1. Introduction

The built environment is responsible for about 40% of Dutch total energy use, half of which is contributed to heating\(^1\). In a more sustainable future, this required low temperature heat of mostly 20-25°C should not be provided by for example burning natural gas at over 1000°C. (Bio)fuels and other high quality energy carriers are far more important for transport and heavy industry.

Fortunately, the low exergetic form of heat tends to be abundantly available in the surrounding environment and can be harvested by various technological means, for example with solar collectors or ground loop heat exchangers. On the other hand, of the many types of energy, heat is among the least transportable ones and therefore rather bound to its location. It can be displaced, but only over relatively small distances, through highly insulated heat networks.

For these reasons, the charting and quantifying of Dutch local heat characteristics – including demand - can give planners and (local) authorities a useful tool in designing and developing sustainable regions based on local (heat) potentials. The method of heat mapping is the latest development of Energy Potential Mapping (EPM)\(^3\) which has been applied and developed at different scales since its first development.

In the 'Heat maps; Dutch heat characteristics mapped' project, the EPM methodology evolved further resulting in three dimensional maps at national and regional scale, this time solely for heat (and cold). Not only the quantity of demands and potentials was visualised, but in a later stage the quality (exergetic value) as well, which improves upon its ability to show potential connections even more.

The Heat Maps project was carried out for the Dutch energy research agency Agentschap NL in order to help develop their online Dutch heat atlas. Within the assignment, the methodology and visualisation of the heat maps was tested for the whole of The Netherlands at a large scale and for two regions at a smaller scale. For these regions, the high density city of Rotterdam and the more regional city of Emmen with its surroundings were used as case studies.

At the national scale large residual heat sources, geothermal potential and other large scale sources for example are shown in a clear overview, whereas on the smaller scale more detailed local energy demands and potentials are also displayed. The differences in the regional cases show how demands and potentials are related to each other at different densities and locations in the Netherlands.
2. Heat mapping methodology

The purpose of a heat map is to provide a geographical overview of the various thermal sources and sinks and heat infrastructures in an area, showing the net energetic and exergetic balance and providing planners and other users a visual catalogue with which to design an energy landscape.

In order to gain a comprehensive overview of an area's heat characteristics, firstly all sources and sinks have to be defined. Following the EPM method, secondly, literature resources have to be identified that give the best available data on quantities, qualities and geographic dispersion, and in case of absence of these, alternate methods need to be used to calculate or estimate this. The available data on these heat sources and sinks is subsequently converted into equivalent units, and, new to EPM, this uniformity of data (encompassing only one type of energy) provides an opportunity to devise a new three dimensional visualisation method in which, finally, exergy is incorporated in such a way as to not make the resulting overview less legible.

2.1 Energy Potential Mapping

Over the past five years, the method of Energy Potential Mapping (EPM) has evolved into a detailed methodology for the development of spatial plans based on energy-effective foundations. By means of EPM the rudimentary features and properties of an area are analysed, made discrete and translated into maps of the specific area (be it a region, city, district or neighbourhood) depicting potentials for energy supply and generation. In the latest studies in accordance with EPM, these energy potential maps are presented as a stack at different heights (above the surface) and depths (underground), showing the maximum potential of an area. Based on these, a proposal can be made for the spatial organisation of the area.

2.2 Sources and sinks

Table 1 lists the input used for the heat maps, and shows which of the variables of location, quantity and temperature (quality) are defined for each type, although not all the data desired turned out to be available during the secondary research phase. For the various natural resources, the annually available amount of heat that can be harvested in a sustainable way, using present day technologies and avoiding single land use, has been calculated.

Locations can either be a point or an area, expressed in GJ or GJ/ha per year (or in suitability, in case of underground storage or heat exchange). The data is divided in the categories demand, supply and infrastructures. The right hand side of the table shows which data is suitable for which scale of map.

With each of the regional and national maps, the data was collected in large spreadsheets detailing each subregion, before translation into visual form.

<table>
<thead>
<tr>
<th>Input: desired data and variables</th>
<th>Heat demand</th>
<th>Heat supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>quantity (units)</td>
<td>temp.</td>
</tr>
<tr>
<td>Bulk consumers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industries</td>
<td>area</td>
<td>GJ/PJ/ha</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>area</td>
<td>GJ/ha</td>
</tr>
<tr>
<td>Hospitals</td>
<td>point</td>
<td>G</td>
</tr>
<tr>
<td>Heating plants</td>
<td>point</td>
<td>G</td>
</tr>
<tr>
<td>large scale consumers</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Residential area</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Commercial buildings</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Residual heat sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powerplant</td>
<td>point</td>
<td>G/PJ</td>
</tr>
<tr>
<td>Incinerator plant</td>
<td>point</td>
<td>G/PJ</td>
</tr>
<tr>
<td>Supermarkets</td>
<td>point</td>
<td>G</td>
</tr>
<tr>
<td>Specific heavy industries</td>
<td>point</td>
<td>G/PJ</td>
</tr>
<tr>
<td>Biorenewables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage treatment plant</td>
<td>point</td>
<td>G</td>
</tr>
<tr>
<td>residual biomass</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Solar collectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>global radiation</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>on roofs</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>on roads</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Geothermal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>underground (0-50m depth)</td>
<td>area</td>
<td>suitability</td>
</tr>
<tr>
<td>shallow (50-300m depth)</td>
<td>area</td>
<td>suitability</td>
</tr>
<tr>
<td>deep (&gt;2000m)</td>
<td>area</td>
<td>G/ha</td>
</tr>
<tr>
<td>Heat infrastructures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>district heating</td>
<td>layout</td>
<td>/</td>
</tr>
<tr>
<td>CHP</td>
<td>point</td>
<td>/</td>
</tr>
<tr>
<td>Biomass installation (CHP/incinerator)</td>
<td>point</td>
<td>/</td>
</tr>
</tbody>
</table>

Table 1: Example of input values for a regional heat calculation.
2.3 Exergy

The exergy of heat is the theoretical maximum work that can be obtained by bringing the heat in thermal equilibrium with the environment using a reversible process\(^2\). Originating from the second law of thermodynamics, exergy quantifies the quality of energy, which in case of heat relates to temperature. When assessing the heat potential of an area, it is beneficial to take this quality of heat into account.

Local industries for example may require higher temperatures than dwellings, and similarly the heat generated in greenhouses may not have a high enough temperature to heat a living room. Upgrading the generally ubiquitous low temperature renewable heat to a (less available) higher temperature with a heat pump requires additional energy, whereas high temperature heat using industries may have lower temperature waste heat available to establish a heat cascade. The resulting exergy landscape will thus make optimal use of the quality of valuable high temperature heat\(^4\).

For the Heat Maps project, sources and sinks have been divided into a number of common temperature ranges (30-50ºC, 50-70ºC, 70-110ºC and 110+ºC), as well as a separate entry for renewable fuels (which, if used for heating purposes, should only provide the highest temperature range).

The resulting area overview (Table 2) shows whether or not it is necessary to import high temperature heat or biofuels, or if it’s perhaps even possible to export these to surrounding areas.

### Table 2: Example of area exergetic heat analysis:
**Oud-Charlois, a Rotterdam neighbourhood.**
2.4 Visualisation

As part of the EPM method, an area analysis results in a stack of energy potential maps which each show the geographical characteristics of a specific type of energy potential, for example geothermal heat availability or electricity potential for wind turbines based on the average local wind speed at nacelle height.

The Heat Maps project builds on this, taking advantage of its focus on a single type of energy by introducing a cumulative third dimension in these maps (Fig. 1). Heat demand is shown as elevated contours; heat supply fills the resulting sink. When all these individual 3D maps are stacked, the resulting 3D landscape quickly shows where potentially demand may outstrip supply, and vice versa. Point sources like supermarkets, swimming pools, industry and power plants are depicted by cylinders, where the colour denotes heat or cold and hollow cylinders represent a net demand for an installation. Larger roads can be equipped with pipes to become giant solar collectors, and are depicted as yellow bands. If present, a district heating grid providing heat transport opportunities is hatched in red.

The next step, visualising the exergetic gradient of available and required heat - without reducing overall legibility - proved to be a challenge. The initial stack for example would be less visible if neighbouring areas have a higher total amount available, and the net balance for individual temperature ranges may be hard to read.

To eliminate these issues, the exergy data has been pictured as a 3D pie chart placed on top of each area (Fig. 2, rightmost model). Divided in equal sections, the outer ring corresponds to the demand for a temperature range, with the slices on the inside showing available supply.

Fig. 2: Evolution of the exergy component.
3. Case studies

To explore the visual component of the Heat Map methodology, case studies were done to areas of varying size. In this section, three of these will be described.

3.1 The Netherlands

For the national scale, available data was grouped into 40 COROP areas (clusters of municipalities). As small heat sources would have a limited national impact and would significantly reduce overall map legibility, only larger ones have been included in the national scale.

The map stack (Fig. 3) shows, from top to bottom:
- heat demand (glass houses)
- heat demand (residential areas)
- solar collector potential (residential and glass houses)
- point sources (power plants, sewage treatment facilities, etc)
- biomass (manure, residential organic waste and trimmings from public parks)
- geothermal potential
- ground source heat exchanger potential
- underground heat storage potential

The 3D composite map (Fig. 4) shows a large heat surplus in the Northern Netherlands (mostly due to geothermal heat), as well as a large net demand in the Rotterdam – Hague area (mostly due to greenhouses). Also visible are the many point sources and heat related installations (power plants, anaerobic digesters, sewage treatment facilities etc).

Fig. 3: Heat potential stack for the Netherlands.

Fig. 4: Composite heat potential map for the Netherlands.
3.2 Rotterdam

At around 600,000 inhabitants, Rotterdam, the second largest city in the Netherlands, has a combination of high rise and low rise dwellings, industry, harbours, an extensive network of (main) roads and various other facilities associated with a densely populated urban area like hospitals, a zoo and a large sewage treatment facility.

As high-rise areas have far less m² of roof per dwelling and are overall somewhat less effective due to shadowing on the lower buildings, a multiplier was applied for some areas to factor this in. As dwellings have a relatively limited range it was possible to estimate heat demand and supply per area. Comprehensive data on heat in industrial processes within the harbour areas along the Maas river was however unavailable due to the highly diverse nature of commercial activity there, but, where possible, individual factories and other installations have been included.

The map stack (Fig. 5) shows, from top to bottom:
- heat demand (residential and glass houses)
- main roads (road solar collector) and rivers (cooling)
- point sources (swimming pools, supermarkets, etc)
- solar collector potential (residential and glass houses)
- biomass (manure, residential organic waste and trimmings from public parks)
- geothermal potential
- an area map
- ground source heat exchanger potential

The 3D composite map (Fig. 6) shows a heat surplus in the relatively sparse populated southern areas, as well as a large net demand in the densely populated city centre.

Fig. 5: Composite heat potential map for Rotterdam.

Fig. 6: Heat potential stack for Rotterdam.
3.3 Emmen

At around 100,000 inhabitants, the regional centre of Emmen provides many facilities for the surrounding areas, like a hospital, swimming pools, a zoo and a large sewage treatment facility. Several district heating systems can be found in the area, although some are reported to currently not be in use. Geothermal potential is moderate but adequate. Comprehensive data on heat in industrial processes within the commercial zones was incomplete, but, where possible, individual factories and other installations have been included.

In order to get a similar size area as the other city level case studies, the map contours do not always follow the city limits, but form a smaller, somewhat rectangular area.

The map stack (Fig. 8) shows, from top to bottom:
- heat demand (residential and glass houses)
- main roads (solar collector potential)
- point sources (supermarkets, swimming pools etc)
- solar collector potential (residential and glass houses)
- biomass (manure, residential organic waste and trimmings from public parks)
- geothermal potential
- an area map
- ground source heat exchanger potential

The composite 3D map (Fig. 7) shows a net demand in the densely populated areas to the west, a significant demand and supply in the greenhouse complex to the east, and a net surplus in most of the sparsely populated areas in the middle.

![Fig. 7: Composite heat potential map for Rotterdam.](image)

![Fig. 8: Heat potential stack for Emmen.](image)
4. Conclusions

The heat map methodology provides an accessible visualisation of the balance between heat demand and supply in an area. The focus on low temperature heat (which can't be transported very far), does mean heat maps on a regional scale will be more useful than the national map. This however is also the reason the maps work well visually: the energy scale for low temperature heat sources is of course relatively limited.

Although the 3D maps developed during the project were intended as a proof of concept and are static in nature, they do give a clearer overall view than in the current situation where this information is hidden in many reports and drawings, and the compounded information in the map can easily be accessed and separated by clicking on objects or turning off layers. This will speed up transition to more sustainable sources of heat, by helping planners make informed decisions on infrastructure investments and which technologies to stimulate where.

5. Future development

During the course of the project, several venues were identified that would increase the value of Heat Maps as a planning tool.

5.1 Heat inventory

The main limiting factor in this project was the availability of comprehensive data on heat production and demand. Although nationwide geothermal data is relatively easy to come by, detailed information on for example age, type and energy efficiency of dwellings or the internal heat cycles of various types of industrial plant was often unavailable. Gathening this data would greatly increase the accuracy of each map.

5.2 Interactive maps

Even though the 3D landscapes can be explored in detail by panning, tilting and turning layers on and off, they are still static models. During the project, more interactive parametric models were briefly investigated with Rhino and Grasshopper, and, given a base vector map of an area, sufficient data and an expanded script, it is certainly possible to use the Heat Map methodology to investigate various future scenarios and their geographical impact on heat distribution, by generating heat maps instantly.

Another venue of interest would be to tie existing data on heat distribution and availability into Google Maps. As the number of data sets available in Google Maps ever increases, the ease at which these can be projected on one another will provide a valuable tool for urban and regional planning, allowing optimisation of heat use while factoring in many other criteria.

5.3 Temperature and time

Many (renewable) heat sources and sinks have outputs and requirements that fluctuate over time, and will operate at different temperature ranges. Although this study initially focused on lump sums of GJ and TJ per year for each category, investigating this temporal component of renewable heat and including an exergetic analysis would make it possible to quantify storage requirements for heat in an area, for example the necessary amounts of biofuels or aquifer storage, thus increasing accuracy of projections.
6. References