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Geothermal energy and the heat transition: An outline for roadmaps to unlock their potential and accelerate investments

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ABSTRACT

Integral roadmaps for the development of sustainable collective heating systems based on active demand aggregation and supply by geothermal heat, waste heat, possible other sources, and heat storage could accelerate investments significantly in the Netherlands, as well as in Europe to the benefit of all.

For such roadmaps to unlock this potential for policy makers, business partners, customers, citizens, and other stakeholders alike, would work in case they make the following conditions work: (1) there is a clear drive and outlook for demand to change from natural gas fired to sustainable heat supply; (2) the option of sustainable collective heating systems turns out to be more advantageous than its sustainable alternatives; (3) active demand aggregation enables the possibility to benefit from larger scale sources, storages, and networks with higher capital and lower operating expenditures; (4) all parts of the integrated collective heating systems work together to achieve their progressive cost- and risk-reduction potential, and their progressive benefits of secure, sustainable, and comfortable heat supply; and (5) the planning and implementation process throughout the value chain takes place in a predictable, transparent, and adaptive way through integral programming. This takes the values of investors, stakeholders, and citizens into account, and works based on a shared consensus on the overall benefits.

In the Netherlands, a new Heat Law that further clarifies which parties will play what roles throughout the transition from natural gas fired to sustainable heat is currently in process. This means that for the Netherlands these conditions may soon turn into an executable reality. Development of integral roadmaps could provide overview, and align parties' activities in a coordinated way to unlock their potential and accelerate investments. Alignment of these conditions across countries in the European Union, and exchange of best practises to make them work could further accelerate investments.

1. INTRODUCTION

Geothermal energy in the Netherlands has been developing into a serious renewable energy source since its first activities in horticulture in the 2000s. At present, there are 28 production locations with 42 production wells, which together produce some 8 PJ of sustainable heat per year, mainly for demand in horticulture, but also for the built environment. The pipeline consists of over 100 projects (GNL, 2024[1]). In addition, since 2018, an extensive national derisking programme called SCAN has been deployed that uses 2D- and 3D-seismic and scientific exploration wells to explore the subsurface for further geothermal development in the Netherlands (SCAN, 2025). Estimates for geothermal energy potential as a sustainable heat source range from some 110 PJ up to over 270 PJ for combined demand in the built environment, horticulture, and industry, which roughly translates to 350 to 700 doublets (NL, 2018; SPG et al., 2018; TNO, EBN, 2018; Berenschot, CE Delft, IF Technology, 2018; Van Wees et al., 2020; Berenschot, Panterra, 2020; Mijnlieff et al., 2022). The recent Acceleration Plan for Geothermal Energy of 2024 aims at 40 to 50 PJ in 2035 (GNL, 2024[2]). These studies consider geothermal energy projects mostly from 1500m – 3000m depth with temperatures between 55°C – 100°C. There is considerable additional potential to unlock at 300m – 1500m depth with temperatures between 25℃ – 55℃ (CE Delft, IF Technology, 2018; Van Wees et al., 2020; Bus et al., 2025).

Besides geothermal energy, other important large scale sustainable sources exist to supply collective heating systems for demand in the built environment, horticulture, and industry. These include residual heat from waste incineration, industry, future electrolysers, heat from (clean) Combined Heat and Power (CHP, e.g. with biomass or biofuels, later maybe hydrogen). It is also possible to upgrade lower temperature heat sources, such as those from datacentres, with heat pumps. Especially in case of larger collective heating systems, which in the Netherlands generally are expected to operate based on 70℃ heating and 40℃ return temperature, these sources can collectively result in a diversified portfolio. This ensures secure delivery to customers and diversification in price and other risks, as energy portfolios are expected to provide over time.

Moreover, heat storages can significantly add value to the development of collective heating systems. Again, especially in case of larger systems, it is possible to develop seasonal or peak storages with lower capital expenditures (CAPEX) and higher operational expenditures (OPEX) that reduce high CAPEX investments in base- and mid-load production assets, while at the same time make them produce at higher load hours. This reduces the total costs of heat (TCOH) of the entire system and deliver additional security of supply as well (GNL, 2022; WINDOW, 2022; HEATSTORE, 2025; NPLW, 2025[1]; EBN, IF Technology, 2023; TKI GROW, 2023).[1]

Much, however, depends on active demand creation, below referred to as demand aggregation. For most new sustainable heat assets to positively contribute requires high utilisation rates with over 6000 load hours a year, but preferably closer to the 8760 hours a year in total counts. As investments in geothermal energy and other larger scale heat sources have high upfront CAPEX and low OPEX, these sources should operate as many load hours as possible. The same accounts for the transport and distribution networks that connect all sources and storages with demand. Active organisation of demand aggregation in the built environment, horticulture, and industry may prove to be crucial for a secure, affordable, sustainable, and comfortable heat transition. Combining demand, heat sources, storage, networks, and their idiosyncrasies in the right development window, requires the use of shared roadmaps. These could improve predictability and transparency of all main activities involved, and facilitate adaptive shared planning that largely increases the opportunities to achieve the targets set. In the next section, the outline of such roadmaps for integral programming is further elaborated on. Each of the following five paragraphs go into one of the five conditions a roadmap should at least address to make them work.

2. AWAY FROM IMPORTED GAS TO DOMESTIC SUSTAINABLE HEAT

Despite changes in the (geo)political spectrum, the EU's view on energy policy has been stable over time. The EU finds itself in such a vulnerable position that, perhaps for different reasons, the majority of people and politicians remain committed to the objectives of secure supply of domestic energy - more independent from energy import from outside the EU, with as little impact on climate and environment as possible, and at affordable and globally competitive prices (Draghi, 2024). This means the EU remains strongly committed to its binding 42,5% renewables and 55% CO_2 reduction targets, and climate neutrality in 2050 as agreed before in the Green Deal, and as fixed in the European Climate Law (EU, 2019; EU, 2021; EU, 2022[1]; EU, 2023[1]; EU, 2025[1]; EU, 2025[2]).

For heating and cooling the Renewable Energy Directive (EU, 2023[2]) has strengthened the former target. It set the legally binding share of renewables by at least 1.1% annually over the period 2026 to 2030, while aiming at an overall effort at EU level of 1.8% annually. The EU also gives member states ample room to take measures to achieve these targets, as well as to integrally approach it in combination with measures to implement the renovation wave in the built environment, and combine this with the energy efficiency and performance targets set under the Energy Performance of Buildings Directive. Decarbonising heating and cooling is one of the focus areas of the EU Renovation wave strategy (EU, 2016; EU, 2023[2]; EU, 2023[3]; EU, 2024[1]; EU, 2025[3]; EU, 2025[4]).

Evidently, the Netherlands operates in line with the above-mentioned. It has an indicative 39% renewable energy target, and a binding 55% CO_2 reduction target for 2030. It aims at a carbon neutral energy system in 2050, laid down in the Dutch Climate Law (NL, 2019[1]). The present government shows itself fully committed to these targets for the same reasons as just described (NL, 2024[1]). In 2018, the Netherlands became a net importer instead of exporter of natural gas due to premature closure of the Groningen field. Since then, its energy system has become as vulnerable to the geopolitical circumstances as that of any other country in the EU. Dutch energy policy drives the transition from natural gas to alternative heat sources, and the country heavily invests in electrification based on off- and onshore wind and solar power, hydrogen, geothermal energy, waste heat, green gas, biomass and biofuels, carbon capture and storage, and additional nuclear energy (NL, 2023; NL, 2025[1]).

In this context, the heat transition in the Netherlands mainly involves two areas of the broader energy transition: the built environment and horticulture with temperature demand between 30℃ and 90℃. It involves industry in two ways: as a user of heat for lower temperature processing activities of some 30℃

[1] For further explanation on the concept of TCOH see the explanatory box at the end of this paper.

to 200°C in among others certain refining processes, and the paper, food and beverage industry. Industry also applies higher temperatures well over 200°C in refining, chemical processing, and CHP up to very high temperature steam up to over 1500°C in cement, glass and steel production (TNO, 2018; ECN, TNO, 2020). From these activities industry can deliver waste heat to horticulture or the built environment. Estimates of net heat demand in horticulture of some 60 PJ, and the built environment of some 370 PJ in 2050 still project a considerable demand for sustainable heat towards 2050 as Figure 1 shows - also after planned energy efficiency measures have been taken. For the built environment, present government policy based on the Climate Agreement of 2019 aims to transition 1.5 million houses from natural gas to sustainable heat by 2030. All 7 to 8 million houses, and another 1 million other buildings in the Netherlands are expected to have switched from natural gas to sustainable heat by 2050. In addition, 1 million new houses will have been built by 2050 (NL, 2019[2]; NL, 2023).

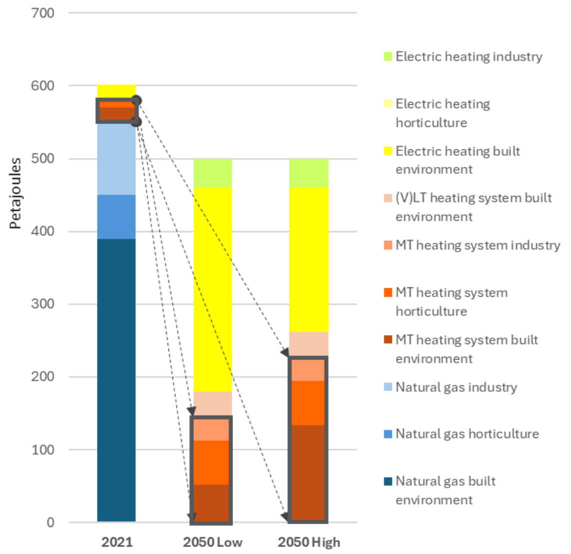

Figure 1: Projected final demand for 30°C to 90°C heat in the built environment and horticulture for a lower and higher scenario of mid-temperature (MT) collective heating systems in the Netherlands in 2050 (NL, 2023), including an estimate for lower temperature industry demand in the Netherlands 2050 (TNO, 2018; ECN, TNO, 2020).

Whereas security of supply by domestic energy sources and protection of the climate and the environment form principal drivers to switch from natural gas to sustainable heat, also the future price outlook for heat starts to point to the advantage of sustainable heat. As Figure 2 shows, gas prices tend upwards and show high volatility. Although it is difficult to predict the exact outcomes, not too far into the future oil and gas exploration and production may well become an increasingly controversial business, which more likely than not comes at a cost. In the end, its use should reduce worldwide, and require the use of carbon capture and storage (CCS). This may raise their costs on the longer run at least for (end) users, as well as further increase their volatility (IEA, 2024[1]).

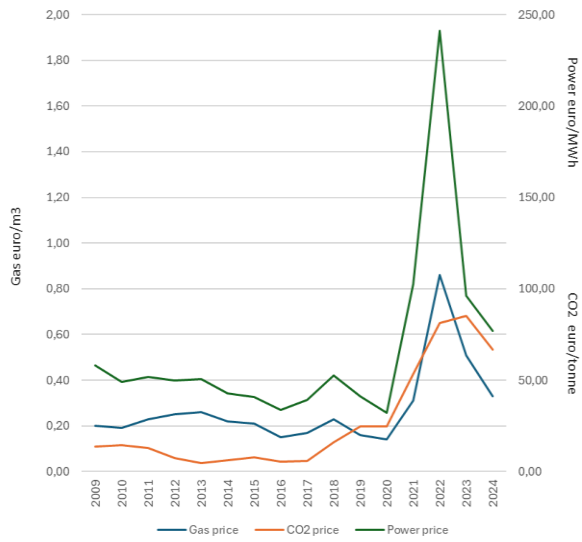

Figure 2: Annual average gas, CO_2, and power prices in the Netherlands excluding taxes (CBS, 2025).

Figure 2 also shows the trend in CO_2 allowance prices. CO_2 prices are foreseen to rise significantly because the EU Emission Trading System (ETS) applies increasingly tighter emission caps towards 2050. This trend is already visible in the CO_2 markets. With the introduction of the ETS-2 in 2027, this process is expected to raise prices on a broader scale (PBL, 2024).

The power price in Figure 2 forms a third important price driver, which for (end) users may increase due to ongoing electrification of our whole energy supply and demand system. This requires still huge investments in the power infrastructure of sources, grids, transformation, storage, and batteries. The volatility of power prices has become very high because of the increase of intermittent renewable energy sources, and decreased availability of conventional power plants. Whereas Figure 2 only shows annual average prices for all commodities, it does not show their highly increased volatility within year, month, week, day, and hour. Power prices now vary between negative and very high positive prices (IEA, 2024[1]; NN, 2025[1]).

Meanwhile, costs of renewable energy production - in particular wind and solar, and battery technology, continue to decrease because of innovation and economies of scale as soon as their value chains starts to function as a whole. Because of the growing scales of demand, suppliers to production sites for solar panels and wind turbines, the production sites themselves, as well as all logistics, design, construction, operation, maintenance, and regulation, policy, consultancy, engineering, finance, legal, and insurance become more and more aligned every day. This explains a large part of why these costs and risks go down. These advantages of scale are high for society, and are expected to continue to progress (IRENA, 2024; IEA, 2024[1]; Toribio-Ramirez et al., 2025).

To get to this increasing scale of renewable energy production, the EU and member states have been putting substantial environmental regulation, taxes, subsidies, and an ETS in place, and they appear committed to continue to do so. Moreover, the latest EU policy package concentrates on streamlining subsidies, as well as environmental and spatial regulation to speed up the implementation of the energy transition. This extraordinary level of attention, indeed, remains necessary for the coming decades to ensure all interconnected value chains of power, hydrogen, biomass, biofuels, sustainable heat, storages, batteries, and active demand response of the integral energy systems fall in place (EU, 2019; 2021; EU, 2022; EU, 2023[1]; EU, 2023[2]; EU, 2025[1]; EU 2025[2]).

Already, the successful introduction of large-scale wind and solar lead to challenges to the transport and distribution grids throughout the EU. In the Netherlands this has led to an alarming level of grid congestion (NL, 2025[1]). At the moment, this is still mainly caused by the volatile supply patterns of these intermittent sources. Moreover, as in the Netherlands the power grid has been designed modestly because of its historically dominant natural gas system, further extensive electrification works still have to come (EBN, 2024[1]; NN, 2025[1]). This means grid congestion remains part of the energy transition for a longer period, despite the substantial investments the Transmission System Operator (TSO, TenneT) and the Distribution System Operators (DSOs) have been planning to implement (NL, 2025[1]; NN, 2025[2]). This makes the development of domestic sustainable heat sources as part of collective heating systems all the more important. They reduce the need for the use of renewable power sources, diversify the energy mix, and relieve the pressure on the grids (CE Delft, 2024).

To conclude, the question whether we move away from fossil fuels towards a sustainable energy system lies behind us. The questions now concentrate on what sources and technologies have what position in the sustainable energy system, also literally in terms of spatial planning; on how can we organise the required investments efficiently based on a secure and predictable portfolio of sustainable energy sources; and on societal consent of a shared understanding of the overall benefits.

3. COLLECTIVE SUSTAINABLE HEATING SYSTEMS AND ITS ALTERNATIVES

For horticulture, larger scale demand aggregation works relatively straightforward: it exists concentrated in large quantities where companies, often clustered together, grow their crops. Indeed, the natural gas and CO_2 price developments of Figure 2 make horticulture companies strongly consider alternative heat sources if they have not already switched away from natural gas. They often prefer geothermal energy or other large scale sustainable heat sources when available (ECW, 2025; WSW, 2025; WSO, 2025).

For the built environment, the answer to the question where to use what alternative heat source is provided by the municipalities. The new Law Municipal Instruments for the Heat Transition, expected to come in force in January 2026, puts them in the position to coordinate and decide which houses in which neighbourhoods will switch from natural gas fired to sustainable heat, and when (NL, 2025[2]). They have to design Heat programmes in which they report on their strategies which sustainable alternative they foresee to apply on neighbourhood level. A so-called Start-analysis tool supports the municipalities in their assessment, and indicates which sustainable heating alternative may fit the kind of buildings in their neighbourhoods best, based on lowest national cost calculations. This tool distinguishes four main alternative sustainable heating strategies, which again fall apart in 18 variations. The four main strategies are (PBL, 2025[1]):

- S1. **Individual electric heat pumps**: ground source or air, delivers 50℃ heat at label B+ insulated dwellings;
- S2. **Collective heating systems**: geothermal and waste heat, delivers 70℃ heat at label B+ or label D+ insulated dwellings;
- S3. **(Very) low temperature collective heating systems**: aquifer thermal energy storage or low temperature waste heat of some 15 – 30℃, delivers via heat pumps 50℃ or 70℃ heat at label B+ or label D+ insulated dwellings;
- S4. **Hybrid heat pump** with climate neutral gas, delivers 70℃ heat at label B+ or label D+ insulated dwellings.

Based on data on all building types in the Netherlands[2], and national costs indicators of the sustainable heating configurations of the four strategies, the Start-analysis provides an indication where which dwellings in which neighbourhoods municipalities can expect what kind of sustainable heating solutions and infrastructure. Municipalities can use this database as a starting point. To make Heat programmes of sufficient quality they have to enrich the tool's outcomes with their own local data, information, and knowledge to determine where to offer what kind of solutions to their customer citizens[3] to switch from natural gas to alternative heat sources. Based on the overall data, municipalities define zones in which they indicate which solution turns out to be the most advantageous one to propose. Figure 3 shows how the Start-analysis accomplishes this for a part of Zuid-Holland. The national programme local heat (NPLW) supports the municipalities in making these programmes, which they should finalise by the end of 2026 (NPLW, 2025[2]).

[2] The so-called public BAG database: BAG Viewer.
[3] The term customer citizen has been chosen here instead of end-user because of the big impact of the change for customer citizens in their living environment when going off natural gas fired to sustainable heat.

For all involved, but especially the customer citizens, it is very important to analyse, design, plan, prepare, and implement the right sustainable heating solution at the right place at the right time as well as possible. For citizens to accept the outcome, they for instance will want to know that they do not structurally pay more than necessary for comfortable heat. This means they should be provided with understandable information regarding costs of alternative solutions for their homes and neighbourhood.

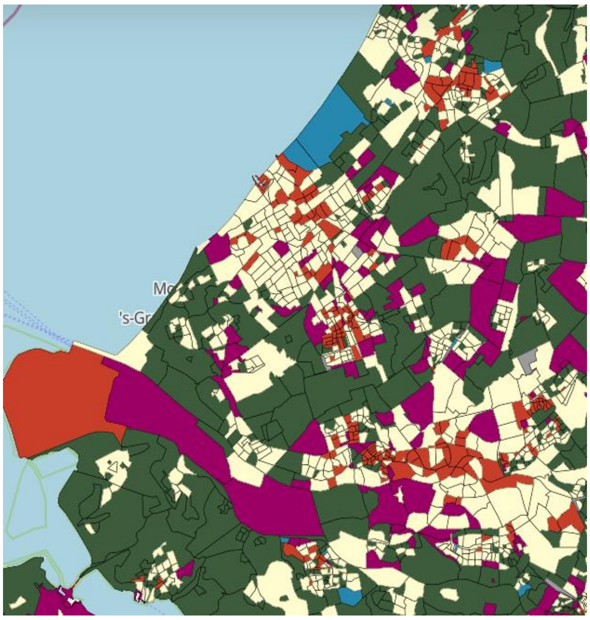

Figure 3: Example of the indicative zones of sustainable heating solutions in part of the Province of South Holland based on lowest national cost calculations of Start-analysis: S1 is blue; S2 is red; S3 is purple; S4 is green. The light yellow areas parts are 'undecided' (PBL, 2025[1]).[4]

This becomes all the more important as the transition from natural gas to sustainable solutions often requires a renovation. Except for new and more recently built dwellings, all four solutions S1 to S4 often require considerable activities within the house to install more (label B+) or less (label D+) substantial insulation measures. Besides insulation measures, citizens have to rearrange space for heat pumps and/or electricity cabling, or install new kinds of radiators and piping. These activities may well entail breaking and rebuilding floors, walls, making holes, and paint jobs.

Outside, streets have to be opened up, either to strengthen the electricity grid and build new substations, or to build collective heat networks and new transfer stations. DSOs have to phase out the natural gas grids as well. People rightfully expect these activities to be undertaken in an intelligently coordinated way, and to see the benefits of the whole operation as soon as possible after some undeniable hassle.

Another reason to analyse, design, plan, prepare, and implement well concerns the inextricable relation between all costs, benefits, and risks throughout the value chain of heat demand, sources, storage, and networks. In general, this equally accounts for all four solutions of S1, S2, S3, or S4. In case one of the parts of a chain does not work, the other parts are affected too. Heat pumps, for example, cannot work well without sufficient capacity on the power grid, which requires anticipating the amount of heat pumps DSOs can expect to come online in neighbourhoods. They also require insulation measures up to label B+ to ensure a warm home in wintertime. Offering insulation measures up to label B+ together with installing heat pumps in S1 neighbourhoods by means of well-prepared collective campaigns could drive costs down considerably, prove a less labour-intensive way of installing them, and reduce the environmental impact of the entire operation.

The need for analysis, design, planning, preparation. and implementation of collective heating systems in S2 zones is perhaps even stronger. For these systems, the TCOH depends strongly on the development costs of available large-scale resources such as geothermal and waste heat with higher CAPEX and lower OPEX, as well as the possibility to have storage in place, and to attract large, concentrated amounts of heat demand. TCOH increases rapidly if demand is too little and decreases as rapidly as well if the system can spread the CAPEX over a large number of customers in a relatively short time window. Proactive analysis, design, planning, and preparation can increase benefits, and are relatively very cheap activities compared to the total investments ahead. Proactive coordination allows for collective heating systems to be implemented in an organised fashion, connecting as much demand as possible in due time. Any business case of investments in heat sources, transport, distribution, and in the citizens' houses benefits from this taking place in a coordinated, transparent, and predicable manner.

Based on the Law Municipal Instruments for the Heat Transition, the role of the municipalities to make and renew their Heat programmes every five years, indeed, concerns this kind of analysis, design, planning and preparation.[5] The municipalities first define the heating zones of S1, S2, S3, and S4 in their Heat programmes. They then assign these zones to the appropriate business partners such as the heating companies to implement within a period of 10 years the most advantageous integral heating solution in these zones. These partners, in turn, will work closely with their consultants, engineering, installation, communication, and construction companies, as well as all other contractors to build the new integral heating systems.

The municipalities now start with this task enriching the starting information from the Start-analysis with all their local data, information, and knowledge. Because

[4] Large horticulture demand in this area for collective heating systems has not been included. The Start-analysis tool only sees to the built environment.

[5] The municipalities made the first more indicative versions of these programmes in 2021, called Heat transition visions. They based these on the first version of the PBL Start-analysis of 2020 (PBL, 2019).

of the complexity of this work within a continuously changing world this process typically takes place in an iterative manner, during which the municipalities can involve heating companies and other business partners, stakeholders and (representatives of) citizens. As the Heating programmes are formally part of the Environmental and Planning Law, they require to include a process of transparent participation to involve all stakeholders and citizens affected (NL, 2024[2]).

Although the heat transition is complex, changing, and different from region to region, from municipality to municipality, and from neighbourhood to neighbourhood, there are a number of main pointers municipalities can take into account, which clarify some important differences to consider between the four different sustainable heating solutions S1, S2, S3, and S4. There are at least three of them to mention here:

This first one to mention is the **coefficient of performance** (**COP**)[6] of the integral heating solutions. The COP for these strategies regards the amount of energy needed to operate the entire system, and the amount of effective heat supplied and used. In the end of the day, all four heating solutions require electric power, which the system turns into more (higher COP) or less (lower COP) useful heat produced for consumption. The higher the COP the more efficient the system energetically works, the less electricity it requires, and the less operating energy costs it takes to run throughout its lifetime. COPs of the four sustainable heat solutions indicatively operate within the following ranges (CE Delft, 2023; PBL, 2025[1]; CE Delft, 2025):

S1. Individual electric heat pumps (ground source, air): **COP = 2** – **6,** depending on their configuration;

S2. Collective heating systems (geothermal energy, waste heat, storage): **COP = 10** – **50**, depending on their configuration;

S3. (Very) low temperature collective heating systems: **COP = 2 – 10**, depending on their configuration;

S4. Hybrid heat pump with climate neutral gas: **COP = 2 – 5,** depending on their configuration.

The logic behind this is rather straightforward: the higher the starting temperature of the heat source, the less electrical energy the system needs to work up to temperatures the dwellings require. In the Netherlands, available heat sources with the highest temperature are waste heat of 120℃ – 30℃, geothermal energy at 3000m – 1500m depth with 120℃ – 55 ℃, moving up to the surface to geothermal energy at 1500m – 300m with 55℃ – 25℃, more up to Aquifer Thermal Energy Storage (ATES) with 25℃ – 10℃, water bodies with 15℃ – 5℃, and air with again lower temperatures to recover heat from in winter. COPs usually give a good indication when comparing alternatives.

The second pointer regards that of the possibility of **demand aggregation**. As discussed, horticulture matches well with the larger scale demand with the right temperatures for geothermal and waste heat, and storage in the Netherlands. Also for the built environment, collective heating systems represent the most efficient option as it has by far the highest COP. However, collective heating systems generally require larger scale, concentrated heat demand. Only this kind of demand can cover the upfront capital investments for geothermal energy and waste heat, together with those of transport and distribution. This demand requirement implies two things: (1) collective heating systems at 70℃ – 40℃ can provide the lowest cost heat in densely populated areas of already existing buildings, which generally are less apt to come to higher levels of insulation (i.e. higher than label D+ or C) without very high costs (RHDHV, 2021; TNO, Deltares, 2024). Moreover, in case this seems to be a possibility, it is important to work based on (2) active demand aggregation as every additional dwelling or other kind of demand (also from adjacent horticulture or industry) can more easily become part of the system. This progressive process can drive costs per joule down significantly, until the system becomes fully utilised. Collective heating systems have progressive benefits. Almost every other dwelling can benefit from this effect, and reduce costs for all other customer citizens.[7]

As an (not totally fictive) example, a low temperature collective heating project (S3) in a neighbourhood should rather not operate adjacent to a higher temperature collective heating system (S2) separately. The return temperature of the higher temperature system of 40℃ is already higher than that of the source of the lower temperature system of 30℃. These systems better connect somehow, for example by using a cascading heating system, to raise their combined COP, and thus save energy and costs. Obviously, in this early development phase, analysis, design, and planning should identify these suboptimal situations beforehand, and eliminate them before realisation, unless overruling other good reasons than ignorance prevail. This saves all involved substantial costs and frustration for the future.

The third pointer to mention regards that of **CAPEX** and **OPEX** levels involved. In case of relatively high CAPEX and low OPEX levels – such as for geothermal energy, waste heat, transportation and distribution networks, and power grids, investments require a large amount of future revenues over time to recover them. In case of sufficiently large demand these can come at reasonable prices. In case of even more demand, prices can even become really low if the system remains efficiently operating at low OPEX over a long time. In case of relatively low CAPEX and high OPEX levels

[6] Or seasonal coefficient of performance (SCOP).

[7] Economists refer to this effect as 'positive network externalities' or 'economies of scale' (Varian, 2020; Mulder, 2021).

such as heat storages or biomass boilers, investments only want to operate at prices higher than OPEX levels, i.e. when there is a (seasonal or higher) peak in demand. This means it is highly important to find out the CAPEX and OPEX breakdown of sustainable heating systems. Most reports at the moment only tell a part of the story as they provide TCOH in term of euros per joule or kWh.[8] This is not enough because it leaves out the CAPEX and OPEX assumptions, as well as the assumptions of the number of load hours the heat source, storage or network can operate on in the envisaged system. Nonetheless, also more thorough reports exist such as the underlying advisory reports of the Start-analysis, and those that advise government to determine subsidy levels for all kinds of renewable energy or CO_2 reducing technologies. They do show their estimates of (parts of) those figures in their spreadsheets. This is valuable information, used below to give an (incomplete) illustration how CAPEX and OPEX levels look like for the four sustainable heating alternatives (CE Delft, 2023; CE Delft, 2025; PBL, 2025[1]; PBL, 2025[2]):[9]

S1. Electric heat pumps (ground source, air):
- Capacity: 5 – 15 kW per house;
- CAPEX: 430 – 1575 euro/kW;
- OPEX: 1 – 2% CAPEX, excl. cost power;
- Investment power grid: + 4 kW per house (300 – 500 euro);[10]
- Investment insulation per house to label B+ level: euro 4.000 – 35.000, depending on starting label.

S2. Collective heating systems (geothermal energy, waste heat):
- Capacity: 5 – 200 MW (or more);
- CAPEX: heat sources 150 – 2232 euro/kW;
- OPEX: 1 – 6% CAPEX, excl. cost power;
- CAPEX heat networks: 300 – 6000 euro/m;[11]
- OPEX heat networks: 1 – 2% CAPEX;
- Investment insulation per house to label D+ level: euro 2.000 – 21.000, depending on starting label.

S3. (Very) low temperature collective heating systems:
- Capacity: 0,5 – 10 MW (or more);
- CAPEX: heat sources 50 – 250 euro/kW;
- OPEX: 3 - 6%, excl. costs power;
- CAPEX: heat pumps 300 – 760 euro/kW;
- OPEX: 3 – 6%, excl. costs power;
- CAPEX heat networks: 300 – 2500 euro/m;[12]
- OPEX heat networks: 1 – 2% CAPEX;
- Investment power grid: + 4 kW per house (300 – 500 euro);
- Investment insulation per house to label B+ level: euro 4.000 – 35.000, depending on starting label.

S4. Hybrid heat pump with climate neutral gas:
- Capacity: 5 – 15 kW per house;
- CAPEX: 380 euro/kW;
- OPEX: 3 – 4%, excl. cost power and gas;
- Investment power grid: + 1 kW (300 euro);
- Investment insulation per house to label D+ level: euro 2.000 – 21.000, depending on starting label.

As expected in a transition, most information available to the municipalities and their business partners does not yet take all parts of the value chain integrally into account. The sector, without doubt, will soon make further progress in this area. Not in the least because some studies have already importantly shown the relevancy of this (RHDHV, 2021; TNO, Deltares, 2024; Greenvis 2024). An increasing number of studies have started to include the integral value chain (CE Delft, 2024; RHDHV, 2025; Ecorys, NN, 2025), but even these are not there yet when it comes to attaching costs estimates to all parts of the value chain, which include the costs of insulation and renovation within the house, and outside connection costs to either the power grids or heat networks, strengthening power grids or building heat networks, and the renewable power or heat sources to develop.[13]

One of the things that currently enhances confusion when it comes to comparing the costs of the sustainable alternatives, especially when making propositions for new customers, is the difference in taxation, socialisation of costs, and subsidies provided to the various parts of the conventional and sustainable heat value chains. To name a few, differences exist in environmental taxes on gas, power, and heat; investments in power grids are socialised contrary to those in collective heat networks; collective heat networks receive subsidy; and all sustainable heat technologies receive different levels of subsidy to compete with investments in conventional energy. This not only causes confusion, but also uncertainty as these arrangements are bound to change over the course of the energy transition. In fact, the most logical base to work on in such dynamic contexts is to take a cost-based view, comparing CAPEX and OPEX of all parts of the value chain. Most probably, regulations, taxes, and subsidies over time align to support the more cost-efficient sustainable solutions with the higher benefits.

[8] See the explanatory box on the concept of TCOH at the end of this paper.

[9] An important number of CAPEX and OPEX related within the house costs for piping, cabling, radiators, heat interface units, metering, tap water, electric cooking, but also outside costs of transformation stations, maintaining or abandoning gas infrastructure, peak and back up, heat losses, project management costs et cetera have not been included in this overview. These number are scattered in the public domain, and difficult to compare as of yet. In this area there is still a lot of work in the heating sector to have appropriate cost indicators available in a transparent database.

[10] Additional to an average existing connection of 3 kW.

[11] Depending on size and location.

[12] Depending on size and location.

[13] This has all to do with the systems boundaries chosen to calculate and compare TCOH of the alternative solutions – see the explanatory box on the concept of TCOH at the end of this paper.

This kind of streamlining of taxation, socialisation, and subsidies is already under the attention of the EU, and also the Dutch government. The same accounts for possible streamlining of yet separate spatial, safety, and environmental regulations and permitting. These too are subject to change as the technologies and infrastructures now rapidly change as well (EU, 2023[2]; EU, 2025[1]; EU, 2025[2]; EU, 2025[3]; NL, 2025[1]; NL, 2024[3]; NL, 2025[3]).

The three pointers mentioned here (i.e. COP, demand aggregation, and CAPEX/OPEX levels) are, of course, not the only ones. In particular at regional and local levels other values can play major roles that overrule the above considerations for very good reasons. The social-economic context within municipalities, neighbourhoods, and behind the front doors, earlier experiences, other infrastructure or nature preservation projects, citizens initiatives, safety and spatial arguments, and desired levels of comfort will form an inextricable part of the considerations among all stakeholders and citizens who really feel how the heat and other transitions in society take place. It would be supportive to all involved, though, if processes of analysis, design, and planning could provide much of the above data and information in a transparent way. This would allow municipalities, their stakeholders, customer citizens, and all business partners to arrive at an insightful consensus about why a certain sustainable heating alternative provides the greater benefits to all at the appropriate places in their community.

4. ACTIVE DEMAND AGGREGATION

As for the other sustainable heating solutions, the question for geothermal heat and the heat transition is not so much one whether there is large potential for development, but much more one of how to unlock it where, and when. As it is not beneficial for any of the solutions to develop projects in the space of the other solutions, it is important to identify well ahead where which solution has its rightful place to subsequently develop it in a way that fits their features best.[14]

Active demand aggregation is of crucial importance to fully benefit from the advantages of larger scale collective heating systems based on geothermal energy, waste heat, storages, transport and distribution systems. This is already heavily discussed in the sector under another name: utilisation risk[15] (SWN, 2022; Rebel, 2024; NPLW, 2025[3]). Referring to this as a passive risk to cover signifies that at present most efforts in the energy transition still focus on stimulating renewable energy production, and much less on active demand creation. This also accounts for sustainable heat.[16]

Active demand aggregation means scrutinising what demand belongs to which sustainable alternative, in this case larger scale geothermal energy, waste heat, storage and collective heating systems. It means identifying any kind of demand in the periphery of the system, whether in the built environment, horticulture, or industry, with revenues higher than OPEX per unit of heat to deliver. All this additional demand adds value to the collective heating system as it recovers some part of the CAPEX. Figure 4 visualises how this first kind (I) of value creation works of active demand aggregation.

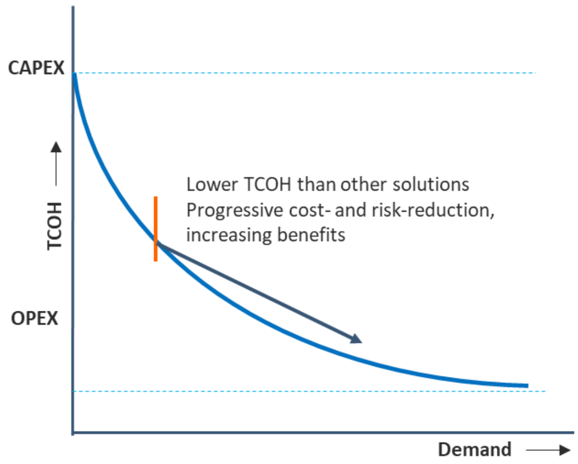

Figure 4: The value of active demand aggregation (I).

Moreover, any possibility to increase baseload by adding demand volume, as well as any possibility to relatively flatten the mid- and peak profiles by adding more demand, always reduces costs under this condition. Increasing baseload and relatively flattening mid- and peak demand further always provides more flexibility to optimise the production assets, networks and storages to invest in, and increases the possibilities to ensure security of supply to manage outages and (un)scheduled maintenance.[17] As mentioned, costs and risks continue to reduce progressively to the benefit of all when demand grows till the point the system becomes fully utilised. With a simple example Figure 5 also shows this second kind of value creation (II) of demand aggregation.

To take advantage of progressive cost and risk reduction and increasing benefits, active demand aggregation should at least analyse, design, and plan accordingly. Hopefully, the municipalities and their partners take this into account in their Heat programmes to carve out the largest possible zones. It makes it easier for the heating companies they will

[14] See also the warning of the National Audit Council that subsidising heat pumps in areas envisaged for collective heat can work contrary to the policy objective to stimulate the heat transition (AR, 2025). It has the attention of the Dutch Government (NL, 2025[4]).

[15] In Dutch called ‘volloop risico’.

[16] Probably two factors play a role here. The first is that renewable power never had to consider active demand creation because it could tap directly in the power markets without too many adjustments (until recently). Sustainable heat, hydrogen, and CCS all three do require intensive demand creation to ensure the value chains to become more viable. Another factor could be that the main (and rightfully so) policy in the heat transition has been to reduce heat consumption through energy efficiency en energy performance.

[17] Optimizing CAPEX and OPEX of investments matching active demand aggregation works by means of analysis of the load duration curves (LDCs) of the integral collective heating systems. This kind of analysis can make lowest costs and progressive benefits for the customers clear.

appoint under the new Heat Law to further detail the design to build, operate, and maintain the collective heating systems with their business partners, and perform in the best way possible at affordable prices.

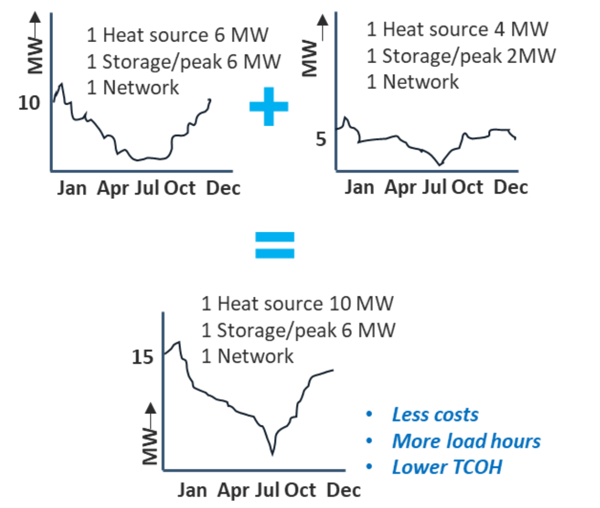

Figure 5: The value of active demand aggregation (II).

To actually realise these benefits, analysing, designing, planning, and carving out these zones is only the first step in active demand creation. To be able to develop and realise all assets throughout the value chain, and to aggregate the largest demand possible as soon as possible, requires active management of all stakeholders and citizens to become enthusiastic to join, and proceed smoothly. This means designing new concepts, methods and campaigns to align all involved in large numbers in the same direction of the progressive benefits of the renovation activities behind the front doors, and construction activities in the streets.

Here, without doubt, there is a world to win. It would take us to the next phase of the heat transition, one that can take advantage of the large numbers of the citizen customers for the citizen customers. This process of active demand creation is bound to accelerate as soon as the zones for collective heating systems identified become increasingly clear, and heating companies can actually start working in them.

5. HEAT SOURCES, STORAGE, AND NETWORKS WORK TOGETHER

5.1 Geothermal energy

Successful active demand aggregation depends on the possibility to work with low cost and risk propositions of collective heating systems. Prospective demand in the built environment, horticulture, and industry should be able to understand well how their benefits compare to their alternatives. Whereas, over the last decade, all parts of the system have been coming more and more in shape to replace natural gas, they all have still a huge potential to unlock, especially as the heat transition starts to move towards the laws of the larger numbers, much required to reach the target for 2050 of a fully sustainable heating system.

As referred to in the introduction, geothermal energy has been developing into a serious renewable heat source in the Netherlands with considerable production activity in horticulture, the first projects in the built environment, and over a hundred projects to develop in the pipeline. The SCAN programme plays an important role in the exploration of promising areas in terms of the quality of the subsurface to develop geothermal energy that matches potential demand (SCAN, 2025).

Figure 6 shows the current view on the geothermal energy potential in the subsurface plays in the Netherlands at depths between 1500m – 3000m, in particularly for the main Rotliegend, Jura, and Trias plays (ThermoGIS, 2025). The deeper red the colour the higher the probability of good geothermal potential in the subsurface. Ongoing analyses match subsurface potential and concentrated demand areas, provide more insightful cost estimates for geothermal projects, and analyse how to reduce costs and risks further (TNO, EBN, 2018; Berenschot, CE Delft, IF Technology, 2020; Van Wees et al., 2020, Berenschot, Panterra, 2020; EBN, GNL, 2021; Mijnlieff et al., 2022; Heijnen et al. 2025). The work is ongoing as the SCAN programme explores and maps the lighter and white areas with yet insufficient knowledge about the subsurface (SCAN, 2025). Also geothermal energy at depths between 300m and 1500m still requires further exploration, only more recently looked into (CE Delft, IF Technology, 2018; Van Wees et al., 2020; Bus et al., 2025).

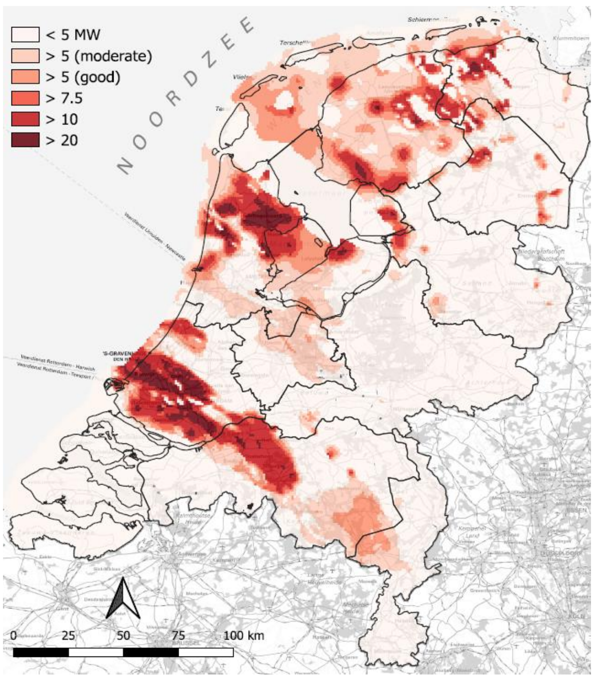

Figure 6: Deeper red areas show good to excellent geothermal potential at 1500m – 3000m. Potential in lighter areas is relatively unknown, which the SCAN subsurface derisking programme further explores (ThermoGIS, 2025; SCAN, 2025).

The growing experience, which goes hand in hand with a broader and stronger resource base of shared expertise and knowledge among policy makers and business professionals; the new highly valuable information on the potential of the subsurface; and growing insight into where prospective demand resides all form important drivers for the present and upcoming developments. Moreover, the sector has more key drivers on its sleeve to propel costs, benefits, and risks into the right direction throughout the heat transition.

One of the key drivers is the play-based portfolio approach. This approach provides large benefits as soon as geothermal operators can change from a stand-alone project approach towards a play-based portfolio approach of multiple projects. This would improve geothermal development significantly by collectively derisking regions with similar subsurface characteristics and repetitive project potential. The approach can accelerate development by unlocking resource potential in areas marked by higher upfront geological risk, effectively reducing the costs of development. It continuously deploys all information acquired by exploration and development to the whole play portfolio of potential projects by trading off the higher risks of the first wells with the lower risks of the later wells in the same play as this information results in strong geological risk reduction. For plays initially considered too risky to start developing, applying this value of information (VoI) concept can derisk the play to such an extent it becomes attractive for the market to develop. Indeed, the active SCAN programme in the Netherlands already follows this approach (SCAN, 2025). Developing geothermal energy this way, increases the probability of projects in the plays considerably, as well as the average profitability of the projects (TNO, EBN, 2018; Berenschot, CE Delft, IF Technology, 2018; Van Wees et al., 2020; Berenschot, Panterra, 2020: Mijnlieff et al., 2022).

Whereas an important part of the increase of value of the play-based portfolio approach lies in the advantage of geological derisking, it has similar advantages on the surface activities as well. A portfolio approach to these activities has demonstrated this renders the possibilities to (1) continuously improve the operators' abilities to apply quality enhancing and cost efficient integrated project development, (2) have significant cost reduction through synergy, efficiency and standardisation – further referred to below, (3) substantially increase optimisation of the appropriate surface heat demand and infrastructure, (4) provide opportunities for more focused research and development (R&D) and innovation, and (5) benefit from financing advantages because the portfolio enables sharing costs, benefits, and risks with shareholders and financial institutes (TNO, EBN, 2018; Berenschot, CE Delft, IF Technology, 2018; Van Wees et al., 2020; Berenschot, Panterra, 2020; Mijnlieff et al., 2022).

In addition, the geological subsurface advantage and the five advantages on the surface progressively reinforce each other. Analysis of the geological advantage alone applied on a future portfolio of 350 doublets producing 70 PJ of the extractable geothermal potential, estimated to lie between some 90 – 275 PJ, shows a cost reduction of some €2 billion for the main Rotliegend, Triassic, and Jurassic/Cretaceous plays in the Netherlands. The analysis also shows additional significant learning effects of synergy, efficiency, and standardisation (TNO, EBN, 2018; Berenschot, CE Delft, IF Technology, 2018; Van Wees et al., 2020; Berenschot, Panterra, 2020; Mijnlieff et al., 2022).

Based on the first and second advantage of the play-based portfolio mentioned above, GNL and EBN have developed an Integrated Cost Reduction Program for Geothermal Energy. With the contribution of over 30 geothermal operators, suppliers and other companies the programme examines geothermal project costs and risks in order to reduce them to position geothermal energy as a competitive heat source compared to its alternatives. By identifying and making use of synergy, efficiency and standardisation efforts based on the larger numbers, the cost of geothermal energy in the Netherlands are expected to reduce by 30% by 2030 and 50% by 2050, while ensuring both safe and responsible development. In this programme operators, knowledge institutes, and service companies together with GNL and EBN have identified multiple options to reduce development, capital, operational and abandonment expenditures throughout the life cycle of geothermal projects in terms of levelised cost of heat (LCOH).[18] The possibilities turn out to be multiple, and rather feasible in this early stage of development. They include measures such as using horizontal wells increasing production capacity lowering the LCOH with some 22%, data collection to standardise construction lowering LCOH with some 20%, or applying lower injection temperatures, increasing flow rates, and sequence drilling lowering LCOH respectively with 19%, 13%, and 11%. Additionally, more measures can be taken (EBN, GNL, 2021; Heijnen et al., 2025).

Notably in the context of this paper, the programme highlights the crucial role of actively developing large scale concentrated heat demand to reduce LCOH. According to their findings, the development of district heating networks appears central to further reducing the cost price. The analysis shows that most measures that increase the production capacity with a limited additional investment have the greatest impact on reducing the LCOH. However, the increase of capacity with two horizontal wells instead of two (sub)vertical ones, for example, only adds value if there is sufficient heat demand. The 14 MWth capacity of the baseline project with 6000 full load hours to measure the cost reductions, already requires an extensive heating network (EBN, GNL, 2021; Heijnen et al., 2025).

[18] LCOH is the same as TCOH – see the explanatory box at the end of this paper.

Moreover, many of the cost reduction options have to be considered in the development phase, particularly in the earlier concept select phase. This phase therefore has a major impact on the final project value. For projects that have already been realised, cost price reduction is possible by collecting additional data so that production can be optimised, increasing the use of geothermal energy above base load, and reducing the costs of reinvestment over the life cycle, keeping in mind safe and responsible projects. Data collection of the subsurface to reduce uncertainties in production parameters has a major impact in this phase of the sector development within the Netherlands. The programme has further identified the importance of aligning project development timelines with regulatory and subsidy frameworks to ensure financial viability. Local factors such as community support, sustainability, and geological uncertainties also play crucial roles in project success (EBN, GNL, 2021; Heijnen et al., 2025).

Regarding the fourth advantage of the play-based portfolio approach the Dutch geothermal energy sector has developed a perennial R&D and innovation programme called Geo4all. Based on the growing experience in the sector captured by a comprehensive report on innovation possibilities in the geothermal sector in the Netherlands, this programme combines the expertise and knowledge of 23 companies, GNL, TNO and EBN. Together they work to increase R&D and innovation levels to structurally develop geothermal energy resources at lower costs, with a strong view on societal impact and sustainability (Geo4all, 2025).

The innovation programme consists of several working packages, which, among others, investigate how to unlock shallow geothermal resources. The sector expects significant opportunities at these depths of 300m to 1500m. Participants will gather and combine existing knowledge and experience, as well as the information from new projects to identify where and how to start and scale up further development. It also has a project under way that focuses on the performance of closed-loop systems at these depths. The programme further investigates how to increase geothermal potential from plays by the use of new drilling techniques, well completion methods, and reservoir management in the deeper subsurface to ensure safety, and improve productivity over the lifetime of geothermal reservoirs. It also builds a database of production data of all the installations of the system such as the Electric Submersible Pump (ESP), injector pumps, and heat exchangers to learn, improve, and innovate to enhance operations and maintenance (GNL, EBN, 2021; Geo4all, 2025).

At the moment of writing, most of the advantages above still have to materialise because of the lagging development of heat demand for the larger scale heat sources, especially in the built environment. There is, indeed, an urgent need to focus attention on the third advantage to connect much more closely with all the activities to create heat demand and surface infrastructure. A recent study on the investment condition of geothermal energy in the Netherlands points to the lack of demand in existing, let alone new, collective heating systems. The study also points at the need to further align subsidies and environmental regulation and permitting requirements, specifically focused on improving the entire value chain, including demand (Rebel, 2024).

The game changer presumed here is to change the perspective, and strongly concentrate on active demand aggregation. This could lower costs and risks significantly, which in turn increases prospective demand to include the demand peripheries of built environment, horticulture, and possibly industry. More demand for the projects means lower costs for the projects, which in turn leads to more demand as discussed above. Progressive cost and risk reductions, as well as progressive benefits reinforce each other. In case this process takes off, the benefits of financing - the fifth advantage described, follow suit. This could be the virtuous process to ignite.

5.2 Waste heat, other sources, and heat pumps

Next to geothermal energy, there are other valuable larger scale sustainable heat sources that preferably interact with each other to develop a diversified secure, lower costs collective heating system to serve local and regional heat demand. Places that have a lot of existing or potential waste heat available provide important additional sources of relatively high temperatures between 40℃ – 120℃. It is important to distinguish between waste heat, which has no other alternative use any more than to use it elsewhere, or co-produced heat of CHPs, whose energy could be used alternatively at its production site as well. Furthermore, there is another relevant distinction as the heat can come from incineration, conventionally fuelled activities (e.g. refining, gas-fired CHPs), from activities fuelled by renewable energy (green electrolysers, biomass CHP), or activities conventionally fuelled but decarbonized by CCS, or even bioenergy with CCS (BECCS). The Heat atlas of the Netherlands gives an indication where, what kind of waste heat (and other heat sources) may be available as a sustainable heat resource. Figure 7 shows the potential of waste heat and other heat sources than geothermal energy for S2 collective heating systems. It has been plotted upon the geothermal potential of Figure 6. It is important to note that estimates of CAPEX and OPEX of potential waste heat and other sources are still rather difficult to find, which affects large-scale development of these sources (CE Delft, 2019; RVO, 2025).[19]

The sustainable heat source that comes next in terms of scale and temperature level is waste heat from datacentres with temperatures between 25℃ – 33℃.

[19] The organisation of data exchange between industry and grid operators in a Datasafehouse may change this.

This waste heat could possibly be upgraded by means of large heat pumps for use in collective heating systems of 70 – 40°C. Upgrading with heat pumps would go at the expense of the COP, and probably turn out to be more expensive in terms of LCOH. However, in case no (more) geothermal energy or higher temperature waste heat is available, this might still turn out to be more advantageous than its alternatives with dwellings that cannot easily renovate to label B+ necessary for S3 (very) low temperature systems or S1 heat pumps. It may well turn out to be the better competitor of S4 hybrid heat pumps for dwellings with label D+ insulation as it delivers higher temperatures again than the next best alternative of shallow aquifer or aquathermal heat (Berenschot, 2018).

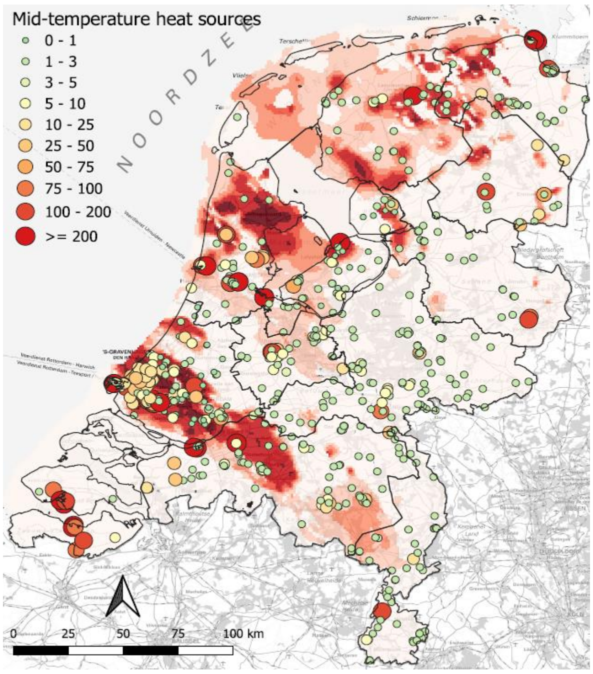

Figure 7: Waste and other heat sustainable sources in MW, and geothermal energy potential for S2 collective heating systems (ThermoGIS, 2025; PBL, 2025[1]).

Ideally, geothermal energy and waste heat of higher temperatures are available to develop S2 larger scale collective heating systems for higher concentrated demand from dwellings with label D+. This configuration largely appears as the lowest cost option, also because it generally has much lower operating electricity costs, and it importantly can relieve grid congestion in the Netherlands (CE Delft, 2024; RHDHV, 2025; Ecorys, NN, 2025).

5.3 Storage

For the energy transition in general, but also for collective heating systems, storage provides a highly valuable possibility to make baseload production assets continue to produce, even when demand is low, and store the energy. The storage can provide the stored energy in times of high seasonal or peak demand. Storage optimises the system both energetically and from an investment point of view by shaving the peaks, while making optimal use of the production assets. It optimises energetically because it takes relatively little electric energy to store and produce energy compared to separately added production capacity for seasonal or peak demand. It optimises investments in terms of CAPEX and OPEX as it has relatively low CAPEX compared to separately added production capacity, and, indeed, somewhat higher OPEX during loading and unloading, but this applies only during the load hours of seasonal or peak demand.[20]

Drawing load duration curves (LDCs) of collective heating systems to cover the aggregated demand profile explains how to optimise the entire system with the appropriate base-, mid-, and peak load production and storage assets as Figure 8 shows. Moreover, storages can serve as back-up in case the system suffers from an outage or goes in (un)scheduled maintenance.

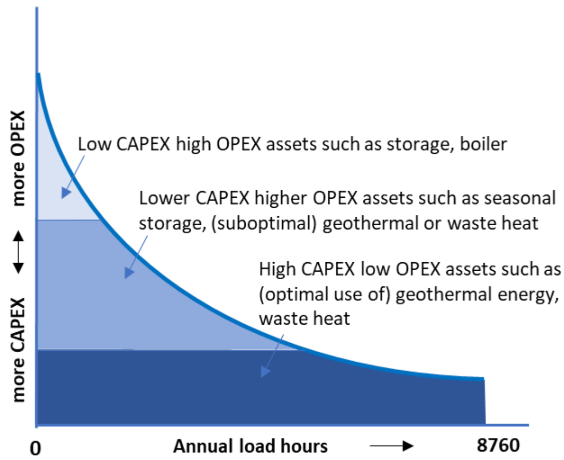

Figure 8: Load duration curve (LDC) and appropriate assets in collective heating systems based on load hours, and their relative CAPEX and OPEX levels.

Storages thus work on top of base- and mid-load production as a seasonal storage and/or peak shaver. An increasing amount of research on the possibilities to develop seasonal high temperature storages (HTS) has become available, and shows further potential can be unlocked. Several interesting options such as insulated water buffers or tanks situated above ground or buried underground have been developed for peak shaving or cross commodity trading purposes, mostly applied in horticulture who are traditionally ahead of this game in the Netherlands because of their history and experience with their vast CHP asset base (GNL, 2022; WINDOW, 2022; HEATSTORE, 2025; NPLW, 2025[1]; EBN, IF Technology, 2023; TKI GROW, 2023).

[20] Storages can further optimise by loading during low or even negative power prices.

It would certainly be valuable throughout analysis, design and planning of collective heating systems to consider scenarios with heat storages, as they may very well reduce costs and risks, and increase security of supply of the total system (TKI GROW, 2023).

Similarly to larger scale heat sources, storages work with the logic of progressive cost and risk reduction, and progressive benefits that result from active demand aggregation when developing collective heating systems. It is very well imaginable that when these collective heating systems are developed, they initially use available natural gas production capacity[21] to cover for mid- or peak demand which will sooner or later be replaced by storages or buffers (RHDHV, 2021).

5.3 Heat networks

Heat networks connect aggregated demand, sustainable heat sources and storages. As said, in case active aggregated demand leads to larger concentrated demand zones that represent the largest possible LDCs for these zones, it is much easier to develop a well-diversified portfolio of larger scale sustainable heat sources and storage to have a secure, low cost, comfortably running collective heating system in place. In that case, it is also possible to design and optimise the typology of the transport, primary and secondary distribution networks. Like the production assets, and to a lesser extent like the storages, these networks have relatively higher CAPEX and lower OPEX, which means they benefit from progressive cost and risk reduction, and progressive benefits with additional demand just as well.

In the Netherlands, there are relatively large existing district heating networks in Amsterdam, Utrecht, and Rotterdam, and somewhat smaller ones in the Drechtsteden[22], Delft, The Hague, Tilburg, Purmerend and Ede. Additionally, there are again smaller district heating networks scattered over the Netherlands in places with relatively high concentrations of heat demand. Similarly, there are extensive heat networks in horticulture areas such as Agriport and Westland. Also Oostland has far-reaching designs developed in cooperation with the regional community to develop a collective heating system. Again, large demand and the conditions to develop these networks because of rising gas and CO_2 prices, together with the targets set to realise a sustainable system, plus the large demand concentrations drive these areas to develop systems supplied by geothermal energy, waste heat, and storages. In the built environment, more new collective heating systems are under development, such as in the Drechtsteden (HVC), Groningen (Warmtestad), and Delft (Netverder). In the Province of South Holland, WarmtelinQ regards another large project underway to transport waste heat from industry in the Port of Rotterdam, and in the future possibly also geothermal heat, across the regions of Rotterdam, The Hague, and Leiden to supply the concentrated demand areas there.

Nevertheless, the speed of the present developments in the Netherlands, especially in the built environment, has been too slow, and realisation is lagging behind target. There are a number of reasons for this, mostly recognised to take away by policy processes underway (Warmtealliantie, 2025; AR, 2025; NL, 2024[3]; NL, 2025[3]; NL, 2025[4]).

One of the main reasons for the slow pace of the heat transition is that natural gas fired heating has continued to remain the cheaper alternative for most end users. The subsidy schemes in place generally were not sufficient to bridge the gap between heat tariffs and gas tariffs. In fact, subsidies were available for separate parts of the sustainable heat value chains only: the production assets could apply for the Dutch subsidy of SDE++, and building owners could apply for the Dutch subsidies focused on heat pumps and insulation measures such as ISDE, SAH, SVVE, DuMaVa, and Warmtefonds. Separate subsidies for investments in (district) heating networks were introduced in 2023 with the so-called WIS for networks in the built environment, and in 2024 with the so-called SWIG for networks in horticulture (NL, 2024[3]; AR, 2025; NL, 2025[2]; NL, 2025[3]).

Before, there was a subsidy scheme focused on learning from pilot projects in which neighbourhoods transitioned from natural gas fired to sustainable heat. These pilots demonstrated that the heat transition in the built environment indeed entails complex, integrated infrastructure, which requires development of a substantial amount of new knowledge and expertise. Findings also showed that energy value chains still had to mature, and cooperate more intricately to scale up. It found that the transition to go off natural gas probably requires more public governance to coordinate the interaction between all activities for all public and private parties involved, as well as for all other stakeholders and customer citizens (BMC, RLI, 2023).

Another explanation for the slow pace of the transition to district heating networks has been that heat pumps appeared the relatively cheaper and easier sustainable heat solution because most costs of this value chain do not fall upon the end user. End users do not have to pay directly for the costs for grid capacity required by heat pumps as they are socialised. At the same time, there was little awareness as to how heat pumps and insulation costs in the neighbourhoods relate. In fact, houses with heat pumps in areas with a high concentration of more difficult to insulate dwellings affect feasibility and costs of the generally cheaper sustainable collective heating solution for the other customer citizens in the neighbourhood as the National Audit Council pointed at (AR, 2025). Other reports also mention the existing differences in taxation,

[21] These again could turn into biogas-, biomass- or hydrogen-fired production capacity, and even BECCS.

[22] The Drechtsteden refers to the region of the municipalities Alblasserdam, Dordrecht, Hardinxveld- Giessendam, Hendrik-Ido-Ambacht, Papendrecht, Sliedrecht, and Zwijndrecht.

socialisation, and subsidies that mainly result from the organisation of the former energy system. These reports show how in the current system, TCOH of district heating systems in areas with larger concentrated demand and available larger heat sources such as geothermal energy and waste heat is considerably lower for society as a whole, but not for individual citizens. For a large number of customer citizens turning to the sustainable heat solutions of heat pumps with higher TCOH still results in lower individual costs (Berenschot, 2024; Warmtealliantie, 2025; RHDHV, 2025; Ecorys, NN, 2025).

An important third reason has been the stalemate of the Law Municipal Instruments for the Heat Transition and the Heat Law, which have to give the municipalities the appropriate instruments, executive power, and decision-making rights to be able to function as the local coordinator of the heat transition. Without this, they are unable to develop the appropriate analyses, designs, and plannings that show for each neighbourhood in their municipalities where what solutions will be offered to citizens to make the transition from natural gas fired to sustainable heating solutions. The first of the two Laws has recently passed the Parliament and the Senate, and will get into force by January 2026. The Heat Law proposal has been finalised by the Minister of Climate and Green Growth and sent to Parliament to be discussed and decided upon before summer 2025 to subsequently go straight to the Senate for their approval. At the time of writing, the Minister aims to have this law in force in January 2026 (NL, 2025[3]; NL, 2025[5]).

6. INTEGRAL PROGRAMMING

For a new sustainable heating system to be developed well connected to an entire new sustainable energy system – which in the Netherlands means to switch from natural gas, takes a number of new, often up to now separately developed, parts of a connected system to evolve. What these larger parts are, and where in the new system they belong together, becomes increasingly clear. It also becomes evident that joint development by public and private parties, stakeholders, customers, and citizens in a transparent and more coordinated manner offers a large potential for costs and risks reduction, and benefits increase.

The above potentially applies to all four sustainable heat solutions S1, S2, S3, and S4 when they scale up, but especially to the integrated value chain of collective heating systems (S2). Nevertheless, this progressive costs and risks reduction, and progressive benefits with additional demand, has two potential directions: (1) In case of a lack of coordination, costs remain high and all activities cumbersome, because the required parts within the value chain hamper each other's beneficial development. This resembles the current situation; Conversely, (2) benefits can be reaped when all parts of the sustainable heat value chains are put into position through transparent, integral coordination, based on analysis, design, and an adaptive planning process.

Over the last few years, an increasing number of analyses and reports point in this promising direction (e.g. RHDHV, 2021; Correlje, Rodhouse, 2022; BMC, RLI, 2023; TNO, Deltares, 2024; NL, 2023; Wagenaar, 2024; Greenvis, 2024; AR, 2025; RHDHV, 2025; Ecorys, NN, 2025). Moreover, an interesting proposal has been made much in line with the play-based portfolio approach for geothermal energy, but now for the entire collective heating system value chain of active demand aggregation, sustainable heat sources, storages, and connecting networks. It suggests municipalities to first do a spatial analysis to determine which of the four sustainable heating solutions S1, S2, S3, and S4 fit where, in line with how they work to develop their Heat programmes. Next, together with their business partners, stakeholders, and representatives of the customer citizens, they further analyse, design, and adaptively plan the integral transition from natural gas to sustainable heat solutions. This analysis now should include the possibilities how to activate demand aggregation, and how to reap the progressive cost and risk reductions, and progressive benefits of additional demand of collective heating systems. Together they can consider how to develop programmes and campaigns to renovate and insulate the dwellings in the neighbourhoods to such an extent that they match the heating solutions envisioned by the S1, S2, S3, and S4 sustainable heating solutions (EBN, 2024[2]; EBN, 2024[3]; Afry, 2024).

At the same time, for each zone with a particular sustainable heating solution, the municipalities, together with their business partners, stakeholders, and representatives of costumer citizens, can further analyse, design, and prepare the development plans of the integral value chain that match the kinds of aggregated demand. For collective heating systems (S2), this means identifying the aggregate demand profile that the zone (or connected zones) together can build up over time, the sequence of sustainable heat sources to develop for base- and mid- load, the possibilities to fill in seasonal and peak load as well as back up for security of supply over time. Together this should develop into a robustly designed configuration and construction plan of the integral heating system. This should cover all activities to ensure demand connected behind all front doors - possibly combined with that from horticulture and industry, for the zone to go off natural gas and connect to the collective heating system (EBN, 2024[2], EBN, 2024[3]; Afry, 2024).

At least two things are essential to progressively reduce costs and risks, and reap the progressive benefits of additional demand. Firstly, it is important to identify all the zones for all prospective demand of all dwellings, together with all associated prospective demand of horticulture, and possibly industry. Secondly, it is important to optimise the order of development of the investments in aggregated demand, with those in heat sources, storages, and networks. If productions assets, storages, and networks with higher CAPEX and lower OPEX are developed too soon, without active development of aggregate demand, this leads to high costs per unit of energy used, i.e. high TCOH. Such a situation may discourage prospective additional demand. In contrast, if there is a good plan to actively develop prospective demand; and production assets, storages, and networks match the rhythm of this demand to connect, total costs and risks of heat become lower, and benefits larger. This situation may very well attract prospective additional demand.

Figure 9 gives a simplified representation for an integral development programme of heating zones. It first identifies all zones for S1, S2, S3, and S4, followed by their socio-economic sequence of development over time. The approach seamlessly can follow up on that of Figure 3, with the difference that it now works based on transparent, coordinated design, investment and development plans that optimise for aggregate demand, heat sources, storages or other mid- and peak load installations, and connecting networks. As a consequence, the approach matches the aspired optimisation of the local or regional load duration curve (LDC) of Figure 8 with the largest possible aggregate demand profile it may obtain for each heating zone(s).[23]

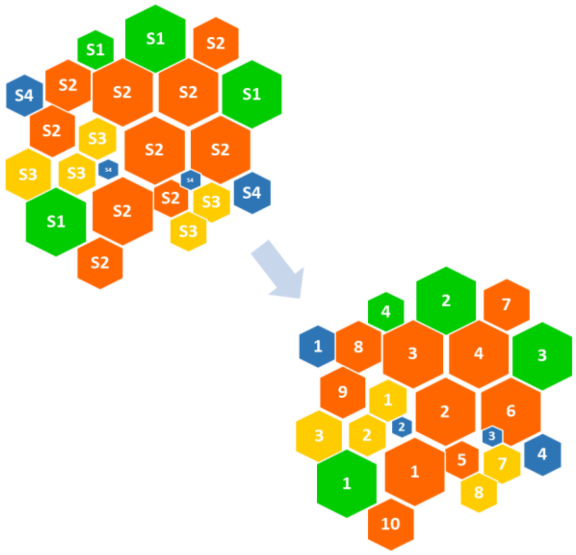

Figure 9: Identifying heating zones for S1, S2, S3 and S4, and their sequence to develop.

Some first indicative and other more in-depth analyses of this kind already illustrate the potential advantages of integral programming. They mirror those of the play-based portfolio approach, and the Integral Cost Reduction programme for geothermal energy, but also involve an integral approach to the activities within the house, as well as for laying out the heat networks. Together these kind of analyses show the advantages of increased predictability, a stable outlook of spatial zones to work in, and the advantages of suppliers to anticipate the kind of Engineering, Procurement, and Construction (EPC), and Design, (Finance), Build, Operate, and Maintain (D(F)BOM) working packages ahead to reduce costs and risks, and increase benefits on every part of the connected value chain.

Based on these analyses, the approach to integral programming of heating zones aimed on development of the heat transition in a coordinated way could look as follows:

1. Define potential heating zones where collective heating systems have lower costs and risks, and higher benefits than their alternatives;
2. Analyse, design, optimise, and plan per heating zone the LDC based on active demand aggregation, available heat sources, storages, possible heat pumps, transport and distribution networks. Make use of the effect of progressive cost and risk reduction, and progressive benefits of collective heating systems to optimise demand aggregation;
3. Define roadmaps of the sequence of developing the heating zones, including the development plans of active demand aggregation, heat sources, storage, and networks;
4. Optimise costs, risks, and benefits in the sequence of heating zones to implement. Re-assure these are well and transparently substantiated more advantageous than its sustainable heating alternative in that zone;
5. Ensure subsidies (in the Netherlands those of SDE++, WIS, and those behind the front door) to match the required investments for the heating companies to invest, and the customer citizens to pay a transparent and fair price. This price should turn out demonstrably more advantageously over the other alternatives. If possible streamline the subsidies into one coherent package to ensure proficient development of the entire value chain – all involved suffer a lot from hampering parts;
6. At least have a complete clear overview of, and preferably streamline, all environmental and spatial regulations and permitting requirements of the investments and activities in the heating zone;
7. Organise the former six steps as an iterative transparent, and adaptive portfolio process over all heating zones.

This approach takes the municipalities as key governmental coordinators, obviously working together in partnerships with the provinces, their regional energy strategy (RES) partners, and central government where the development of collective systems requires this, and heating companies as their trusted business partners. In this cooperative process, all partners should involve all other stakeholders and customers citizens in the built environment, horticulture, and industry, as well as their supplying value chain of consultants, engineering, installation, communication, and construction companies, and other contractors to build, operate and maintain the new integral heating systems. After all, collective heating

[23] As mentioned before, every unit of additional demand is beneficial to all as long as it contributes more to the system than its marginal operational cost of the system.

systems require coordination of all activities and partners from source to demand. Figure 10 depicts the steps of the suggested iterative transparent, and adaptive portfolio process, as well as the kind of coordination and involvement of all actors and stakeholders (Afry, 2024).

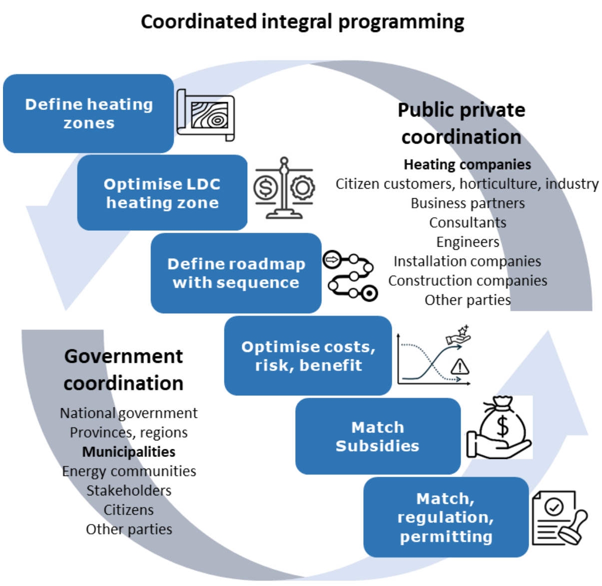

Figure 10: Iterative adaptive portfolio process of integral programming in roadmaps.

The need for a more integral approach has already been noted by the Ministry of Climate and Green Growth as well. The Ministry has consulted stakeholders to discuss opportunities to further align and streamline the separate subsidies that now support sustainable heat sources, networks, and renovation and insulation activities within the house (NL, 2025[6]).

In this context, it is interesting to note that the European State Aid Rules move member states more and more towards subsidy schemes that support the integral development of the energy system, and also collective heating systems, preferably by providing subsidies through transparent competitive tenders. To facilitate this, they empower the member states to allow for the highest subsidy levels possible, and with the highest subsidy intensity factors of 100% coverage of the eligible costs. It may be possible to come to a design of a subsidy scheme that supports the eligible cost difference per heating zone for the entire value chain of collective heating systems, which would reflect the difference between the TCOH of the proposed system, and the heating price customer citizens (and possible other customers) pay. By working with contracts-for-differences in such schemes both government providing subsidies and the public and private business partners could fairly share all price risks throughout the EPC and DB(F)OM packages that development of the heating zones will entail (EU, 2022[2]).

Similarly, it may prove worthwhile to make an analysis of all main (and sub) activities involved in the heating zones and all spatial and environmental legislative, regulatory, and permitting requirements. Based on such an overview, it is possible to identify how certain requirements or permits could be combined. The objective would be to ensure safe, sustainable, social, and environmental development, while taking out all unnecessary doublures, review periods, and interlaced regulatory risks of the permits. Probably a large part of the requirements could be prepared upfront and collectively by the government, or through public private forms of cooperation with the heating companies and other stakeholders before the heating companies have to make major investments in the heating zones. Having to interrupt the development process during, or even after, large investments take place would have large cost effects that burden all (Afry, 2024).

Upfront analysis, design, planning, and coordination play a crucial role to achieve these advantages. However, whereas highly important for many, national costs, risks, and benefits are not the only factors that play a decisive role how to shape the heating transition. Precisely therefore, it is all the more important to have them transparently in view as soon as possible to include them together with the other important values and factors that play such as how to share the costs, risks and benefits among each other; how to work with the public and private space involved; and how to involve citizens initiatives of energy corporations within the organisational framework and portfolio.

The governance process to manage this kind of iterative analysis, design, planning, and coordination thus also requires a high level of transparency, openness, and the possibility to adapt to the values and conditions that stakeholders and customer citizens bring up rightfully as well. Adaptively set up for all heating zones, the approach can work as a total development and investment portfolio of adaptive change, whereby large parts of the development plans in the portfolio probably remain relatively stable, while certain parts may change for the better without jeopardising much of the overall transition.

Already, this kind of transparent, integral programming more or less takes place in countries such as Denmark (DDHA, DBDH, 2025; TNO, 2025). However, to gain better insight into all parts of the value chains of the alternative sustainable heating solutions, and how they work together in the regional and local situations, it is important to intensify the exchange of this kind of information among all parties involved in Europe (and beyond). Best practices, learnings, concepts and methods to reduce costs and risks, and increase benefits to customer citizens, and other users in this phase of the heat transition have a large impact on acceleration. This process has recently been gaining more momentum through important initiatives of the European Strategic Research and Innovation Agenda on Geothermal energy by ETIP-G, the Future of Geothermal Energy by IEA, and the joint efforts of EGEC and Euroheat and Power to approach the heat transition more integrally

(ETIP-G, 2023; IEA, 2024[2]; EHP, 2023; EHP, 2024; EGEC, 2025; SAPHEA, 2025). Also the EU, as said, already has a Heating and Cooling Strategy in place since 2016, and an Energy Performance of Buildings Directive since 2010, which it revised in 2024 to follow the policy of a Renovation wave. The EU acknowledges the importance to continuously look more integrally at this, and expressed the intention to develop a further strategy (EU, 2016; EU, 2023[3]; EU, 2024[1]; EU, 2024[2]; EU, 2025[4]; GSEU, 2025; EU, 2025[5]; EU, 2025[6]). Without doubt, unlocking the potential of these activities throughout Europe also helps companies to take a broader market outlook to invest to scale up.

7. NEW HEAT LAW AND POLICY

In the Netherlands, much of the work described above is already under way in some shape or form. The unlocking of the potential of this work, and before any kind of roadmap to become really effective, however, requires approval of the new Dutch Heat Law. Together with the Law of Municipal Instruments for the Heat Transition already approved, this new Law carves out the process by which the coordinating municipalities find their partners of 51% or more publicly owned heating companies to accelerate and scale up the heat transition already under way (NL, 2025[2]; NL, 2025[5]) .

Both Laws organise the main two coordinating roles the municipalities and the heating companies closely have to play together throughout the heat transition. The Laws also steers them well balanced into the direction of an integral systems approach too, and of taking advantage of the economies of scale while remaining sensitive to, and cooperative with the local stakeholders, energy communities, and customer citizens involved.

The main process it organises is that by means of the Law of the Municipal Instruments municipalities are in charge of designing the Heat programmes and their successors. These serve as the basis for the municipalities to decide which neighbourhoods switch from natural gas fired to alternative solutions and have to transition within a certain amount of time to one of the four sustainable heating solutions. As an instrument of last resort to, this Law has given the municipalities the authority to switch off gas supply in neighbourhoods in case they offer a reasonable sustainable alternative.[24] The new Heat Law, if approved, brings them the majority owned public partners they prefer throughout this sensitive process close to their citizens, which requires a lot of work behind the front doors, and in the public streets to coordinate.[25]

The new Heat Law proposes the present Dutch DSOs to become involved in all four sustainable heating solutions. It allows them to form, together with municipalities, provinces, the State (probably in the form of EBN), existing public heating companies, energy cooperations (heating communities), and privately owned heating companies, pension funds, and possible other organisation, to form 51% (or more) publicly owned heating companies. This certainly helps to more integrally analyse, design, and plan the appropriate sustainable heating solutions to fall in place. After the municipalities have identified the potential heating zones, and the roadmaps with the sequence of developing them, these new public majority owned heating companies can actually develop and realise them. Once the Laws have both been approved, they could join forces to bring all the work already done together, and fully activate and organise the integral programming activities underway.

At the moment of writing this paper, the proposal has been sent to parliament for debate and approval. Not too surprisingly considering all developments, most parts of the proposal underpin the analysis of this paper, and aim to organise the heating transition in a way it unlocks the potential described (NL, 2024[3]; NL 2025[3]).

It is expected that once the Heating Law has been approved, and subsidy schemes and regulation and permitting continue to receive appropriate attention, the heating transition can accelerate considerably. As argued here, preparing well organised roadmap processes based on integral programming to iteratively plan, design, and build the new heating systems may organise this acceleration in a way that can actually achieve the target of a fully sustainable heating system within the coming 25 years. Development of these roadmaps should probably come from the municipal, provincial, and national governments, who can make them together with the forthcoming heating companies, involving their consultants, engineering, installation, communication, and construction companies, as well as all other contractors who contribute to the sustainable heat value chains.

Again, it is important to align well with the European context, and vice versa, as many parts of the value chains are subject to the European regulations and policies of the Renewable Energy Directive, Energy Efficiency Directive, Energy Performance of Buildings Directive, the Renovation wave, the Heating and Cooling Strategy, and State aid regulation, all in place to support the transition (EU, 2016; EU, 2022[2]; EU, 2023[2]; EU, 2023[3]; EU, 2024[1]; EU, 2025[3]; EU, 2025[4]). More integrated roadmaps on this level may well help to connect, and ensure empowering alignment on national, regional, and local level.

8. CONCLUSIONS

This paper brings the main developments and insights of the Dutch heat transition together, and how geothermal energy can play its rightful role in this by

[24] They can only use this authority after a well-prepared process of involving their citizens over a longer period of time with convincing proposals to transition to a sustainable alternative.

[25] This applies to the large-scale development of installing heating pumps (S1 or S4), (very) low temperature collective heating systems (S3), and that of larger scale collective heating systems (S2) alike.

making use of the development of roadmaps to integrally programme and coordinate the development of collective heating systems. It's important that the parties who make these roadmaps address a number of conditions to make them work.

These developments have been on their way already for some while. They have resulted in a number of successful large scale collective heating systems in horticulture, and the first projects in the built environment. Many efforts over the past years have not yet resulted in the number of new collective heating systems hoped for. They have been contributing substantially to a deeper, wider spread, and shared understanding of what technologies and activities throughout the value chains can help us make the transition from natural gas fired to sustainable heat in a secure, cost-efficient, fair and comfortable way. Because of all this work, acceleration is now around the corner once the new Heat Law gets approved. The next step could be to prepare roadmaps that translate the upcoming Heat programmes into optimal, adaptive spatial development and investment plans.

At this moment, these development are about to fulfil five conditions necessary for public and private parties, stakeholders, customers, and customer citizens to change gear, and accelerate to invest in, and realise sustainable heating projects on a large scale throughout the Netherlands. Through the use of roadmaps they can activate them, and make them work together.

The first (1) condition represents the need for an underlying stable, societal drive and outlook of the energy transition itself as this forms the main engine to transition from natural gas to sustainable heat over the next 25 years. Due to the vulnerable position of the EU and the Netherlands as a country importing conventional energy, policy drivers clearly point towards a steady buildup of renewable or decarbonised domestic energy. Rising gas and CO_2 prices make sustainable heating alternatives increasingly attractive, and the use of natural gas more costly and unpredictable. Moreover, the sustainable heating alternatives all still have a large potential to reduce costs and risks, and increase benefits as they are on the brink of growth and scale. In the longer run, regulation and subsidies keep on shaping the transition towards sustainability.

To be able to accelerate the development of sustainable collective heating systems, it is, secondly (2), necessary to clearly understand for all involved how each sustainable heat alternative works throughout its entire value chain, as well as how it compares to its alternative sustainable heating solutions. It is important to be able to jointly identify which option turns out the most advantageous where. Municipalities are in the lead for this. They draw up Heating programmes where they indicatively determine which dwellings and neighbourhoods fall into heating zones of either (S1) Heating pumps, (S2) Collective heating systems, (S3) (Very) low temperature collective heating systems, or (S4) Hybrid heat pumps, each with distinctive characteristics. They importantly differ with regards to their COP; the relative CAPEX and OPEX that together to a large extent make up TCOH; and how this matches with the possibility to deliver to smaller or larger concentrated demand aggregations. Collective heating systems have an advantage in these comparisons as they generally have substantially higher COPs than their alternatives, and thus require much less electric power to heat. As they represent larger scale heat investments with higher CAPEX and lower OPEX in geothermal energy, waste energy, storages, transportation and distribution networks, they do require larger demand aggregations.

It is important to analyse, design, and plan the four heating solutions well in the Heating programmes and their successors based on these characteristics. These indicative designs and plans can form the input for involvement and discussion with all stakeholders and costumer citizens to take their values, dilemmas, and wishes into account, which play a decisive role to develop them at local and regional level.

The third condition (3) to work on with much vigour regards active demand aggregation. This activity of municipalities, regions and provinces, as well as heating companies or other developers enables to take advantage of larger scale sources, storages and networks with higher CAPEX and lower OPEX. It is crucial to not approach demand aggregation as a 'utilisation risk' only, but as active work to scrutinise all possibilities to add demand units of energy to the total demand aggregation per system. Every unit of extra demand that pays more than the marginal OPEX, reduces TCOH for all as it contributes to repay the CAPEX. Any possibility to increase base load demand, and relatively flatten the mid- and peak loads in the aggregated demand profile by adding more demand reduces costs under this condition, and increases the possibilities to ensure security of supply. Costs and risks reduce, and benefits for all progressively increase up to the point of full utilisation of the system.

Active demand aggregation also provides the possibility to come up with new concepts, methods and campaigns to organise the now often highly fragmented kind of activities on individual house-per-house basis to connect the customer citizens, and renovate their houses accordingly to their sustainable heating solution. This can reduce costs, risks, and raise benefits for the customer citizens significantly.

Wherever possible, active demand aggregation should combine demand from the built environment, horticulture, and industry together in one heating zone of connected collective heating systems when the above conditions apply as this benefits all.

The progressive cost and risk reduction potential, as well as that of progressive benefits of secure, sustainable, and comfortable heat supply generally applies to all four sustainable heat options. This means that a fourth (4) condition is that all parts of their value chains have to continue to get in shape and work together. For certainly, because of their higher CAPEX and lower OPEX, the parts of the value chain of the integrated collective heating systems require an integral approach to achieve these advantages. This starts with fulfilling the former condition of active demand aggregation, which demonstrates how all these conditions are interlinked. Demand aggregation should amongst others match the possibilities of the play-based approach of geothermal energy. This has a large cost and risk reduction potential to achieve because of the huge geological exploration and development advantages this brings. It has further considerable advantages to improve integral project management, operational cost and risk reduction of surface installations and activities, more focused R&D and innovation, and financing advantages.

Further important benefits can be gained in case geothermal energy can become part of a diversified portfolio with waste heat or other heat sources, maybe with additional heat pumps, storage and buffers. This makes it possible to construct the optimal portfolio to match the aggregated demand profile the collective heating system serves. By means of analysing, designing and planning LDCs, it is possible to optimise the demand aggregation process with the different production and storage assets, transport and distribution networks, all with different CAPEX and OPEX. This can reduce overall TCOH, and ensure a well-diversified portfolio of heat supply over the longer run.

A final fifth (5) condition of integral programming requires the planning and implementation process throughout the sustainable heat value chains to take place in a predictable, transparent, and adaptive way. This can take the values of investors, stakeholders, and citizens into account, and work based on a well understood shared consensus on the overall benefits. To make this condition work importantly stands or falls with the appropriate coordination in place. The process to organise this has already been underway for quite some time. It is expected to make, again, an important step forward with the new Heating Law. This law, together with the Law Municipal Instruments for the Heat transition, gives the municipalities and the 51% (or more) publicly owned companies the lead in the coordination of this transition.

With approval of both these Laws in sight, the development of roadmaps on municipal, regional, provincial, and national level won’t be long. They can implement the five conditions into concrete development plans. With these, the awaited acceleration of investments is bound to take place.

Alignment of these conditions across countries in the EU, and exchange of best practises based on roadmaps also on this level could further support acceleration of these investments.

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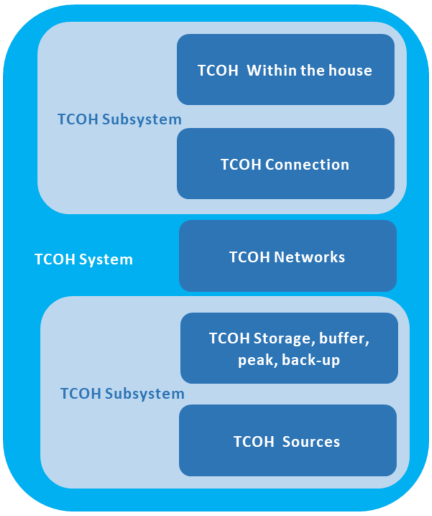
Total cost of heat (TCOH) or **levelized cost of heat (LCOH)** is a total cost of ownership (TCOO) calculation of a technology or system per Joule or kilo watt hour (kWh) of heat generated. It calculates the present value of these costs over its lifetime, converted to equal annual payments. Costs include development expenditures (DEVEX), capital expenditures (CAPEX), operation and maintenance expenditures (OPEX), power (or other fuel) costs, abandonment expenditures (ABEX), and the cost of capital at a discount rate, usually the weighted average costs of capital (WACC):

$$TCOH = \frac{\sum_t^T \frac{(DEVEX)_t + (CAPEX)_t + OPEX)_t + (power\ costs)_t + (ABEX)_t}{(1+r)^t}}{\sum_t^T \frac{production_t}{(1+r)^t}}$$

TCOH = total cost of heat in euro's per Joule or kWh produced
r = discount rate of the estimated cash flows based on the WACC

Each technology or system can have different DEVEX, CAPEX, OPEX, power costs, ABEX, WACCs, lifetimes, COPs, and load hours. It is important to consider what system boundaries a TCOH calculation takes into account.



Explanatory box on the concept of TCOH.

GLOSSARY

ABEX	Abandonment expenditures
ATES	Aquifer thermal energy storage
BECCS	Bioenergy with carbon capture storage
CAPEX	Capital expenditures
CHP	Combined heat and power
CCS	Carbon capture storage
COP	Coefficient of performance
DEVEX	Development expenditures
DuMaVa	Subsidieregeling duurzaam maatschappelijk vastgoed (Dutch subsidy to make public real estate more sustainable)
D(F)BOM	Design, (finance), build, operate, maintain
DSO	Distribution systems operator
EPC	Engineering, procurement and construction
HT	High temperature (some 110°C)
HTS	High temperature storage
ICRP	Integral cost reduction programme
ISDE	Investeringssubsidie duurzame energy en energiebesparing (Dutch subsidy to make houses more sustainable)
Label B+	Energy performance label of very well isolated existing dwellings (not recently built or new dwellings) – See: alles over het energielabel | Energielabel
Label D+	Energy performance label of relatively well isolated existing dwellings (not recently built or new dwellings) - See: alles over het energielabel | Energielabel
LCOH	Levelised cost of heat
LDC	Load duration curve
LT	Low temperature (some 50°C)
MT	Middle temperature (some 70°C)
OPEX	Operating expenditures
RES	Regional energy strategy
SCAN	Seismic campaign for geothermal heat in the Netherlands
SAH	Stimuleringsregeling aardgasvrije huurwoningen (Dutch subsidy to make rental property more sustainable)
SCOP	Seasonal coefficient of performance
SDE++	Stimulering duurzame energieproductie en klimaattransitie (Dutch subsidy to support sustainable energy production and climate transition)
SVVE	Subsidieregeling verduurzaming voor VvEs (Dutch subsidy to make houses of owners associations more sustainable)
SWIG	Subsidie warmte-infrastructuur glastuinbouw (Dutch subsidy for heat networks in horticulture)
TCOH	Total costs of heat
VLT	Very low temperature (some 30°C)
WIS	Warmtenetten investeringssubsidie (Dutch subsidy for district heating networks)

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