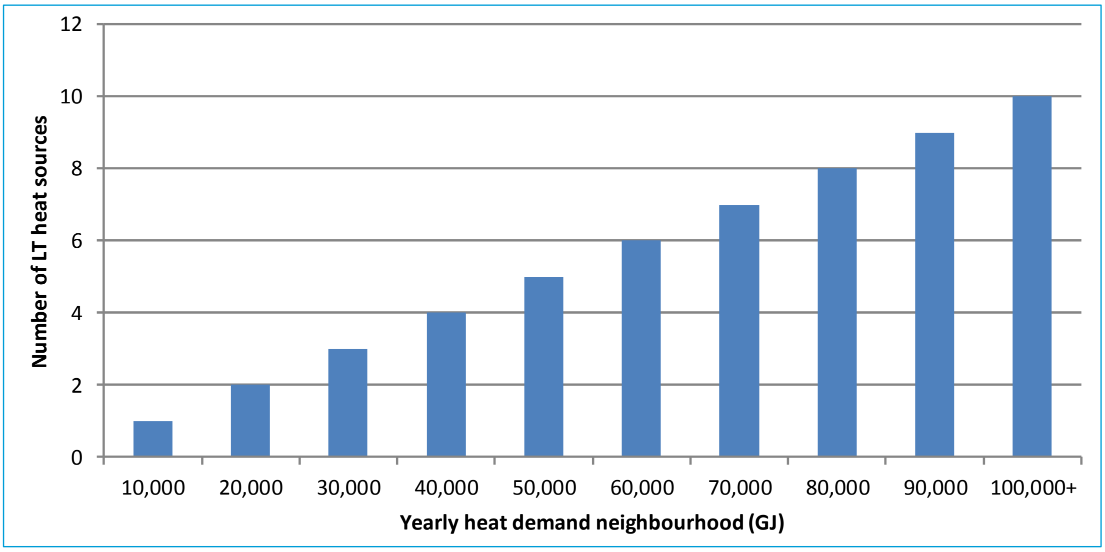
4 Based on address density, Statistics Netherlands (CBS) assigns to every Dutch neighbourhood an 'urbanization class': 1: highly urbanized, > = 2,500 addresses/km^2; 2: very urbanized 1,500-2,500 addresses/km^2; 3: moderately urbanized 1,000-1,500 addresses/km^2; 4: scarcely urbanized 500-1,000 addresses/km^2; 5: non-urbanized < 500 addresses/km^2.

5 In general these are larger-scale industries in a higher environmental zoning category; industries with plenty of waste heat available are also often in a high zoning category.

Source	Type	Assumption
Animal-feed plants	Heat supply	List based on members of Nevedi
Food industry	Heat supply Cold demand	List based on members of Dutch food industry trade association FNLI
Other potential sources of LT waste heat	Heat supply	Based on analysis of RVO dataset '*ligging industrie en CO_2-emissies*'

By overlaying the sources listed in Table 15 on a map of neighbourhoods (within 500 m) with a CBS urbanization class of 3 or higher, an estimate was made of the potential scope for roll-out of the Minewater concept in the Netherlands. For these selected neighbourhoods we determined the current heat demand of homes and utility buildings, with cold demand being assessed solely for the latter category (current situation). The heat demand per neighbourhood and the number of potential LT heat sources within a radius of 500 m then form the basis for deciding whether a neighbourhood is potentially suitable for the Minewater concept. Because Dutch neighbourhoods vary widely in size, a linear scale was adopted for the minimum number of sources required. For each neighbourhood this minimum was determined by dividing its heat demand by 10,000 GJ (lower-bound assumption) or 20,000 GJ (upper-bound assumption) heat output per LT source and rounding this to an integer between 1 and 10; see Figure 30. The heat and cold demand of the neighbourhood was set using CBS data and indices from the SWING and CEGOIA models developed by CE Delft.

Figure 30 - Minimum number of LT sources per aggregate neighbourhood heat demand (GJ)



This method is only approximate, indicating potentially suitable areas based solely on the presence of potential thermal sources, but without assessing the true availability of heat or cold. Our calculations are therefore reported with a range; the parameters adopted for the upper and lower bounds are shown in Table 16.

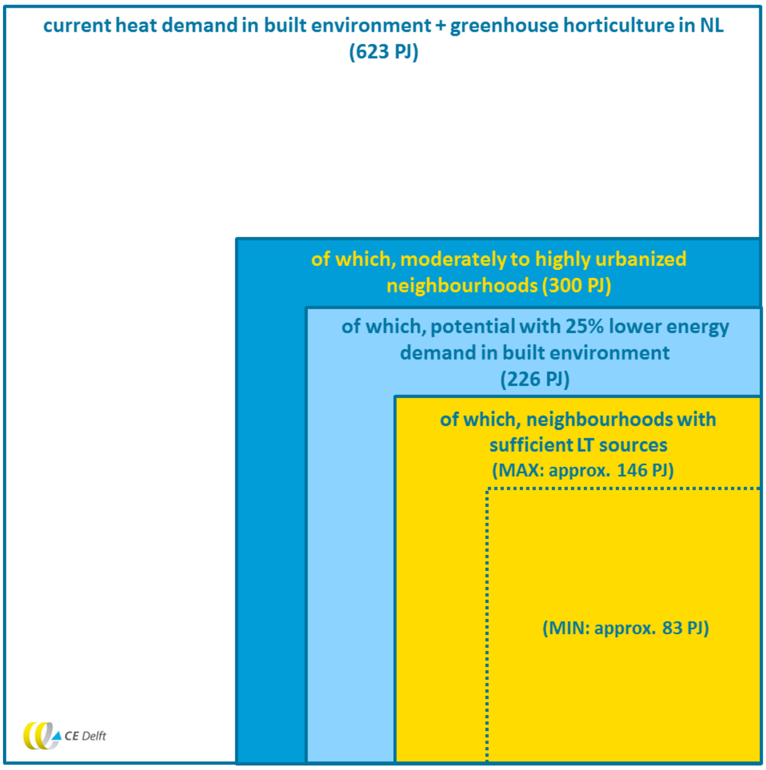
Table 16 - Parameters for upper and lower bounds used in assessing potential

Parameter	Lower-bound potential	Upper-bound potential
Assumed production per (heat) source	10,000 GJ/source	20,000 GJ/source
Maximum environmental zoning category of industrial park	Category 3 or higher	Category 2 or higher (incl. wholesale warehouses & light industry/manufacturing)

Two situations are distinguished: current and future, the latter assuming a 25% decrease in heat demand and 5% increase in cold demand due to label improvement. These percentages are merely indicative, assuming reduced heat demand driven by a variety of factors, including autonomous increase of energy efficiency, savings necessitated by LT heating, comfort savings and cost-driven savings. Increased cold demand is assumed to derive from better insulation of homes, on the one hand, making comfort cooling in the summer desirable/essential, and from warmer climatic conditions leading to increased cooling demand, on the other.

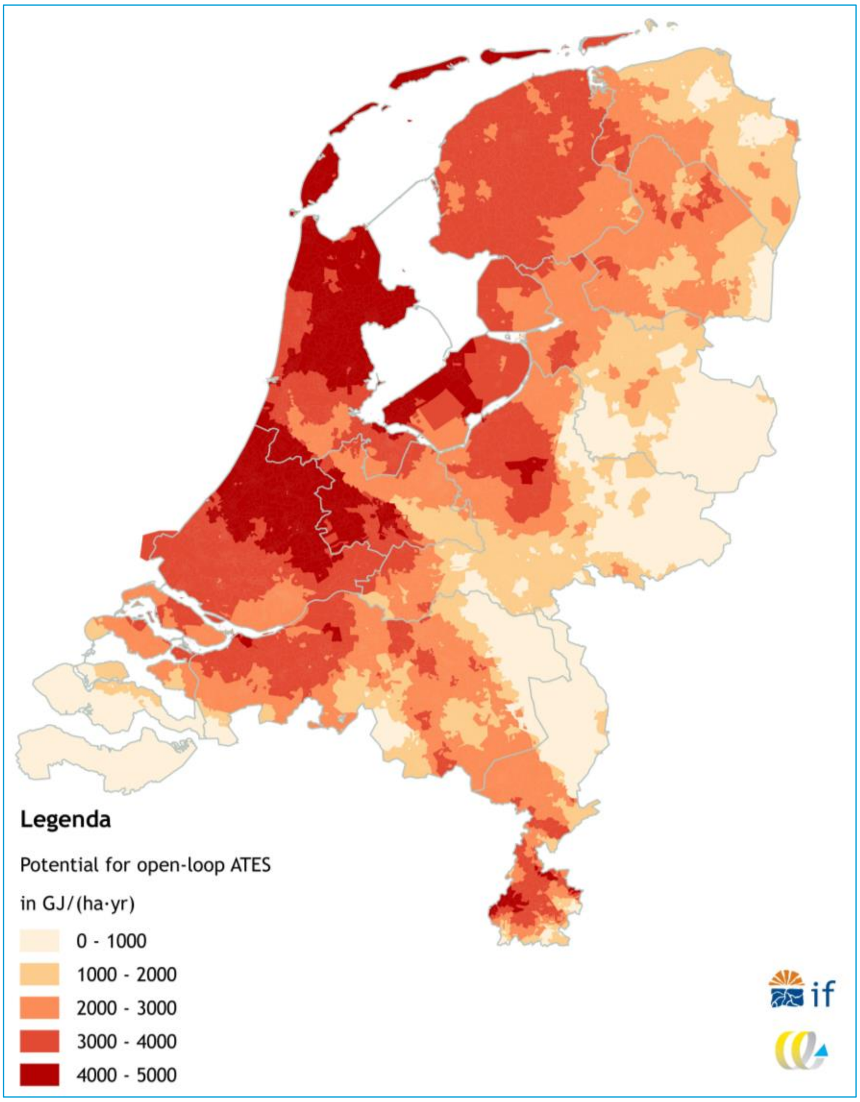
To put it all into perspective, Figure 31 provides an illustration (to scale) of the approach adopted, showing the potential contribution of the Minewater concept to meeting future Dutch heating demand (both upper- and lower-bound analysis).

Figure 31 - Schematic representation of the approach adopted for future heat demand



Besides LT heat sources and inter-building exchange, heat and cold storage is also an essential part of the Minewater concept. A number of options are available for this purpose, such as an underground storage tank or aquifer storage (open-loop ATES). For the time being, the latter option is the cheapest. There is scope for ATES at numerous sites throughout the Netherlands, with varying potential per location; see Figure 32.

Figure 32 – Potential per neighbourhood for heat/cold storage in aquifers (open-loop ATES) in GJ/(ha·yr)



Where there is no scope for aquifer storage, use can be made of buffer tanks. These (large) tanks must be dug in, which in very densely built-up areas is sometimes unfeasible.
As storage requirements and underground storage capacity per district are unknown, in our selection of suitable neighbourhoods for the Minewater concept we have worked with a range, with the upper bound set on the assumption that sufficient storage capacity is to be found in every district, the lower bound on the assumption that this will be unfeasible in very densely built-up areas, for the reason cited.

Based on this analysis there are between around 2,650 to 3,750 neighbourhoods (22-31% of the Dutch total)[6] potentially suitable for a Minewater-type system (proceeding from an assumed future situation of 25% reduced heat demand). The maps of Figure 33 (current) and Figure 34 (future) show the location of the neighbourhoods deemed suitable.

6 This translates to approx. 2.0 to 3.6 million dwellings.

Figure 33 – Map of the Netherlands showing neighbourhoods potentially suitable for the Minewater concept, present situation

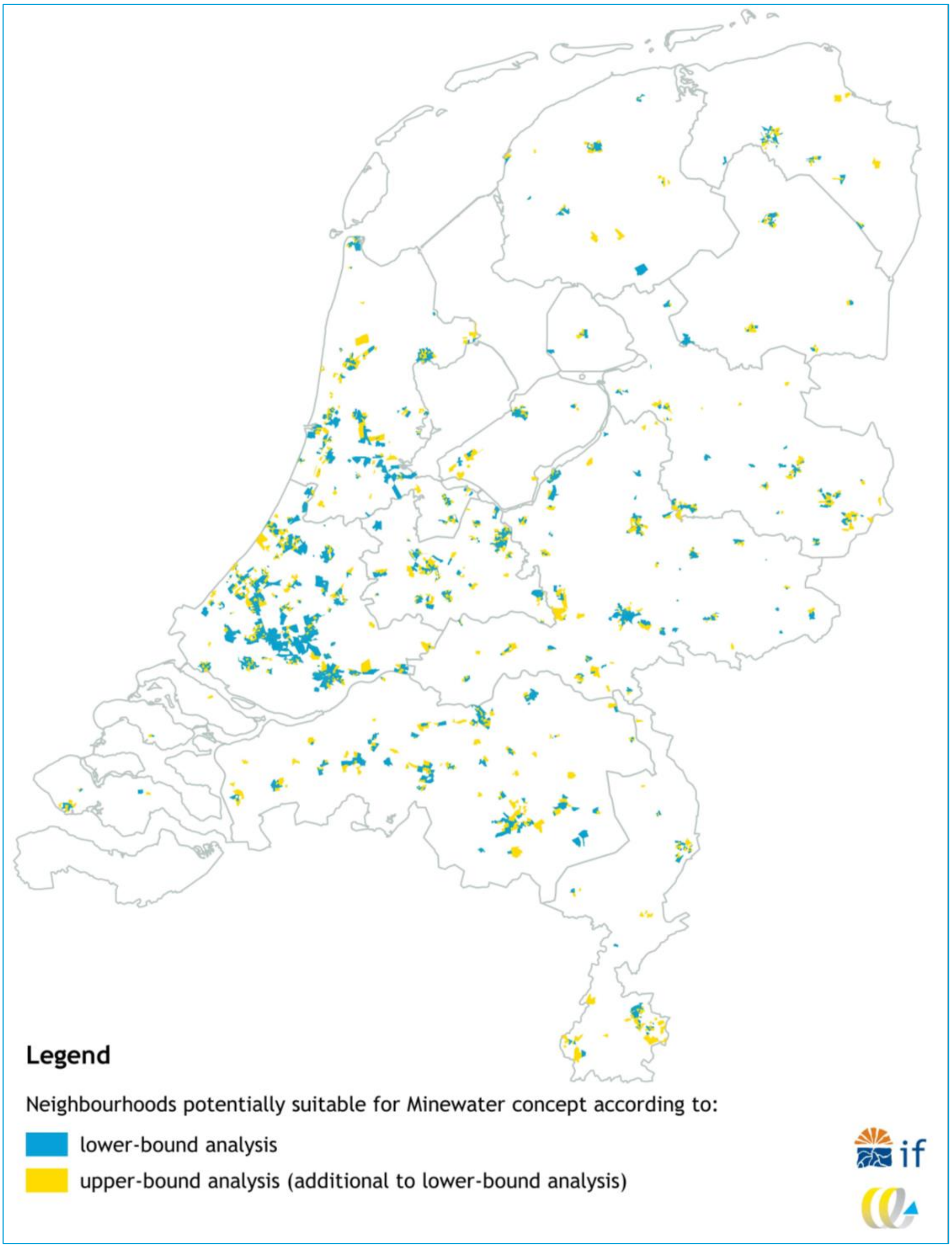
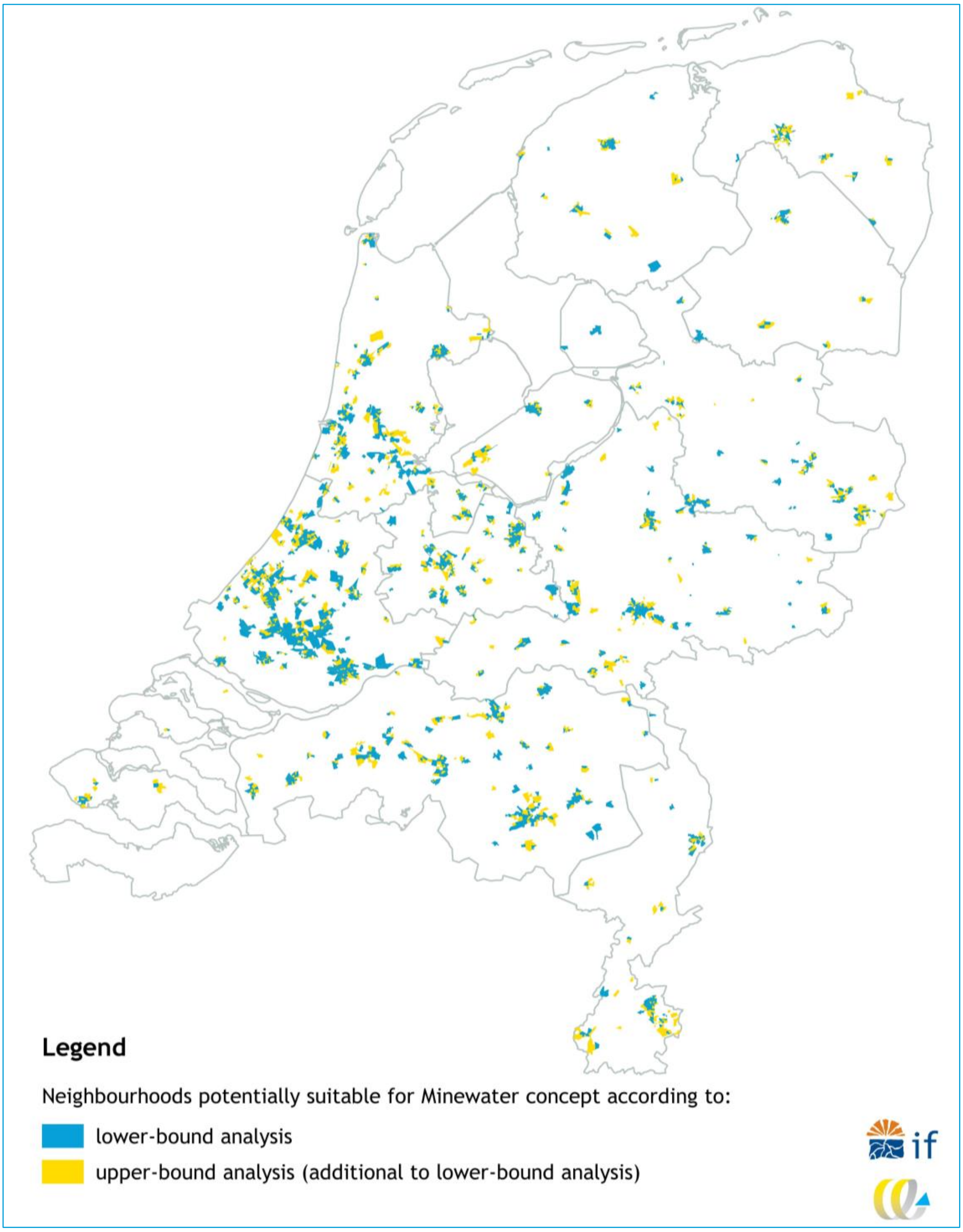


Figure 34 – Map of the Netherlands showing neighbourhoods potentially suitable for the Minewater concept, future situation with 25% lower heat demand



3.5.3 Potential contribution to heat transition

In the previous subsection, neighbourhoods potentially suitable for implementing the Minewater concept were identified, assessing their potential based on above-ground heat and cold demand. These neighbourhoods thus have a minimum number of LT sources available. With the data presently available in the Netherlands it is unknown, however, whether the LT sources can deliver enough to meet the required heat/cold demand. Presumably, though, this will be the case for a significant percentage of such neighbourhoods. The remainder will have to be supplied via inter-building exchange and heat pumps.

In the calculated potential reported in the following tables it has been assumed that some form of the Minewater concept can meet the heat/cold demand of the entire neighbourhood. The cited figures thus refer to the maximum theoretical potential of the Minewater concept, which sums to 85.7-159.5 PJ heat; under the assumption of 25% lower heat demand in the future, the potential drops to 83.2-146.3 PJ heat. For cold the potential is 2.3-4.1 PJ; assuming 5% growth in cold demand due to energy label improvement, this potential still remains about the same: 2.4-4.3 PJ.

Table 17 - Aggregate potential of Minewater concept (lower bound)

Aggregate heat demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. heat demand
Current	PJ	85.7	56.5	28.0	1.3	14%
Future, with 25% lower demand	PJ	83.2	56.3	25.6	1.3	13%
Aggregate cold demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. cold demand
Current	PJ	2.3	0.7	1.5		17%
Future, with 5% growth due to energy label improvement	PJ	2.4	0.8	1.6		18%

Table 18 - Aggregate potential of Minewater concept (upper bound)

Aggregate heat demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. heat demand
Current	PJ	159.5	111.7	46.3	1.5	26%
Future, with 25% lower demand	PJ	146.3	102.8	41.8	1.6	23%
Aggregate cold demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. cold demand
Current	PJ	4.1	1.5	2.5		31%
Future, with 5% growth due to energy label improvement	PJ	4.3	1.6	2.7		32%

3.6 Financial aspects

Implemented in a built environment, a Minewater-type system has a multitude of elements. In broad brushstrokes the following can be distinguished:
- Source and backbone:
  - thermal buffering;
  - backbone infrastructure;
  - pumping stations.
- Cluster grids:
  - cluster infrastructure.
- Minewater connection, including:
  - distribution from/to suppliers/consumers;
  - operating ICT[7] (smart control of supply/demand/energy flows);
  - other provisions (further process control, architectural, mechanical/electrical).
- Energy plant, including:
  - heat/cold sources (connection to/from connected suppliers/consumers);
  - centralized and distributed generation (central or individual heat pumps);
  - other provisions (process control, architectural, mechanical/electrical).

Besides the elements of the Minewater system itself, there may also be a need for modifications to connected buildings, such as:
- improved building insulation required for LT heating;
- changes to heat-delivery systems within the buildings.

Building-side modifications will depend very much on the type of building (construction year, envelope quality, current heat-delivery systems) and the temperature of the heat output.

In the present elaboration of the Minewater concept in Heerlen, each connection is unique in terms of execution and component array. While there are many recurring elements, the huge scope for variation in precise implementation makes it far from straightforward to provide an unambiguous review of component costs. In the cost estimates for each component and apsect reported in the following sections, we distinguish between costs that are highly dependent on mode of execution and those that depend mainly on project scale.

3.6.1 Aspects highly dependent on mode of execution

There are two aspects for which costs depend almost entirely on how they are implemented:
- source and buffers;
- building-side modifications.

As developed in Heerlen, the Minewater concept originally used the flooded mines as both a source and a buffer. Following recent changes, though, they are being used ever less as a thermal source and primarily as a buffer. In the vast majority of the Netherlands mines are lacking, however, which means using other types of large-scale buffer. These can be natural (aquifers) or artificial (large underground storage tanks). The associated costs (CAPEX and OPEX) will be highly dependent on local conditions and on dimensioning, making it hard to provide any solid figures.

[7] There is also process control at the level of individual buildings (energy plant).

Expenditure on building-side modification is very dependent on the initial situation (good or poor envelope quality) and the balance opted for between insulation and delivery temperature. All-out insulation improves the scope for LT space heating, but involves substantial outlay on insulation and delivery systems. Poorer insulation necessitates a higher delivery temperature and increases energy consumption (and energy bills), but means considerably less outlay on building-side modifications. The optimum balance will differ from location to location, depending on the building stock involved.

3.6.2 Aspects dependent on project scale

The Minewater concept also has a number of components that are roughly the same in all execution variants, but that vary mainly according to the scale of the project:
- backbone infrastructure;
- distribution grids (clusters and sectors);
- energy plant.

The core Minewater infrastructure has a price tag governed mainly by its total length and project location. Here, it has been dimensioned commensurate with the size of the envisioned supply area. Hooking up additional connections or an extra cluster obviously requires additional investment. This holds not only for the infrastructure, but also in particular for the distributed energy plant for inter- building heat/cold exchange. The more buildings, the greater the investment in energy plant.

Figure 35 – Battery of pumps in an underground Minewater pumping station

3.6.3 Business model

Mijnwater B.V. not only has a track record of technological innovation and sophisticated system design; it has also come up with an innovative concept for charging and clustering of connections, developing an innovative business model for supplying its customers with energy (CE Delft, 2017).

Charging for comfort delivery

While traditional energy suppliers charge customers per unit energy supplied (production delivery model), in many cases Mijnwater B.V. charges per 'unit comfort delivered' (service delivery model). Table 19 summarizes the differences between these charging models.
It should be noted that contracts for small-scale consumers must comply with the terms of the Heating Supply Act.

Table 19 – Differences between charging by Mijnwater B.V. and by traditional energy supplier

	Traditional energy supplier (gas, power)	**Mijnwater B.V. as energy supplier to large-scale consumers**
Model	**Production delivery model**	**Service delivery model**
Unit price	€/kWh, €/m^3 (euro per unit consumption)	- €/m^2 floor space (euro per 'unit comfort delivered) based on fair-use agreement - traditional, as per Heating Supply Act
Net tariff	Yes, annual gas + power	
Energy tax	Yes	
Initial costs	Purchase of central heating unit (HE boiler), delivery system and connection costs	Fee for installation of energy plant and connection
Space for energy plant	Limited	Substantial
Provider & contract	Choice among multiple providers; short-term contracts feasible	Mijnwater B.V. is sole provider; long-term contract (c. 30 years)
Energy grid	Gas and power: standing charge and capacity tariff; contract for indefinite period	Mijnwater B.V. connection: charge for comfort enjoyed, or as per Heating Supply Act. Electricity: charge for comfort enjoyed, or standing charge and capacity tariff; contract for indefinite period
Cost changes	Based on energy-price fluctuations	Correction based on CPI

NB: This is a rough indication; in specific cases the situation may differ.

Delivery contracts for large-scale consumers are tailormade; if so desired, they can opt to be charged according to a traditional production delivery model. Mijnwater B.V., for their part, listen to the individual customer and make an attractive offer based on the total costs of ownership (i.e. the total costs of the customer's end of the energy system for the term of the contract). This offer is grounded in a comparison of the total costs of ownership of the Mijnwater system versus a mutually agreed alternative, encompassing CAPEX, energy costs, avoided investments on improving 'energy performance score', grid costs, maintenance, plant efficiency and so on.

Small-scale consumers with a connection not exceeding 100 kW are covered by the terms of the Heating Supply Act (see text box) and are charged according to the tariff structure laid down there.

Heating Supply Act
Consumers with a connection not exceeding 100 kW are subject to the terms of the Heating Supply Act. Private homes and small-scale commercial consumers generally all fall into this category. This legislation protects such consumers by setting requirements that heat providers must meet with respect to contracts, prices, metering, service and organization. Each year the Dutch Consumer & Market Authority (ACM) sets maximum tariffs for heat supply based on the 'not-more-than-otherwise' (NMTO) principle, which stipulates that "the cost to an average consumer of heat (in any year) may not exceed the cost to an average consumer of gas (in that year). The cost of gas includes, *inter alia*, energy tax and distribution and delivery costs" (ACM, 2017). These maximum tariffs are set for heat delivery (fixed charge + GJ price), a metering tariff and connection costs. The latter do not include the cost of the heat exchanger (or energy plant). The Heating Supply Act does not apply to cold, for which no regulations are yet in place. For delivery of cold, an additional charge may be made.

Clustered power connections

As a relatively large-scale user, Mijnwater B.V. itself pays a lower price for the electricity it buys as well as relatively little energy tax. As the company's various power connections — including those of its customers' energy plants, which the company owns — are part of a coherent, interconnected system, for tax purposes these power connections can be considered 'clustered' (referred to in the legislation as '*complexbepaling*'), with the following conditions met:
- Mijnwater exercises ownership over all the objects where the entry points are located;
- the entry points are all owned by the same legal entity.

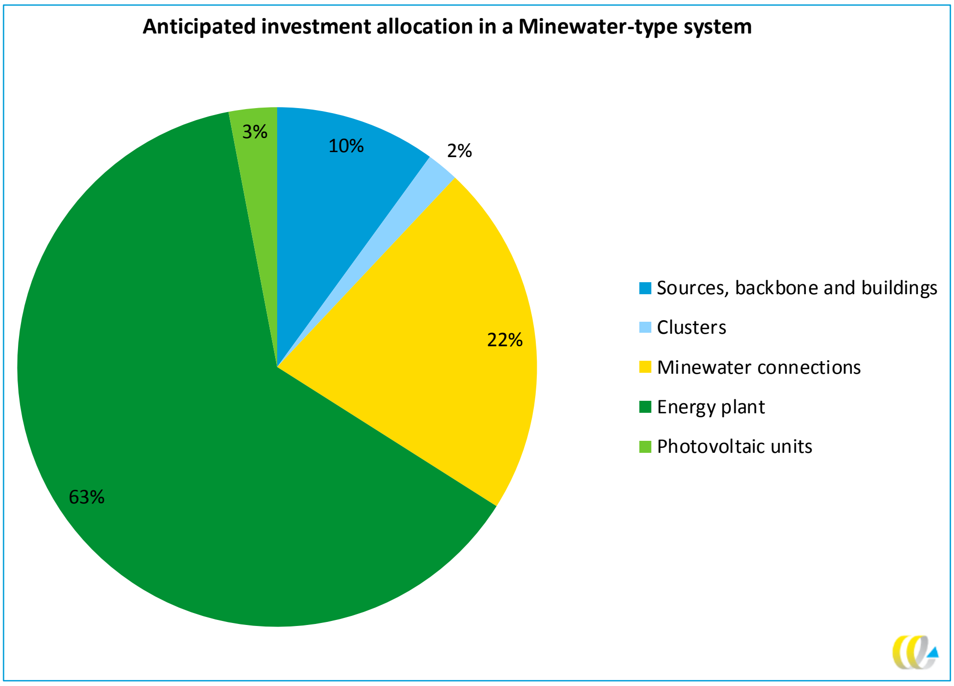
Thanks to this clustering, Mijnwater's aggregate power consumption falls in the lowest tax bracket, in force for large-scale commercial consumers, which means they pay little energy tax. The electricity that end-users buy from Mijnwater is charged at the tariff they would have had to pay if they had been supplied by their own traditional provider. As end-users generally fall into a higher energy tax bracket, per unit Mijnwater is paid more than they themselves are charged. The options and benefits of the overall system are explained to the customer and discussed transparently. This margin is an integral part of the company's business model.

With buildings where solar PV has also been installed by Mijnwater, a single power connection is sufficient if the company also uses it to supply its electricity. This connection is owned by Mijnwater, so for the customer it is as if Mijnwater is supplying all the energy (electricity, heat and cold). The solar panels then supply a major part of the building's requirements as well the Mijnwater energy plant.

3.6.4 Approximate investment allocation

Based on the current operations of Mijnwater B.V. in Heerlen, a rough indication can be given of the approximate allocation of the investments across the various elements of the Minewater concept. The pie chart of Figure 35 shows allocation if the first phase of continued development of Mijnwater B.V. proceeds ('Minewater 3.0'). As is immediately apparent, almost two-thirds of the investements is in the energy plant, which includes the heat pumps for delivering heat and cold to users. The second largest element are the Minewater connections: the distributed infrastructure connecting the energy plant to the backbone. The backbone and buffers themselves represent about 10% of total investments.

Figure 36 – Anticipated investement allocation for a Minewater-type system



3.7 Approximate business case

In the previous section the key financial aspects of the Minewater concept were reviewed. These make it far from straightforward to outline a business case, even an approximate one, as every project component will have its own configuration and mode of implementation. To provide some insight into the dynamics of the Minewater business case nonetheless, rough calculations have been made for two characteristic types of project[8]:
- connecting a supermarket to a Minewater cluster;
- connecting existing dwellings to a Minewater cluster.

The cited expenditures and revenues are exclusive of subsidies, taxes and price-index adjustments.

3.7.1 Connecting a supermarket

When connecting a supermarket, Mijnwater provides a service contract for heat delivery, based on a fixed 'comfort' price per square metre floor space (laid down in the contract). This means the supermarket pays a fixed annual sum, regardless of actual heat demand. For Mijnwater the challenge is then to supply the heat as efficiently as possible.

[8] While fictional, the figures cited in these business cases are based on real project plans, but slightly adjusted to respect confidentiality.

Expenditures

In this business case, expenditures derive primarily from investments in the Minewater connection and energy plant, and, to a lesser extent, from annual energy and maintenance costs. Energy costs are for the power consumption of the heat pumps in the distributed energy plant, while maintenance costs also relate to elements of the energy plant.
The expenditures are summarized in Table 20.

Table 20 - Expenditures, supermarket business case

Expenditure item	Approximate sum
Investment, Minewater connection (one-off)	€ 70,000
Investment, energy plant (one-off)	€ 500,000
Energy costs (annual)	€ 7,500
Maintenance costs (annual)	€ 1,000
Other costs (annual)	€ 1,000

For investments in the Minewater connection 50 years write-off was assumed, in the energy plant 28 years.

Revenues

The supermarket pays for heat as a ‘service’, according to a tariff per square metre, making it essentially an annual standing charge. As explained above, this option for customer charging is available to Mijnwater B.V. because supermarkets do not come under the price rules of the Heating Supply Act. The charge level is set, on the one hand, with reference to the costs the supermarket would have paid if it had not had a Minewater connection. This gives a rough indication of the maximum investment capacity available to Mijnwater B.V., who from here can make a proposal that is (always) better than the alternative. Then, on the other hand, Mijnwater considers the true costs of their heat delivery[9], with this figure being used to assess the project’s profitability. The revenues on this basis are given in Table 21.

Table 21 - Revenues, supermarket business case

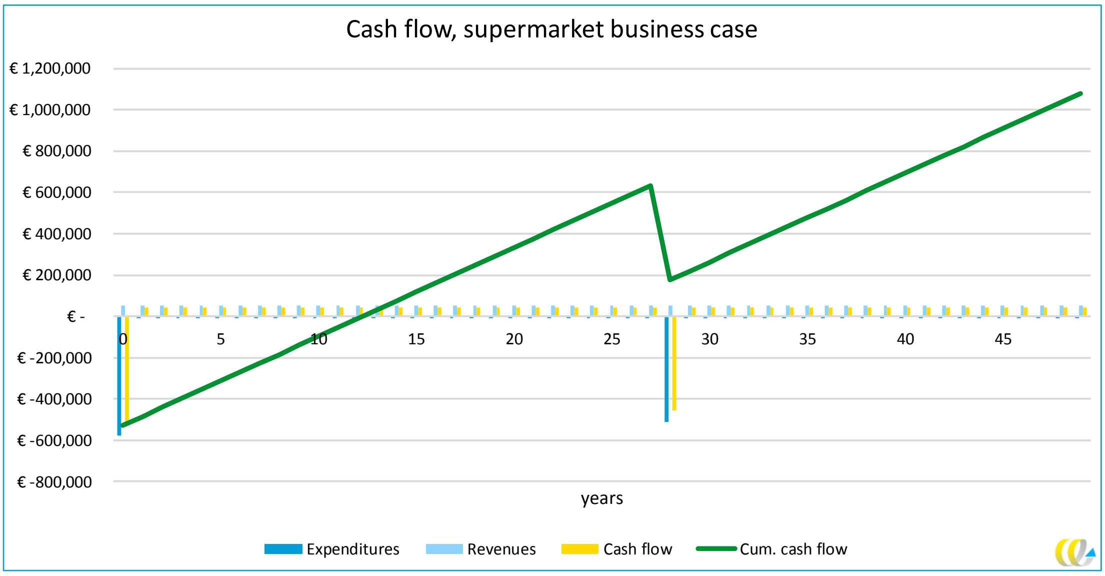
Revenue item	Approximate sum
Standing charge for heat delivery (annual)	€ 52,500

[9] If it turns out that Mijnwater is currently unable to make a viable proposal, it may be decided not to let the project go ahead.

Cash flow

Project cash flow is shown in Figure 37. As can be seen, for Mijnwater a project with a supermarket represents a very favourable proposition, given the conditions in place.

Figure 37 - Cash flow, supermarket business case



3.7.2 Connecting existing dwellings

The business case for connecting existing homes differs from that for a supermarket. First, the site will involve existing buildings and streets, making alterations and infrastructure more expensive. Second, homes are covered by the Heating Supply Act, which means the revenue side of the equation is regulated. The figures reported in Table 22 are for approximately 1,000 dwellings.

Expenditures

The expenditures in this business case relate to the elements paid for by Mijnwater. The expenditures required for making the buildings suitable for heat/cold delivery are for the building owner. The expenditures in this business case consist mainly of the investments to connect the homes to the Minewater infrastructure and the energy plant for heat/cold delivery. These can be distributed (one in each dwelling) or centralized (multiple homes connected to a single plant). Besides capital outlay, there are also annual expenditures on energy, maintenance and 'other costs'; see Table 22.

Table 22 – Expenditures, dwellings business case

Expenditure item	Approximate sum
Investment, Minewater connection (one-off)	€ 1,400,000
Investment, energy plant (one-off)[10]	€ 8,825,000
Energy costs (annual)	€ 162,500
Maintenance costs (annual)	€ 75,000
Other costs (annual)	€ 60,000

Revenues

Supplying private homes via a heat grid comes under the terms of the Heating Supply Act. This means revenues are regulated via a maximum price for both the annual standing charge and the heat delivered. Nor is it possible to apply a tariff structure, as with supermarkets. What differs in this business case is that comfort cooling and hot tap water are also supplied, in addition to heat for space heating. Table 23 reports annual revenues.

Table 23 – Revenues, dwellings business case

Revenue item	Approximate sum
Standing charge, heat (annual)	€ 390,000
Standing charge, cold (annual)	€ 140,000
Standing charge, hot tap water (annual)	€ 120,000
Consumption, heat (annual)	€ 175,000
Consumption, cold (annual)	€ -
Consumption, hot tap water (annual)	€ 140,000

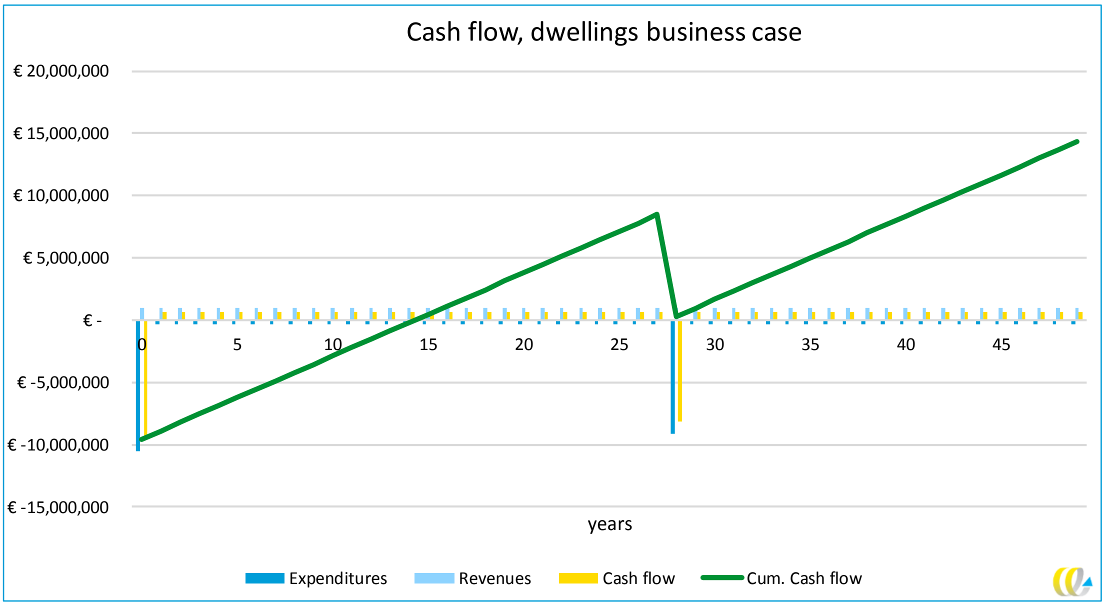
NB: No charge is made for consumption of cold.

[10] The one-off connection fee is included in CAPEX, Minewater connection and energy plant.

Cash flow

Project cash flow is shown in Figure 38.

Figure 38 – Cash flow, dwellings business case



3.7.3 Funding of backbone and R&D

In the business cases presented two key cost items were not included, as they cannot be allocated directly to a specific project: the costs of the backbone infrastructure and overheads like R&D and office costs. These costs are borne by Mijnwater B.V. and must be recovered via margins earned on the overall project. This means projects like those discussed need a minimum return-on-investment (ROI) if they are to have long-term commercial viability.

To operationalize this, Mijnwater B.V. currently works with an organizational structure in which project development and operation are handled separately, with projects first being developed by a development company and subsequently transferred to an operating company for a 'market price' that factors in all the costs and efficiency demands associated with operation. This includes the costs of the backbone and certain others. This market price is separate from the cost price of the project. This means the development company can either earn or lose on the project.

3.8 Opportunities and barriers

3.8.1 Suitable sectors

The Minewater concept is suitable for implementation in the built environment. Given its focus on optimizing heat and cold delivery to the buildings connected, it is ideal if these have a range of different functions. However, this does not mean the concept is unsuitable for areas where there is primarily demand for heat, for example, as this points above all to the need for nearby sources of LT heat that can be used to meet that demand.

Because the concept is so eminently suited to heterogeneous areas, then, it is suitable for both dwellings and utility buildings, newbuild as well as existing. In its present elaboration, in Heerlen, the concept is still focused on the utility sector, but the first (newbuild) dwellings are soon to be connected. Given the great flexibility of the heat grid in combination with heat pumps, the concept has promise in the vast bulk of the built environment –both for well-insulated buildings with low heat and/or cold demand and for less well-insulated ones with high demand for higher-temperature heat. The concept's main restriction is its use of relatively expensive heat and cold infrastructure, making it attractive above all for the more urbanized districts of the Netherlands.

3.8.2 SWOT analysis

To gain a better understanding of the potential role of the Minewater concept in the energy transition a SWOT analysis was carried out to assess its strengths and weaknesses. These are mainly factors intrinsically relevant to the technology's application, but consideration was also given to its potential market performance, governed principally by external factors over which there is little influence. The results of this SWOT analysis are shown below, with the most important aspects in bold letters:

Strengths	Weaknesses
- **Optimum utilization of waste flows/synergy, reducing need for generation/transport** - **Scope for connecting numerous heat sources owing to LT** - **Can be rolled out nationally** - Demonstrated in Heerlen - Lower energy losses due to LT and less transport - Combination of heat and cold in a single grid - Suitable for utility buildings because of cold - No noise nuisance (heat pumps) - Supplementary electricity business model/clustered connections - Demand-driven supply - Easy to extend, flexible, optimum use of local resources - Easy to combine with ATES (aquifer storage)	- **Integrally dependent on a range of thermal sources/stakeholders** - **Extensive infrastructure, intelligence (complex)** - **Dependence on local sources of waste heat/cold** - **Works better if there is demand for cold** - Building modifications (insulation, LT delivery, etc.) in existing buildings (not necessarily essential) - Min. 500 dwelling-equivalents (backbone) - Diversity of customers required - Not at level of individual buildings - Storage hard to implement if no aquifers available - Limited implementation capacity (firms with know-how and practical experience) - Peak demand - Special licence required for ATES > 30°C
Opportunities	**Threats**
- **'Betond gas' movement, Paris climate agreement, Energy Agenda, etc. are creating a market for zero-gas heat** - **Old gas grids will no longer be replaced in the future** - **Numerous renewable LT sources available** - **Individual solutions can be facilitated with a collective grid** - Combination with ATES/surface water (cold) - No NIMBY impacts - Export opportunities for know-how/expertise - Innovation opportunities of LT grids - Image of small-scale local projects/players	- **Competition from individual solutions (air/water source heat pumps, ground-source heat pumps)** - **Lack of know-how and conservative plumbing sector** - Public opinion on collective grid - Heating Supply Act may be constraining (interruptions, fixed/variable) - Larger scale level with more energy-efficient newbuild dwellings - Multiple parties involved in implementation - Contractual complexity - Dependence on electricity price and electricity CO_2 emissions

The main opportunities of the Minewater concept lie in its major scope for roll-out in the Netherlands as a means of fleshing out the heat transition. It also has advantages lacking with other collective heat technologies. At the same time these also represent a sizeable threat, as it is precisely the market's unfamiliarity with these advantages that appear to stand in the way of large-scale implementation in the short term.

A key strength of the Minewater concept is that it makes use of a very substantial 'waste flow' that is not currently utilized in the Netherlands: low-temperature waste heat, which in this system can be used for heating and cooling buildings. One weakness is the system's complexity, with multiple stakeholders ('prosumers' of heat and cold) requiring interconnection and (semi-)time-dependent interaction. This needs a considerable amount of infrastructure, which comes at a price. However, this is not essentially different from alternative heating technologies, which likewise make use of energy infrastructure. While it is true that attractive business cases can currently be made, for large-scale roll-out of the concept the entire heat-supply playing field will need to be substantially overhauled if the concept's true potential is to be realized. Such an overhaul is unavoidable, though, if a large-scale energy transition (LT heat transition) is to be accomplished in the built environment.

3.8.3 Leigislation and regulations

The various legal and regulatory issues of relevance for the Minewater concept are now discussed.

Heating Supply Act

Consumers with a connection not exceeding 100 kW are subject to the terms of the Heating Supply Act. Private homes and small-scale commercial consumers generally all fall into this category. This legislation protects such consumers by setting requirements that heat providers must meet with respect to contracts, prices, metering, service and organization. Each year the Dutch Consumer & Market Authority (ACM) sets maximum tariffs for heat supply based on the 'not-more-than-otherwise' (NMTO) principle, which stipulates that "the cost to an average consumer of heat (in any year) may not exceed the cost to an average consumer of gas (in that year). The cost of gas includes, *inter alia*, energy tax and distribution and delivery costs" (ACM, 2017). These maximum tariffs are set for heat delivery (fixed charge + GJ price), a metering tariff and connection costs. The latter do not include the cost of the heat exchanger (or energy plant). The Heating Supply Act does not apply to cold, for which no regulations are yet in place. For delivery of cold, an additional charge may be made.

Mandatory connection to heat grid under 2012 Building Decree

Municipal authorities implementing a heat grid in a particular area have the right to make it mandatory, under their local 'heat programme', for newbuild to connect to it and for existing buildings to undertake 'sweeping renovation'[11]. The obligation to connect no longer holds if the scheduled number of connections has been attained, the heat programme expires after ten years and no new programme is in progress, or if exemption is granted based on 'equivalence' (as explained in the next paragraph). Neighbourhoods and districts with a heat grid installed (or planned) have no (new) gas grid and no longer have a statutory right to a gas connection[12].

The rights of municipal authorities in this regard stem from the 2012 Building Decree. However, this Decree also provides scope for individual parties or a collective of buildings to reject such a connection, provided these buildings have their own 'equivalent' solution for meeting their functional heating requirements. This 'equivalence' to the heat grid is solely in terms of energy efficiency and environmental footprint, with no consideration given to costs or other criteria like complexity, innovation or user convenience.

A municipal heat programme helps the local authority and the project initiators gain clear insight into the available potential. It sets out the energy and environmental parameters of the heat grid, which can then serve as a benchmark for any alternative initiatives. It also states how calculations on such alternatives are to be performed, so there is no comparison of 'apples and pears', the aim being to make a solid pronouncement on energy efficiency and environmental footprint.

For Minewater-type projects, the advantage of a heat programme plus mandatory connection is that it thus gains a kind of monopoly position, which is favourable for the business case and ultimately also for the financial proposition to customers.

Energy performance of buildings

Based on the European Energy Performance of Buildings Directive (EPBD) the Netherlands has implemented national policy on the energy performance of newbuild. There are minimum standards in force for the energy performance of individual buildings (EPC requirement), covering both energy efficiency and sustainability aspects, and for energy-performance provisions at 'district' level, relevant for heat grids.

The EPC requirement is being incrementally tightened. In line with the National Energy Agreement, as of 2021 it will be superseded by the Near-Zero-Energy Buildings (BENG) standard. A heat grid using sustainably sourced heat can help meet the third BENG requirement, that at least 50% of the primary energy consumption of a newbuild dwelling must be renewable (LenteAkkoord, 2017).

Water Act

On this aspect, see the text under Low-Temperature Geothermal (Section 2.8.3).

[11] The term 'sweeping renovation' is defined in Section 3.2 of the Regeling Bouwbesluit 2012: "A sweeping renovation as intended in Section 5.6, par. 3, of the Decree means that over 25% of the surface area of the building envelope (calculated according to ISSO 75.1, July 2014 edition) is renewed, altered or extended, with this renewal, alteration or extension relating to the integral envelope".

[12] See ACM, *Gebiedsindeling Gas. Onderdeel van de vooreaarden als bedoeld in artikel 12b van de Gaswet*.

Subsidy schemes: SDE+, ISDE

To support renewable energy production, the SDE+ subsidy scheme is available to both commercial and non-commercial parties to compensate for the so-called 'unprofitable component': the difference between the production cost per unit energy and the reference cost price. The level of the subsidy is laid down for fifteen years and is corrected annually on the basis of actual energy prices. In 2017 the scheme covered the following categories of renewable energy: biomass (heat and electricity), geothermal (heat), hydro (electricity), wind (electricity) and solar (heat and electricity). The SDE+ scheme does not apply to heat and cold recovered by means of thermal exchange.

A second national incentive scheme is the Investment Subsidy for Renewable Energy (ISDE), providing financial support to both private and commercial parties for investment specifically in renewable heat technologies, viz. solar boilers, heat pumps, biomass boilers and wood-pellet stoves. There is a list specifying the type of plant and equipment eligible for the subsidy. The ISDE scheme provides scope for subsidies on the distributed heat pumps used in the Minewater concept.

4 Synthesis

In this chapter we consider the longer-term potential of the Minewater and low-temperature geothermal (LTG) concepts, and in particular how they can be combined with the ultimate aim of achieving a built environment that is no longer dependent on gas. This would be an incremental process essentially comprising four phases:

- **Phase 0**: initial situation: conventional heating and cooling.
- **Phase 1**: stand-alone Minewater smart thermal grid and stand-alone LTG.
- **Phase 2**: connection of Minewater smart thermal grid and LTG to a backbone.
- **Phase 3**: upscaling to a zero-gas urban environment.

These phases are schematic and have been kept simple to make the contours of the transition as clear as possible. Each phase will each require several years and involve numerous intermediate steps. These component steps are beyond the scope and aim of the present study and are not considered in the discussion below.

For further clarity, in discussing each phase we first provide a visual picture of the situation, followed by a concise summary of its key features:

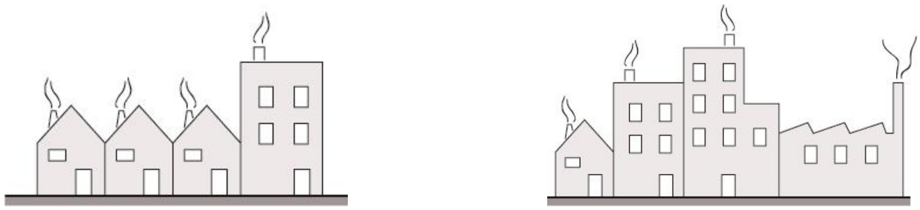
- basic description;
- technical aspects;
- financial aspects;
- organizational aspects;
- Innovation;
- strengths & weaknesses;
- sustainability.

Section 4.3 considers the potential for implementing a combined Minewater+LTG concept in the Netherlands as a whole, while Section 4.4 examines the scope for innovation in its various elements. Section 4.5, finally, discusses the policy opportunities associated with the cobined technology.

First, though, on the following page we provide a compact synopsis of the four phases of combined implementation.

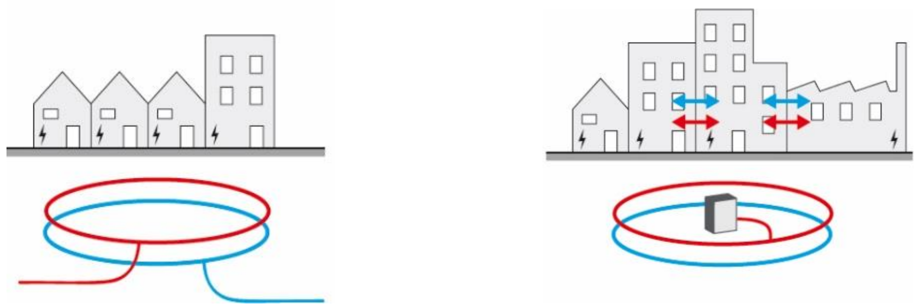
4.1 Overall synopsis

Phase 0 – Initial situation



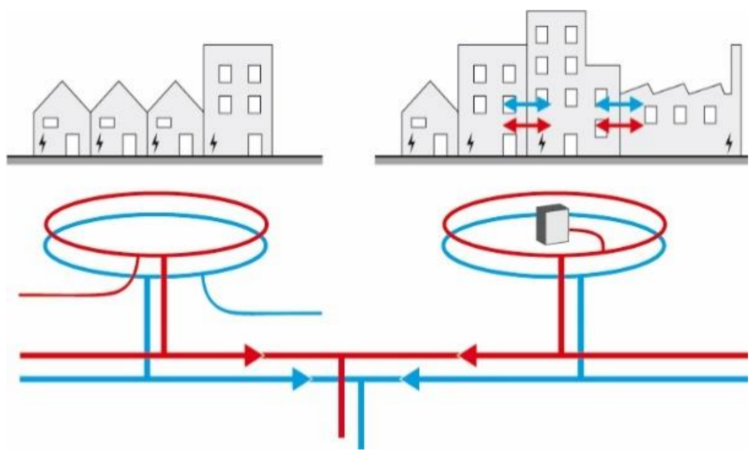
The point of departure is an urban district taken to comprise two neighbourhoods, one mainly housing, the other a mix of homes, utility buildings and facilities. The homes and other buildings are all conventionally heated and cooled. Sustainability is very low and dependence on gas is high.

Phase1 - Stand-alone concepts at neighbourhood level



The transition to zero-gas has begun, with a sustainable energy system now installed in each neighbourhood. The housing area has LTG, that with a mix of homes and utility buildings a smart thermal grid (Minewater concept). This transition is dependent on government policy and the natural replacement cycles of conventional plant and therefore takes a number of years to complete. Ultimately, two zero-gas neighbourhoods emerge that score high on sustainability. Substantial initial investment is required, but this is later recuperated.
Due attention needs to be given to thermal depletion of the geological reservoir and the potential mismatch between supply and demand.

Phase 2 - Synthesis



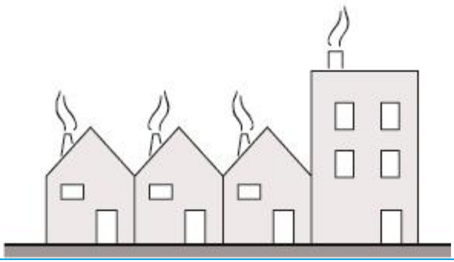
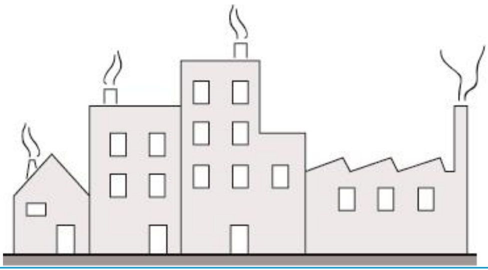
In this phase the two concepts are integrated around a shared backbone, creating an optimized, sustainable energy concept in which the subsurface can be used indefinitely as a heat source and buffer, and supply and demand of heat and cold are optimally balanced. The backbone provides excellent scope for further system upscaling.

Phase 3 - Upscaling
New neighbourhoods and heat sources can be cost-effectively connected to the backbone, kicking off the transition to the zero-gas city of the future.

4.2 Four-phase transition

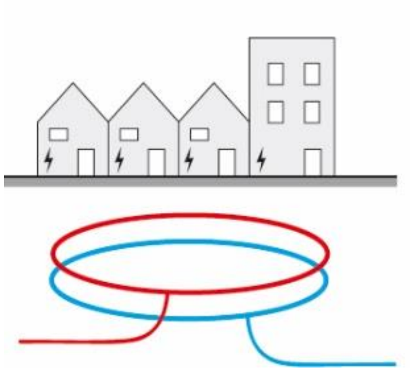
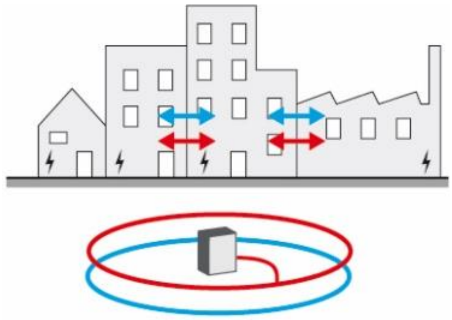
4.2.1 Phase 0: Initial situation

The point of departure is an urban district taken to comprise two neighbourhoods, one mainly housing, the other a mix of homes, utility buildings and facilities. The homes and other buildings are all conventionally heated and cooled. Sustainability is very low and dependence on gas is high.

Existing housing	Utility/housing mix
	
Basic description – Existing building stock at district/neighbourhood level comprising mainly dwellings (low- and high-rise). – Insulation levels poor to reasonable. – Some homes already insulated and double-glazed. – Little demand for cold. **Technical aspects** – Home heat-delivery systems: traditional high-temperature radiators – Heating with conventional gas-fired CH boiler. – Infrastructure: natural-gas grid with individual connections at home and/or block level. – Temperature level for heating typically 70-90°C. **Financial aspects** – Building owner finances hardware and pays annual energy and maintenance costs. **Organizational aspects** – Home ownership: part private, part housng corporation. **Innovation** – Mature technologies. **Strengths & weaknesses** – Existing technologies robust. – ‘Future-proofness’ low. **Sustainability** – Heating system unsustainable.	**Basic description** – Existing building stock at district/neighbourhood level comprising a mix of dwellings, utility buildings and facilities. – Insulation levels poor to reasonable. – Some buildings already (further) insulated and double-glazed. **Technical aspects** – Buildings with traditional heat-delivery systems; HT heat and LT cold. – Heating with conventional gas-fired CH boiler. – Utility buildings and facilities (part-)cooled with electrically driven cooling units. – Temperature level for heating typically 70-90°C, for cooling 6°C. **Financial aspects** – Building owner finances hardware and pays annual energy and maintenance costs. **Organizational aspects** – Ownerhip: part private, part corporation, part commercial. **Innovation** – Mature technologies. **Strengths & weaknesses** – Existing technologies robust. – ‘Future-proofness’ low. **Sustainability** – Heating and cooling systems both unsustainable.

4.2.2 Phase 1: Stand-alone concepts at neighbourhood level

The transition to zero-gas has begun, with a sustainable energy system now installed in each neighbourhood. The housing area has LTG, that with a mix of homes and facilities a smart thermal grid (Minewater concept). This transition is dependent on government policy and the natural replacement cycles of conventional plant and therefore takes a number of years to complete. Ultimately, two zero-gas neighbourhoods emerge that score high on sustainability. Substantial initial investment is required, but this is later recuperated. Due attention needs to be given to thermal depletion of the geological reservoir and the potential mismatch between supply and demand.

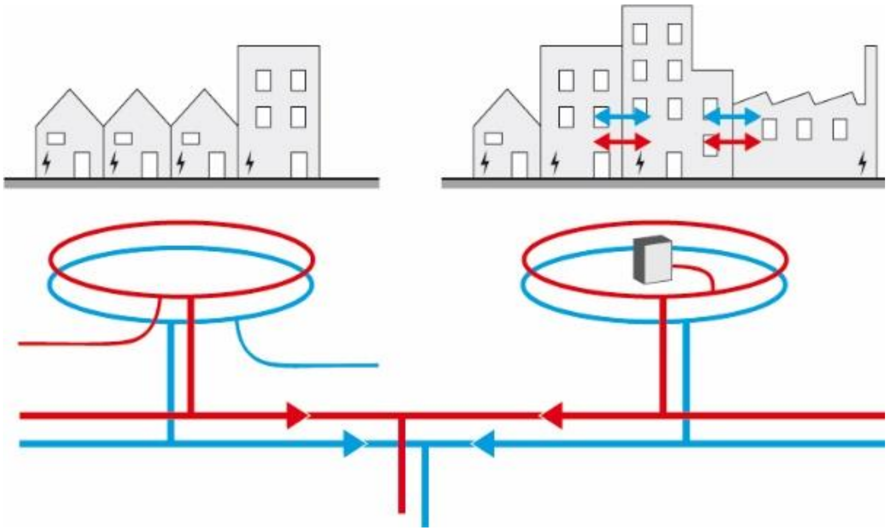
Existing housing with LTG	Utility/housing mix with Minewater
	
Basic description – Homes connected to LT grid fed with shallow geothermal heat. **Technical aspects** – LTG doublet at neighbourhood level, with an in-house connection set. – Home CH boilers replaced by heat-grid supply sets. – For use of LT heat, home heat-delivery systems modified or replaced. – Home insulation status improved by added insulation. – Infrastructure: LT grid with individual connections at dwelling and/or block level. – Temperature level for heating typically c. 55°C. – Booster heat pumps for hot tap water. **Financial aspects** – Single-party investment in collective energy system. – Initial investments unavoidable. – CAPEX partly passed on to end-users via connection fee. – End-users buy heat at current tariff. – Home owners invest in required building-side modifications. – Financial benefits of local renewable power generation combined with smart-grid solutions. **Organizational aspects** – Single party selected for energy system	**Basic description** – Homes, utility buildings and facilities exchange energy via smart, demand-driven grid comprising heat infrastructure, heat sources and short-term buffer. **Technical aspects** – Homes and other buildings connected to heat/cold grid through which heat/cold are exchanged. – Local heat/cold sources connected to grid (e.g. waste heat from supermarket, data centre, hospital). – Home CH boilers replaced by heat/cold-grid supply sets. – For use of LT heat, home heat-delivery systems modified or replaced. – Home insulation status improved by added insulation. – Infrastructure: LT heat/cold grid with individual connections at dwelling and/or block level. – Temperature level for heating typically c. 55°C. – Cold supply via HT cooling. – Booster heat pumps for hot tap water. **Financial aspects** – Single-party investment in collective energy system. – Initial investments unavoidable. – CAPEX partly passed on to end-users via connection fee.

installation and operation. – Terms of supply contractually agreed with customers. **Innovation** – Heat sourced from LTG system, with wide scope for innovation, e.g. drilling technology, efficiency improvements, lower-cost materials, enhanced heat-delivery systems, smart insulation methods. **Strengths & weaknesses** – Heat demand met locally. – Customers relieved of responsibility for heating. – Resident participation in heating supply. – Due attention to LTG doublet and heat infrastructure in existing area. – Over time, thermal depletion of geological reservoir. **Sustainability** – Zero-gas neighbourhood. – Significant CO_2 emissions reduction. – Clean (zero flue-gas, particulate and heat emissions). – Further sustainability gains as more renewable power used.	– End-users buy heat at current tariff. – Building owners invest in required building-side modifications. – Financial benefits of local renewable power generation combined with smart-grid solutions. **Organizational aspects** – Single party selected for energy system installation and operation. – Terms of supply contractually agreed with customers. **Innovation** – Wide scope for innovation in demand-driven heat/cold exhange, e.g. smart control, enhanced software. **Strengths & weaknesses** – Local utilization of waste-heat flows. – Customers relieved of responsibility for heating/cooling. – Resident participation in heat supply. – Organizationally complex: multiple stakeholders and dependencies. – Due attention to integrating heat/cold infrastructure in existing area. – Supply/demand mismatch means need for long-term (seasonal) buffering. **Sustainability** – Zero-gas neighbourhood. – Significant CO_2 emissions reduction. – Clean (zero flue-gas, particulate and heat emissions). – Further sustainability gains as more renewable power used. – Waste-heat utilization.

4.2.3 Phase 2: Synthesis

In this phase the two concepts are integrated around a shared backbone and additional renewable heat sources are fed in, such as solar heat and surface-water heat.
An optimized, sustainable energy concept is created in which the subsurface can be used indefinitely as a heat source and buffer, and supply and demand of heat and cold are optimally balanced. The backbone provides excellent scope for further system upscaling.

Integration of existing housing (LTG) & utility/housing mix (smart thermal grid/Minewater)



Basic description

- The two energy concepts are integrated via a shared backbone through which heat and cold are exchanged. Additional renewable energy sources are added.

Technical aspects

- A backbone connects the two systems.
- The LTG doublet serves not only as a heat source but also as a long-term heat buffer and is thus integrated into the Minewater system.

Financial aspects

- Implementation of backbone requires additional investment.
- Greater financial efficiency through synergy.

Organizational aspects

- Contractual arrangements between operators of both grids.

Strengths & weaknesses

- Use of LTG doublet as heat buffer precludes thermal depletion and avoids Minewater thermal disequilibrium.
- Maximum energy efficiency through economies of scale and higher efficiency.
- Integration provides scope for further upscaling.

Sustainability

- Additional to Phase 1: LTG doublet can be deemed an undepletable source/buffer.
- Aggregate energy savings of integrated system exceeds summed savings of individual concepts.

4.2.4 Phase 3: Upscaling

New neighbourhoods and heat sources can be cost-effectively connected to the backbone, kicking off the transition to the zero-gas city of the future.

Basic description
- Upscaling enabled by backbone permitting multiple new connections.

Technical aspects
- Extension of heat grid and connection of new areas and heat sources.

Financial aspects
- Optimum return on prior initial investments.

Strengths & weaknesses
- Standing project organization and experience gained make upscaling cost-effective.
- Increased operational reliability.

Sustainability
- Upscaling culminates in full transition from zero-gas neighbourhood to zero-gas city of the future.

4.3 Potential of Minewater concept combined with LTG

In the previous chapters the Minewater and LTG concepts were considered separately, but LTG can also serve as one of the low-temperature heat sources for a Minewater-type system. The LTG potential in neighbourhoods across the Netherlands was identified and described in Section 2.5. Below, we feed this analysis into the Minewater concept, using the degree to which LTG can meet a neighbourhood's heat demand to determine the minimum number of additional LT heat sources required. This is an assumption used to chart potentially suitable locations. In doing so we used the same distribution as for the Minewater concept without LTG (Figure 30), but reducing the minimum number of LT sources by multiplying this by a factor governed by the LTG fraction, as reported in Table 24, and then rounding to an integral number of LT sources.

Table 24 - Weighting factor per LTG fraction

LTG fraction of neighbourhood heat demand	Factor for LT sources
< 0.2	1
≥ 0.2	0.8
≥ 0.4	0.7
≥ 0.6	0.6
≥ 0.8	0.5

Because fewer LT sources are now required for a viable Minewater system, more neighbourhoods are eligible, as shown in Figure 39 and Figure 40, creating greater scope for a combined Minewater & LTG system than for stand-alone Minewater; see Table 25 and Tabel 26.

Figure 39 – Map of the Netherlands showing neighbourhoods potentially suitable for combined Minewater + LTG, present situation

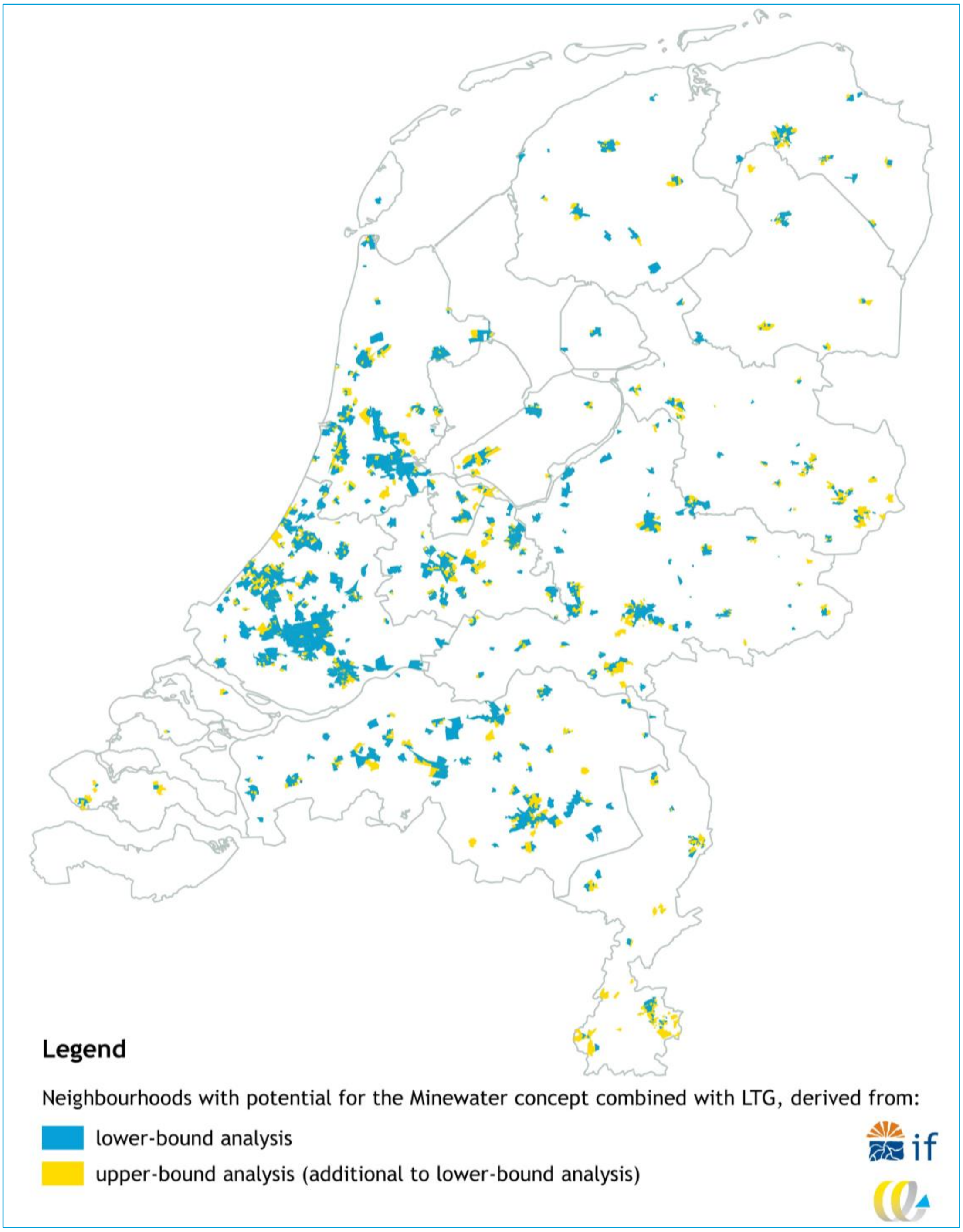
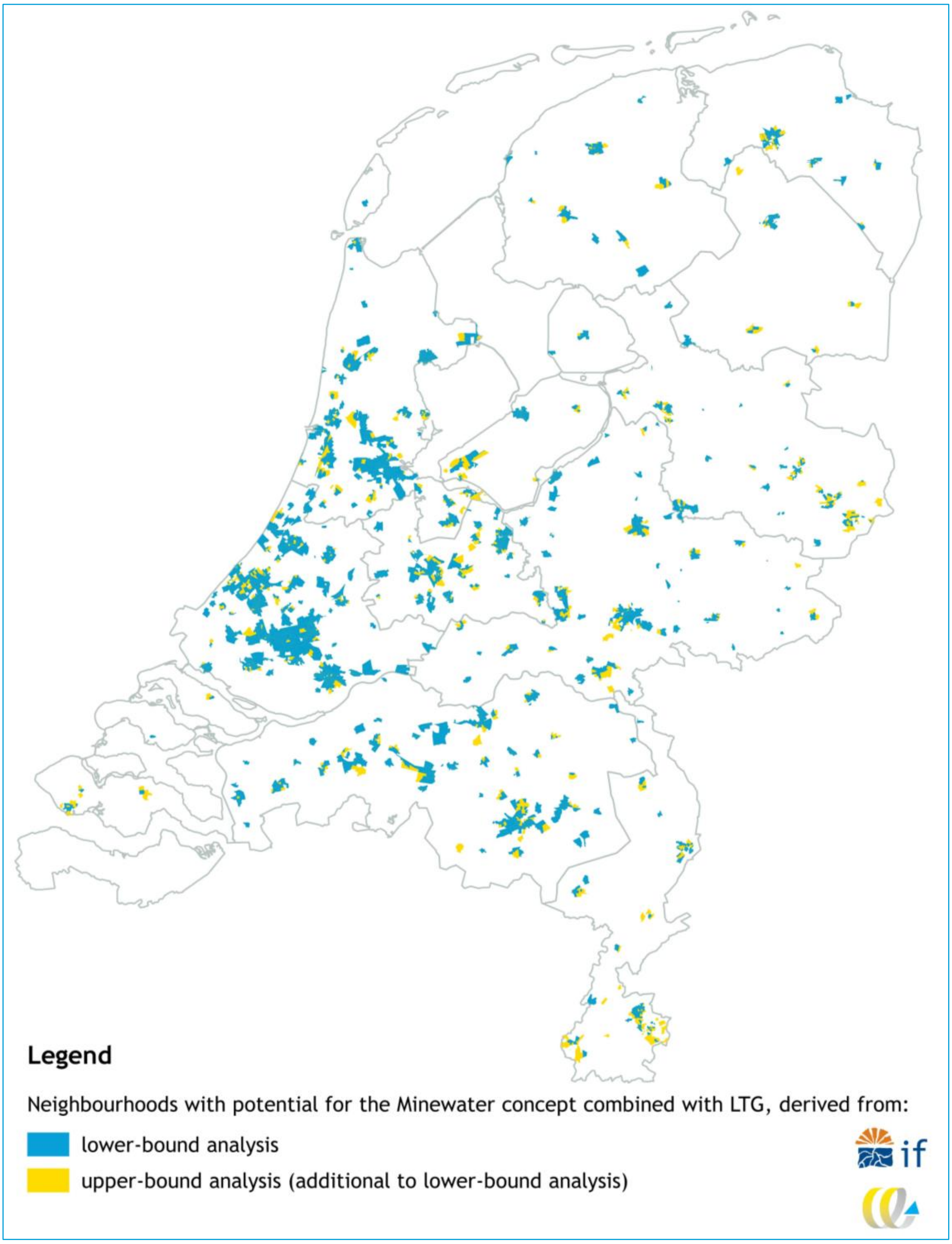


Figure 40 – Map of the Netherlands showing neighbourhoods potentially suitable for combined Minewater + LTG, future situation with 25% lower heat demand



Proceeding from the future situation with 25% lower heat demand, 396 to 835 additional neighbourhoods now come into the picture compared with a stand-alone Minewater concept, which means heat/cold demand fulfilment is now up to doubled. The total number of potentially suitable neighbourhoods now lies between 3,494 and 4,161, which is 29-34% of all Dutch neighbourhoods[13].

Table 25 – Total potential of combined Minewater + LTG (lower bound)

Aggregate heat demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. heat demand
Present	PJ	170.6	115.7	52.8	2.2	27%
Future, with 25% lower demand	PJ	145.0	98.7	44.1	2.2	23%
Aggregate cold demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. cold demand
Present	PJ	4.4	1.5	2.9		33%
Future, with 5% growth due to energy label improvement	PJ	4.6	1.6	3.1		35%

Tabel 26 – Total potential of combined Minewater + LTG (upper bound)

Aggregate heat demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. heat demand
Present	PJ	226.7	158.4	65.9	2.4	36%
Future, with 25% lower demand	PJ	186.4	129.9	54.0	2.5	30%
Aggregate cold demand						
		Total	Dwellings	Utility	Greenhouses	% of agg. cold demand
Present	PJ	5.8	2.1	3.7		44%
Future, with 5% growth due to energy label improvement	PJ	6.1	2.2	3.9		46%

Potential of Minewater concept with solar-thermal systems

In an alternative elaboration of the Minewater concept, heat can be fed in from large-scale solar-thermal plant instead of, or in addition to, LTG. This plant can be used to supply heat in the summer months that is stored in the thermal buffers for use at a later date.
This option was not analysed in in the present study[14].

4.4 Scope for innovation

The following sections go briefly into the scope for innovation in both LTG and the Minewater concept (smart thermal grid). Taken together, they provide an indication of the scope for innovation with respect to a combination. These innovations are not all exclusive to the concepts, but may also derive from developments relating to other heat concepts.

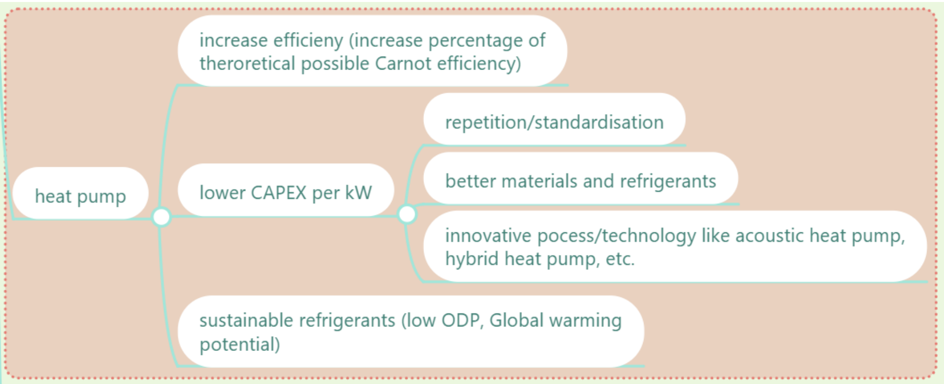
[13] This translates to approx. 3.5-4.5 million dwellings.

[14] While aquathermal energy is another potential option, the lower temperatures currently make it a less obvious choice.

4.4.1 Scope for innovation in combined system

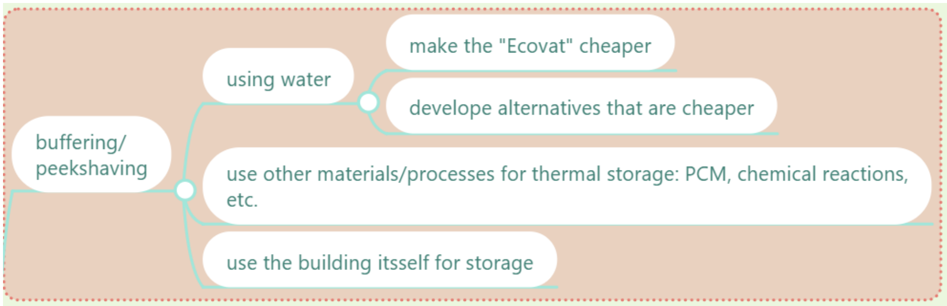
The main aim of innovation is to reduce the future cost of renewable heat, to at least a level at which no subsidy (SDE+) is required for economically viable exploitation. There is room for innovation on all aspects, but they will not ultimately all make the same cost-cutting contribution. The following figures provide a one-glance view, which is followed by a brief discussion.

Heat pumps



In some areas there is relatively little remaining scope for improvement (the Carnot efficiency could be boosted from 65 to 75%, for example, but this also increases CAPEX) and not all elements contribute equally to the cost price of the heat.

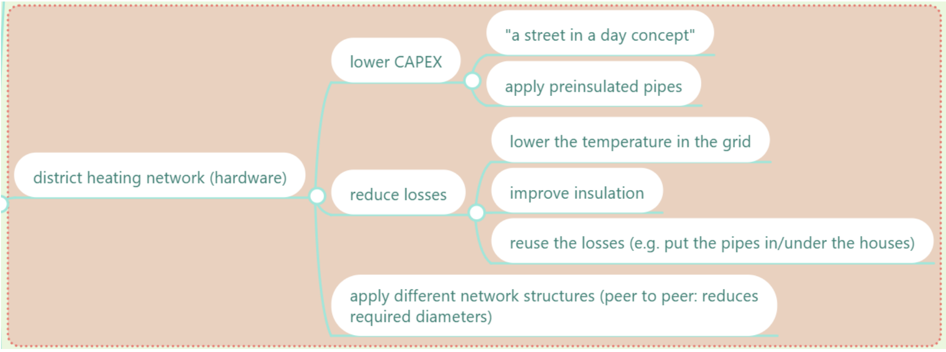
Buffering



Distributed heat buffering is a key element of the Minewater concept and innovations in this area can make a major contribution to reducing the heat price, by:
- shifting electricity demand to low-tariff periods;
- using day-night and/or week-weekend heat exchange to match supply and demand, and improved use of waste heat from ‘neighbours’ at home at different times;
- reducing investments in back-up/peak-load systems, because the buffer can contribute more.

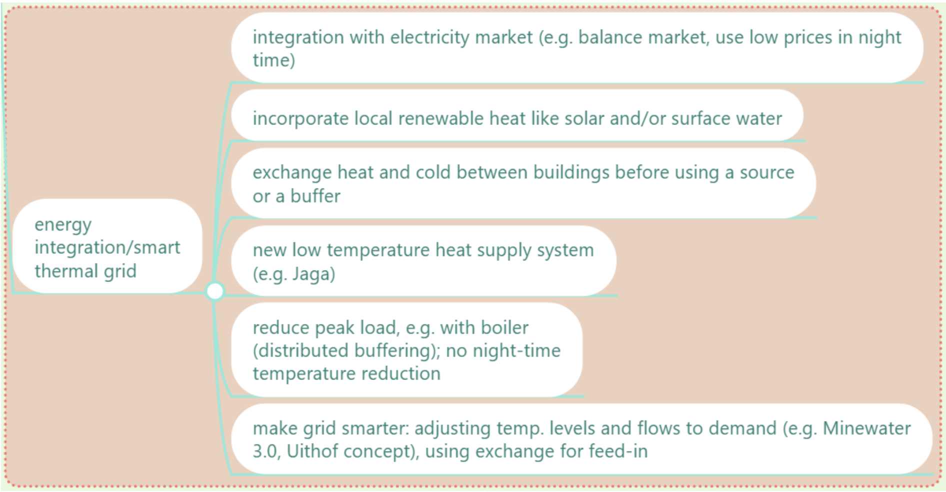
On various fronts[15] work is in progress on new heat-storage methods (e.g. EcoTank, WINST project). In the future, as electricity prices come to fluctuate more, the importance of buffering will only increase still further. There are therefore major opportunities for innovation in this area.

Grid



The grid is a major contributor to CAPEX. Its share is very dependent on the extent to which demand is concentrated, but can be over 50%. Various parties are working on innovative cost-cutting solutions, including the 'street in a day'[16] and 'heat through the air' concepts[17].

Energy integration/system integration/smart thermal grids



15 https://app.tki-urbanenergy.nl/projects/warmte-infrastructuur-nederland-met-verlaagde-systeem-temperatuur
16 https://thermaflex.com/nl/oplossingen/straat-in-een-dag
17 http://www.warmtenetwerk.nl/assets/jaarcongres-2017/Weijers-Waalwijk-Warmte-door-de-lucht-WNW-15-juni-2017.pdf

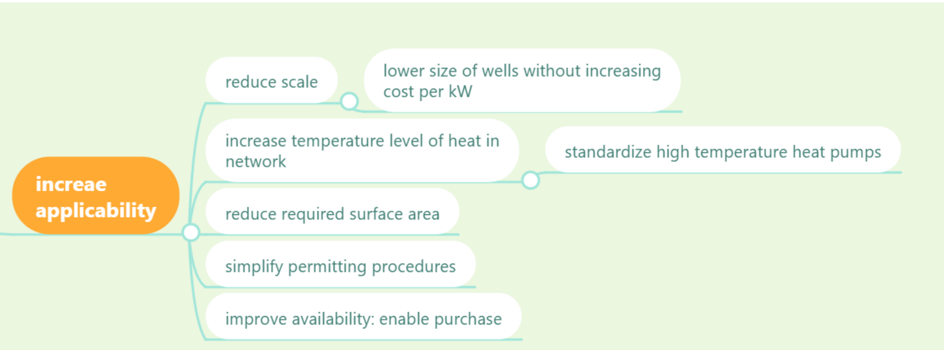
With this element, too, there is ample scope for improvement. In essence the Minewater concept consists of district-wide system integration of heat/cold demand, linked to the electricity market and using buffering and smart technology to optimize use of the various energy flows. Similar concepts have also been implemented for aquifer storage, for example in the DATES concept presented by Velvis & Buunk (2017) at the international Heat Pump Conference. The end of such developments is not yet in sight. Greater use can made of predictive control, for instance, and building heat balances could be controlled not to a local but to a district optimum (if heat demand in the district is high, it does not matter if a building needs a lot of cold in the summer), etc.

Necessity, options and priorities

Moving forward, the cost price of LTG/Minewater heat needs to come down, to end the technology's dependence on SDE+ subsidies and make it more competitive with other options like air/water-source heat pumps. As things stand at present, there would appear to be plenty of scope for reducing the cost price of heat from LTG and combined Minewater + LTG. Innovative efforts are underway on many fronts and LTG and Minewater are still both only just getting started.

Innovation in several of the above fields is currently being driven mainly by markets other than LTG/Minewater, particularly by the markets for heat pumps and grids. This means the focus for LTG/Minewater should be on reducing the cost of the source and short-term buffer and on further development of smart thermal grids.

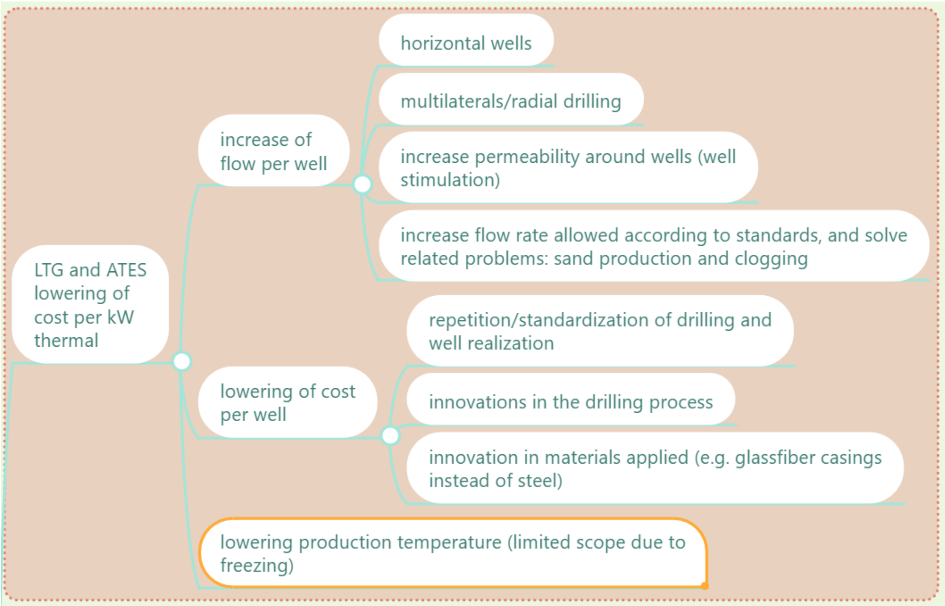
Improving market penetration



The cost price of heat is not the only factor governing the technology's market success; some of the others are cited in the figure. The in-building delivery temperature is crucial, for example. Many of today's buildings require at least 70°C. For smooth, rapid market penetration it is important that this temperature can be delivered, too. In addition, scale (how high does my minimum heat demand need to be?), availability (can I buy an LTG/Minewater system somewhere, or is it something that has to be worked out from location to location?), permit regime and space requirements are important.

4.4.2 Specific scope for LTG innovation

Investments in output (source & conversion): euro/kW



After factoring in SDE+ 2017, a figure of approx. 1,700 €/kW for geothermal CAPEX is estimated by ECN. In this study we arrive at around 1,200 €/kW for LTG. For ATES, investments come to about 300-500 €/kW, as does the heat pump, at around 200-500 €/kW (depending on scale and temperature level). This makes the heat pump and source about equally important if ATES is used and means that the greatest scope for improvement when it comes to LTG lies in reducing source-related CAPEX. As yet there is no sign of either component outpacing the other in terms of price reduction. For both there still appears to be plenty of scope for innovation, and this is indeed underway. Investments in heat pumps by equipment manufacturers have little or no relation to the LTG/Minewater market. However, the price of air/water-source heat pumps is currently falling to such an extent that ground-source heat pumps are becoming ever less competitive. From the LTG/Minewater supply side, then, the focus should be on cutting expenditure on the heat source itself.

4.4.3 Specific scope for Minewater innovation

Optimization and automation of heat/cold flows

Minewater was originally designed as a system in which a heat source (the disused mines) was used to heat buildings using LT heat. Since then the concept has been further developed, en route to a sophisticated grid for exchange of heat and cold involving multiple parties. At the moment the number of parties is still limited and grid control relatively straightforward. As that number increases, though, with ever-diversifying profiles in terms of heat and cold demand, automation and optimization become increasingly crucial. Mijnwater B.V. is currently collaborating with several partners on these issue in a European project. With the newly gained knowledge, the Minewater concept can be further optimized while at the same time expanding its potential area of application. Through smart control of supply, demand and heat/cold buffering, the concept can be rolled out at far more locations than Heerlen (cf. analysis of potential in Section 3.5).

Storage management

Although storage/buffering is part and parcel of the optimization of grid energy flows, as described above, it also represents opportunities for innovation in its own right. What makes Minewater unique in the Netherlands at the moment is its capacity for large-scale storage and buffering of thermal energy at different temperatures. The reason for this is that Minewater disposes over multiple wells. The knowledge gained in operating these can be put to use in a wider context, providing a better understanding, for example, of how aquifers elsewhere in the Netherlands could be managed to create a similar situation, using multiple aquifers as buffers at different temperatures, moving beyond traditional use of aquifers and using them for medium and high-temperature storage, too. What is essential here is that the energy is stored at the *optimum* temperature, minimizing energy losses and putting subsurface capacity to maximum use.

Business-model innovation

Mijnwater B.V. currently employs a business model that takes a different approach to small- and large-scale consumers .The former group is covered by the Heating Supply Act, which at present offers little if any scope for improving their particular business model. In contracts with large-scale consumers, on the other hand, Mijnwater has introduced a number of innovations. As a provider, Mijnwater supplies heat and cold as a ‘service’, charged not in terms of GJ heat, but as providing an agreed building comfort level. And as Mijnwater can use its energy plant to supply customers electricity, too, at a superior tariff, it can deliver a ‘total energy package’. Although these options are not yet available to small-scale, private users because of the Heating Supply Act, there are still potentially opportunities for innovation, with similar contracts available for an attractive, competitively priced ‘total package’ comprising all-round comfort and electrical power.

4.5 Policy opportunities

There are a range of policy opportunities when it comes to further development of sustainable LT solutions in general and LTG and Minewater in particular, which are briefly discussed below. With suitable policy decisions, the LTG/Minewater concept can be further developed over the coming decades, so such systems can contribute to creating a sustainable heating and cooling supply.

The situation today: the Paris climate accord and the Rutte-III coalition agreement

The Paris climate accord forms the starting point of Dutch climate policy and haes the same status in the coalition agreement of the third Rutte government. To achieve the minimum 2-degree target envisioned in Paris, the Netherlands needs to reduce CO_2 emissions by 85-95% by 2050 (relative to 1990); for the preferred 1.5-degree target they need to be cut by over 100%[18] (PBL, 2016). To achieve either of these goals, sustainable heating systems are indispensable, and Minewater is one such concept.

On its inception in 2017 the four-party Rutte-III coalition set out its policy intentions in an agreement (VVD, CDA, D66 & CU, 2017) that included the following relevant points:
- A National Climate and Energy Agreement will be established.
- By the end of its governing period, newbuild homes and other buildings will as a rule no longer be gas-heated. Incrementally, the market for 'greening' the existing housing stock will also be set in motion. As the building sector gains more expertise and experience, costs will fall and the 'sustainability market' will be able to stand more on its own feet.
- Working with local and provincial government, grid operators and water boards, for each region a sustainability plan for the built environment will be drawn up enabling a programmatic approach involving an optimum mix of energy conservation, sustainable heat and renewable generation.
- The 'duty-to-connect' for gas will be replaced by a 'right to heat', under which end-users can claim connection to a (heavier-duty) electrical power grid or heat grid.
- In line with this, newbuild energy performance standards will be further tightened and new housing estates will no longer be provided with a gas grid as a matter of course.
- New regulations will be created for energy cooperatives, making it easier for residents to participate in renewable energy projects in their own direct vicinity.

'Heat vision'

In 2015 the Ministry of Economic Affairs published a 'Heat Vision' (Ministerie van Economische Zaken, 2015) emphasizing the importance of heat grids and the 'beyond gas' movement, as well as admitting the poor financial viability of waste-heat projects, due partly to the 'not-more-than-otherwise' principle in regulated tariffs. It should be noted, though, that this situation will improve somewhat in the years ahead as the energy tax on gas is set to rise. The minister has indicated that he intends to look into the effectiveness of the present regulation methodology and consider new potential market models as well as funding barriers. The scope for 'open heat grids' will also be examined. In the start-up phase, regional (waste) heat projects will receive government support.

Upcoming: the Environmental and Planning Act

The Environmental and Planning Act is a new piece of Dutch legislation that is currently being prepared and expected to come into force in 2021. Today, spatial planning regulations are included in numerous articles of legislation and in the new act all rules and regulations with a spatial planning component will be brought under a single Act.
The Environmental and Planning Act will thus supersede a whole series of laws, including the General Provisions for Environmental Law Act, Air Pollution Act, Spatial Planning Act, Water Act, Environmental Management Act and Housing Act, to name just the main ones.

Under the new regime there will be greater policy freedom for local and provincial authorities, operationalized via the following instruments:
- **'Environmental and planning vision'**
  The 'environmental and planning vision' (*Omgevingsvisie*) is an integrated vision comprising the chief strategic long-term policy choices with respect to the physical

[18] This means 'negative' carbon emissions are also required, through CO_2 capture and storage or afforestation, for example.

environment. This vision is laid down by national, provincial and municipal government bodies for their economy and territory. In concrete terms, this means the vision considers the interconnectedness between the sum total of spatial planning issues: water, environment, nature, landscape, traffic/transport, infrastructure, cultural heritage and so on.

- **'Environmental plan'/'Water board regulation'/'Environmental regulation'**
  The 'environmental plan' (*Omgevingsplan*) is an elaboration of the 'environmental and planning vision' that specifies the regulations and policies for implementing the vision.
- **'Environmental values'**
  Authorities can also lay down 'environmental values' (*Omgevingswaarden*) for their territory: concrete targets for air quality or noise, for example. If these targets have not yet have been achieved, the authority must draw up a programme to do so. Such programmes are sectoral and indicate the steps the authority itself intends to take in the given area to achieve the aim of securing the 'environmental value'.
- **Programmes**
- **'Integrated environmental permit' (current Wabo, flora/fauna exemptions, etc.)**
  The 'integrated environmental permit' (*Omgevingsvergunning*) is an instrument that allows a government authority to validate that activities are having an acceptable impact on the physical environment. Examples include licences for expanding industrial sites or the felling of forests.

'Transition path for LT heat'

Following on from the so-called Energy Agenda, an exploratory study on a 'Transition path for low-temperature heat' has been carried out jointly by two ministries: Economic Affairs & Climate and Interior & Kingdom Affairs (EZK, BZK, 2017). This policy report sets out a roadmap for achieving a low-carbon urban environment in 2050 with a sustainable low-temperature heat supply, as envisaged in the 2016 Energy Agenda (Ministerie van Economische Zaken, 2016).

This roadmap has numerous reference points for Minewater-type projects:

- Rapid kick-off of regional heat transition at the local level. Before 2022, local authorities draw up plans for where and when alternative heating systems are to be implemented.
- Reducing space-heating demand of buildings through insulation measures and making homes suitable for LT heating systems (< 70°C), so that "new heat sources like geothermal and waste heat from e.g. data centres are better utilized and efficiency improved with respect to transport losses (heat grids) and peak loads (power grids)".
- Besides innovations in the realms of heat demand reduction and infrastructure, these are also cited with respect to 'greening' the heat supply: "There is to be priority focus on geothermal (seismology, new materials, well management), (re)use of lower temperatures, upscaling of green gas production, use of gas grids for hydrogen, seasonal storage and smart grids. There also needs to be substantial cost-cutting and product improvement (efficiency, space requirements, noise levels) with respect to electric heat pumps".
- The spatial implications of a sustainable LT heat supply are also mentioned: "The choice for an alternative to natural gas is highly dependent on the spatial configuration of an area. A heat grid requires high building density and a certain minimum demand, for example. Thanks to the Netherlands' post-war urbanization policy (incl. 'bundled deconcentration') the country is relatively well-placed for large-scale heat grids.
  In addition, sustainable heat sources are needed in proximity to demand. Alongside the large high-temperature point sources currently in use, in the future there is major

potential for smaller-scale sources within the built environment, such as supermarket refrigeration. When (re)designing and developing an area these relatively small sources can be brought into play. A business with a particular heat profile could then assess where it is most attractive to locate."

A number of possible measures are cited with potential scope for a Minewater-type concept:
- Replacement of the 'duty-to-connect' for gas by a 'right-to-heat'.
- Where necessary, support for the 'right-to-heat' by a subsidy scheme to fund the required building modifications, including insulation.
- More central steering by national government with respect to heat infrastructure, comparable with electricity and gas infrastructure, such as designated regions where heat grids are to be created.
- Separate regulation of production, distribution and delivery where this improves market efficiency. Examples might include non-discriminatory grid access, separate tariffs for heat connection, distribution and delivery, and cost-oriented grid tariffs.
- Switching to cost-oriented heat tariffs, using cost-plus regulation per heat provider via a new Heating Supply Act, for example.
- Giving regulated grid operators a statutory responsibility to administer heat grids.
- A distinction between large-scale transport grids and smaller-scale distribution grids. In legislation, specific focus on small-scale private and cooperative heat grids.
- Research on scope for assigning grid operation via a concessionary system every 10-15 years, with required standards for efficiency, investment levels and sustainability.
- Incentives for development of LT heat grids (< 70°C).

Environmental Management Act and 'MJA3'

Under the Environmental Management Act industries and institutions consuming over 50,000 kWh electricity or 25,000 m^3 natural gas-equivalents a year have a statutory obligation to implement all energy-efficiency measures having less than 5 years' payback. This obligation can be enforced by municipalities, the competent authority; prioritization of enforcement is indeed part and parcel of the National Energy Agreement (SER, 2013). If a business case with less than 5 years' payback can be made for waste heat utilization by a company (in particular, industry), local authorities can oblige it to do so. This can help acquire sufficient heat for realizing a Minewater-type project.

In certain branches of industry, such measures may also be counted as contributing to a company's so-called 'MJA3' performance. This is a reference to the third round of multi-year agreements on energy efficiency (giving the Dutch acronym MJA3): voluntary yet binding agreements between the government and individual sectors on improving energy efficiency. The target is a 30% improvement over the period 2005-2020. In exchange for meeting their MJA3 obligations, the companies receive financial government support, in the form of a rebate on energy tax, among other things. For companies with an obligation of this kind, area-based heat exchange can be included as a measure for improving supply chain efficiency (RVO, 2014). As such, then, MJA3 can also be seen as an incentive for this category of companies to participate in a Minewater-type project.

5 Analysis, conclusions and recommendations

5.1 Analysis

Low-temperature geothermal heat (LTG) and Minewater-type systems are promising technologies that can potentially play a significant role in the Dutch heat transition. Both have clear advantages over alternative technologies, but at the same time have their own challenges.

Low-temperature geothermal heat

As yet, virtually no use has been made of LTG in the Netherlands, and in discussions on greening the country's heating systems it is a topic that is consistently ignored. As the analyses in this report show, however, this is misguided, for LTG can make a substantial contribution to a successful heat transition. In terms of technical potential and constraints, it can be implemented at numerous locations. Financially, too, it has interesting prospects, which can only improve as use of natural gas becomes increasingly discouraged in the Netherlands. LTG has a number of variants, of which horizontal directional drilling is the one presently being developed and rolled out in our country. In the near future the first practical results will be coming in.

Combining LTG with the Mijnwater concept greatly expands its potential, with the above-ground Minewater thermal exchange system reducing demand for geothermal heat, while the LTG resource is used as a buffer for Minewater surplusses. This has a positive impact on the 'useful life' of the LTG resource[19] and long-term security of delivery. The technical potential of LTG in the Netherlands amounts to 229 PJ per annum, sufficient to cover 37% of present heat demand in the Dutch built environment. In the heavily urbanized environment (where heat grids are most likely to be rolled out) 70% or more of heat demand could even be met by LTG.

Minewater

While the Minewater concept started out as the first LTG project in the built environment, today it can best be described as a smart thermal grid supplemented by large-scale thermal buffering. What were originally LTG sources have now become buffers and the core of the concept has shifted from underground to overground. It is now primarily a low-temperature, buffered heat exchange system. Now the subsurface is no longer seen as a source but as a buffer, this opens the way to thinking about the concept's potential outside the mining area where it was originally implemented. The present analysis shows the Minewater concept could meet a very substantial percentage of heat demand in the Dutch built environment, potentially serving 2.0 to 3.6 million homes. This figure could be even higher, if new, sustainable LT heat production is also added in the form of solar thermal and/or surface-water heat. The option of combining LTG and Minewater would also boost the contribution,

[19] It has no impact on calculated potentials, though, as these are annual potentials that make no allowance for whether or not the resource is depleted.

putting the number of homes up to around 3.5-4.5 million. If utility buildings in such areas are also supplied, in the Netherlands as a whole a Minewater-type system could potentially supply 85.7-159.5 PJ heat heat and 2.4-4.3 PJ cold (in relation to the current demand).

5.2 Conclusions

The following conclusions can be drawn in general terms and for LTA, Minewater and a combination of both.

5.2.1 General

- There are just a few parties in the Netherlands that are knowledgeable on the Minewater and LTG concepts. This report is the first (publicly available) analysis of these concepts, individually and combined, as technologies relevant for the heat transition in our country.
- There is very little experience with either technology: both have been rolled out at only a very small number of sites.
- Both concepts can potentially make a promising contribution to the heat transition in the Netherlands.
- Minewater and LTG are concrete examples of LT heat grids. The variants elaborated (LT heat supply and 70/40 grids) may potentially be the next steps in 'greening' current HT heat grids and the entire heat supply in the Dutch urban environment.

5.2.2 Low-temperature geothermal heat

- As yet, virtually no use has been made of shallow geothermal energy for space heating in the built environment in the Netherlands. The variant with horizontal filters (Horizontal Directional Drilling, HDD) has never been applied.
- The technical potential of LTG in the Netherlands amounts to 229 PJ per annum, which means it could cover 37% of present heat demand in the Dutch built environment. In the heavily urbanized environment (where heat grids are most likely to be rolled out) 70% or more of heat demand could even be met by LTG.
- HDD has various advantages over traditional vertical wells, the most important of which is that more heat can be recovered from thin geological formations.
- LTG can be used directly for LT heating or indirectly, with heat pumps. Business case analyses show that the latter option is currently financially most appealing. It also creates flexibility, since heat delivery via heat pumps reduces dependence on the production temperature of shallow geothermal sources.
- In the built environment the most interesting market are (existing) dwellings, characterized mainly by heat (rather than cold) demand. Other potential large-scale consumers of LT heat (approx. 40-70°C) include the greenhouse horticulture sector.
- LTG uses a multi-pipe heat-transport grid. Given the high cost of this kind of infrastructure, the most logical places to implement it are the relatively compact urban environment and greenhouse horticulture areas, where there is high heat demand.
- Compared with gas-fired heating systems, LTG systems reduce primary energy consumption and thus CO_2 emissions. As the share of renewables in the Dutch electricity mix increases, emission cuts from using LTG will rise yet further.
- While there are multiple geological sediments from which LTG can be recovered, these are not present throughout the country. This means LTG is available at many, but not all, locations.
- There are major areas in the Netherlands with potential for LTG where there is little or no scope for 'conventional' geothermal.

- At present there is little if any use of the sediments suitable for LTG (aquifer thermal energy storage (ATES) is shallower, geothermal/oil/gas are deeper). This means little interaction with other interests (strength), but also a relative paucity of data (weakness).
- Although current legislation is not a direct impediment to further development and large-scale roll-out of LTG, the current 500 metre transition point between the Water Act and Mining Act is an issue that needs to be reviewed.
- LTG currently presents Dutch industry with major opportunities for innovation, particularly in the field of heat pumps, resource output, buffering and heat-transport infrastructure.
- As yet, no positive business case can be made for LTG use in existing homes. This would require a one-off connection subsidy of about € 2,000-4,000 per dwelling. It should be noted, though, that the business case is still far from unambiguous, precluding a robust picture at present.
- A key area of uncertainty is the suitability of today's building stock for low-temperature space heating. Required expenditures on building-side modification are very dependent on the initial situation (good or poor envelope quality) and the balance opted for between insulation and delivery temperature.
- Use of a low-temperature heat grid (20-40°C input) means low-temperature heat sources like LTG can be fed in. An added benefit is that an LT heat grid is relatively low-cost.
- LTG can be excellently combined with a Minewater-type system in areas where heat heat demand exceeds local availability of waste heat and there is LTG capacity at hand. This means the combination can be rolled out in phases — a major strength, given the complexity of implementing large-scale heat projects.

5.2.3 Minewater

- Minewater (MW) is a smart thermal grid designed for exchanging heat and cold among connected parties, with thermal buffering in underground or artificial buffers an integral part of the concept. In its current and sole implementation, in Heerlen, disused mines are used as a geothermal buffer.
- In the Netherlands as a whole, MW-type systes could potentially supply 85.7-159.5 PJ heat and 2.4-4.3 PJ cold, thus delivering climate-neutral heat and cold to around 2.0-3.6 million buildings.
- MW is a flexible concept that can rolled out in a very wide range of situations.
- MW brings together numerous technologies not innovative in themselves, but creating a unique, innovative concept through their combination and through integrated process control.
- MW is currently implemented in utility buildings and newbuild dwellings, but there is also scope for roll-out in existing homes, the technical and financial parameters of which are currently being elaborated.
- Implementation in current building stock requires building-side modifications, primarily in heat-delivery systems, but also to a limited extent in the building envelope. The more the envelope is improved, though, the greater the building's energy efficiency, while the financial optimum does not necessarily coincide with maximum savings.
- Its flexibility and broad scope for implementation makes MW a complex concept that can be rolled out in a wide range of variants. Translating these to a limited number of unambiguous reference systems will be a challenge.
- A Minewater-type system can be implemented at numerous locations in the Netherlands; the presence of mines is not a prerequisite. Implementation is optimized, though, if there is demand for both heat and cold in the area concerned and/or a source

of LT waste heat. The options are increased and system control improved if there is scope for large-scale thermal buffering, whether underground or in tanks.
- MW uses a multi-pipe grid for transporting heat and cold. Given the high cost of this kind of infrastructure, the most logical place to implement such systems is the urban environment.
- At present a positive business case can be made only for utility buildings and newbuild dwellings. In existing homes, today's low prices for gas heating and the terms of the Heating Supply Act are a barrier to large-scale roll-out. Work is underway on propositions that factor these issues in.
- As the price tag on the reference (gas heating) rises, as it is set to do in the years ahead, MW will become a financially attractive concept in existing housing stock, too.
- MW currently presents Dutch industry with major opportunities for innovation, particularly with respect to automated optimization of thermal flows and storage management as well as in terms of business models.

5.2.4 Synthesis

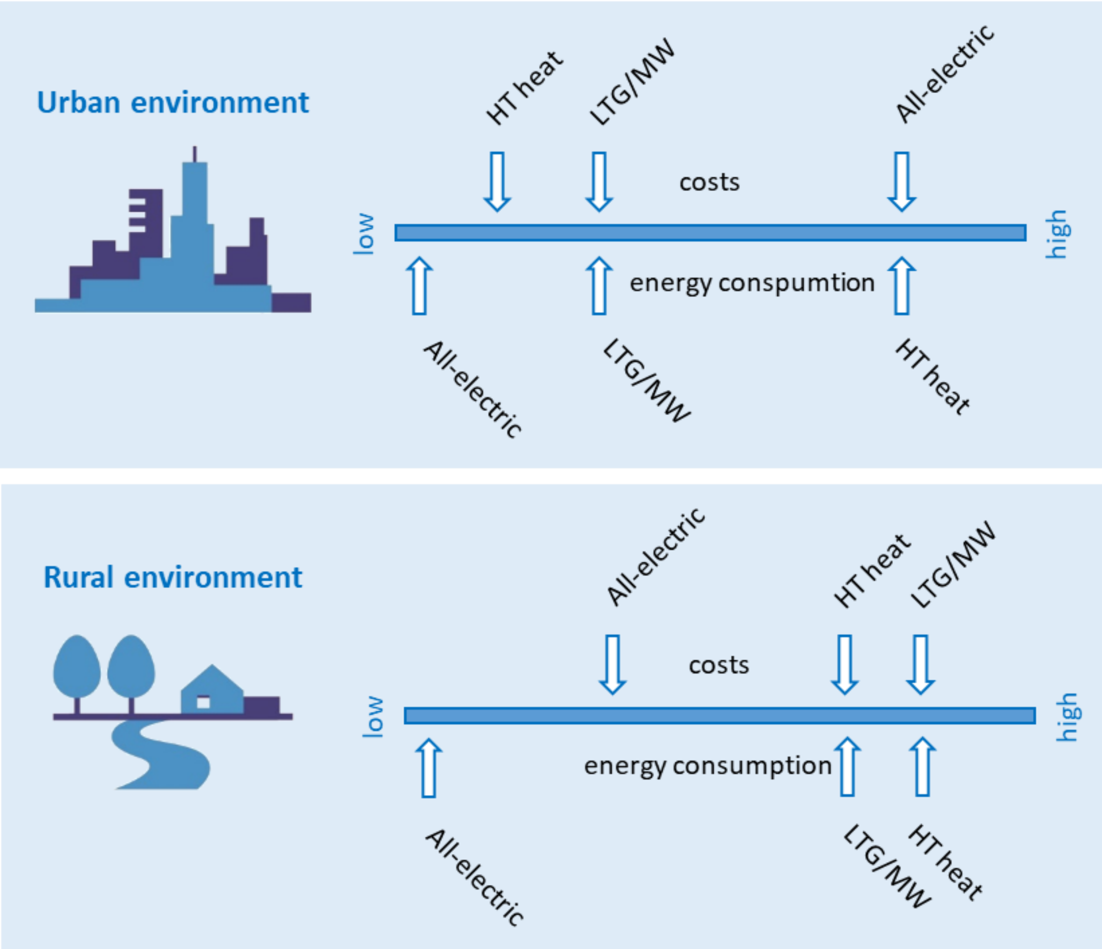
- MW and LTG can be excellently combined, with LTG serving as source or buffer for MW, or both.
- It would seem feasible to develop the concepts independently, for combination at a later stage. At the same time they can be simultaneously developed in certain projects, permitting direct synergy gains.
- LTG can complement the MW concept at locations where there are insufficient surface thermal sources for adequate inter-building exchange. By tacking on LTG, MW can be rolled out in more Dutch neighbourhoods, an estimated 3,500-4,150 in all.
- The combined potential of MW+LTG in the Netherlands is 171-277 PJ heat and 4.4-5.8 PJ cold, which means around 3.5-4.5 million homes can be supplied with climate-neutral heat and cold.
- MW can also complement stand-alone LTG, as above-ground optimization reduces the demand that needs to be met by geothermal, thus extending the lifetime of the LTG resource. At the same time the MW system can regenerate the resource, by transferring heat surplusses there. This has no impact on calculated potentials, as there is no way of factoring source lifetime or need for regeneration into these calculations.

5.2.5 Status of LT heat grids in the heat transition

LTG and MW are both variations on the theme of low-temperature heat grids, differing as follows from alternative climate-neutral heating technologies:
- Compared with traditional HT heat grids employing waste heat or deep geothermal heat, an LT system based on LTG and/or Minewater can be deployed at many more locations, because there are vastly more LT heat sources and they are distributed throughout the country. In energy terms LT systems are more efficient than HT systems, with less distribution losses, limited need for building-envelope improvements and higher-efficiency conversion for space heating and tap water. LT systems are more expensive, though. Although the grid itself costs slightly less than an HT grid, LT systems also require heat pumps as well as limited modifications to buildings.
- There is less geographical scope for rolling out LT grids than there is for all-electric solutions, i.e. heating methods that require no heating infrastructure at all, which means they can be deployed in thinly populated areas, too. At the system level there is very little difference in energetic efficiency between the two approaches. Per dwelling the LT infrastructure costs less, because of the required expenditure on building alterations for all-electric.

Figure 41 provides a *rough indication* of the relative appeal of the various options, according to the parameters of ‘cost’ and ‘energy consumption’. In practice the relative performance will differ from district to district and neighbourhood to neighbourhood, depending on local conditions.

Figure 41 - Rough indication of relative appeal of zero-gas heating technologies



5.3 Recommendations

Based on the results of the present study the following recommendations are made:

General recommendations

- Bring LTG and Minewater to the attention of potential end-users and intermediaries via relevant media and have these options included in the various publically available databases. Inclusion in the RVO Heat Atlas is a possible starting point to this end.
- With both options there is a ‘chicken-and-egg problem’: what comes first, connecting homes or developing resources? A strategic choice needs to be made on this issue. The small-scale nature of the two concepts is of advantage in this context.
- Make a detailed comparison of the costs of LT and HT heat *infrastructure*.

- Conduct additional research on how existing buildings can be primed for LT heating (heat delivery systems, envelope improvement, hot tap-water provision, etc.). This aspect applies to all 'green' heating systems and is not specific to the LTG or Minewater concept.
- For a 100% sustainable heating system it is very important that peak heat demand is not much higher than average winter demand. Among other things, this means the share of the back-up/peak-load system (generally gas-fired) in the total supply is minimized, with maximum heat being derived from the main, sustainable source. The technical means of achieving this cost-effectively is an issue that needs researching and then demonstrating. Potential options include distributed storage and temporarily stopping night-time temperature reduction.

Recommendations on LTG

- In this study the potential of LTG has been calculated based on the thickness and temperature of sandy sediments. For the economics, though, the sediments' permeability is also of key importance, so this parameter needs to be better mapped.
- A national-scale map does not suffice for establishing local potential. It is therefore recommended (for decision-making at municipal level, for example) to map LTG potential (including permeability) in greater detail in a number of areas on a regional/municipal scale, prioritizing areas where there is a demand for heat but few alternative heat sources like deep geothermal or waste heat.
- Given the status of LTG technical development, it is recommended to set up more demonstration projects in a variety of surface and subsurface situations.
- There is substantial LTG potential between ground level and 500 m deep, depths having the great advantage that cheaper drilling methods can be used and smaller-scale projects are feasible. The downside, though, is that these depths rule out eligibility for subsidies under the SDE+ scheme. We therefore recommend extending the scope of this scheme to include shallower depths, preferably up to and including grade level, but if this is unfeasible in connection with the present ATES market, then from a depth of around 250 m (below which there is virtually no ATES).

Recommendations on the Minewater concept

- Roll out of the Minewater concept on a wider scale requires a better understanding of the potential of low-temperature heat sources in the Netherlands: number, location, volume, capacity, profile, etc. There are still many gaps in the picture that need to be filled in.
- At present, the terms of the Heating Supply Act mean the innovative Minewater business case can only be implemented for large-scale users. It is therefore recommended that this legislation be revised so this innovative business case can also be used for small-scale consumers.
- For a thorough analysis of the match between thermal demand and LT heat supply and implied buffering requirements, it is essential to build up a detailed picture of the demand profiles of heat and cold consumers (both homes and utility buildings). Only when this has been done can it be assessed how many sources and how much buffering are needed to meet heat and cold demand.
- Besides the example of Minewater in Heerlen, in the Netherlands there are only a very limited number of other demonstration projects involving higher-temperature buffering in the deeper subsurface environment. Our knowledge about these issues therefore also needs to be improved, whether by further analysis of the limited number of existing systems or by establishing new demonstration projects.

- The scope for combining large-scale solar-thermal and/or aquathermal systems with LTG and/or Minewater needs to be investigated, on the one hand as a heat source for Minewater-type projects, on the other for regeneration of LTG.

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A Specifications of Mijnwater Heerlen

A.1 Geothermal buffers

Table 27 provides a synopsis of the capacity, energy output and other parameters of the various geothermal heat and cold sources/buffers (wells) in the Heerlen project rolled out by Mijnwater B.V.

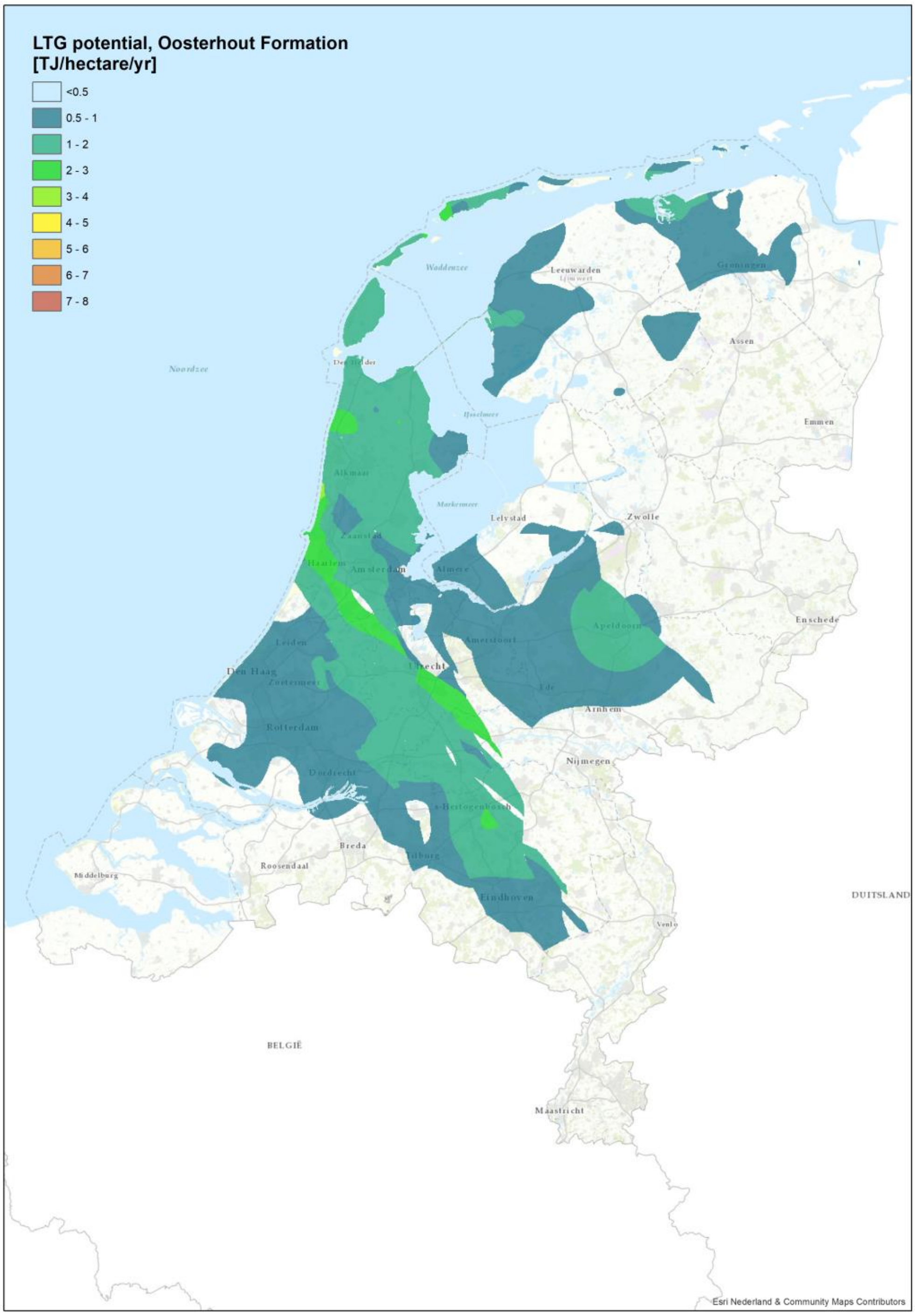
Table 27 – Capacity and energy output of Heerlen wells

Type	Direction (in 2017)	Hydraulic capacity (m^3/h)		Capacity (approx., MW)		Full-load hours (h)		Output (TJ)	
		Actual	Potential	Actual	Potential	2014	2015	2014	2015
Hot well 1	Bidirectional	120	180	2	3	580	1,200		
Hot well 2	Bidirectional	120	180	2	3	580	1,200		
Hot back-up	Bidirectional	0	360	0	6				
Total hot		240	720	4	12			4.2	8.8
Cold well 1	Bidirectional	240	360	4	6	420	480		
Cold well 2	Bidirectional	240	360	4	6	420	480		
Total cold		480	720	8	12			6.0	6.9

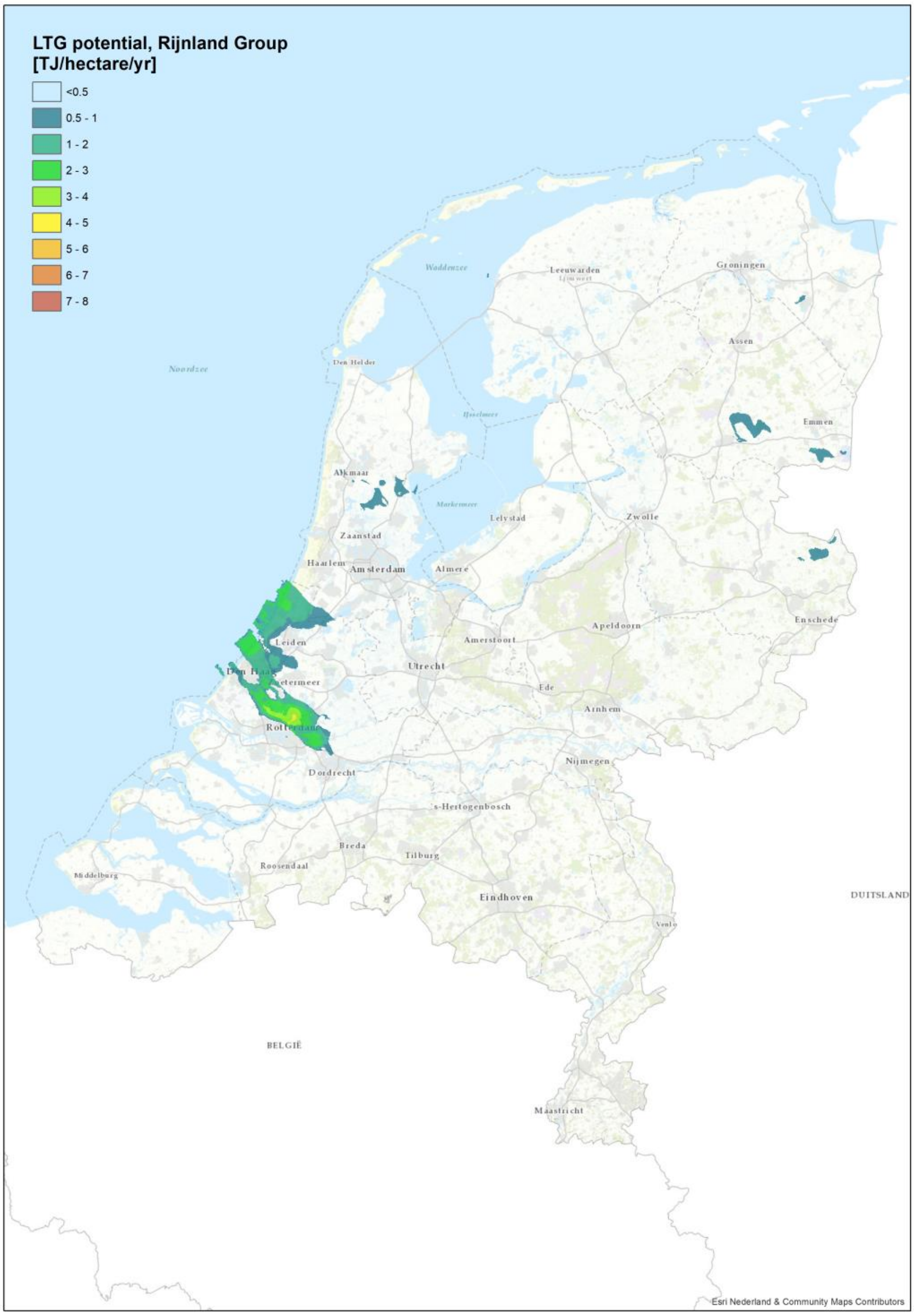
Source: Data supplied by Mijnwater B.V.

B LTG potential maps

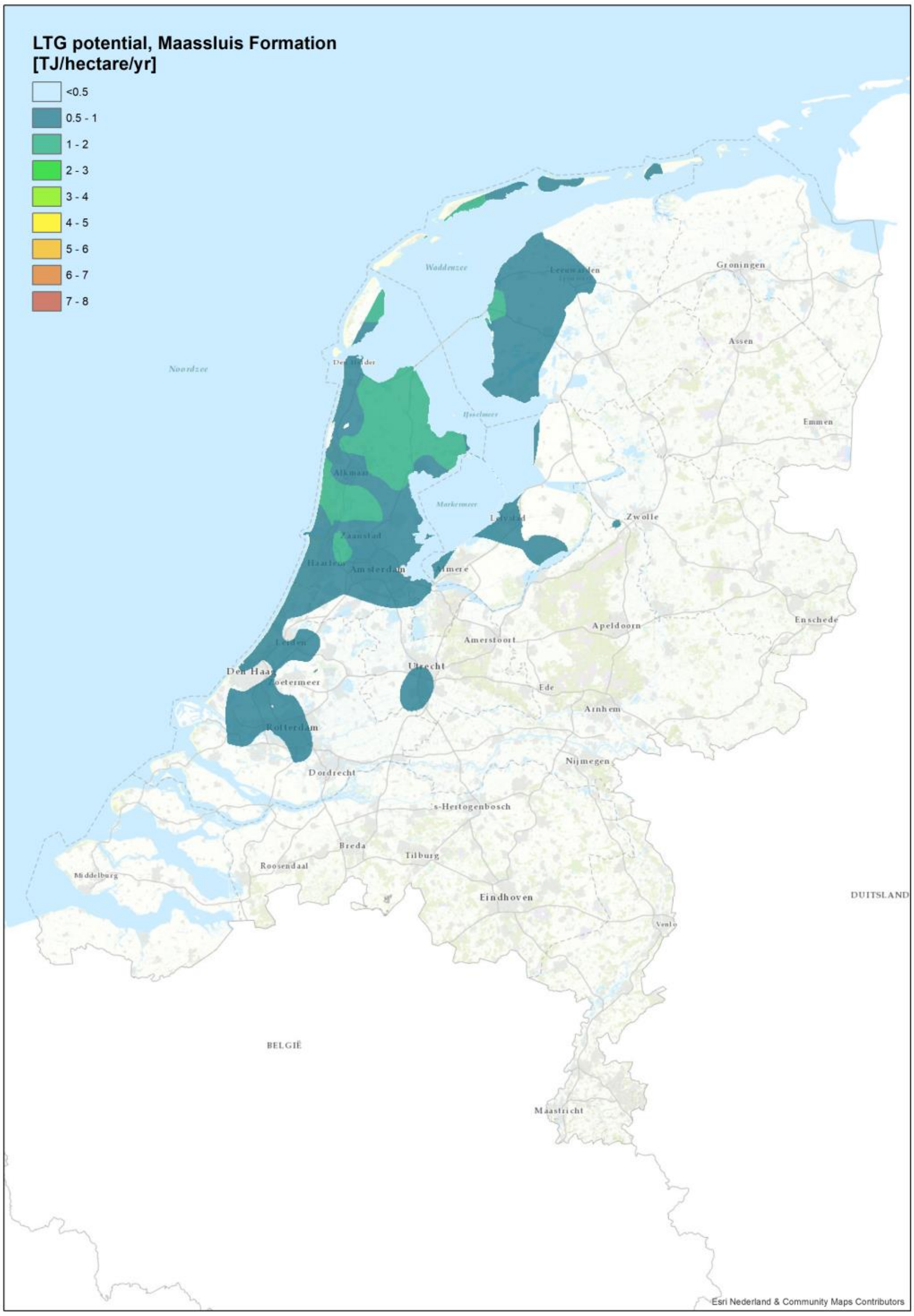
B.1 Oosterhout Formation



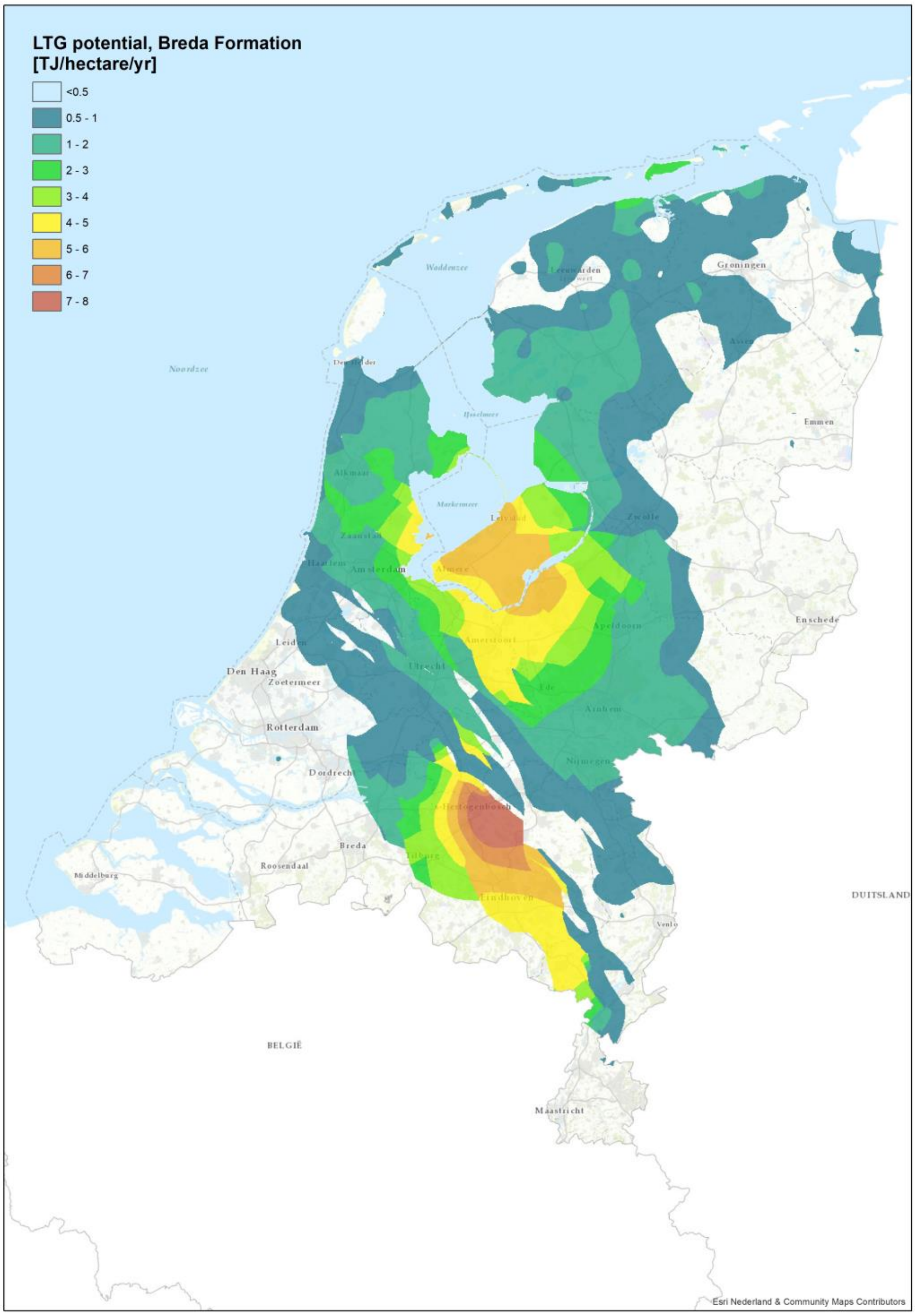
B.2 Rijnland Group



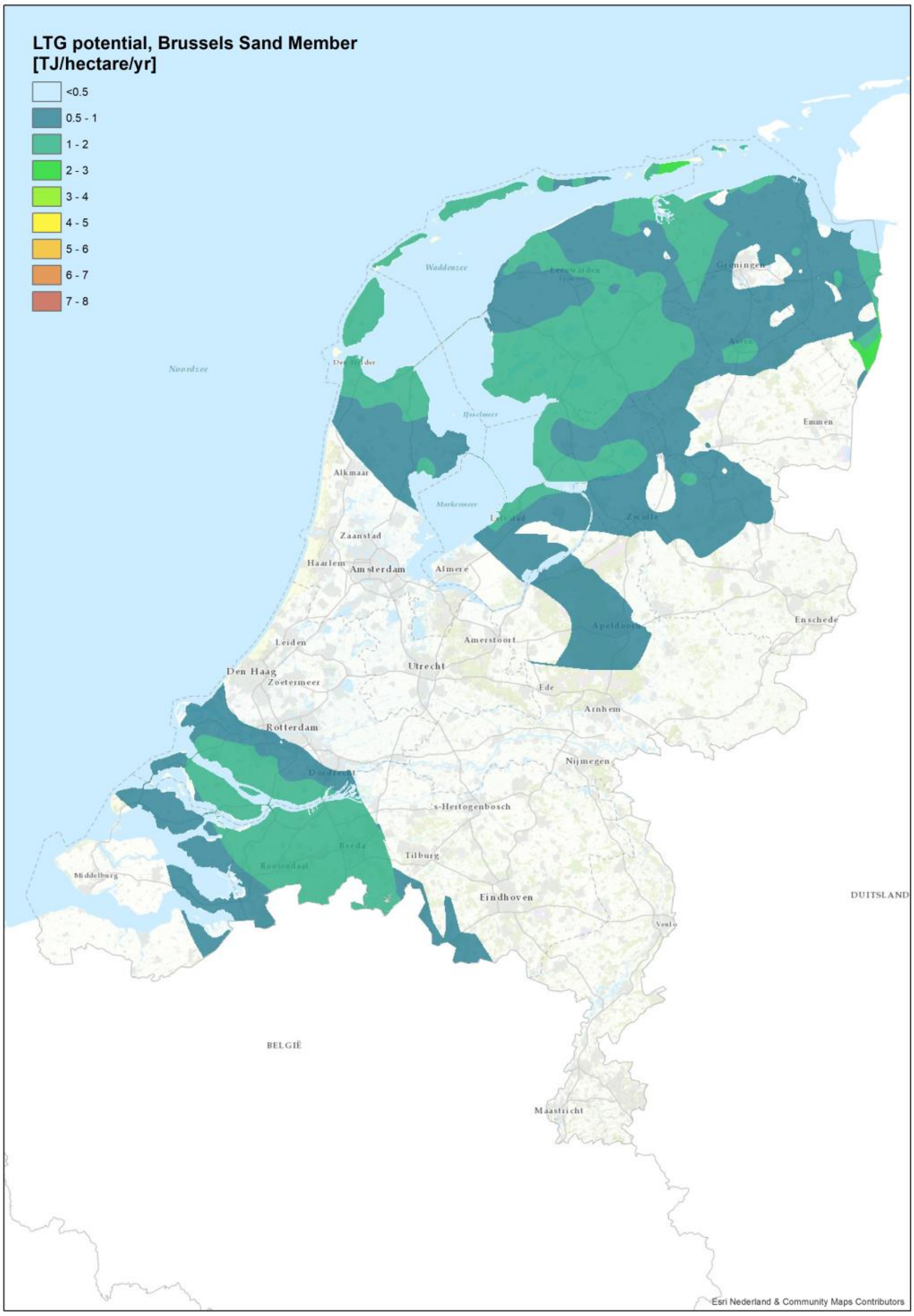
B.3 Maassluis Formation



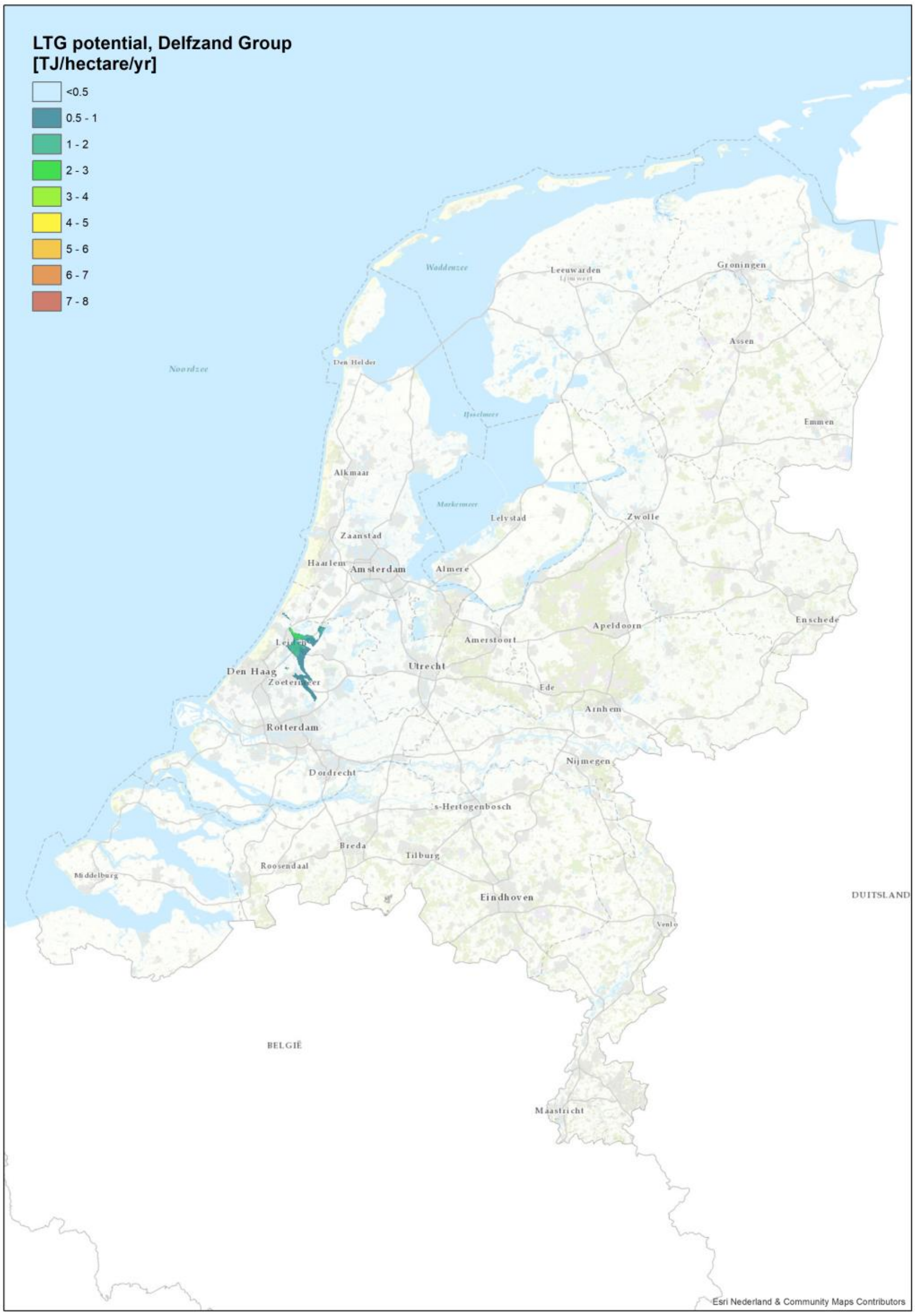
B.4 Breda Formation



B.5 Brussels Sand Member



B.6 Delfzand Group



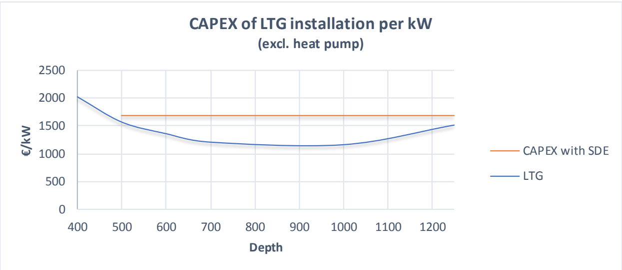
C Estimated cost of LTG doublet

Basic parameters (assumed)							
Depth	**m BGS**	**400**	**500**	**600**	**700**	**1000**	**1250**
Horizontal screen path	m	500	500	500	500	500	500
Drilling length per well	m	1100	1200	1300	1500	1700	2000
Drilling costs	€/m	2500	2400	2300	2300	2400	2850
Production temperature	°C	19	23	26	31	40	49
Injection temperature	°C	8	8	8	8	8	8
Flow rate	m^3/h	300	300	300	300	300	250
Capacity (source side)	MW	3.8	5.2	6.3	8.0	11.1	11.9

CAPEX, LTG doublet (all figures excl. VAT and +/- 10%)							
Depth	**m BGS**	**400**	**500**	**600**	**700**	**1000**	**1250**
Doublet design and execution	€	5,500,000	5,760,000	5,980,000	6,900,000	8,160,000	11,400,000
Liner hanger (2x)	€	100,000	150,000	150,000	150,000	300,000	300,000
Heat exchanger and submerged-pump power unit & certiQ meas.	€	175,000	239,000	287,000	366,000	510,000	544,000
Submerged pump	€	125,000	125,000	125,000	125,000	175,000	200,000
Power connection, cabling	€	50,000	75,000	100,000	125,000	150,000	200,000
Risk-management measures (for analysed known risks)	€	250,000	250,000	250,000	250,000	250,000	250,000
Process control	€	105,000	105,000	105,000	105,000	105,000	105,000
Site, BARMM (mining regulations), access	€	200,000	200,000	200,000	200,000	200,000	200,000
Energy & other variable costs (saline discharge) in drilling phase	€	200,000	219,000	237,000	273,000	310,000	364,000
Blow-out preventer (BOP), diverter	€					200,000	300,000
Degassing plant (provisional)	€					500,000	500,000
Other operating expenditures	€	200,000	200,000	200,000	200,000	200,000	200,000
Contingencies for wells >1,000 m BGS	€					700,000	1,900,000
Project management, SDE, permits	€	200,000	200,000	200,000	200,000	250,000	300,000
Insurance	€	280,000	300,000	310,000	360,000	480,000	670,000
Flow control, measures, clean-out	€	354,000	386,000	415,000	475,000	537,000	626,000
Total CAPEX (excl. heat pump)	**€**	**7,739,000**	**8,209,000**	**8,559,000**	**9,279,000**	**13,027,000**	**18,059,000**
CAPEX per KW	€/kW	**2,022**	**1,573**	**1,366**	**1,216**	**1,170**	**1,519**

Remarks:

- All figures excl. VAT.
- Costs excl. buffers, grid, control building, zoning plan costs.
- Filter spacing underground assumed 1,000 m.
- Conductor to 75 m depth assumed.
- Reference CAPEX with SDE for geothermal based on SDE 2017.
- Permeability and therefore capacity may vary per formation.



Operation & Maintenance (all figures +/- 20%)							
Depth	**m BGS**	**400**	**500**	**600**	**700**	**1000**	**1250**
Maintenance	€/yr	60,000	60,000	60,000	75,000	140,000	190,000
Operator staffing	€/yr	40,000	40,000	40,000	40,000	40,000	40,000
Administrative costs	€/yr	10,000	10,000	10,000	10,000	10,000	10,000
Monitoring system/telephone	€/yr	20,000	20,000	20,000	20,000	20,000	20,000
Insurance	€/yr	10,000	10,000	10,000	10,000	10,000	10,000
Spare parts	€/yr	15,000	15,000	15,000	15,000	15,000	15,000
Waste-disposal costs	€/yr	5,000	5,000	5,000	5,000	5,000	5,000
Contingencies	€/yr	10,000	10,000	10,000	10,000	10,000	10,000
Total Operation & Maintenance	**€/yr**	**170,000**	**170,000**	**170,000**	**170,000**	**250,000**	**300,000**

D Alternative heating concepts

D.1 Introduction

This chapter provides a brief description of alternative heating concepts that are competitive with the Minewater concept and low-temperature geothermal or could supplement it. These include both centralized and distributed options.

D.2 District heating with (fossil) waste heat

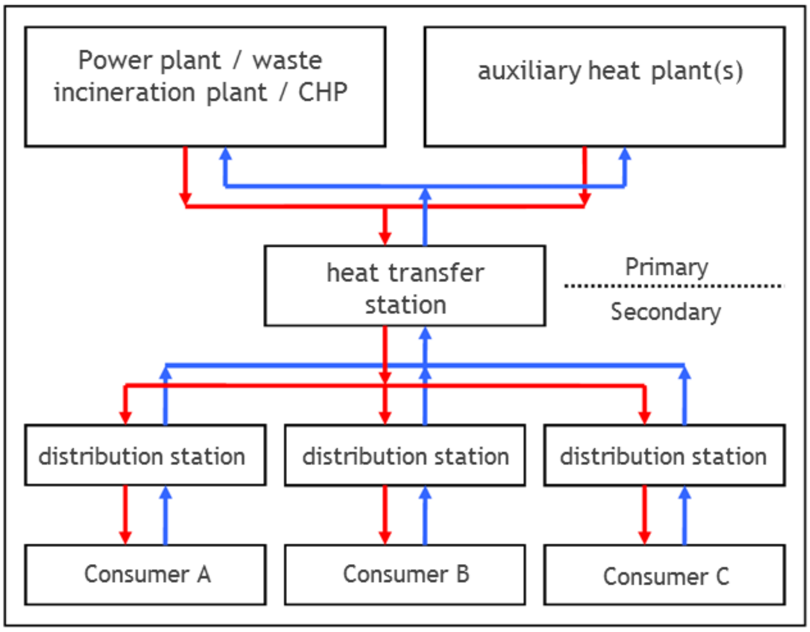
Characteristics:
- collective HT heat distribution ('district heating'); no building modifications required;
- waste heat supplied by one or very few sources;
- peak demand generally met by auxiliary boilers;
- waste heat use is energy-efficient, but generally fossil-sourced;
- supply-driven, very limited storage, no cold.

Most of the heat grids currently in service in the Netherlands use (fossil-derived) waste heat at a high temperature (approx. 90°C input) for supply-driven distribution to homes and businesses in built-up areas. The waste heat can come from a variety of sources: the ten biggest, accounting for 95% of the heat market, are biomass-fired boilers, aquifer thermal energy storage (ATES), waste heat from domestic refuse incinerators, industrial waste heat, fossil-fired cogeneration plant and boilers, geothermal and biomasss/biogas-fired cogeneration plant (Eneco, Ennatuurlijk, Eteck, HVC, NUON & SVP, 2017). For peak demand and security of delivery, back-up combustion plant is generally available for extra heat when there is a shortfall from the primary source. Figure 42 gives a schematic view of a typical large-scale district heating system.

Because of the high return temperature (≥ 50°C), the return line cannot be used directly for cooling. Conventional district heating grids therefore provide only heat, with any cold requirements being met in individual buildings by conventional means.

Given the high-temperature of the heat, any building can in principle be hooked up without the need for additional in-building measures. Table 28 summarizes the salient differences between high- and low-temperature heating. LT heat sources are far more widely available than HT waste heat sources.

Figure 42 - Basic structure of a typical large-scale district heating grid



Source: (CE Delft, 2009).

Table 28 - Salient differences between LT and HT heating

	High-temperature heat	Low-temperature heat
Input temperature	80-90°C	25-55°C
Heating system	CH boiler, conventional heat grid ('district heating')	HCS, LT heat grid, heat pump
Thermal delivery system	Radiator, convectors, possibly after temperature reduction; also underfloor/wall heating and via air feed	Underfloor/wall heating, LT radiators/convectors, radiating elements and via air feed
Building characteristics	Suitable for all buildings, but the better insulated the lower the heat demand for the same level of comfort	Reasonably to well insulated buildings and modified delivery system; LT delivery systems create a healthier indoor climate than HT radiators (RVO, 2001)

Suitable locations for district heating systems need to meet two requirements: a high density of buildings (where heat demand is consequently high) and a (waste) heat source in the vicinity that can supply sufficient heat at the temperature needed. These are generally urban areas. Figure 43 shows the Dutch municipalities where large-scale (waste) heat grids with over 2,000 connections have already been implemented or are planned (to our knowledge). Figure 44 shows the location of current potential industrial waste heat sources (CE Delft, 2016).

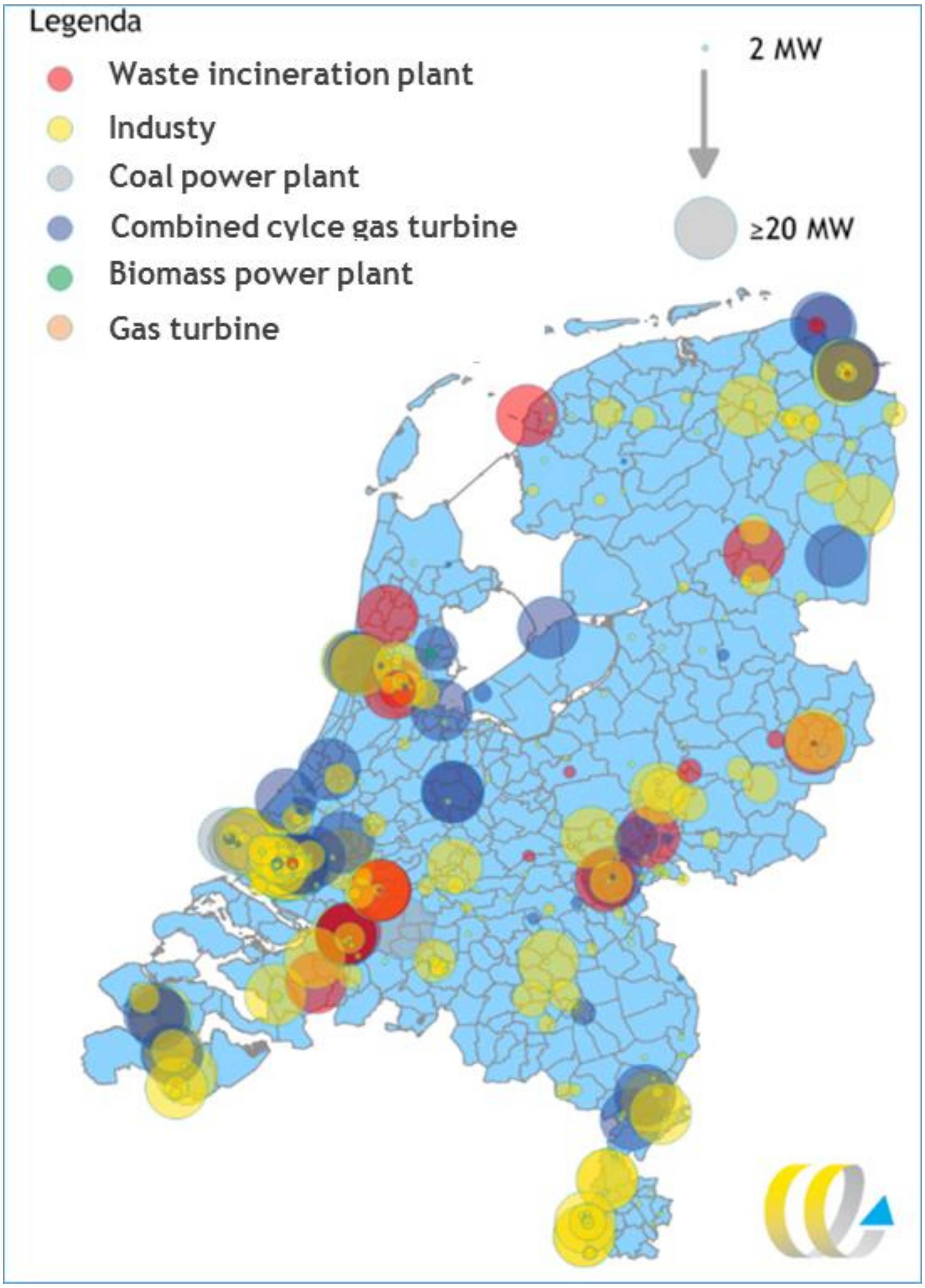
The heat sector itself anticipates that by 2050 geothermal will be the main source for district heating (Eneco, Ennatuurlijk, Eteck, HVC, NUON & SVP, 2017). A the end of 2016 CE Delft published a study in which the lowest-cost climate-neutral domestic heating system in 2050 was identified for each individual neighbourhood in the country (CE Delft, 2016). This study indicates that in 2050 grid-distributed waste heat can potentially supply 1.3 million homes (60 PJ heat demand), compared with 0.3 million homes in 2012; see

Figure 45. It should be noted that in a climate-neutral 2050 not all today’s waste heat sources will still be available, with heat from coal-fired plant particularly uncertain.

Figure 43 - Present and future large-scale (waste) heat grids and primary source (> 2.000 connections)

Source: (CE Delft, 2016).

Figure 44 – Location of potential sources of industrial waste heat

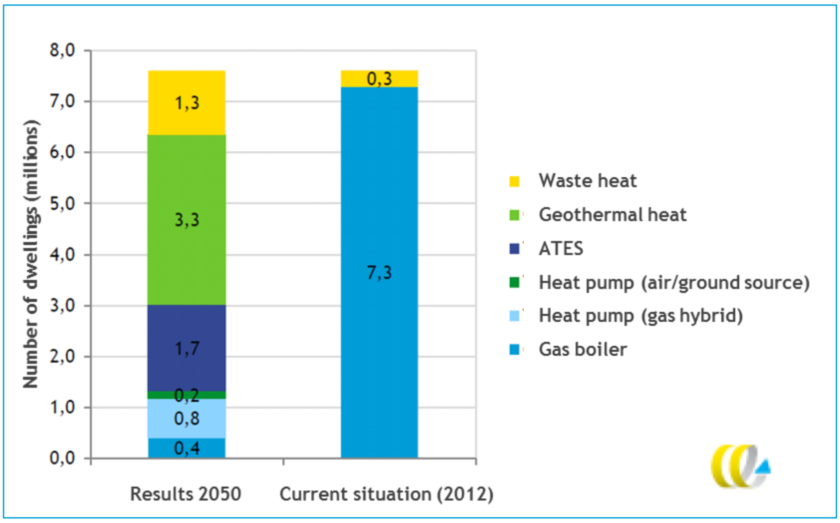


Source: (CE Delft, 2016).

Utilization of industrial waste heat does not count as 'renewable', nor as a reduction of final energy consumption and is therefore not taken as contributing to the targets laid down in the National Energy Agreement. There are at present no statutory provisions that encourage use of this category of waste heat (PBL, 2017).

A heat grid's environmental footprint depends on how the heat is sourced. Transport of high-temperature heat involves relatively high transport losses of around 25% (CE Delft, 2016). Because of these transport losses, the consumption of auxiliary power and (almost inevitably) gas-fired back-up, even 'sustainable' heat sources have CO_2 emissions. In Table 29 the CO_2 emissions of grids using various heat sources are compared with those of a gas-fired high-efficiency boiler (in the individual home).

Figure 45 - Number of dwellings per technology; 2050 versus present situation (2012)



Source: (CE Delft, 2016).

Table 29 - Total emissions of heating chain per GJ heat delivered (kg/GJ_{th}) for selected heat sources compared with heat from gas-fired HE boiler (situation in 2015)

(emissions in kg CO_2-eq./GJ_{th})	CCGT	Waste inciner.	Geo-thermal	Biomass (Dutch, wood chips)	Biomass (Canadian, pellets)	Waste heat	Reference: HE boiler
Indirect emissions	**3.4**	**3.4**	**1.6**	**10.5**	**18.9**	**0.9**	**3.7**
– Gas recovery	0.6	0.6	0.6	0.6	0.6	0.6	0.6
– Gas transport	0.1	0.1	0.1	0.1	0.1	0.1	0.1
– Biomass production				6.7	13.4		
– Biomass transport				2.9	4.6		
– Power consumption	0.1	0.1	0.9	0.1	0.1	0.1	0.4
– Power loss	2.5	2.5					
Direct emissions	**32.5**	**23.1**	**23.4**	**15.3**	**15.3**	**20.6**	**62.7**
– Conversion, main source (80%)	14.6	6.6	6.9	0.0	0.0	4.5	57.7
– Conversion, aux. source (20%)	12.0	12.0	12.0	12.0	12.0	12.0	
– Transport losses	4.7	3.3	3.3	2.1	2.1	2.9	
– Auxiliary power	1.2	1.2	1.2	1.2	1.2	1.2	5.0
Total	**36.0**	**26.5**	**25.1**	**25.8**	**34.2**	**21.5**	**66.4**
Savings rel. to reference	**46%**	**60%**	**62%**	**61%**	**48%**	**68%**	

Source: (CE Delft, 2016); 'indirect emissions' are those occurring upstream, i.e. from fuel recovery to heat source utilization.

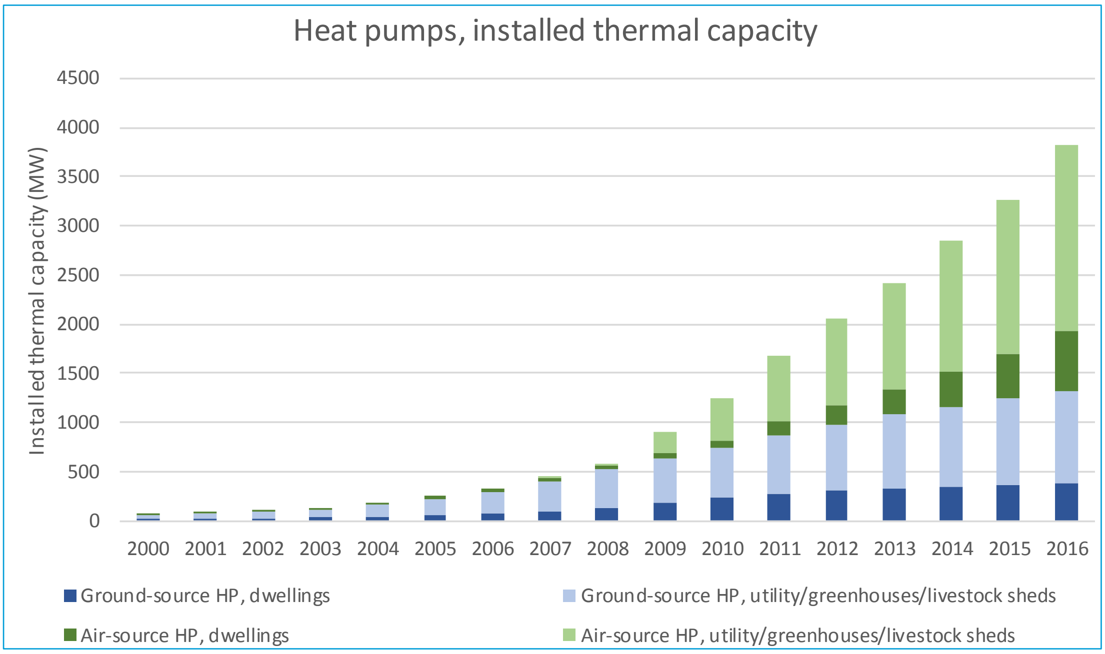
D.3 All-electric with individual heat pumps

Homes and other buildings can be effectively heated with electrically powered heat pumps (HP), obviating the need for connection to the gas grid. The HP used in the built environment generally fall into one of four categories:

- centralized, combined with ATES for district-level heat supply (district heating grid);
- individual, connected to a centralized ATES system (source-heat grid);
- individual, provided with a specific ATES system at dwelling/building level (open source or closed-loop);
- individual, with (ambient) air as heat source at dwelling/building level, consisting of air/water and air/air heat pumps.

In the Netherlands HP are being increasingly used to heat both homes and utility buildings. Figure 46 shows the growth in installed capacity (based on CBS data), broken down by soil- versus air-source HP and dwellings versus utility buildings, greenhouses and livestock sheds.

Figure 46 - Trend in installed thermal capacity of heat pumps in the Netherlands



Source: CBS 2017

As the graph shows, there has been rapid growth in total installed HP capacity in recent years.

Heat pumps fulfilan excellent role in the transition to zero-gas housing estates. They also play a key part in the LTG and Minewater concepts, where low-grade heat is recovered/exchanged from a collective system and centralized and/or distributed HP are generally used to boost the heat to the desired temperature. Use of these concepts requires collectivity/scale.

This stands in contrast to use of individual HP, where each home or utility building has its own dedicated ground-source or air/water-source unit.

It is above all air/water-source HP that are promoted by the plumbing sector as a sustainable alternative for gas boilers in the renovation market. These can be readily combined with locally sourced renewable power to create a sustainable or even energy-neutral heating system. This variety
draws in air from outside the building, heats it up and feeds it into the domestic heat-delivery system. Heating efficiency depends on the temperature of the outside air: the cooler it is, the lower the efficiency. It consts of an outdoor and indoor unit. The outdoor unit comprises a fan to draw in heat from the outside air and a heat exchanger that transfers the heat to a cooling agent, which the indoor unit then transfers to the home heating system and to the boiler for warm tap water.

Figure 47 – Air/water-source heat pump

There are also HP models on the market that can deliver both heat and cold. This cold supply is permanently available, with power consumption similar to that of a conventional aircon unit.

Compared with low-temperature geothermal, air/water-source heat pumps have several drawbacks:
- Outdoor units can be installed on the ground, on roofs or on building faces. In newbuild there is scope for integrating them in the architecture itself, but in existing buildings local circumstances must be duly allowed for, and they may be an eyesore in the neighbourhood or estate.
- Noise production needs to be considered. Although the fans in the outdoor units are designed to be relatively quiet, the noise they produce may still be perceived as a nuisance, particularly at night. This effect may be aggravated with large-scale HP use in the built environment and may induce resistance on the part of residents.
- At very low ambient temperatures (heavy frost) the efficiency of an air/water-source HP drops so low that it needs a great deal of electrical power, thus putting a substantial burden on the grid. With large-scale use of this type of HP the local power grid therefore needs to be ramped up.

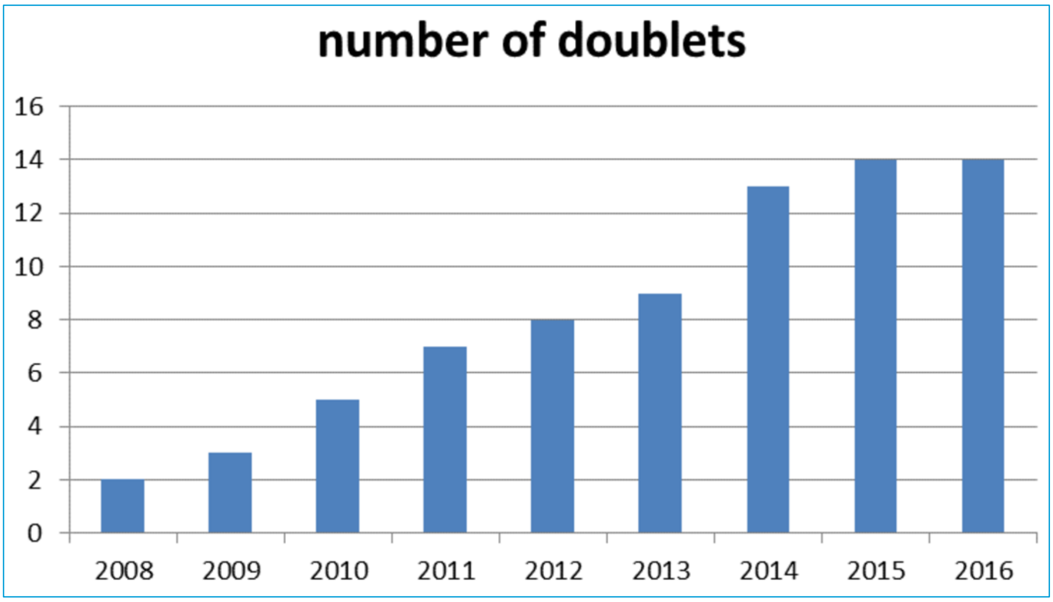
Figure 48 – Examples of outdoor unit installation

Air/water-source HP also have several advantages over low-temperature geothermal:
- individual all-electric application, i.e. independent of external heat supply;
- relative ease of installation and large-scale, phased implementation in the natural replacement cycle of existing heating plant, with no prior investments required.

D.4 Deep geothermal (> 1,250 m)

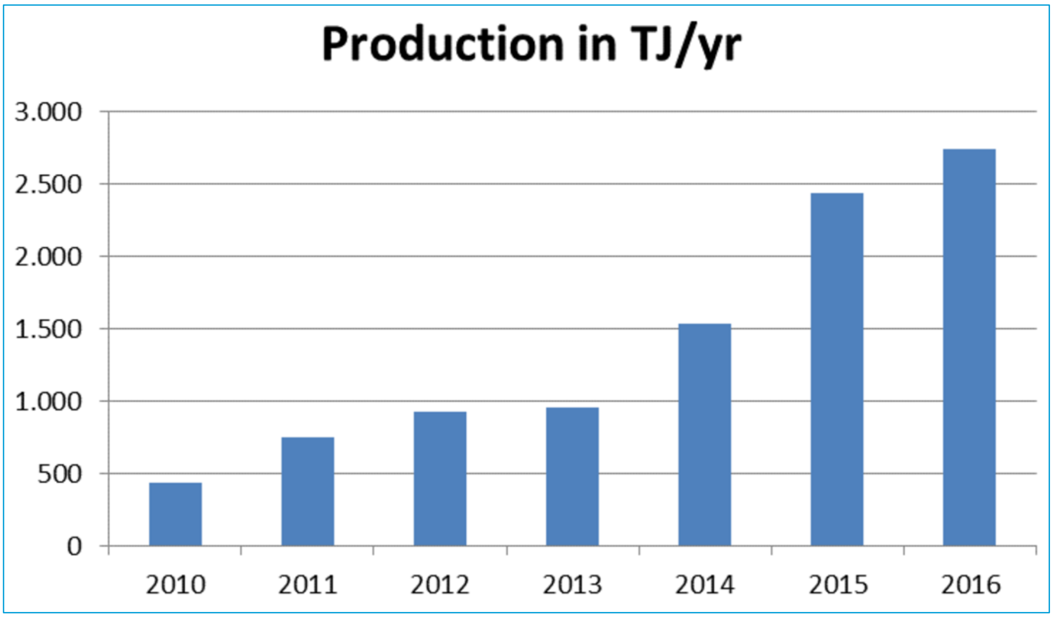
The 'conventional' deep geothermal market is developing apace, as is amply illustrated in the following two figures showing trends in the Netherlands over the past decade:

Figure 49 – Trend in number of geothermal doublets in the Netherlands



Source: Platform Geothermie.

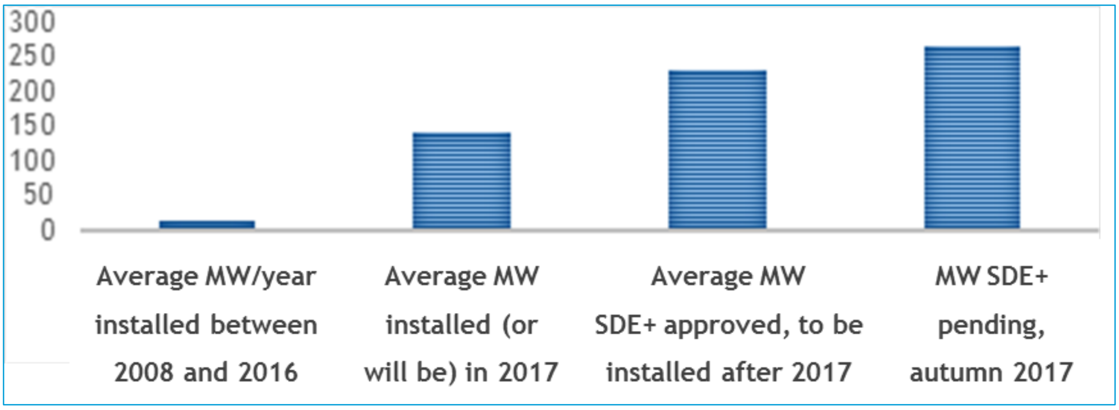
Figure 50 - Trend in geothermal output in the Netherlands (TJ/yr)



Source: Platform Geothermie.

This trend is expected to continue in the years ahead, based on approved and pending SDE+ subsidies and on new applications for exploration licenses.

Figure 51 - Recent and near-future trends in installed, approved and pending SDE+ budget-geothermal (MW_{th} capacity)



SDE+ applications may only be filed for projects that have received an exploration license. Figure 52 reproduces a map (from NLOG.nl) showing the location of such SDE+ applications (status per 21-11-2017).

Figure 52 – Sites where geothermal exploration licenses have been granted (green) or are pending (green-hatched) and ditto recovery licenses (purple, purple-hatched respectively)

Source: NLOG.

Given the large number of licensing applications still pending, installed capacity looks set to increase still further. Most of the SDE+ applications are thought to be for 'deep' geothermal. Among the projects already approved there is just one for low-temperature geothermal: at Zevenbergen.

Despite the rapid growth of the geothermal market, there are also problems. The following stand out:

- The State Supervision of Mines (SodM) has published a critical 'status report' on the geothermal sector, recommending better integration of safety and environment issues in operating procedures.
- The technical problems encountered in projects (e.g. casing corrosion, scaling, clogging) lead to relatively high operating costs and low operational reliability and in some projects follow-on investments are required for well repair and/or replacement.
- With the 'Warmtestad' project (in Groningen province, where decades of gas mining has caused subsidence and damage to homes) a public debate has arisen about risks associated with seismic activity and the technical expertise required of the operator.

These problems may affect public perceptions of geothermal energy, as well as initiator and investor attitudes, adversely impacting its development. In a recent position paper Minister Wiebes announced his intention to take action to steer the process in the right direction (Rijksoverheid, 2018).

Besides the cited technical problems, there are also several financial and organizational issues affecting development of geothermal (IF Technology, 2016a):

- The SDE+ subsidy scheme is not (yet) well-attuned to geothermal in the built environment, one of the reasons almost all projects to date are in greenhouse horticulture.
- Deep ('conventional') geothermal projects are so large-scale (averaging over 10 MW per doublet) that large numbers of homes need to be connected for a project to be financially viable.
- Safe drilling requires a substantial amount of space; for geothermal projects in the built environment space restrictions may therefore be a limiting factor.
- In areas where there is little data from oil/gas exploration, it is very hard for projects to claim an RNES guarantee, limiting the area where geothermal can be rolled out.
- Drilling costs are relatively high and investors face considerable risks of cost overrun due to unforeseen drilling problems. It is no easy matter to get a lump-sum price for this project phase.
- Many initiators/owners of geothermal projects are not mining companies and are involved in just one project. This means a limited learning curve and that every project needs a P90 business case for that particular project. Economies of scale are also out of the question.

The main advantages of LT geothermal compared with 'conventional' lie in the following areas:

- less saline intrusion, reducing scaling and corrosion problems;
- shallow formations mean less risk of gas; relatively low max. volume dissolved gas means no degasser is required;
- less space needed for drilling;
- lower drilling costs and risks; lump-sum price feasible;
- smaller project scale: fewer connections required;
- also feasible in areas where 'conventional' geothermal has no potential but shallow does, possibly as a fall back-scenario.

The main drawbacks of LT geothermal compared with 'conventional' are:

- The low temperature of LT geothermal usually means more heat pump capacity is required, increasing the system's environmental footprint (at least as long as the electricity is not 100% renewable) and operating costs.
- LT geothermal is less suitable for supplying higher temperatures (above approx. 70°C).
- The potential of LT geothermal is relatively limited (in GJ/ha) for a given sediment thickness.
- LT geothermal has not yet been widely demonstrated and there is therefore a slightly higher risk perception vis-à-vis unforeseen problems; the supply side of the market is also still under-developed.