The European District Heating Database and Mapping European District Heating Systems

CAMPUS
Geel

Joris Put

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**PREFACE**

For my master thesis I have chosen to go abroad as an extra challenge and because I wanted to have a unique experience. Thanks to the great support I received from my parents, this has been possible. The moment this subject was available for a master thesis and I had shortly been explained what district heating was about, I immediately accepted it. I find it very interesting to learn about new ways of dealing with energy more efficiently, reducing the impact on the environment, saving energy, new forms of energy, etc. Therefore the decision to work on this project was easily made, and it brought me here, to Halmstad in Sweden.

The thesis has taught me that we still have to do a lot of work if we want to make district heating more present at the heating market. But it is not impossible. Sweden is a country that has a 60% market share for district heating, so travelling to Sweden to work on this subject and also experiencing that it works really good, made it very easy to believe that this is feasible on a relatively short notice. Sweden shows us that it is possible and that they have the knowhow. Now the biggest issue is to convince other countries that district heating works there as well. And that is where I hope my master thesis can help a little bit.

I would like to thank Sven Werner, professor of Energy Technology at Halmstad University, for the opportunity. It is thanks to his approval that I could come to Halmstad and contribute to this project. He also provided me with extra data and tips about how the database should work and which maps should be created.

I would also like to thank Urban Persson, PhD student at Halmstad University and director of studies, Energy Technology at Halmstad University. He helped me with building the database, gave advice, cooperated and helped searching for extra data and maps.

Also Annette Böhm, researcher at Halmstad University, deserves a word of thanks, because she gave Urban Persson and me the short but very good and necessary tutorial about ArcGIS. Without this tutorial I would not have been able to create the maps that I have today. These maps are a useful instrument for drawing and illustrating conclusions from the database. Without them I could not have stated the conclusions I made at the end.

Since this master thesis is in English, I would like to thank Dominique Kimpen. She did a tremendous job on correcting the text after the largest part of the thesis was finished. After that, when the master thesis almost had to be finished, she reviewed it again to make sure all mistakes were gone.

Last but not least, I would like to thank my teacher Geert Van Ham. He made the initial contact with Sweden after I had registered myself for a master thesis abroad. Besides, he guided me through the project and gave some advice on how to write this text. Without his help I probably would not have been to Sweden in the first place. At the end he corrected my text as well, to eliminate all errors and make sure the phrases were evident.
SUMMARY

District heating is a relatively unknown method for heating purposes, yet it is one of many solutions to reduce our impact on the environment and our need for primary energy sources. In order to make it more familiar, research has to be done to see where it is already well established, and where improvement is possible. Therefore, it is useful to have a central database where all the important data concerning district heating facilities and their cities or countries are centralized. Furthermore, maps of Europe created with this data can give a clear overview of where improvement could be possible.

Creating this database was a big task, since it had to contain almost all the cities in Europe. Nevertheless, the result is a useful database with all the available data. Besides that, adding data is easy, which makes it a very user-friendly database. The data revealed that there were only a few countries that had established a good district heating network, namely Sweden, Finland, Denmark and Iceland. Other countries such as France and Switzerland have rather small systems, resulting in a low amount of heat generated for such countries.

The maps drawn from the data in the database support these earlier conclusions: the Nordic countries have a well-developed district heating network. Improvement is possible in other countries, certainly with today’s high oil and gas prices.
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ABBREVIATIONS

CHP   Combined Heat and Power
UTF-8 8-bit Unicode Transformation Format
EU    European Union
EFTA  European Free Trade Association
CC    Candidate Countries
NUTS  Nomenclature d’Unités Territoriales Statistiques
W     Watt
J/s   Joule per second
Ws    Watt second
J     Joule
Wh    Watt hour
GWh   Gigawatt hour
MWh   Megawatt hour
TJ    Terajoule
SI-unit Système International d’Unités
GJ    Gigajoule
SEK   Swedish Kronor
INTRODUCTION

District heating is an excellent yet rather simple solution to deal with today’s problems as to the heating of buildings: environment and carbon dioxide emissions, using oil (derivatives) and gas to heat buildings and the cost of heating this way.

The main goal of this master thesis is to dispose of a central database containing all the present data concerning district heating systems in EU27. Also a graphical presentation of those data using maps has to be developed for drawing and illustrating conclusions from the database. These maps clearly show the current situation and possible improvements in the European district heating network. The maps have been generated by the means of the computer program ArcGIS.

Before starting to construct the database and the maps, a basic knowledge of district heating was necessary. By the means of an introductory course, these basics were acquired thanks to a good cooperation with Sven and Urban.

The first chapter of the text briefly discusses the education and research at Halmstad University.

The second chapter discusses the fundamentals of district heating, its historical background and the current situation in Europe. Also the different forms of district heating are discussed on a basic level.

The database that has been constructed contains demographical and geographical information, as well as information about the existing district heating systems. Chapter three describes how the database is constructed, what use it has and how it can contribute to the expansion of district heating systems.

In chapter four the data from the database are displayed on maps of Europe. These maps make it more clear where district heating is represented and where expansion possibilities are present. There are maps showing the size of district heating systems, but there are also maps showing the specific deliveries of district heating. The latter gives a clear view of how many people can benefit from district heating systems today and how many people could benefit if the capacity would increase in the future.
1 **Halmstad University in Sweden**

Halmstad University is one of the larger universities in Sweden with almost 15000 students this academic year. Of those students, over 1000 of them are foreigners. It is one of the more popular universities to study abroad. Halmstad is located in the south of Sweden:

![Map of Sweden](https://via.placeholder.com/150)

*Figure 1.1  Map of Sweden (Source: Google)*

Halmstad University originated in 1970, when the authorization was given to start up a university in Halmstad. Three years later the first project began. In 1975 the Swedish parliament approved the university to start higher education and two years after that, the higher education program started. In the next 5 years several courses and programs were started such as after-school assistant, sports education, pre-school
teacher and innovation engineer. This widened the university’s offer. The university was formally inaugurated in 1983 and consequently became a fully independent university. After 5 years already, in 1988, the university moved to its current location in Larsfrid.

6 years later, in 1994, Halmstad university received the permission to deliver master degrees. From then, the university expanded their offer of specializations with the introduction of a College of Nursing, the permission to examine master students from computer technology, Health Science, Business and Economics ... The university also invested in expanding their accommodation. This was necessary to continue to deliver the quality education and also because they had a continuously wider offer of degrees. For the Health Science they introduced the new health and sports centre, built in 2006.

Besides Swedish students, the university is also welcoming a large number of exchange students each academic year. A lot of students with plans to study abroad are coming to Halmstad. Thanks to The Student Union it is easy to travel to and to live in Halmstad. The Student Union is an organization integrated in the university that helps foreign students with finding student homes, filling out administrative documents, etc. Because of all these resources is was not only easy but also a privilege to go to Halmstad for my master thesis.

The department for this master thesis was the School of Business and Engineering. This department educates in economics, engineering and natural sciences. Besides education they also offer the opportunity for PhD students to do research as well as for postgraduate students by the means of a research school. There are three research centres: Biological and Environmental Systems (BLESS), Centre for Innovation, Entrepreneurship and Learning research (CIEL) and the Mechanical Engineering and Industrial Design (MTEK). These centres conduct research on applied natural sciences, biomedicine and biomechanics, ecology and environmental sciences, but also on innovation and product development work, strategy, management, finance, etc. There is also the Rydberg Laboratory. This is a laboratory where they research in the field of natural sciences, related technical sciences and mathematics. The Rydberg Laboratory
works closely with the School of Information Science, Computer and Electrical Engineering, also a division of Halmstad University. This master thesis is part of the research in the BLESS research centre, where Sven Werner conducts two research projects: Remote heating system technology and Swedish energy system solutions. The “remote heating system technology” project actually comprises several projects concerning future heating needs and also the competitiveness of remote heating in the future. The “Swedish energy system solutions” project is a sub-project where this master thesis is a part of. It is a project that tries to expand the knowhow from Swedish remote heating systems over Europe.
2 DISTRICT HEATING

2.1 What is district heating

The title already tells what it means: heat for a whole district. The idea is to generate heat from a centralised source and deliver it to the people. The fuel used is an energy source that otherwise would not be used or energy (heat) that otherwise would be lost. The heat is then delivered to the customers through a network of pipelines, mostly located underground. The heat customers consist of residential buildings, office buildings, small industrial buildings, etc. “The five suitable strategic local energy resources are waste heat from thermal power stations ( cogeneration); heat obtained from refuse incineration; useful waste heat from industrial processes; natural geothermal heat sources; and fuels difficult to manage, such as wood waste, peat, straw, or olive stones.” (Werner, 2004). These different energy resources give rise to different methods and systems for district heating. The location where the heat will be delivered, the heat demand, the cost effectiveness, etc. also influence the choice of a specific district heating method.

A good example of strategic use of a local energy source is Iceland. This volcanic island uses the geothermal heat available on the spot to create a district heating network almost over the entire island. The result is that nearly every building can be heated by connecting it to a district heating network. This way, Iceland uses almost no primary energy sources for heat generation and saves an enormous amount of carbon dioxide every year, helping the environment. This shows that a district heating network is feasible and can be economically justified if you have a local energy source that is cheap enough to compete with conventional ways of heating.

Figure 2.1 shows the principles of district heating.

![Figure 2.1 Principle sketch of district heating (Source: http://www.bd-heatech.com)](http://www.bd-heatech.com)

The hot water delivered to the buildings has a temperature between 70 °C and 150 °C. This temperature changes with the outdoor temperature. On cold days the supply temperature is high because the heat demand is high. The delivered heat is then used for heating purposes as well as for hot domestic water. On warmer days the supply temperature is lower, because the heat demand is lower then. There is still a certain hot water delivery because of the need for hot domestic water. The return temperatures vary between 35 °C and 70 °C. This also depends on the weather, but
could also indicate defects or a relatively small heat market in the considered area. A low return temperature means a lot of heat is dissipated. So if the return temperature is higher than usual, people are not using a lot of heat, the circuit of pipelines is short, or there is a defect in the installation.

Transportation of heat (hot water) always results in a certain amount of heat losses to the environment. About 5% to 10% of heat losses, depending on the scale of the network, are common in a district heating system, but the losses can reach up to 20% or 30% if the heat market in that area is small.

2.2 Historic background

The oldest district heating system is located in Chaudes-Aigues, in France. This system is based on geothermal heat and was operational in the 14th century. Wooden pipes were used to distribute the hot water from the source. It is still operational today and therefore the oldest system known.

The first commercial district heating system was created by inventor and hydraulic engineer Birdsill Holly. As an experiment to prove his concept, he installed a steam heating system in his garden in 1876. The system consisted of a boiler in his house as the steam generator, a long network of pipes under the ground so he could prove that he could transmit heat over a long distance and a connection to his living room. With this system he convinced investors that his invention worked. One year later, in 1877, he started up his company called Holly Steam Combination Company in Lockport and it resulted in the first steam supply system. After his invention, several district heating systems started in the United States.

In Europe, the first district heating system appeared around 1900 in Dresden, Germany. It took almost 20 years before other large cities started a real commercial district heating system as well. Hamburg, Berlin and Frankfurt in Germany followed the example of Dresden, after which several other cities in Germany started with district heating as well. Outside Germany, cities like Copenhagen, Paris, Reykjavik, Stockholm, Helsinki ... started district heating systems. All in a time span of 30 years starting in 1925 in Copenhagen and up to 1953 in Stockholm and Helsinki. In Germany meanwhile, after World War I and II district heating was promoted. The main driving force was the high fuel prices. Russia developed the most comprehensive district heating system around that time, thanks to their plan to reduce the fuel demands.

Not only the systems themselves have undergone an evolution, the pipelines under the ground have too. The very first district heating system used wooden pipes for delivery. Later, when the first commercial district heating systems were created, the pipelines were steel pipes insulated with mineral wool. They were placed in a concrete box and put into the ground. This was done to maximize insulation. Nowadays modern technology has stepped in. Modern systems use steel or plastic pipelines surrounded with insulating foam and put them in a plastic case. The evolution of modern plastics resulted in a cheap way of construction, and in high insulating properties of the foam used.
There are two ways of constructing the pipelines:

Large district heating pipes are often buried under the ground in two separate pipes, one flow pipe and one return pipe (figure 2.2). These large pipes are used to deliver a high flow of hot water. Small district heating pipes often consist of one pipe (figure 2.3). A cross section of the pipe reveals that the two pipelines are cased in one plastic casing, of course highly insulated by the foam. This makes systems and installation costs low and connection easy.

2.3 European heat market

After a while it became clear that district heating had a significant market share in the Nordic countries. The reason for that is rather obvious. Since these countries are in a colder climate, they have a better organized heating system to survive the cold days. This better organized heating system also involves district heating. As the technology and knowledge started to grow, the market share grew as well.

In Sweden there is another reason why district heating is so present. When in the 80’s the oil price climbed dramatically, the Swedish government introduced the high taxes on oil and natural gas. This was done to punish out the oil in order to reduce oil dependency. About 10 years later, in 1991, the government introduced the carbon dioxide taxes, which made the price of oil and natural gas climb even more. All this seems like bad planning of the government, but they thought this very well trough. These measures gave alternative energy sources a chance to develop themselves, so that they could be competitive with oil and natural gas. And of course district heating developed as well. It is because of these measures the market of district heating share climbed to 60% today, and oil dependency dropped to just 5%.

What is the reason this does not work in other countries? First of all if the government does not punish out the oil, it will not lose its market share because it is an established energy source and therefore still easy and cheap. Low prices of oil and natural gas mean that investing in alternative energy sources, like district heating, is economically not interesting because the development and implementation costs are too high compared to the price of oil and natural gas. Another problem is that there always has to be an entrepreneur taking the initiative to start up such a district heating system and
thus he or she has to have a lot of money available. It is not always such a problem to find investors for such projects, but they expect that their investment pays itself back in a couple of years. But that is not how it works with district heating, which could take more than 10 years to pay itself back. This is why it is often the municipalities that have to take the initiative to start up a district heating system.

Besides punishing out oil and encouraging investors to invest in district heating systems, there are some other things that can be done to make district heating more present at the European heat market. One of the main things to do is to make it more transparent. This means to make it more accessible to customers and market analysts. For instance, the prices of oil are updated weekly in Europe, and you can download them free. Unlike the prices of district heating, which are not available or there are no data. If the prices from countries with district heating are available, one can compare these with prices of oil or gas. Spreading the benefits can help as well and improving communication to the people, scientists, engineers, politicians ...

One can say that the European heat market has a high diversity. Different forms of heating are used in different climates. The Nordic countries have a highly developed heating system because of the cold climate they are in, with a significant market share for district heating. On the other hand there is the south of Europe where the heating system is rather undeveloped since there is almost no heat demand due to the warmer climate. Then there is the intermediate climate of the intermediate countries where there is a high diversity of heating methods. All these methods, as well as the politics, cost ... form the European heat market. It is very difficult to capture this market in one definition.

2.4 Different forms of district heating

Depending on the energy source, several forms of district heating are available:

- Combined heat and power generation (CHP)
- Waste-to-energy
- Surplus heat
- Geothermal heat
- Combustible renewables
- Solar district heating
- Nuclear heat
- Others

The following paragraphs discuss these forms more in detail.

2.4.1 Combined heat and power generation (CHP)

"Throughout the world history of district heating, CHP has been the main driving force for district heating” (Werner, 2006). It is actually a very good example of using energy more efficiently. When a conventional plant wants to generate electricity, it generates heat to create steam under high pressure. This steam will then propel a turbine that is connected to a generator and that produces electricity. But after the steam has passed the turbine, it has completed its cycle and has to return to the starting point of the cycle again as water. So the steam will be cooled by using cooling towers and the excess heat is released in the atmosphere.
So part of the primary energy (oil, natural gas, coal ...) is converted into electricity and part of the energy is lost into heat. Instead of just throwing the heat away, this heat can be used for a district heating system. In a very simple and rudimentary example, it is sufficient to install a heat exchanger behind the turbine to heat up the water of the district heating system using the heat of the steam that comes from the turbine as is shown in the next figure:
This hot water can then be transported to buildings to heat them. By using this principle, the same amount of primary energy is used in the power plant, but more people have benefitted from it. The buildings that are connected to the district heating network do not need to have a heating system based on oil or natural gas. This means that the efficiency has gone up. Conventional power generating plants using oil, natural gas or coal as energy source have an efficiency of around 40%, depending on the technology used. State of the art plants can have efficiency ratings up to 55%. So around 45-60% of the energy put in to the plant is lost in heat! When having a CHP plant, these efficiency ratings can reach up to 80% for the most modern facilities. This is a considerable amount of energy that is being saved. It is obvious that reaching higher efficiency ratings means saving energy and reducing carbon dioxide emissions. The next figure points out the savings possible with CHP:
A conventional power plant uses a certain amount of energy to generate electricity. This used energy is also converted into lost heat. These losses could partially be recovered with a CHP plant. As one can see in figure 2.6, the CHP plant uses the same amount of energy, yet it is able to meet the heat and power demand resulting in a more efficient use of energy. The conventional methods on the other hand have to use a second energy source to meet the heat demand (usually a local boiler). This results in a more efficient use of energy.

### 2.4.2 Waste-to-energy

The waste is converted into energy, in this case heat, by incineration. Since there are a lot of waste incineration plants, this is an opportunity for district heating. Otherwise the waste is just burned and the heat is released into the atmosphere. Of course the most important step in waste management is to recycle as much waste as possible. This is the best and most environmental-friendly solution to the waste problem. When recycling is not possible, waste incineration is the next solution. District heating makes it possible to use the produced heat for heating buildings. If incineration is not possible, landfill will be the solution.

It seems paradoxical, but incineration is better for the atmosphere than landfill. This is because landfill produces methane, also known as landfill gas, and methane causes a 21 times stronger greenhouse effect on our atmosphere than carbon dioxide. So by burning the waste, the amount of waste that otherwise would end up as landfill is reduced and also the impact on the environment is reduced because this waste cannot produce any landfill gas.
Recently, the city of Houthalen-Helchteren in Belgium delivered the permit for a company called Bionerga to build a new waste incineration plant in Houthalen next to the old one. The old one has a capacity of burning 100000 tons of waste a year; the new one will have a capacity of 200000 tons a year and eventually will replace the old one. This is a great opportunity to integrate a district heating system for this city.

A quick calculation explains what implementing a district heating system in this plant could mean:

Municipal waste has a calorific value of approximately 9 MJ/kg. This value can vary slightly depending on the content of the waste. This means that the amount of heat that can be generated by the plant is:

\[
Q = 200 \text{kT/a} \cdot 9 \text{MJ/kg} = 1,8 \text{PJ/a}
\]

Suppose the installed heat exchanger has an efficiency of 80% and the district heating network has an energy loss of 10%. This means 70% of the heat is recovered. This is a total of:

\[
Q_{\text{rec}} = 1,8 \text{PJ/a} \cdot 0.7 = 1.26 \text{PJ/a}
\]

- **Savings with respect to heating with oil:**
  The oil used for heating purposes has a calorific value of \(S_{\text{oil}} = 35.8 \text{MJ/l}\). An average family uses between 2500 l and 3000 l a year to heat their houses and to meet the hot water demand. Thus every family needs an amount of heat in between:

\[
2500 \text{l} \cdot 35.8 \text{MJ/l} = 89500 \text{MJ/a}
\]
\[
3000 \text{l} \cdot 35.8 \text{MJ/l} = 107400 \text{MJ/a}
\]

This means that a district heating system, using the recovered heat of the waste incineration plant can provide a lot of families with sufficient energy to heat their houses. The exact number of families that can be provided with heat is:

\[
\frac{1.26 \text{PJ/a}}{89500 \text{MJ/a} \cdot \text{family}} = 14078.21
\]
\[
\frac{1.26 \text{PJ/a}}{107400 \text{MJ/a} \cdot \text{family}} = 11731.84
\]

Depending on the average amount of oil used (2500 l or 3000 l), the district heating system could deliver heat to 11731 up to 14078 families. The district heating system also reduces the CO\(_2\) emissions. The amount of oil saved by the system is:

\[
11731 \cdot 3000 \text{l} = 35195000 \text{l}
\]
\[
14078 \cdot 2500 \text{l} = 35195000 \text{l}
\]
Burning 1 l of oil emits 2,7 kg CO\(_2\). Therefore the amount of CO\(_2\) emissions that could be saved is:

\[
35195000 \cdot 2,7 \text{ kg CO}_2/1 = 95026500 \text{ kg CO}_2 = 95026,5 \text{ tons CO}_2.
\]

- **Savings with respect to heating with natural gas:**
  
  An average family uses approximately 23260 kWh a year for heating and other purposes such as warm water. Natural gas used for heating purposes has the following calorific value:

  \[
  S_{\text{gas}} = 8,8 \text{ kWh/m}^3
  \]

  \[
  S_{\text{gas}} = 31,7 \text{ MJ/m}^3
  \]

  Therefore an average family consumes annually:

  \[
  \frac{23260 \text{ kWh}}{8,8 \text{ kWh/m}^3} = 2643 \text{ m}^3
  \]

  \[
  31,7 \text{ MJ/m}^3 \cdot 2643 \text{ m}^3 = 83789 \text{ MJ/a}
  \]

  Similar as in the calculation above the number of families that could benefit from district heating can be calculated:

  \[
  \frac{1,26 \text{ PJ/a}}{83789 \text{ MJ/a} \cdot \text{family}} = 15037,8
  \]

  Hence 15037 families could benefit from the district heating system. The amount of natural gas that is saved is:

  \[
  15037 \cdot 2643 \text{ m}^3 = 39742791 \text{ m}^3
  \]

  Burning 1 m\(^3\) natural gas emits 2 kg CO\(_2\). Therefore the amount of CO\(_2\) emissions that is saved is:

  \[
  39742791 \text{ m}^3 \cdot 2 \text{ kg CO}_2/\text{m}^3 = 79485582 \text{ kg CO}_2 = 79486 \text{ tons CO}_2
  \]

  Burning waste of course also emits CO\(_2\). Depending on the kind of municipal waste, burning 1 kg of waste emits between 0,7 kg CO\(_2\) and 1,2 kg CO\(_2\). When the plant is burning 200000 tons a year, this means that it is emitting between 140000 tons CO\(_2\) and 240000 tons CO\(_2\). The district heating system does not cancel the CO\(_2\) emissions from the waste incineration plant. However if the plant just burns the waste and there is no district heating system, the total CO\(_2\) emission will be higher because the families will burn oil or natural gas for heating their houses. Installing a district heating system results in a reduction of CO\(_2\) emissions of about 95000 tons compared to heating with oil and of about 79500 tons compared to heating with natural gas. Graph 2.1 shows this:
The graph has two columns. The dark column represents the CO₂ emission when 1 kg of waste emits 0.7 kg CO₂. The lighter column represents the CO₂ emission when 1 kg of waste emits 1.2 kg CO₂. The graph shows that burning natural gas results in less CO₂ emission than burning oil. The most important conclusion however is that district heating can substantially reduce the CO₂ emissions. Moreover, a substantial amount of oil or natural gas is saved. Implementing district heating on each waste incineration furnace has a great potential for saving oil or natural gas and the corresponding CO₂ emissions.

This is only a rough calculation. The numbers vary if one uses different assumptions. One of the largest influences is the content of the waste. Depending on the waste the plant will incinerate, the calorific value and the amount of recovered heat changes as well as the amount of CO₂ emissions. It is also important to note that the annual calculation is not completely correct since during the winter months the heat demand is much larger than during the summer months (when there is only a small demand for hot domestic water). So when implementing district heating, more accurate calculations are necessary. The calculation in this paragraph was made just to give an idea of what district heating could mean for saving energy resources and reducing carbon dioxide emissions.

That said, the plant built by Bionerga will not be an unsophisticated waste incineration plant. It will be a state of the art plant using the latest technology to reduce emission. They call their plant a “biosteam power station”. It will be a plant using the heat from the incineration process to generate electricity. According to their presentation and calculations it will power around 55000 families. However, as shown by the calculation, installing a district heating system could further reduce the environmental impact.
2.4.3 Surplus heat

Surplus heat is excess heat available in industrial plants. The district heating system will use the excess heat to warm up the water for the heat consumers with the help of a heat exchanger. The risk with this form of district heating is that if the plant closes down in a couple of years the district heating system also stops. This makes it very difficult to find investors for this kind of district heating. Moreover the payback times of district heating are quite long, so the investors need the guarantee that the plant does not close in the next years. However for the managers of the plant district heating can also mean an extra financial source that helps staying longer in business and can reinforce the market position of the plant.

2.4.4 Geothermal heat

District heating systems working with geothermal heat use the heat Mother Nature provides us with. If there is a hot water spring under the ground, it is very easy to use this water for district heating. That is why almost all Iceland is heated with district heating: there are a lot of hot water springs on this volcanic island. Figure 2.7 shows a principle sketch of geothermal district heating:

![Figure 2.7 Principle sketch of a geothermal district heating system](http://geothermal.marin.org)

The red arrows represent the hot water that is pumped from the ground. This is sent through a counter current flow heat exchanger (for maximum heat transfer). The cooled water, represented by the blue arrows, is then sent back to the source where it can heat up again. In the heat exchanger, the heat from the hot water is transferred to the water from the district heating network. It is then pumped around the network to provide the different users of the network with hot water.

The biggest problem (and cost) is drilling the holes to get to the hot water. But once the holes are drilled, only a pump is needed to get the water to the surface and to distribute it. This means that the running costs are very low.
Most of these boreholes were not drilled to find hot water, but to find oil or natural gas. This is because oil is much more profitable than hot water, as is proved below. The amount of heat energy that can be extracted from a hot water source equals:

\[ Q = m \cdot c_p \cdot (t_s - t_r) \]

\( Q \) = thermal energy
\( m \) = mass
\( c_p \) = heat capacity of water = 4.19 kJ/kg\( \cdot \)\( ^\circ \text{C} \)
\( t_s \) = supply temperature of the water
\( t_r \) = return temperature of the water

Suppose that the supply temperature is 100 °C and the return temperature is 40 °C and we have 1 l or 1 kg of water. The thermal energy per kilogram or heat value is:

\[ \frac{Q}{m} = 4.19 \text{ kJ/kg} \cdot \text{°C} \cdot (100 \text{ °C} - 40 \text{ °C}) \]

\[ \frac{Q}{m} = 251.4 \text{ kJ/kg} \]

For oil the thermal energy per kilogram is approximately:

\[ \frac{Q}{m} = 42000 \text{ kJ/kg} \]

It is obvious that finding oil is much more profitable than finding hot water of 100 °C. The heat value of oil is 167 times the heat value of water:

\[ \frac{42000 \text{ kJ/kg}}{251.4 \text{ kJ/kg}} = 167.06 \]

However it does not mean that finding hot water is useless. As explained above the running costs of a district heating system using geothermal heat is relatively low. Iceland is the best example of this. It is a volcanic island, which means that there is a lot of hot water under the ground. They installed several district heating systems with the result that almost all of Iceland is heated with district heating. Iceland is not a very densely populated country, but given that almost the entire population uses district heating, this results in two major benefits. First, the amount of CO\(_2\) emissions saved annually is enormous. Second, the amount of primary energy resources saved is also substantial, since otherwise the people had to heat their houses with oil, natural gas ... The very cold climate Iceland is in would result in an even higher use of these energy sources than average in Europe.

2.4.5 Combustible renewables

According to the ECOHEATCOOL Work Package 4 by Werner (2004) the combustible renewables consist of:

- Solid Biomass such as woodchips and bark from the forest industry, sawdust and shavings from the saw-mills, etc.
- Biogas, which are gasses consisting mostly of methane. Sources are landfill (landfill gas), agricultural waste, etc.
- Liquid biomass such as methanol, ethanol, etc.

This form of district heating systems can be a solution for remote regions that have limited access to primary energy sources such as oil and natural gas but are close to
energy sources of this kind. Also, using this kind of renewables means using waste or by-products that otherwise would be considered as useless.

This could also be an opportunity for a CHP plant on a remote location. Using these renewables as the fuel to produce high pressure steam and using the waste heat to meet the heat demand in that area.

2.4.6 Solar district heating systems

The sun can be used to generate electricity with photovoltaic solar cells, but it can also be used for district heating systems. By placing large collector fields in an open area with a respectable amount of hours of sun, these collectors can create hot water for the purpose of district heating. The technology behind it is simple. A basic solar collector consists of a panel with a transparent top and a dark bottom in the sun to maximize absorption of solar irradiation. Between the top and the bottom plate a piping system is placed, in which the water is warmed by the sun. The next figure shows a detailed image of such a panel:

![Flat Plate Collector](http://www.southface.org)

Figure 2.8 Detail of a solar district heating panel (Source: http://www.southface.org)

New technologies have changed the design of the panels and it is starting to become more common to have panels with pipe shaping’s. By placing a large amount of panels in a field and connecting them to a warm water storage tank, the generating part of the district heating system is created. When the sun is shining it also keeps houses warm. This results in a lower heat demand. By creating a buffer this problem could be bypassed. This buffer could for instance be a storage tank.

For now solar district heating systems are only available in Denmark, Sweden and Germany. But those systems can also be used in countries in a warmer climate, since heat can also be used to satisfy local cooling demands with the help of an absorption chiller. The heat coming from a solar district heating system can drive the absorption chiller and thus create cold air for air conditioning or other cooling purposes. Paragraph 2.7 further explains this.

A personal experience has learned that in Turkey solar collectors are quite common, although not on an industrial scale. Almost every house, no matter how small, has a solar collector on its roof. This means that every house is self-foreseeing in its heat demand, which is most of the time rather small since Turkey is in a warmer climate.
2.4.7 Nuclear heat

This is a less frequently used way of district heating. This method is actually an alternative way of CHP. Heat of a nuclear reaction is transferred to the water from the district heating system through a heat exchanger. This also creates a barrier against possible nuclear contamination of the water because there is no contact between the cooling water of the nuclear reactor and the water of the district heating system. There is the safety of a "wall" between them. But this form of district heating is not often used because by using heat from the system, capacity to generate electricity is reduced. Since electricity has a higher direct market value it is more profitable to generate electricity instead of using the heat for district heating. Also, there is the problem of distance. Most nuclear plants are located far from the cities, so there has to be a major investment in connecting pipes to transport the hot water to the city.

2.4.8 Others

There is also the possibility to use electric boilers, heat pumps or surplus electricity for district heating purposes, but these methods proved to be less efficient than the other technologies discussed above, and therefore are not often used. Surplus electricity is the excess electricity a country produces at a given moment (electricity that is not consumed at that moment). For instance Iceland is a country that is not connected to any international power grid. If Iceland should encounter a problem with surplus electricity they could create some sort of buffer where the excess electricity would be converted to heat in electric boilers. This heat can then be distributed in the district heating pipeline network. The stability of the electricity grid is guaranteed and the energy is used so that the district heating network can benefit from it. But nowadays almost all countries are connected to an international power grid and can sell their excess electricity on an international market. This means that this system of surplus electricity is outdated. Besides that, the existing facilities will not be upgraded when needed, because other technologies have proved to be more efficient and more modern. Therefore these systems will not be further discussed.

2.5 Final end user costs

For a district heating network to pay itself back, the end user has to pay the heat he consumes. The consumed heat is recorded by a heat meter, measuring the water flow and the difference in temperature between the flow and return pipes of the customer. From those measurements the heat meter calculates the heat volumes (GJ, kWh, etc.). A private owned district heating system often maintains higher prices than municipal owned systems, because for private owned systems the payback time is more important. Also their prices often vary according to the prices of the heating alternatives (oil, natural gas, etc.). According to Werner (2004), typical prices for district heat deliveries were $6-13/GJ in OECD countries (Organisation for Economic Co-operation and Development) in 1999 and 2000. The geothermal system in Reykjavik was an exception, with only $4/GJ. Eastern Europe prices were around $3-7/GJ. To have an idea of the general costs of other heating alternatives in 2000, the next calculation shows the costs of heating with oil in Belgium:

In January 2000 the heating oil cost 12,14 Belgian franc (BEF) per litre. In the same period, 1$ equalled 39,8406 BEF. Therefore:

$$12,14 \text{ BEF}/l = 0,3047 \frac{5}{l}$$
Oil has a calorific value of 35.8 MJ/l or 0.0358 GJ/l. The price of oil in terms of calorific value is then:

\[
0.3047 \text{\$/l} = \frac{0.3047 \text{\$/GJ}}{0.0358 \text{GJ}} = 8.51 \text{\$/GJ}
\]

This result shows that for Belgium district heating was not necessarily more expensive than the conventional methods of heating in 2000. For natural gas there was no data found of the costs in 2000.

A research by the Nordic Energy Perspective Research Group revealed the prices of district heating in Sweden and Finland. The prices in Sweden varied between 351 SEK/MWh and 621 SEK/MWh in 2006. In January of the same year, 1$ cost 7.73 SEK. This means that the prices for district heating vary between 45.4 $/MWh and 80.3 $/MWh. As shown in paragraph 3.4.3:

1 GWh = 3.6 Tj. Therefore:

1000 MWh = 3600 GJ or 1 MWh = 3.6 GJ

The prices in Sweden for district heating converted to $/GJ are:

\[
\frac{45.4 \text{$/MWh}}{3.6 \text{GJ}} = 12.6 \text{$/GJ}
\]

\[
\frac{80.3 \text{$/MWh}}{3.6 \text{GJ}} = 22.3 \text{$/GJ}
\]

In the same period, heating oil cost 0.5908 €/l in Belgium. The exchange ratio in January 2006 was: €1 = 1.21$, resulting in a price of 0.715 $/l for heating oil. Conversion to $/GJ results in:

\[
\frac{0.715 \text{$/l}}{0.0358 \text{GJ}} = 19.97 \text{$/GJ}
\]

This shows that at that time heating with oil in Belgium almost cost as much as the most expensive district heating network in the research, situated in Stockholm. This result shows that in 2006, district heating could be a cheaper way of heating.

The prices of district heating in Finland were approximately €50/MWh. In 2007, €1 was worth 1.3$. Therefore, the district heating prices in Finland were 65 $/MWh. Converted to $/GJ:

\[
\frac{65 \text{$/MWh}}{3.6 \text{GJ}} = 18.06 \text{$/GJ}
\]

The oil price in Belgium was €0.5174/l in the same period, or 0.67 $/l. When converted to $/GJ the price was:

\[
\frac{0.67 \text{$/l}}{0.0358 \text{GJ}} = 18.79 \text{$/GJ}
\]

This shows that heating with oil in Belgium was more expensive than district heating in Finland. It is also a good example that district heating can be an affordable alternative to the conventional methods of heating.
Today, the prices for oil are skyrocketing. Heating oil costs €0,8679/l in Belgium. The exchange ratio for euro and dollar is: €1 = $1,46. This means that heating with heating oil today costs:

\[
0.8679 \text{ €}/l = \frac{0.8679 \text{ €}}{0.0358 \text{ GJ}} = 24.24 \text{ €}/\text{GJ} = 35.39 \text{ $}/\text{GJ}
\]

This shows that in a period of 11 years, the prices for oil have more than quadrupled. Oil prices will continue to rise as the world continues to run out of oil. District heating can help in three areas: First, it can reduce the cost for heating, especially when oil prices are continuing to rise. Second, it improves the efficiency of the current use of fossil sources (oil, natural gas, etc.), or it can use alternative energy to produce heat. And as a third, it can reduce the CO₂ emissions.

### 2.6 Disadvantages and barriers

District heating has to compete with the established methods of heating, this is one of the main barriers for district heating. Low oil or electricity prices can make district heating a less favourable method for heating, since it has no extra advantage on these conventional methods. In order to expand district heating systems, times of high oil and electricity prices have to come. As the calculation in paragraph 2.5 showed, these times are coming and district heating can expand.

Another disadvantage of district heating is the fact that it demands a large capital investment. The largest cost is the pipe network under the ground. This results in two extra barriers. The first is the fact that the heat has to be generated at a relative short distance from the targeted heat market so that the cost of a pipe network is as low as possible. The second barrier is that it requires entrepreneurs willing to invest in a long term investment. They prefer short term investments, but that is not quite possible with district heating.

A way of keeping building costs down, the heat market should be as dense as possible. I.e. a large amount of customers situated together as close as possible. Because they are close together, there have to be fewer pipelines installed resulting in a lower investment cost. This also affects the price the customer has to pay, since there are less thermal losses in the network.

Since the investment is a long term commitment, often the municipalities have to take the initiative. When it becomes clear to other companies that the district heating system is profitable, municipalities can sometimes sell it to a private owner. This shift from municipal to private ownership often results in less investment for expansion and modernisation of a local district heating network. As private companies try to keep the running costs as low as possible and focus on investments on national or international level, rather than on the local level.

Publicity is a key factor for district heating to be able to expand. More specific, politics should try to promote district heating. It is a relatively unknown method of fuel savings, CO₂ savings, etc., but it can be a significant part of the solution. Yet on international conventions debating about the environment, district heating is (almost) not mentioned. The problem there is its unfamiliarity. Promoting it, encourage entrepreneurs, putting it on the discussion agenda as part of the solution, etc. can solve this problem. Another method to encourage all alternative and renewable energy sources is to apply high taxes on oil and natural gas. This can however harm the poor part of the population, making it extremely hard for them to generate heat, use electricity, etc. This is a social barrier.
2.7 District Cooling

In conventional methods for cooling compressors are often used. However there is an alternative method to cool a room, using an absorption chiller. This is an ingenious chiller that uses heat to cool down a cooling liquid. Absorption chillers are very suitable to be integrated in a district cooling network.

Water boils at 100 °C at atmospheric pressure. The boiling temperature however strongly depends on the pressure of the atmosphere above the water. If it is possible to lower the pressure above the water, it boils at a lower temperature. An absorption chiller uses this principle. By using Lithiumbromide (LiBr) as an absorbent for the water vapour, and the low pressure, the two basic principles are fulfilled (having a LiBr solution that absorbs water vapour and water boiling at a low temperature as a result of the low pressure).

Consider containers 1 and 2 in figure 2.9, one with water and one with a salt solution containing the LiBr, connected together. The cooling process of the water happens because of the evaporation of the water. If water transforms from liquid into vapour, it withdraws some heat to make this transformation. Therefore, the water that stays in the bottom of the container cools down. Since there is a very low pressure in the container, the water will evaporate fast. The water vapour is absorbed by the LiBr absorbent in container 2. But once the absorbent starts to become saturated, the absorption of the water vapour reduces and the entire process will eventually come to a standstill, entering a state of balance.

The solution for this problem is to introduce heat to the LiBr absorbent. It will be pumped to a separate container (number 3) where the absorbent will be heated. This will evaporate the absorbed water vapour from the absorbent, and if returned to the original container, keep the process running. This is where district heating can help. Instead of using electricity, natural gas, oil ... to generate this heat, one can use district heat. It then becomes an environment-friendly way of cooling. To reduce the amount of used water, the water vapour driven out from the LiBr absorbent can be transferred to a heat exchanger where it becomes a liquid again and thus can be used in the cycle again as is shown in container 4. It is also important to keep a vacuum system, since the working pressure is very low.
To summarise: container 1 contains the water, container 2 contains the salt solution of LiBr, container 3 is the container where the LiBr is heated to remove the absorbed water vapour, and container 4 returns the removed water vapour to its liquid state. In between container 2 and 3 there is a heat exchanger to preheat the LiBr that comes from container 2. This is done to improve efficiency since otherwise the heat from the returned LiBr solution has to be removed to the atmosphere. Also notice the need for cooling water in container 2. The absorption of the water vapour by the LiBr generates heat, which has to be removed in order to keep the container at its correct working temperature. For the cooling water in container 2 and 4 river water and cooling towers can be used for large systems. Note the spray systems above container 1 and 2. Those systems are installed because sprayed water evaporates faster, and sprayed LiBr absorbs the water vapour faster.

Absorption chillers provide possibilities for district heating systems, especially in warmer countries. In a warm climate it is relatively easy to harvest the heat of the sun and to deliver it to the people. By means of an absorption chiller the people can cool down their living areas without using air conditioning systems. Or a large absorption chiller can cool down a cooling liquid and deliver it to the houses. These are just very simple suggestions, but they are not that unrealistic. Since this text is focused on district heating, district cooling will not be treated anymore.
3 The European District Heating Database

3.1 Implementation

The structure of the database is largely based on two sources. The first source is the text file downloaded from the World Gazetteer website [6]. Conversion of this compressed text file to a Microsoft Excel spread sheet has provided demographical and geographical information of most of the cities in the world.

The second source is the original database, containing the information of district heating systems gathered by previous students. Excel functions were used to retrieve the correct information and put it into one central database. In order to let the database work properly, the two folders containing the databases should be kept together on the same data carrier at any time (hard drive of a computer, USB stick and other portable data carriers). This is very important. Otherwise, excel will not be able to link to the correct file to get the data, and therefore will return errors.

3.2 The World Gazetteer download

The download from the World Gazetteer website is a compressed text file, which is easily decompressed with free software from the internet (WinRAR, WinZip, ...). This website contains information, such as administrative divisions, surface area, languages from countries and cities all over the world as well as statistics on population etc. The reason why this file was selected as the fundamentals of the database was because it contained the geographical coordinates of nearly every city in Europe. This was necessary to create maps in a later stage. After careful checking some randomly selected cities, the file proved to have reliable coordinates.

The next step is to import the text file in Excel. This has been done by simply selecting all the info in the text file and pasting it in Excel. The file achieved this way is called “Gazette download original”. However a lot of this information appeared to be unreadable. This is because Excel does not understand the UTF-8 format that is used in the original file. Fortunately, the World Gazetteer website also has a macro available that can convert the used combination of signs into normal letters. The download of this Excel file with macro was no problem, but it was a file in Excel 2003 format. This format has a maximum of 65536 rows.

Since the original file had a total of 324413 rows, the conversion had to be done in parts by selecting the first 65536 rows, place them in the first tab and then convert them, selecting the next 65536 rows etc. Therefore the conversion file called “Gazette download in parts” was created. But this was not yet a very good source file, because one large file with all the data is more useful than one divided in different parts. So a next file was created, where all the converted data was centralized in one tab meaning that there were no restrictions. This file is called “Gazette download (full) with conversion”.

A closer look at this file revealed that the first 130000 rows do not contain useful information for this database and only made the Excel file unnecessarily large. Since the research area was Europe, a final file was made called “Gazette download EU27,EFTA,CC”. As the name already tells, this file has the useful information of the 27 EU countries, the 4 EFTA countries and the 4 CC. But also Albania, Belarus, Moldova, Russia, Serbia and Ukraine are included, which makes a total of 40 countries (Iceland is an EFTA country as well as a CC). This was done by simply going through the “Gazette download (full) with conversion” file, selecting the 40 countries needed for the database and placing that information in the new “Gazette download EU27,EFTA,CC” file.
The “Gazette download EU27,EFTA,CC” has 12 columns containing the following data:
the first column is an ID number. It is a unique number of 9 digits that is linked to one specific city. The second column is the city name. Generally this is the city name in the original language of the country, but for big and international cities it is more likely that it is the English version of the city name. The third column contains the possible alternative names of the city. This could be the name in other languages, different spellings, etc. The fourth column contains the original name of the city in Greek, Cyrillic or Arabic. Excel cannot convert these signs, even with the help of the macro, so this column has no function so far.

The fifth column contains the geographical type of a given row. A geographical type means it represents what kind of data is in that given row. For instance most of the data is a locality, meaning it is data on a local level (city, population, geographical coordinates etc.). But the “Gazette download (full) with conversion” file also contains data where the geographical type is “County” or “Agglomeration” meaning that it contains the name and the population of for instance a county in the United States. In the “Gazette download EU27, EFTA, CC” file this is all a locality, since data on a local level was required.

The sixth column gives the population of the city, the seventh gives the latitude in decimal degrees and the eighth column gives the longitude in decimal degrees. The ninth column is the country in which the city is situated. The tenth, eleventh and twelfth column respectively give the first, second and third level of the district the city is in. Note that these levels are not always given. The first level is often given, the second less and the third is rather rare. The next figure shows how this database is constructed:

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</tr>
</tbody>
</table>

Figure 3.1 Gazette download EU27,EFTA,CC database

Take for example row 9149 (the first row in figure 3.1). Column A shows the unique ID number of the city in column B. Column C is reserved for an alternative name. Since this city does not have one, it is left empty. Column D is also empty because it is reserved for the original name of a city in Greek or Cyrillic. Column E shows that the data of this row is on a local level. If for instance the counties in the United States are needed, this column contains “County” if one searches in the file “Gazette download (full) with conversion”. Column F shows the population of the city, in this case only 69 people live there. Column G and H contain respectively the latitude and longitude of that city. This number has to be divided by 100 to have the correct number. This means that in this case the latitude is 49,33 degrees and the latitude is the 15,77
degrees. Column I contains the country where the city is situated. Column J, K and L contain respectively the first, second and third level of the district this city is in.

For this work all data has been used from the “Gazette download EU27,EFTA,CC” file, since these countries are the ones in the subject area. If the project requires information outside this area, it can be found in the “Gazette download (full) with conversion” file.

3.3 NUTS levels

NUTS is an abbreviation for “Nomenclature d'Unités Territoriales Statistiques”, or in English Nomenclature of Territorial Units for Statistics. It is the subdivision of the countries of the EU, EFTA and the CC into smaller regions. As the name suggests, this subdivision was made for statistical purposes.

Every country that is subdivided by NUTS levels has three NUTS levels. The first level is NUTS1, which divides the country in smaller “blocks”. For example Belgium has three NUTS1 levels: Flanders, Wallonia and the Brussels-capital region. The second level is the NUTS2 level: each NUTS1 level is subdivided into several NUTS2 levels. In the case of Belgium, the NUTS2 levels are all the provinces. The NUTS2 levels can be subdivided again creating the NUTS3 level. For Belgium the NUTS3 level means that the provinces are divided into their districts.

For smaller countries such as Belgium the NUTS3 level is not that important since the NUTS2 level already divides the country in small fractions. NUTS3 can be useful for larger countries such as France, Germany, Spain ... To be completely correct, there is one extra NUTS level, the NUTS0 level. This is just the country itself, and therefore not often used.

All these NUTS levels have their own code. The NUTS0 code is very simple: two letters of the country name. Belgium then becomes BE. But it is most likely that these letters do not correspond to the English name of the country, because these letters are chosen from the name of the country in its original language. Therefore the NUTS0 code of Germany is not GE but DE (Deutschland), the code of Sweden is not SW but SE (Sverige) ... The NUTS1 code is the NUTS0 code with one number added, referring to that specific region. For example Flanders is BE2. NUTS2 also adds a number. The first number still refers to the NUTS1 level and the second number refers to the smaller subdivision that has been made. E.g. the province of Limburg is BE22. Finally, NUTS3 adds a third number with the same function as the previous two. E.g. the district Hasselt is BE221. Note that if there are more than 9 subdivisions, there will be continued with a capital letter A and one follows the alphabet as long as needed.

These NUTS levels are important to draw conclusions for a small area regarding the district heating data. It is important that the same NUTS level is used throughout the entire database to have a consistency on which to draw these conclusions. NUTS1 levels proved to have areas which are too large, and NUTS3 levels proved to be too much work compared to the small increase in accuracy gained. Therefore, NUTS2 levels were used.

3.4 Structure

The database is constructed in such a way that the data it contains are always generated from the original file, mostly through the VLOOKUP function of Excel. That way the database is always up-to-date, which is important because data will definitely be added when this project continues.
3.4.1 City Info tab

There are several tabs in the Excel database. The first tab, called “City Info”, contains the geographical and demographical information of the cities. It has as a first column: the ID. This is the same ID as in the “Gazette download EU27,EFTA,CC” file. The second column gives the city name, linked to the ID number with the vertical lookup command. It is important to link to the original file through the ID number, because some cities have exactly the same name. They even can be in a different country. Since the ID number is a unique number for every city, no confusion can occur. The third column contains the alternative name of the city, the fourth the NUTS2 level, the fifth the country in which the city is situated. The sixth, seventh and eighth columns respectively contain the population, latitude in decimal degrees and longitude in decimal degrees. The data in all these columns were also retrieved from “Gazette download EU27,EFTA,CC” through the vertical lookup command. The next figure shows how this tab of the database looks like:

![City Info tab of the database](image)

3.4.2 NUTS2 level files of countries

To find the correct NUTS2 level, files were created for every country. In these files there are the ID numbers, cities, alternative city name, region and country coming from the “Gazette EU27,EFTA,CC” file. The region of the city gives the information needed to find the NUTS2 level of the city. Depending from country to country, it varied if that information corresponded with NUTS2 or NUTS3 level.

Due to different spelling of these regions, the region names in these files were not always the same as in the “NUTS file” in the original database. These regions had to have the same spelling to be able to link the correct region to the correct NUTS2 level using the vertical lookup command. Therefore, a conversion table was created next to the last column, to help converting the region name into the correct spelling, so that the NUTS2 or NUTS3 level could be extracted from the “NUTS file”. Figure 3.3 and 3.4 show the construction of the file for Belgium as well as the conversion table.
In the case of Belgium the regions given by the “Gazette EU27,EFTA,CC” file are provinces. In the conversion table the left column contains the provinces as given by the “Gazette EU27,EFTA,CC” file, the right column contains the provinces as given by the “NUTS file”. Our intuition tells us that these are exactly the same, but to Excel these two ways of writing are completely different. Therefore Excel will not find the correct NUTS2 level in the “NUTS file” if it searches with the names in the left column. To retrieve the correct NUTS2 level, the provinces had to be linked to the corresponding provinces with the correct spelling. The vertical lookup command in Excel retrieved these corresponding provinces and they were placed in a new column called alternative region name. Another vertical lookup command then could link the correct region name to the “NUTS file” to extract the NUTS2 level. If it was a NUTS3 level that was found in the region column, the function LEFT was used to display only the first four characters, since that gives the correct NUTS2 level. Most of the time this was rather easy, only for Germany this was difficult and for the United Kingdom this was almost impossible. For Germany the NUTS2 levels are as correct as possible, but the NUTS2 levels for the
The European District Heating Database and Mapping European District Heating Systems

United Kingdom are not correct. No consistent data from the region column could be obtained, and the data could vary between NUTS2 and NUTS3 level, making it very hard to get it right.

3.4.3 DH Info tab

The second tab, called “DH Info”, contains the district heating info of all the cities in the “City Info” tab. The first column is the ID, the same ID as in the “City info” tab. The second column contains the city name, the third the NUTS2 level and the fourth the country of the city. These four columns obtained their data from the “City Info” tab through the use of a function like this: =‘City Info’!A2. This means it has the same data as in A2 in the “City Info” tab.

Working with this function has been chosen above a vertical lookup command for two reasons. First, in this way a faster working database is obtained. Otherwise, there were once again some 400000 extra vertical lookup commands that would make the database noticeably slower. Second, manually adding a city is easier this way. Only a row has to be added in the “City Info” tab and the data has to be put where it belongs. Afterwards a row at exactly the same place in the “DH Info” tab has to be added and the functions from the row above have to be copied (Excel adjusts these functions automatically). If vertical lookup commands would have been used, new ID numbers had to be defined, which would possibly become a cause for troubles since consistency in the ID numbers cannot be guaranteed anymore.

The fifth column contains the city name used from the different Excel files that have the district heating values of the countries. The sixth column contains the district heating company (or companies in case of multiple district heating systems in one city), the seventh contains the district heating deliveries in TJ, the eighth contains the district heating deliveries in GWh, the ninth contains the total length of the district heating pipelines, the tenth column contains the year in which the statistics were found or published and the eleventh column is a place for comments or remarks. The data in these last seven columns were found with the vertical lookup command that links to the correct district heating file of the given country. Except for the Remarks/Comments column and the DH delivery [TJ] column. The first one is just text and the second one is just a multiplication by 3,6 of the column DH Delivery [GWh]. This is because:

\[ 1 \text{ W} = 1 \ T/J \]
\[ 1 \text{ Ws} = 1 \ J \]
\[ 1 \text{ Wh} = 3600 \ J \]
\[ 1 \text{ GWh} = 3600 \cdot 10^9 \ J \]

Because: \[ 1 \text{ TJ} = 1 \cdot 10^{12} \ J \]

Thus: \[ 1 \text{ GWh} = 3,6 \text{TJ} \]

This transformation has to be made because Wh (or GWh) is not a SI-unit and thus not recognized everywhere. But as these formulas prove, a transformation from one unit to the other is easy and can be done fast. The next figures show how the second tab is constructed:
Some cities have more than one district heat supplier. The corresponding district heating delivery from each supplier is available separately in the district heating file of each country. But in the database, only the total sum of district heating deliveries is important, so the different values had to be added up. This was done with the function DSUM of Excel. This function requires some criteria to know which values have to be added up. That is why the tab “Criteria for multiple DH systems” has been created. It contains the criteria for all the different DSUM functions. It is very important that this tab will not be adjusted in any way, unless the DSUM function is adjusted as well. Otherwise, the resulting values are wrong or an error can occur.
3.4.4 DH per NUTS2 level tab

The fourth tab, called “DH per NUTS2 level” contains the added values of the district heating deliveries per NUTS2 level. To get this sum of values, once again the DSUM function was used. This time a horizontal database has been created, containing the criteria, and the third row of this database has the sum of “DH delivery [GWh]”. To transform this in a vertical database, the TRANSPOSE function was used. A third column has been added to this vertical database, containing the values in TJ, and a fourth column containing the values in GJ. For Poland an exception has been made. There were no data for the district heating systems in Poland on city level available, only on NUTS2 level in a different file. This file is called “Poland 2007”. These data have been added in the third column, but not in the second since GWh is not an international unit. Figure 3.7 shows the content of the fourth tab.

![Figure 3.7 DH per NUTS2 level tab of the database](image)

3.4.5 Population per NUTS2 level

The fifth tab, called “Population per NUTS2 level” contains the population for every NUTS2 region, as the name already suggests. These data come from the Eurostat database [7], where an Excel file “Eurostat NUTS2 population” was downloaded containing this information. To link the name of each region, and thus the population to the correct NUTS2 level, a second tab had to be made. The first column contains the name as in the first tab, called “Sheet0”, of each NUTS2 region. The second column can contain an alternative way of writing the region name, if it could not be found in “NUTS file”. The third column gives the name used to find the information in column four. The fifth column contains the population linked to the correct NUTS2 region. These last two columns used the vertical lookup command to find the information. The reference year for the population is 2005. 2005 is the most recent year for which complete information was available. Then a vertical lookup command in the tab “Population per NUTS2 level” has been used to extract these populations. The left part of figure 3.8 shows a small part of this tab.

3.4.6 GJ per capita tab

The sixth and last tab in the database, called “GJ per capita” contains a small database with two columns: the NUTS2 level and the GJ/capita. The data in this last column were calculated by dividing the amount of GJ per NUTS2 region found in tab “DH per NUTS2
level” by the population per NUTS2 level, found in the previous tab called “Population per NUTS2 level”. The right part of figure 3.8 shows this sixth tab.

As one probably will have noticed, this database has a rather complex structure. This was not possible in another simpler way, since the data coming from different files had to be centralized in one database. To better understand this complex structure, figure 3.9 shows an overview of all the important links to the central database.
The European District Heating Database and Mapping European District Heating Systems

Figure 3.9  Structure of the database
3.5 Using the database

This database can be used as a central point that contains all data concerning district heating. New data can be added by creating separate files to which only has to be referred to add the data. In this way the database itself does not have to be adjusted. This helps keeping the database usable for different people. Because if everyone starts to adjust the database itself, different ways of adding the data will be used, the database is no longer up-to-date unless you edit all the data yourself, etc. The main goal is to have a central point of reference for district heating, one central data access point that can provide anyone with the data one needs. The database replaces the many (uncomplete) databases different people in different countries use now. This database makes it also possible to draw some general conclusions about the current state of district heating in Europe.

Other parameters can be added to the database, e.g. population per city. This database contains the population as provided in the Gazette download, but this might not be accurate and recent enough. Also new information like the district heating values on city level for Germany or Poland can be very interesting. For now we only have values on NUTS1 level for Germany, and NUTS2 for Poland.

Since this project is still continuing, this database can be used to show where there is room for improvement. Data show that the Nordic countries are ahead on the rest of Europe with district heating installations. When more data has been added to this database, it can also be used as a proof that district heating works, by showing the numbers. Recommendations could be made based on the data, hopefully to make other countries see that district heating can be a solution.
4 MAPPING EUROPEAN DISTRICT HEATING SYSTEMS

4.1 Source maps

For graphical representing the information of European district heating systems, good source maps containing geographical data of the NUTS levels in Europe are needed. Since good maps had to be created in a short time, creating those maps ourselves was no option. This would mean an extended amount of work. But after a careful search on the Eurostat database good source maps have been found [7]. NUTS0 up to NUTS3 level were available in just one map. This source map is called “NUTS_BN_03M_2006”. Each NUTS level has been extracted from this map and a shapefile for each of these levels has been created. A shapefile is a file for the ArcGIS program that can represent the boundaries of countries, provinces, cities, rivers ...

A difference has been made between EU countries and all the countries available in the source map, hence the different shapefiles of the NUTS levels. The one called e.g. “NUTS2_ALL” contains the NUTS2 level of all the countries available, the one called e.g. “NUTS2_EU” only contains the NUTS2 level of the 27 countries of the European Union. It is the same for the other levels. The download also had a shapefile with it that draws the borders of all the countries in the world. This makes it very easy to see the different countries even when Europe is divided in NUTS levels. Of course the coordinate system is very important. Using different systems can lead to problems with the placing of cities on the maps for example. Therefore an attempt was made to give the maps the same coordinate system: WGS 1984. This stands for World Geodetic System, a mathematical system used for global positioning. It is this system that is most likely used in the GPS systems all over the world as standard. The number 1984 refers to the year it was introduced.

To give an idea of the NUTS levels in Europe and where they are situated, figure 4.1 shows a map with all the NUTS2 levels available in Europe (Country name abbreviations, see appendix 1):
Figure 4.1 European NUTS2 levels
4.2 District heating systems in Europe

Uploading data in ArcMap (the actual mapping program in the entire ArcGIS program) is very easy. A complete Excel file (only 97-2003 format) can be uploaded, so all the data needed can be entered. Because ArcMap is not compatible with newer versions of excel, the tabs “City Info” and “DH Info” had to be divided in two since there are more than 65536 rows in those tabs. For this reason there is a file called “DB Joris_test for ArcMap with extra ID” has been constructed. This file is adjusted for ArcMap and the manually added cities have been given a temporary ID because this was required. Also, an extra column was added, called “Size Rank”. This column ranks the size of the district heating systems in 7 categories:

- 0: 0 TJ or no data available
- 1: 0 TJ – 100 TJ
- 2: 100 TJ – 500 TJ
- 3: 500 TJ – 1000 TJ
- 4: 1000 TJ – 5000 TJ
- 5: 5000 TJ – 10000 TJ
- 6: 10000 TJ – Maximum amount of heat delivery

To make work less complicated, the latitude and longitude columns were also added. ArcMap had troubles identifying the “DH Delivery” columns as numeric columns if the data of the “DH Info” tab are added to the “City Info” tab with a join. Combining all data in one tab makes the process of mapping easier. This way a map can be created showing the cities that have district heating systems and from which the data were in the database. Also, the size of the district heating systems is shown by the size of the circle on the map:
Figure 4.2  Size of cities with district heating
This map shows that district heating is well represented in Denmark, Sweden, Finland, Lithuania, France and Switzerland. Bulgaria also does rather well with district heating. Other countries like Italy and Croatia do have district heating systems but not that much. The reason is that these countries are in a warmer climate, thus need less heating facilities than the Nordic countries. We know that Germany and Poland have district heating systems as well, but there is no data available yet on city level. Later, when more accurate data is gathered, this could be entered in the database and create a better analysis for the district heating systems in Europe.

If we zoom in on Denmark, Sweden, Finland, France and Switzerland the size of these district heating systems can be made clearer. These maps are shown respectively in appendix 2, 3 and 4. Note that these maps might seem to be stretched out, but ArcGIS takes the curvature of the earth into account. Conventional maps mostly do not which make them look more compressed than these. Looking at the maps of France and Switzerland, one can see that the district heating systems are small systems. Also for France, only in the area around Paris there are a lot of district heating systems. On the other hand district heating systems in Denmark, Sweden and Finland are rather large systems, spread over the entire country.

One also has to take into account where the cities in the given country are situated. The map of the cities in Europe can be found in appendix 5. This map shows that France has a very large number of cities. In the database one can find that there are approximately 32000 cities. Comparing this to the map of the cities that have district heating in France, it is clear that the amount of district heating facilities in relation to the amount of cities is rather small. The same holds for Switzerland. Denmark also has a large number of cities. However the amount of district heating systems in relation to the amount of cities is much better than France. Sweden and Finland do even better. For those countries district heating is very well represented in most of the cities.

Other countries, like Belgium, the United Kingdom and Ireland do not have district heating at all. Even though they are in a climate where district heating could be benefited from. This also applies to the countries in central and east Europe. By introducing district heating to these countries, the market share of district heating in all of Europe could rise a little bit.

If these values are put into a graph on country level, the differences can be easily compared:
This graph shows that Sweden generates the largest amount of heat from district heating systems, followed by Finland and Denmark. The last two countries that generate a large amount of district heat are France and Poland. But this can lead to false conclusions, as will be explained in the next paragraph. This graph also states that the systems in Switzerland have a rather small capacity. It can be an opportunity to increase the capacity since there are a lot of district heating systems already available.

The importance of this graph is to show that large amounts of heat can be generated by district heating systems, as illustrated by the numbers of Sweden, Finland and Denmark. Besides that, it is easy to spot countries that could improve their amount of district heating systems. But to make the best recommendations for countries, this graph should be analysed together with the data in paragraph 4.3.

### 4.3 GJ/Capita

The GJ/capita shows the amount of heat delivered by district heating systems with respect to the people living in that area. Or in other words: the heat a person could receive if all people would be connected to a district heating network. This map gives a better view of the district heating available in an area. This also gives a better overview of the amount of district heating in all of Europe, so that it is clear to see where improvement is possible and where district heating is already well represented. The following map shows the amount of GJ/capita:
Figure 4.3  GJ/capita in Europe
The white areas mean that these regions either do not have district heating systems or that there are no data available. In this map it can clearly be seen what was said before: the Nordic countries have considerably more district heating available than the rest of Europe. Iceland is the leader, with 268.5 GJ/capita. The area around Copenhagen in Denmark also has a very high amount of district heating deliveries.

The map also shows that even though it looked like France had a lot of district heating systems, compared to the population it is rather a low amount of heat generated. Some countries (Belgium, the United Kingdom, Ireland ...) do not have any district heating at all. Even Spain has some district heating systems and yet it is in a relatively warm climate. Bulgaria is also well foreseen of district heating, given that this is also a country in a warmer climate.

For Poland we have data available on this NUTS2 level. We know that there are district heating systems in Germany, but the data were only at NUTS1 level. These areas are too large to draw conclusions. Therefore they were not taken into account when creating this map. For Switzerland one can see that there is a large amount of district heating systems but they are rather small, resulting in a lower GJ/capita than could have been expected. The north of Italy and Croatia also have a rather low GJ/capita. The Netherlands have some district heating systems, but there were no data available of the deliveries.

Here it is also useful to put the values in a graph on country level, this makes it easier to compare the GJ/capita of each country:

![GJ/capita per country](image)

Appendix 6 contains a map with the combination of the GJ/capita and the size of the district heating systems in Europe.

To show the variations in population, appendix 7 contains the population per NUTS2 level. This map clearly shows that the countries in the north have a lower population than Central and Southern Europe. Especially the region of Paris in France is extremely densely populated.
CONCLUSION

The database

The database is a good starting point for gathering all the data about district heating systems. It can be used as a central saving point for these data, so that anyone who needs these data knows where it is available. But there are still some data missing, for example of Germany. The best scenario is to have the data on city level. This could create the possibility to draw conclusions on how well district heating is progressing in Europe. But it would be a good start to have the data on NUTS2 level such as for Poland. However city level data for each country would mean progress on having a European database that is as accurate as possible.

For this report, the population per NUTS2 level proved to be sufficient. This accurate information has been found on the Eurostat database. Our database also has a column with population per city, but we highly doubt that this information is accurate. Finding new figures of population on city level will have higher priority. With that information it is possible to show the demand for heat in a given area.

It is clear that every column has its own specific and important role in the database. All columns contribute to the expansion of district heating, providing the researchers with the correct information they need. Given that the database contains all the information of all the cities in Europe, it could become very important if it stays up-to-date.

The database pushed Excel to its limits. With two tabs of each 100000 rows, in total 10 columns with formulas, this results in roughly one million formulas Excel has to recalculate. This is sometimes a cause for the database to crash. For this project it was a prerequisite to build the database in Excel. For the future however, it is advised to transform the database into an Access file or to use other specific software for large databases.

Mapping the European district heating systems

A safe and clear conclusion is that the Nordic countries, and more specific Sweden, Finland, Denmark and Iceland, have a very well developed district heating system. All these countries have a great number of district heating systems. Iceland is actually an exception. Because of the large amount of heat available under the ground, a district heating network that connects almost all the inhabitants is possible. In other countries this is hardly possible. In Sweden, district heating has approximately a market share of 60%. This is a more realistic and feasible percentage of market share.

France and Switzerland also seem to have a high number of district heating systems, but when looking closer at the map in appendix 4, it is revealed that these systems are rather small. Fortunately this is a step in the good direction if one wants to spread district heating all over Europe (and further). Knowing that these systems are available, they can be upgraded, expanded ..., resulting in more people benefitting from district heating.

Besides it is clear that some countries should try to invest in district heating. One of the main barriers is the cost. Investing in district heating is a long term investment. Due to the private energy market the main goal for investments is to have short term investments. Because of this conception, district heating does not seem to be a good investment. However, it is almost guaranteed that it will pay itself back. To conquer this barrier is a main step forward in stimulating district heating.
When looking at the map of the population density in appendix 7 or at the map of the cities in Europe in appendix 5, one can see that these Nordic countries have a rather low population density and less cities when compared to the rest of Europe (except for Denmark). Nonetheless, they have invested in district heating knowing the benefits of it. This resulted in a high amount of GJ/capita delivered, with Iceland ahead of the rest. It also means that they have a lower oil dependency for heating purposes. Other countries could follow them. France and Switzerland have some small district heating systems, but it is better than having none. Also Germany and Poland are doing well, but the data we gathered are not accurate yet, especially for Germany.

Other countries such as Belgium, The Netherlands, Great Britain ... should try to invest in district heating. It is a long term investment but it will pay off. As a first step politicians should try to encourage district heating systems just like they are encouraging other alternative energy sources such as photovoltaic solar panels, all kinds of insulation for houses, wind energy ... If district heating could be added to this list, it will gain popularity with the people because they start to see the benefit of it. Besides, the companies will be more likely to invest in it since the government is prepared to fund these projects as well. The process of integrating district heating in these countries will probably take longer than in the Nordic Countries since they have a lower population.

At this moment, oil prices are climbing to new record heights again because of the troubles and protests in the Middle East. This results in numerous complaints about how expensive everything gets. It is clear that most of our countries depend on oil. District heating could therefore be a solution to reduce the dependency. Besides, it could also result in families having to pay less to heat their houses.

The calculation in paragraph 2.5 revealed that district heating can be less expensive than conventional methods. Since it is clear that district heating could reduce the amount of CO$_2$ emitted, it could help reach the Kyoto goal which states that the European Union should reduce the amount of CO$_2$ and other greenhouse gasses by 8% compared to its level in 1990 by the year 2012. Recently, Europe also imposed an agreement where they will try to reduce their CO$_2$ emissions by 20% compared to its level in 1990 by the year 2020. They will also reduce their total use of energy with 20% and increase the use of renewable energy with 20% by 2020. This agreement is therefore called the 20/20/20 goals. This agreement is a perfect opportunity to consider district heating as a part of the solution.

Besides Europe, district heating could also work in other parts of the world. Therefore, expansion of the knowledge is necessary. Once again one should mention Sweden. With its oil dependency of just 5% and a district heating market share of 60%, Sweden is the perfect example that it is possible.
**BIBLIOGRAPHY**


APPENDIX

Appendix 1. Abbreviation of countries

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Appendix 2. Size of cities with district heating in Denmark

Figure 4.4  Size of cities with district heating in Denmark
Appendix 3. Size of cities with district heating in Sweden and Finland

Figure 4.5 Size of cities with district heating in Sweden and Finland
Appendix 4. Size of cities with district heating in France and Switzerland

Figure 4.6 Size of cities with district heating in France and Switzerland
Appendix 5. Cities in Europe

Figure 4.7  Cities in Europe
Appendix 6. GJ/capita and size of district heating systems

Figure 4.8  GJ/capita and size of district heating systems
Appendix 7. Population per NUTS2 level in Europe

Figure 4.9  Population per NUTS2 level in Europe