Investigation of a district heating network expansion possibility with a 60% share of renewable energy input: A case study – Sevran district heating network in France

Renaud de Montaignac
Investigation of a district heating network expansion possibility with a 60% share of renewable energy input: A case study – Sevran district heating network in France

Abstract

Climate change is making energy an important matter for scientists, politics and industries. Public concerns and energy supply limitations are changing the rules of energy markets. Fossils fuels are becoming expensive and energy policy makers encourage the development of renewable energies. Every energy sector is impacted by those changes.

With a significant potential in reducing greenhouse-gas emissions and fossil fuels dependency, the heating market is moving towards greener solutions. It is within this context that Dalkia is developing district heating solutions. This French company is one of the two large actors in the heating market in France and try to keep being part of the energy sector.

This thesis work was realized within Dalkia and focuses on a study case: Sevran district heating network. This network provides about 50 GWh of heat with a 60% share of renewable energy (biomass). Developing this network is one way of increasing the renewable share in France. This master thesis tackles two extension possibilities. The study case starts with drawing the state of the existing district heating network. This allows to know a consumption limit in order to keep the 60% share of renewable energy. The district heating network is then modelled with a software called Termis to know hydraulic limits. Extension projects are simulated with this same model to evaluate their technical feasibility. An economical study is finally performed. The study concludes that both extensions are technically feasible, but only one is economically relevant for Dalkia.

This master thesis was also the opportunity to observe the French heating market from an industrial point of view. Sevran study case is a typical example of how district heating companies are changing considering economy, energy policies and public acceptance.
Preface

During this master thesis, I discovered district heating systems through a study case application. I started my work with the energy-related knowledge I learnt at Ecole polytechnique and at KTH and complete them both from research papers and Dalkia’s documentation. I am now convinced that district heating systems are an efficient way of making heating sustainable. I had the opportunity of using various tools: P1-tool, SIME and Termis (versions 2 and 5). Using two different tools for the same task was a chance for comparing strengths and weaknesses of each tool.

This master thesis was the opportunity to discover district heating systems in an industrial environment. Meeting operational teams was a chance. First it provides me support on a technical side. My results were compared with the reality. Secondly, it helped me understand how district heating installations worked and how they looked like: boilers, heat exchangers, pumps, pipes... Finally, I met technicians who explained me their work.

In parallel to the main work of this master thesis, I also learnt a lot about the energy sector in France. There are many possible contracts for a consumer to have heat delivered in its home. District heating systems are considered as a public service and there are thus numerous requirements. Furthermore I learnt a lot about energy markets: gas, electricity and gas-CHP. Energy regulation is changing in France and this master thesis was thus a real opportunity for understanding these changes.

Finally I am proud of having participated in the development of a district heating network and giving Sevrán hospital heating system the opportunity of becoming more sustainable.
I would like to thank Dalkia IDF and his director, Jean-Philippe Buisson, for hosting me during this work. I really enjoyed working in such a pleasant atmosphere. I want to thank the whole pre-feasibility study for helping me in my work, giving me support and information when needed; but also for being so sympathetic with me during the last six months. Every engineer in this service learned me something valuable at one time. Stéphane gave me interesting projects and took time to explain me technical equipments. Yann helped me a lot and I spent a great time learning Termis with him in his heart-town. Déborah shared her knowledge on energy contracts. And all the others listened to my numerous questions and tried to answer me, you were so helpful.

I especially thank Celia, for the work accomplished with her help, but also for making me discovering her job and her projects. She gave me plenty of positive remarks on my work. I would like to thank Gilbert, Chantal and Mohamed for spending time with me at Sevran. A great thanks to the technician who spent a whole day with me opening valve chambers in the streets of Sevran.

The team helped me learning the job at Dalkia and I discovered a lot of interesting installations for producing heat or cold at Les Ulis (thanks to Pierre-Jean), Suresnes and La Defense (thanks to Pascal and Delphine), at Osny (thanks to Vincent). Visiting those installations was interesting and will be so useful for my future work.

I want to thank my professors at KTH and the energy department for learning me so much. This was a real pleasure to study there. Courses and projects were constructive with a high technical knowledge. This master thesis made me realize how useful my learning in Stockholm was. Spending a year in this city was a marvellous experience that I will never forget. I am very honoured to become a graduate from Kungliga Tekniska Högskolan. I want to thank especially Assist. Professor Jeevan Jayasuriya for his lecture on Heat and Power technologies and for having been my supervisor on this work.

Finally, I would like to thank Benoît for hosting me in his service during six months. His interest towards my work and his constructive remarks made me improve my skills. Thanks you for your opened door.

To finish these greetings, I would like to thank my family and my friends, both in France through Europe for supporting me every day. Thanks to Claire, I owe you so much.
Contents

Abstract .......................................................................................................................... 2
Preface ........................................................................................................................... 3
Acknowledgements ......................................................................................................... 4
Contents .......................................................................................................................... 5
List of figures ................................................................................................................... 7
List of tables .................................................................................................................... 8
List of acronyms ............................................................................................................... 9

1 Introduction .................................................................................................................. 10
  1.1 Definition .................................................................................................................. 10
  1.2 District heating in France ......................................................................................... 10
  1.3 Resources in Paris region ........................................................................................ 12
  1.4 Dalkia ....................................................................................................................... 13
    1.4.1 Presentation of the company .............................................................................. 13
    1.4.2 Organization .................................................................................................... 14
    1.4.3 Some references ............................................................................................. 14

2 Objectives .................................................................................................................... 15

3 Background .................................................................................................................. 16
  3.1 Preliminary notions .................................................................................................... 16
    3.1.1 Description of a district heating system ............................................................ 16
    3.1.2 Advantages and disadvantages of district heating systems ................................ 16
  3.2 Economic aspects ..................................................................................................... 18
    3.2.1 Incentives ......................................................................................................... 18
    3.2.2 CHP in France .................................................................................................. 20
  3.3 Technical issues ........................................................................................................ 21
    3.3.1 Temperature and pressure based classification .................................................. 21
    3.3.2 Substations design ............................................................................................ 21
    3.3.3 Thermal issues .................................................................................................. 22
    3.3.4 Pressure issues in a district-heating system ...................................................... 24
    3.3.5 Degree day principle ....................................................................................... 25
    3.3.6 Extending a network ....................................................................................... 26
  3.4 Presentation of Sevran district heating network ....................................................... 28
  3.5 Tools ......................................................................................................................... 30
    3.5.1 Termis ............................................................................................................... 30
    3.5.2 P1-tool/SIME .................................................................................................... 32

4 Methodology ............................................................................................................... 34
  4.1 How much energy is currently consumed in the network? ..................................... 34
4.2 How many additional consumers can be connected? ........................................... 36
4.2.1 Renewable share .................................................................................................. 36
4.2.2 Technical feasibility .............................................................................................. 38
4.3 Which consumers may be connected to the district heating system? ....................... 42
4.3.1 Town centre .......................................................................................................... 42
4.3.2 Hospital .................................................................................................................. 42
4.4 How to connect those consumers to the network? .................................................. 43
4.4.1 Drawing path to connect consumers ..................................................................... 43
4.4.2 Simulating paths in Termis .................................................................................. 45
4.5 At what price the future consumers will be connected? ........................................... 46
4.6 Summary of methodology ....................................................................................... 47
5 Results ......................................................................................................................... 48
5.1 Existing network ....................................................................................................... 48
5.1.1 Consumption level ............................................................................................... 48
5.1.2 Renewable share .................................................................................................. 48
5.1.3 Today’s network analysis ..................................................................................... 49
5.2 City centre extension ............................................................................................... 54
5.2.1 Consumption analysis .......................................................................................... 54
5.2.2 Simulations .......................................................................................................... 54
5.2.3 Economic feasibility ............................................................................................. 58
5.3 Hospital extension .................................................................................................... 59
5.3.1 Consumption analysis .......................................................................................... 59
5.3.2 Simulations .......................................................................................................... 59
5.3.3 Economic feasibility ............................................................................................. 61
5.4 Tools comparison ..................................................................................................... 62
6 Conclusion .................................................................................................................... 63
7 Bibliography ................................................................................................................ 64
List of figures

Figure 1: District heating example (Dalkia n.d.) .......................................................... 10
Figure 2: Share of final energy consumption per sector in France (Ministère de l'écologie, du
développement durable et de l'énergie 2013) .......................................................... 10
Figure 3: Energy consumption by end uses per dwelling in Europe in 2009 (European Environment
agency 2012) .................................................................................................................. 11
Figure 4: Consumption of households per year for space heating (Odyssee n.d.) ..................... 11
Figure 5: French targets for 2020 (Ministère de l'écologie, du développement durable et de l'énergie 2011) ..................................................................................... 12
Figure 6: Four directions to increase renewable resources in heating systems (CETE de l'Ouest 2011) .... 12
Figure 7: Dogger resource map around Paris (ADEME-BRGM n.d.) Blue: low / Green: medium / Yellow: high / Orange: very high ................................................................. 13
Figure 8: Dalkia’s organization ...................................................................................... 14
Figure 9: Flow of thermal energy in a district heating network (Steer, Wirth and Halgamuge 2011) ........ 16
Figure 10: CEE market: prices and quantities in 2013 (Registre national des certificats d'économie
d'énergie n.d.) .............................................................................................................. 20
Figure 11: Principle of a substation (ADEME 2013) ....................................................... 22
Figure 12: Natural compensation against mechanical constraints (Lee 2013) ......................... 22
Figure 13: Heat losses calculation ................................................................................. 23
Figure 14: Effect of insulation thickness on the annual cost in a nominal pipe size of 150 mm for
geothermal energy (Keçebas, Ali Alkan et Bayhan 2011) .............................................. 24
Figure 15: Comparison of energy savings for all nominal pipe sizes by using (a) geothermal and (b) fuel-oil
as an energy source (Keçebas, Ali Alkan et Bayhan 2011) ............................................. 24
Figure 16: Sevran in the region of Paris .......................................................................... 29
Figure 17: Sevran network (Termis picture) .................................................................. 29
Figure 18: Termis user interface .................................................................................... 31
Figure 19: Termis user interface .................................................................................... 31
Figure 20: Termis user interface (Inputs and Outputs) .................................................... 32
Figure 21: Illustration of P1-tool principle through the cumulative load curve over a year ........ 33
Figure 22: Frequency of outdoor temperature in hours/year at the meteorological station ........ 36
Figure 23: Cumulative load curve ............................................................................... 37
Figure 24: P1-tool result .............................................................................................. 37
Figure 25: SIME cumulative load curve for season 1995-1996 ......................................... 38
Figure 26: Pump curves from catalogue for Chanteloup branch ........................................ 39
Figure 27: Parallel pumps ............................................................................................ 39
Figure 28: Pumps in series ........................................................................................... 39
Figure 29: Photo of parallel pumps on site .................................................................... 40
Figure 30: Planned extension in city centre (Geoportail n.d.) ............................................. 43
Figure 31: Hospital (in dark blue with its own boiler room in light blue) next to Rougemont branch (dark
lines) ............................................................................................................................. 44
Figure 32: Restricting pipes in Rougemont .................................................................... 44
Figure 33: Possible connections to the hospital (hospital located at green point, with paths in light blue) .. 45
Figure 34: Example of cumulative cash flow ................................................................. 46
Figure 35: Methodology in brief ................................................................................... 47
Figure 36: Renewable share depending on additional consumption (SIME results) ................. 49
Figure 37: Required power in substations for each branch depending on outside temperature .... 49
Figure 38: Temperatures in the network depending on outside temperature ......................... 50
Figure 39: Rougemont overview – pressure gradient in pipes ......................................... 51
Figure 40: Pressure through the critical route in Rougemont ............................................ 51
Figure 41: Pressure gradient through the critical route in Rougemont ............................... 52
Figure 42: Perrin overview – pressure gradient in pipes .......................................................... 52
Figure 43: Pressure through the critical route in Perrin ......................................................... 53
Figure 44: Pressure gradient through the critical route in Perrin ........................................... 53
Figure 45: Chanteloup overview – pressure gradient in pipes .............................................. 53
Figure 46: Extension project in city centre .............................................................................. 54
Figure 47: Pressure profile in the critical route (CV1+CV2+PRIV2) ....................................... 55
Figure 48: Friction pressure gradient in the critical route (CV1+CV2+PRIV2) ....................... 55
Figure 49: Pressure profile in the critical route (CV1+CV2+PRIV2+PRIV1) ......................... 57
Figure 50: Friction pressure gradient in the critical route (CV1+CV2+PRIV2+PRIV1) .......... 57

List of tables

Table 1 : Average temperature per month in Paris and Stockholm (Eurometeo n.d.) ..............11
Table 2: CEE calculation for households (Ministère de l’écologie, du développement durable et de
l’énergie n.d.) ......................................................... 19
Table 3: CEE calculation for public buildings, offices and hospitals (Ministère de l’écologie, du
développement durable et de l’énergie n.d.) .......................................................... 19
Table 4: The future production system .................................................................................. 28
Table 5: General characteristics of the network .................................................................... 28
Table 6: Inputs and outputs for a simple Termis simulation .................................................... 30
Table 7: Meteorological data for substation 28 ..................................................................... 34
Table 8: Consumptions for substation 28 .............................................................................. 35
Table 9: Consumption assumptions for unknown buildings ................................................... 35
Table 10: Pumps characteristics ............................................................................................ 38
Table 11: Pipes catalogue ...................................................................................................... 40
Table 12: Reference hypothesis for Sevrain network ............................................................... 41
Table 13: Reference consumption in Sevrain network at 2300 degree-days ......................... 48
Table 14: Renewable share of heat depending on modes and additional consumption ..........48
Table 15: hydraulic results of simulations ............................................................................. 50
Table 16: Thermal results of simulations .............................................................................. 50
Table 17: Consumption in town centre at 2300 degree-days .................................................. 54
Table 18: Optimal diameters (CV1+CV2+PRIV2) ................................................................. 56
Table 19: Results for CV1+CV2+PRIV2 ............................................................................... 56
Table 20: Optimal diameters (PRIV1) .................................................................................... 57
Table 21: Results for CV1+CV2+PRIV2+PRIV1 ................................................................. 58
Table 22: Hospital consumption at 2300 degree-days ............................................................ 59
Table 23: Results for hospital extension with a load factor of 1.15 on existing substations ......59
Table 24: Results for hospital extension with a load factor of 1.00 on existing network ..........59
Table 25: Hospital powers at -7°C and 0°C ......................................................................... 60
Table 26: Results for hospital extension with a load factor of 1.15 on existing substations ......60
Table 27: Results for hospital extension with a load factor of 1.00 on existing substations ......60
Table 28: Results for hospital extension with a load factor of 1.15 on existing substations ......60
Table 29: Results for hospital extension with a load factor of 1.00 on existing substations ......60
Table 30: Comparison of P1-tool and SIME ........................................................................ 62
Table 31: Comparison of versions 2 and 5 of Termis ............................................................ 62
List of acronyms

ADEME Agence De l’Environnement et de la Maîtrise de l’Energie
CEE Energy Savings Certificates
CHP Combined Heat and Power
DD Degree Day
DN Nominal diameter
EU European Union
SST SubSTation
1 Introduction

1.1 Definition

A district heating system is a collective heating system made of one or several heat plants, a network to transport the heat and substations to deliver the heat. The distribution network consists in a hot fluid – usually liquid water or vapour – circulating in pipes. This hot fluid goes from the plant to consumers in supply pipes. The heat is then taken off of the fluid toward a secondary network (basically water circulating in room heaters) in heat exchangers – the substation. Finally, the “cold” fluid goes back to the plant in return pipes. Consumers may be public buildings, offices, industries or collective houses. A storage system can also be installed.

![Figure 1: District heating example (Dalkia n.d.)](image)

1.2 District heating in France

March 2007, the European Union (EU) decided to fix its so called Energy 2020 goals: 20% reduction of green-house gas emissions, 20% share of renewable energy in total consumption and 20% increase in energy efficiency (European commission 2011). District heating allows both reducing fuel consumption due to larger – and more efficient – installations and using renewable resources that are too expensive for individual uses. Developing such systems is thus one of the numerous possible solutions to achieve EU targets.

![Figure 2: Share of final energy consumption per sector in France (Ministère de l’écologie, du développement durable et de l’énergie 2013)](image)

-10-
Transports and agriculture may not need additional supplies of heat, contrary to industries, households and services. In the industrial sector, the quality of heat – its temperature – is fixed by industrial processes and chemistry/physics laws. Providing heat is thus very dependent on the type of industry. On the contrary every households and service needs similar condition of heat: a low temperature heat for space and water heating. In France, heating households and services represents one third of the greenhouse gas emissions (Ministère de l'écologie, du développement durable et de l'énergie 2011).

Figure 3 shows that space and water heating represents a major part of the energy consumption of households in the whole Europe. In France, water and space heating account for around 80% of the energy demand of a dwelling; this is thus a key point on the overall energy system. Figure 4 shows France has already reduced its energy consumption related to space heating, but can still significantly decrease its consumption. Indeed, French consumption for space heating is comparable to Sweden even though climate is warmer in France (see Table 1).

<table>
<thead>
<tr>
<th>Month</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris</td>
<td>3°C</td>
<td>4°C</td>
<td>6°C</td>
<td>9°C</td>
<td>13°C</td>
<td>16°C</td>
<td>18°C</td>
<td>18°C</td>
<td>15°C</td>
<td>11°C</td>
<td>7°C</td>
<td>4°C</td>
</tr>
<tr>
<td>Stockholm</td>
<td>-3°C</td>
<td>-3°C</td>
<td>-1°C</td>
<td>4°C</td>
<td>10°C</td>
<td>15°C</td>
<td>17°C</td>
<td>16°C</td>
<td>12°C</td>
<td>7°C</td>
<td>3°C</td>
<td>-1°C</td>
</tr>
</tbody>
</table>

Table 1: Average temperature per month in Paris and Stockholm (Eurometeo n.d.)
In France in 2011, there were 418 district heating utilities producing around 6% of the needs for space and water heating in households and services (Ministère de l'écologie, du développement durable et de l'énergie 2011). The share of citizens connected to a district heating system was 7.4% (Euroheat & Power 2011). Natural gas is the most common fuel for heating systems in France, and domestic fuel oil has strongly receded. In 2011, renewable and recovery resources accounted for 31% (Ministère de l'écologie, du développement durable et de l'énergie 2011). Developing district heating network using renewable resources is one of the solutions France has chosen to achieve the EU 2020 targets.

To achieve those goals, French government set four directions for district heating solutions: switching from fossil resources to renewable resources in existing networks, building extensions in existing networks, densifying existing networks and creating new networks.

### 1.3 Resources in Paris region

Paris region has a large geothermal resource. The “Dogger” is a limestone aquifer located from 1600 to 1800 meters deep. The available temperature goes from 55°C to 80°C. It is necessary to use a heat pump to increase the temperature above 90°C and use it in a district heating installation. Given the high investment needed for drilling, this resource can only be used in large heating systems. Figure 7 shows resources around Paris. The highest potential is located South and West of Paris.
The second large renewable resource is biomass. Forests represent 30% of French territory with a possible resource of 10 Mtoe\(^1\)/year (Ministère de l'écologie, du développement durable et de l'énergie 2011). Previsions in Paris region shows that resources may reach 266 ktoe\(^2\)/year in 2015-2020 and 530 ktoe/year in 2030-2050 (Région Ile-de-France & ADEME 2012), which is still very low compared with the total potential resource. Developing biomass boilers is thus possible. Nowadays 80% biomass boilers in France are small installations (under 3MW) (Ministère de l'écologie, du développement durable et de l'énergie 2011).

Another way to get heat is to recover excess/waste heat from industries. Paris is surrounded by numerous industries, but they all are specific cases. There is no standard scheme. Finally, heat can also be recovered from incineration processes.

1.4 Dalkia

This master thesis work has been performed in an industrial environment at Dalkia.

1.4.1 Presentation of the company

Dalkia is a French company created in 1998 from two Générale des Eaux subsidiaries: Compagnie Générale de Chauffe and Esys Montenay. Dalkia provides energy services both on production and

\(^1\) Million tons of oil equivalent
\(^2\) Thousand tons of oil equivalent
consumption side. In 2012, 49,800 employees created €8.9 billion revenue in 35 countries, managing around 133,000 facilities (Dalkia n.d.). Dalkia has two industry-leading shareholders in environmental services and electricity: Veolia Environnement (66%) and Electricité de France (34%). Recently Electricité de France and Veolia came to an agreement: French business unit of Dalkia will belong totally to Electricité de France while the rest of the company will be fully part of Veolia.

The company has four main activities related to energy savings and improving local resources use:

- District heating and cooling networks (34% of total revenue)
- Industrial utilities (19% of total revenue)
- Thermal and multi-technical services (38% of total revenue)
- Specific expertise through subsidiaries

### 1.4.2 Organization

![Dalkia's organization](image)

Figure 8: Dalkia’s organization

This master thesis has been performed in the pre-feasibility department of the Technical direction and major projects, in Dalkia Île-de-France (region of Paris).

### 1.4.3 Some references

Here are examples of Dalkia's realisations in Europe:

- A storage tower of 37,000 cubic meters of hot water has been installed in Boras (Sweden) in order to store heat. It allows solving the wintertime energy use peak that needed conventional fossil resources by storing excess production from low demand periods.
- The second largest heating network in Poland, in Łódź, is managed by Dalkia. The three cogeneration units supplies 8,000 points.
- In Paris Val d’Europe, Dalkia is recovering heat from a data centre to a district network providing heat to 600,000 square meters of services and households.
2 Objectives

This work focuses on a study case: the district heating of Sevran, a medium town in the region of Paris. The purpose of this master thesis is to explore extension possibilities in the neighbourhood and check the technical and economic feasibility of additional connections. Indeed, this may lead to a better heating system in the neighbourhood and an extra valuation of the district heating network. To achieve this goal, various questions have to be answered:

1. How much energy is currently consumed in the network?
2. How many additional consumers can be connected?
3. Which consumers may be connected to the district heating system?
4. How to connect those consumers to the network?
5. At what price the future consumers will be connected?

Various tools are used to answer technical questions and to provide a sensitive analysis considering simplifications in models. This work is also the opportunity of comparing these tools.

This main work on Sevran network will give a significant knowledge on district heating networks feasibility from an industrial point of view. Finally, confrontation between this study case and literature will be performed.
3 Background

3.1 Preliminary notions

3.1.1 Description of a district heating system

As written in the introduction, district heating systems are collective heat production systems. Three subsystems can be defined (Rezaie and A. Rosen 2011) to explain how such systems work: the thermal production unit, the distribution network and end-users.

The first subsystem is the production unit. It consists in a thermal production plant and is the source of the thermal energy. Thermal energy can be produced from many primary resources, fossils or renewables. Contrary to individual heating system, a large panel of energy sources is available for district heating solutions and various energy sources may be mixed. Natural gas, domestic oil and coal are three traditional fossil fuels for district heating. Production units’ size allows using many alternative solutions that could not be used in an individual system (Lund, et al. 2010). It is usual to focus on five main renewable resources when considering district heating systems: “combined heat and power, waste incineration, industrial surplus heat, geothermal heat and fuels difficult to handle locally” (Reighav and Werner 2008). Indeed these primary sources require high investment cost that can only be profitable in a large heating system and in a long term. Biomass is often implemented in district heating systems; they are part of those fuels that are difficult to handle locally. Indeed individual biomass boilers are quite bulky and it is difficult to reach them in an urban area. Trucks must come often without having large parking areas. Furthermore biomass has to be transformed as pellets to be used in such system, and district heating systems may accept raw – or less transformed – biomass.

The second subsystem is the distribution network, made of supply and return pipes, in order to deliver the heat towards consumers. Thermal losses occur in this subsystem due to heat transfer through pipe walls. Such losses do not exist in individual heating systems.

The third subsystem gathers end-users. They may be dwellings, public buildings, offices or industries. The heat is delivered to end-users through substations, which basically consist in a heat exchanger transferring heat from the distribution network to radiators in buildings. Sanitary hot water is also produced in substations.

Thermal production unit and distribution network belong to the primary side, while end-users belong to the secondary side. The limit between primary and secondary sides is materialized by the heat exchanger in the substation.

![Flow of thermal energy in a district heating network](Steer, Wirth and Halgamuge 2011)

3.1.2 Advantages and disadvantages of district heating systems

Literature places savings in primary energy consumption on the top of the advantages list, and district heating systems often reduce social and environmental costs. Various comparisons exist in literature between individual heaters and district heating systems. Most papers conclude with social and environmental benefits of district heating systems (Bowitz and Trong 2000). Biomass is often referred as
the best solution because of its independency on electricity markets and waste policy (Eriksson, et al. 2007). Natural gas combustion for CHP applications is also promoted, but only when the marginal electricity production would have been generated from fossil fuels (Eriksson, et al. 2007). Indeed with higher efficiencies, gas-CHP applications save primary energy. Waste incineration is also recommended, but only if it does not replace a recycling policy (Eriksson, et al. 2007).

It has been studied that district heating systems are still relevant, even with 100% green electricity (Lund, et al. 2010). Indeed, district heating allows high efficiencies and local renewable resources utilization.

Other identified advantages are the flexibility of changing energy sources with the possibility of mixing energy sources (due to larger installations requiring several boilers), local management of energy and greater control for authorities (Rezaie and A. Rosen 2011).

District heating systems also have drawbacks that should not be forgotten. Large installations in an urban area may have high local impacts. For instance NOx emissions may reach significant levels (Genon, et al. 2009). Comparing gas-based solutions, local installations may have fewer impacts on environment and better efficiencies when its deals with latest technologies (condensation gas boilers) compared to traditional large district heating solutions (Lazzarin and Noro 2006). It is thus important to upgrade old gas-based district heating systems. Furthermore life cycle assessments on district heating systems (Oliver-Solà, Gabarrell and Rieradevall 2009) revealed that impacts are mainly located in thermal production units and dwelling components.
3.2 Economic aspects

The heating market is very developed in France and has been successfully standardized a few years ago, dividing contracts in four main categories: P1, P2, P3 and P4 (Duplessis, et al. 2012). P1 involves the fuel supply expenditures; P2 concerns the everyday-operations and maintenance; P3 includes the major repairs; and P4 concerns investments to improve the heating installation. It is possible to have a contract including every category, or four contracts for each category. In practice it is impossible to have a P3 contract without having the P2 contract; indeed P3 contracts are strongly related to the everyday maintenance (P2). Prices and indexations are divided in the same four categories. For district heating systems, prices are also divided in the same three categories. Nevertheless P2, P3 and P4 are fixed prices and are gathered in one unique sum under a R2 term. This term does not depend on the consumption level but the power requirement. An R1 term exists and equals to the P1 price; it is proportional to the consumption.

To understand how the financial balance is made in district heating systems, it is important to understand costs and to be able to differentiate them. Costs may be geographically classified in three parts (Rezaie and A. Rosen 2011). The first one is the cost of produced heat. It depends on energy sources in production units. The second one is distribution costs. It is mainly determined by the length – and thus the heat losses – of the network. Finally connection costs refer to the required components to connect consumers. This thesis work focuses on extensions in district heating networks. Connection costs are thus the main issue.

One criterion used in the literature (Reighav and Werner 2008) to evaluate feasibility of a district heating project is the heat density: heat consumption over a year per pipe length in the network. A typical reference may be calculated to know if a district heating network may be profitable. Of course, this reference will depend on many parameters, like the average heat price, and has to be calculated regionally. This reference is neither a perfect indicator: investments from one project to another may be very different. For instance it is strongly different to install pipes under a road or in a field. Every project must thus be studied more deeply than just with this simple indicator. Another indicator, very similar, is the maximal power over the network length. In France a typical value for this indicator is 4 kW/m (Narjot, Réseaux de chaleur - Chauffage urbain 1986).

Those two indicators reveal that the consumption is an important parameter to determine the profitability of a project. This basically means: the highest the consumption, the better the profitability. Of course this goes against the EU target of reducing consumptions. It is thus relevant to wonder if incentives for reducing consumptions in households are not stopping the development of district heating networks. Without surprise, literature shows that district heating systems may loss competitiveness in low density areas (Persson and Werner 2011).

3.2.1 Incentives

Even if district heating networks have great benefits on environmental and social aspects, they are not always profitable and incentives may be required (Lazzerin and Noro 2006). In France, two types of incentives exist to support district heating development. The first one “Fonds chaleur” is delivered by ADEME (Agence de l’Environnement et de la Maitrise de l’Energie), a public institution providing funding for energy projects. In the case of district heating systems (ADEME 2013) it is possible to get subsidiaries through the “Fonds chaleur” program if the network extension:

- is longer than 200 meters,
- provides at least 290 MWh/year (in substation) from renewable resources,
- and has a density over 1.5 MWh/meter of network/year

In the case of Sevran network, it is also mandatory to power future extensions with at least 50% of renewable energy. This is an additional requirement for network extensions. Furthermore VAT is reduced if the renewable share is at least 50% (Syndicat National du Chauffage Urbain et de la Climatisation urbaine n.d.).
Subsidiaries are calculated according to the length of the future network and pipe diameters. Funding cannot exceed 55% of the total investment. In practice it depends on the total funding capacity of ADEME and the number of demands over a year (around 250€/meter last year).

The second mechanism is the energy saving certificates market (i.e. white certificates). The principle of energy saving certificates (CEE) in France consists in making energy producers (electricity, gas, heat...) encourage their consumers to reduce the energy consumption level (Ministère de l'écologie, du développement durable et de l'énergie n.d.). Basically energy producers have to pay certificates every 3 years according to the amount of sold energy. The unit of certificates is the “kWh cumac”. It equals to the number of kWh saved during the life time of the new equipment. “Cumac” means “cumulated” and “actualised”

The first 3 years period went from mid-2006 to mid-2009 with a goal of 54 TWh cumac of energy savings. This was a success with 65.3 TWh cumac reached, exceeding the target. A new 3 years period started in 2011 with a goal of 345 TWh.

Certificates are created for each operation that reduces the energy consumption level. Many operations are standardized and calculation sheets provide help to calculate the number of created certificates. It is also possible to get certificates for non-standardized operations through a specific procedure.

Extensions of district heating networks belong to the standardized operation BAR-TH-37 for households and BAT-TH-27 for public buildings, offices and hospitals. It is called “Connection to a district heating network powered by renewable energies”\(^3\). The number of kWh cumac earned with the operation is calculated according to the climatic region. There are three zones: H1, H2 and H3. Paris region belongs to H1. The calculation is also different if the district heating provides hot water production or not. Calculations principles are presented in Table 2 and Table 3.

<table>
<thead>
<tr>
<th>Climatic region</th>
<th>Space heating only</th>
<th>Space heating and hot water</th>
<th>x</th>
<th>Number of dwellings</th>
<th>x</th>
<th>Share of renewable energy in the district heating network with the new extension [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>220 000</td>
<td>280 000</td>
<td></td>
<td>280 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>180 000</td>
<td>230 000</td>
<td></td>
<td>230 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>120 000</td>
<td>150 000</td>
<td></td>
<td>150 000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: CEE calculation for households (Ministère de l’écologie, du développement durable et de l’énergie n.d.)

<table>
<thead>
<tr>
<th>Climatic region</th>
<th>Space heating only</th>
<th>Space heating and hot water</th>
<th>Total heated surface [m²]</th>
<th>Factor on building type</th>
<th>x</th>
<th>Share of renewable energy in the district heating network with the new extension [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>2 200</td>
<td>2 400</td>
<td>2 200</td>
<td>Offices</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>1 700</td>
<td>2 000</td>
<td>1 700</td>
<td>Education</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>1 100</td>
<td>1 300</td>
<td>1 100</td>
<td>Hotels and restaurants</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: CEE calculation for public buildings, offices and hospitals (Ministère de l’écologie, du développement durable et de l’énergie n.d.)

Dalkia is a large energy certificates generator and is selling them to other energy producers who do not manage to reach their own targets. Market prices (in blue) and quantities (in yellow) for year 2013 are presented in Figure 10. The price at the end of 2013 was around 3 €/MWh cumac.

---

3 Translated from French: “Raccordement d’un bâtiment résidentiel à un réseau de chaleur alimenté par des énergies renouvelables ou de récupération”
3.2.2 CHP in France

In this section the case of gas-based CHP is described in the French context. Feed-in tariffs exist for gas-based CHP. Basically the tariff is divided in fixed incomes and proportional incomes, depending on:

- Installed power
- Efficiency of the installation
- Electrical connection (voltage)
- Availability
- Gas price

There are various conditions to feed-in tariffs. First the cogeneration unit must not exceed an electrical power of 12 MW. Then the gain in efficiency, compared with two different installations (one for heat and the other for electricity), must be significant. Finally the ratio “heat recovery over electricity production” must be higher than a minimal value.

Feed-in tariffs are based on a winter tariff – from November to March – and a summer tariff. Indeed heat needs occurs in winter; only hot water is produced during summer. Prices are indexed on various market prices and taxes.

The idea, through this feed-in tariff system, is to provide incentives for CHP when heat can be recovered, and when electricity price is high (during winter). As seen in section 3.1.2, gas-based CHP applications are environmentally interesting only when the marginal electricity is produced by other fossil fuels. In France the major part of electricity comes from nuclear power plants and then from hydro-power. During peak demands gas combine cycles are started and gas-CHP units become environmentally interesting.
3.3 Technical issues

3.3.1 Temperature and pressure based classification

Three technologies of fluids are currently used in district heating applications: vapour, high pressure water and lower pressure water (Narjot, Réseaux de chaleur - Chauffage urbain 1986).

Vapour networks work with a saturated vapour at 20 to 25 bars (at production point). The vapour is sometimes slightly superheated (20°C) to avoid condensation in the pipes. Vapour networks requires smaller pipes (especially for the return pipe which is liquid water) and smaller pumps (only working on the return side). In case of problem in the network, it is also easy to empty. Nevertheless this type of network implies higher heat losses and corrosion from condensate. It is also necessary to install purging valves in every low point to evacuate the condensate.

High pressure networks works with liquid water around 180°C. This high temperature allows a high temperature difference between supply and return and thus limited flows in pipes. This leads to relatively small pipes, but return pipes are larger than in vapour networks. It is harder to empty one section of the network, but the overall network also has a higher inertia which means easier regulation. Pumps are needed on supply side and elevations in the network have a high impact on the pressure requirements.

Low pressure networks works with liquid water around 110°C. They are very similar to high pressure networks and share many pros and cons. Lower temperature means smaller temperature difference at the delivery point, which leads to higher flows. Those networks thus need larger pipes. Nevertheless they have a better thermal efficiency due to smaller losses in the network. Furthermore security is higher due to lower temperature.

Distribution networks tend to reduce their temperatures to improve efficiency. Indeed supply temperature is the main cause of heat losses in a district heating network (Comakli, Yüksel and Comakli 2004).

3.3.2 Substations design

A substation is a room where the heat is delivered. It is the limit between the primary (production and distribution) and secondary (consumption) sides. The main components are:

- A heat exchanger to transfer heat from the primary side to the secondary side
- A regulation valve (2-way or 3-way) to regulate the flow going through the heat exchanger on the primary/secondary side. It regulates the supply temperature on the secondary side.
- A circulating pump to make the secondary fluid circulate in the building
- A calorimeter to measure heat sold to consumers

Figure 11 shows a typical substation. Many arrangements are possible: hot water can be produced instantly or through a storage balloon. There may also be a specific heat exchanger for hot water production. Hot water production may be located on primary or secondary side.
3.3.3 Thermal issues

3.3.3.1 Thermal expansion

There are kilometres of pipes in a district heating system, and the temperature of the fluid circulating varies a lot. This implies thermal expansion that has to be taken into account while designing a district heating network to avoid high mechanical constraints and pipe breaks. The thermal expansion $\Delta L$ of a material is:

$$\Delta L = \alpha \cdot L \cdot \Delta T$$

Equation 1: Thermal dilatation law (Wikipedia n.d.)

Where $\alpha$ is the thermal expansion coefficient (0.012 mm/(m.K) for steel), $L$ the length of the considered pipe and $\Delta T$ the temperature variation.

A pipe of 100 meters with temperature variation of 50°C will “grow” by 6 cm due to thermal dilatation.

In addition to the thermal dilatation, pressure is also creating constraints in pipes. The most common solution to absorb those mechanical constraints consists in using natural compensations (see Figure 12). Flexible pipes or bends can also be used but are often more expensive, more complex to install and less reliable in the long term.

3.3.3.2 Thermal losses

In a district heating system a hot fluid is circulating in pipes. There are thus heat transfers through the pipe walls. Heat transfer in one point of the network $\dot{Q}$ is evaluated with the following equation:

$$\dot{Q} = U \cdot A \cdot \Delta T$$
Where $U$ is the overall heat transfer coefficient (W/(m².K)), $A$ the surface of the pipe walls and $\Delta T$ the temperature difference between the pipe and the outside temperature.

$\dot{Q}$ is a loss that has to be integrated in the whole network. To calculate it let’s consider the following pipe section between $x$ and $x + dx$ (length coordinates).

The heat entering the section during a period $dt$ is $\rho \cdot c_p \cdot \frac{\pi \phi^2}{4} \cdot v \cdot T(x) \cdot dt$, while the heat leaving the section is $\rho \cdot c_p \cdot \frac{\pi \phi^2}{4} \cdot v \cdot T(x + dx) \cdot dt$ where $\frac{\pi \phi^2}{4}$ is the cross section of the pipe. Between $x$ and $x+dx$, the heat loss is $U \cdot (\pi \phi \cdot dx) \cdot [T(x) - T_{ext}] \cdot dt$, where $\pi \phi \cdot dx$ is the surface of the pipe walls. This leads to the following equation:

$$\rho \cdot c_p \cdot \frac{\pi \phi^2}{4} \cdot v \cdot [T(x + dx) - T(x)] = -U \cdot (\pi \phi \cdot dx) \cdot [T(x) - T_{ext}]$$

Where $\rho$ is the density of the fluid, $c_p$ is the heat capacity of the fluid, $T(x)$ the temperature of the fluid at point $x$, and $T_{ext}$ the external temperature.

Making $dx \rightarrow 0$ and solving the linear differential equation:

$$T(x) = T_{ext} + (T_0 - T_{ext}) \cdot e^{-\frac{4U}{\rho \cdot c_p \cdot \phi \cdot v^2}}$$

Where $T_0$ is the temperature at $x = 0$, the beginning of the pipe.

The higher the temperature is, the higher the losses are. Thermal losses increase with the length of the pipe but decrease with the flow speed.

The heat transfer coefficient of pipes is thus very important in a district heating network to limit heat losses. From an environmental point of view it is better to have the minimum heat transfer coefficient but that implies high costs. An optimal solution between perfect and expensive insulation and cheap inefficient insulation can be found (Keçebas, Ali Alkan et Bayhan 2011). On result of this study is shown in Figure 14. A thin insulation gives immedates results on the annual cost; indeed heat losses (fuel cost) quickly decrease with the insulation thickness. To the contrary total annual cost increases when the insulation is already thick enough. Indeed savings are limited but investment costs due to insulations are high. Figure 15 shows the difference of insulation effect on energy savings depending on energy source. Savings strongly depend on the cost of primary energy and on pipe size. Indeed the more expensive the fuel is, the more expensive losses will be.
3.3.4 Pressure issues in a district-heating system

Pressure is basically the main issue to deal with in a district heating network. The pressure equation in a closed circuit is:

$$\sum \Delta \rho \cdot g \cdot \Delta h + \Delta p_{pump} = \Delta p_f$$

Equation 3: Pressure equation for a fluid in a closed circuit (Havtun, et al. 2011)

Where $\Delta \rho$ is the density difference of the circulating fluid, $g$ the gravity acceleration, $\Delta h$ the height difference between points where the fluid density changes in the circuit (height where the fluid is cooled down minus height where the fluid is heated up), $\Delta p_{pump}$ the pressure increase due to pumps and $\Delta p_f$ the pressure losses.

$\Delta p_f$ is computed with the following equation:

$$\Delta p_f = \Delta p_{f,f} + \Delta p_{f,s}$$

$$\Delta p_{f,f} = f \cdot \left( \frac{L}{d_i} \right) \cdot \left( \frac{p \cdot v^2}{2} \right)$$
Equation 4: Pressure losses equations (Havtun, et al. 2011)

\[ \Delta p_{f,s} = K \left( \frac{\rho \cdot v^2}{2} \right) \]

Where \( \Delta p_{f,f} \) equals to friction losses, \( f \) the friction factor, \( L \) the pipe length, \( d_i \) the internal diameter of the pipe, \( \rho \) the density of the fluid, \( v \) the flow speed. \( \Delta p_{f,s} \) equals to singular pressure losses (due to junctions, valves and other singular changes in the network) and \( K \) is a geometric coefficient.

The friction factor may be estimated with the Colebrook equation:

\[ \frac{1}{\sqrt{f}} = 1.74 - 2 \times \log \left( \frac{2e}{d_i} + \frac{18.7}{Re \cdot \sqrt{f}} \right) \]

Equation 5: Colebrook equation (Havtun, et al. 2011)

Where \( e \) is the absolute roughness of pipe internal surface.

It is thus possible to calculate friction losses knowing the pipe characteristics (internal diameter, roughness and length) and the fluid speed in every point of the network.

Due to the great number of singularities in a network (from production unit to substations), it is not reasonable to compute all the singularity losses precisely at a prefeasibility state. Studies usually evaluate singularity losses as 15% of friction losses (Dalkia 2011).

It is usual to consider 3 m/s and 1 bar/km as maximum acceptable values for flow speed and pressure losses per kilometre (Narjot, Réseaux de chaleur - Transport 1986) in order to limit the pump size.

3.3.5 Degree day principle

The degree day (DD) is a measurement unit used in order to compare heat consumptions on various years. Indeed some winters are colder than others, it is thus necessary to have a method to compare heat consumptions between a cold and a warm winter.

1 DD equals to a complete day while the external temperature is one degree under the reference temperature. In this master thesis, the reference temperature is 18°C, which is the temperature from which heaters are turned down. Thus, one day at 17°C equals to 1 DD. There is no negative degree day.

In practice, the exact formula for DD over a day is:

\[ DD = \int_{t \text{ over a day}} (18°C - \text{outside temperature})_t \cdot dt \]

Equation 6

The shorter the time step is, the more accurate the result will be in this calculation. Nevertheless it is not reasonable to compute the DD every second. One method exists to compute it from maximum (\( T_{\text{max}} \)), minimum (\( T_{\text{min}} \)) and average (\( T_{\text{average}} \)) temperatures over a day:

\[
DD = \begin{cases} 
18°C - T_{\text{average}} & \text{if } 18°C > T_{\text{max}} \\
0 & \text{if } T_{\text{min}} > 18°C \\
(18°C - T_{\text{min}}) \times (0.08 + 0.42 \times \frac{18°C - T_{\text{min}}}{T_{\text{max}} - T_{\text{min}}} & \text{if } T_{\text{min}} \leq 18°C \leq T_{\text{max}} 
\end{cases}
\]

Equation 7(Meteo France - Direction de la Climatologie 2005)

\(^4\) “(...)” means that negative values of the expression are considered as zero.
Equation 2 shows that heat losses (and thus heat power requirement) is directly proportional to the temperature difference. Considering a fixed temperature inside a house (18°C), the heat power is directly proportional to the external temperature. This means also that the yearly consumption will be directly proportional to the degree day measurement for this year.

Degree day principle also enables establishing an equation between consumption and power:

$$ P_{heating}(T_{ext}) = \frac{Q \times [18°C - T_{ext}]}{DD \times 24} $$

Equation 8

Where $P_{heating}(T_{ext})$ is the heating power in kW for an outdoor temperature $T_{ext}$, $Q$ the annual heat consumption in KWh, 24 the number of hours per day, and $DD$ the number of degree days for the considered year.

Comparing two different years is thus simple. The value “Annual consumption divided by number of degree days” is supposed to be constant. It is thus possible to estimate the consumption for a reference degree day value (i.e. a reference year).

Of course, this is an approximation and the “Annual consumption divided by number of degree days” is not exactly constant. First installations are getting older every year and efficiencies vary, and consumers' habits can evolve. Secondly the phenomenon is not purely linear. Transition modes, varying flows, operation troubles exist. Degree day principle is an approximation but still rather accurate in an industrial environment.

The Degree day principle can only be applied on space heating consumption. For water heating consumption, the principle is the same. The consumption is considered constant over a year. Calculating the equivalent power is thus simple considering:

$$ P_{Hot\ water}\ [kW] = \frac{Annual\ hot\ water\ consumption\ [kWh]}{365\ [days] \times h\ \frac{\text{hours}}{\text{day}}} $$

Where $h$ is the number of hours of hot water consumption over a day. For private collective buildings, it is approximate by 9 hours (3 hours in the morning, 3 hours at midday and 3 hours in the evening). For public buildings, only 6 hours are considered (a working day without lunch break).

Literature provides many consumption models for heating systems. Nevertheless it is possible to keep simple models to evaluate demand curves. It has been shown that external temperatures and human behaviours are the two significant parameters playing on heat demand (Arvatson 2001). The effect of weather conditions is of secondary importance. The model described above is not perfect but give an idea for a feasibility study. Furthermore it is not important in this master thesis to understand the hourly behaviour of the system. As Erik Dotzauer did (Dotzauer 2002), the model described above only takes into account those two most significant parameters.

3.3.6 Extending a network

Adding new consumers to an existing network requires having all those technical points in mind. Basically a network is designed considering consumers need. This means pipes diameter and pump characteristics are designed so it is possible to provide heat through the network, even in restrictive conditions (minimal outside temperature and maximal power requirement). Adding consumers to the network implies higher power requirements; pipes and pumps may thus not be large enough.

Basically connecting new consumers implies a higher power requirement. In pipes, this means a higher mass flow in existing pipes. A higher mass flow implies higher friction losses (see Equation 4). Pump work have thus to provide more flow, with a higher pressure difference. Pump work is thus increased, and so is the
electrical pump consumption. Increasing the flow has also a positive effect on heat losses (see section 3.3.3.2). Indeed water is going faster through the network so the dissipation through pipe walls is shorter.
3.4 Presentation of Sevran district heating network

Dalkia won a public call for tender in 2011 and is in charge of the district heating network in Sevran. The company is, among other things, engaged in renovating the production unit. The future production system is detailed in Table 4 below. It will allow producing at least 60% of the annual heat from renewable resources (biomass). This figure will be checked in the study.

<table>
<thead>
<tr>
<th>Unit type</th>
<th>Number</th>
<th>Capacity (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas boiler</td>
<td>3</td>
<td>7 MW</td>
</tr>
<tr>
<td>Gas boiler</td>
<td>1</td>
<td>9 MW</td>
</tr>
<tr>
<td>Cogeneration gas engine</td>
<td>2</td>
<td>2.465 MW of heat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.485 MW of electricity</td>
</tr>
<tr>
<td>Biomass boiler</td>
<td>2</td>
<td>3.750 MW</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>42.430 MW of heat</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>4.970 MW of electricity</strong></td>
</tr>
</tbody>
</table>

Table 4: The future production system

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of network</td>
<td>Low pressure</td>
</tr>
<tr>
<td>Maximum temperature supply</td>
<td>105°C</td>
</tr>
<tr>
<td>Total network length</td>
<td>5 754.35 m</td>
</tr>
<tr>
<td>Static pressure at heat plant return</td>
<td>4.5 bars</td>
</tr>
</tbody>
</table>

Table 5: General characteristics of the network

The client of Dalkia is a public institution called SEAPFA. This institution owns the district network. A contract links Dalkia and SEAPFA, fixing heat price for consumers, quality of services… One condition fixed in the contract is to have at least 60% of renewable energy in the annual energy. Indeed this 60% share is fixed in the contract through the heat price. Each consumer pays a bill:

\[
\text{Bill} [\text{€}] = \text{Amount of heat consumed [MWh]} \times R1 \left( \frac{\text{€}}{\text{MWh}} \right) + \text{Capacity [kW]} \times R2 \left( \frac{\text{€}}{\text{kW}} \right)
\]

\[
R1 = 60\% \times R1_{\text{wood}} + 40\% \times R1_{\text{gas}}
\]

R2 is a constant price and represents costs due to maintenance, investments and fixed prices in gas and electricity prices. R1 is a proportional price based on wood price and gas price. It is supposed to pay for the wood and gas consumption to produce heat. R1 is divided in wood and gas costs; wood represents 60% of the total. As wood is cheaper than gas (partly due to tax incentives) it is more interesting to produce energy with wood rather than gas. Dalkia is thus encouraged to get the maximum renewable share every year.

In order to reach the 60% share of renewable energy, and to reduce the heat price (biomass is cheaper), biomass boilers are supposed to be used as much as possible. Nevertheless cogeneration units are producing both heat and electricity and are more profitable from November to March due to feed-in tariffs. Gas boilers are turned on in order to deal with peak demands or failures.

Sevran network is divided in three branches: Rougemont, Perrin and Chanteloup. Each branch has its own pumps but production units are shared. Two possible extensions are studied: the town centre (on Perrin branch) and the hospital (on Rougemont Branch).

The maximal temperature at plant is 105°C, but there is a regulation on supply temperature and supply flow to adapt the production to the consumption. Both supply temperature and flow are variable, which is one of the best regulation strategies (Pirouti, et al. 2013). Team on site uses curves to get the optimal supply temperature and flow depending on the outside temperature.
Figure 16: Sevran in the region of Paris

Figure 17: Sevran network (Termis picture)
3.5 Tools

3.5.1 Termis

Termis is a software developed by the company 7T and now owned by Schneider-Electric. With this software it is possible to simulate a whole district heating network. The software is able to simulate flows in pipes, temperature in every point of the network, thermal losses, and friction pressure losses. The inputs are basically consumers’ needs and the network layout. The outputs are the power production, heat losses and pump requirements.

A Termis model is divided in the same three parts that was evoked in literature review (Rezaie and A. Rosen 2011): production, distribution and consumption. Each part has its own object type: plant, pipe and consumer. Table 6 shows parameters (inputs) and variables (output) for each object type in the model.

<table>
<thead>
<tr>
<th>Object</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>Temperature output</td>
<td>Power output</td>
</tr>
<tr>
<td></td>
<td>Static pressure</td>
<td>Pressure difference at pump</td>
</tr>
<tr>
<td></td>
<td>Pressure control</td>
<td>Flow at pump</td>
</tr>
<tr>
<td></td>
<td>• Control substation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimum pressure at substation</td>
<td></td>
</tr>
<tr>
<td>Pipes</td>
<td>Length</td>
<td>Pressure</td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>Flow speed/ Mass flow</td>
</tr>
<tr>
<td></td>
<td>Heat loss coefficient</td>
<td>Friction pressure gradient</td>
</tr>
<tr>
<td></td>
<td>Roughness</td>
<td>Heat losses</td>
</tr>
<tr>
<td>Consumers</td>
<td>Power demand</td>
<td>Flow</td>
</tr>
<tr>
<td></td>
<td>Return temperature/Temperature difference</td>
<td>Pressure difference at substation</td>
</tr>
</tbody>
</table>

Table 6: Inputs and outputs for a simple Termis simulation

The software may also be used for more advanced calculations. In this work optimal pipe diameters will be calculated with Termis: the smaller pipe diameter among a pipe catalogue is chosen in order to keep acceptable friction pressure losses and flow speeds.

Figure 18 and Figure 19 show the user interface of the software. A background map (in brown) with geographic measures gives an accurate location of every element in the model. Power plants (in the middle of the map, with a little red star) supply power. Nodes (in white) symbolize cross points or substations. Consumers (in pink) are not part of the hydraulic model. They are simple objects to easily enter consumers’ data. Consumption parameters are then transferred to the closest node for the hydraulic simulation. Pipes (in black) make connection between nodes. Each pipe line is both a supply and a return pipe. It is possible to close the return or the supply side of a pipe if necessary.

It is possible to activate/deactivate zones. In Figure 18 deactivated zones are symbolized by blue pipes (top-right and bottom-left zones are deactivated).

Pipes characteristics are set up in a table: pipe types are defined with a roughness, a heat transfer coefficient and a diameter. In Figure 19 it is possible to read “100” written in red next to the pipe. This means that this pipe is a “100” type (nominal diameter of 100 mm).
Figure 18: Termis user interface

Figure 19: Termis user interface
Figure 20: Termis user interface (Inputs and Outputs)

Figure 20 shows an example of inputs (left window) and outputs (right window) for pipes. Inputs and outputs from Table 6 can be observed.

The software can also be used as an operational tool, taking real-time data as input and warning the operator when problems are detected compared with the model. At Dalkia the version 2 of the software is currently used. The company is currently switching toward version 5. Both versions will be used.

### 3.5.2 P1-tool/SIME

P1-tool and SIME are two Excel®-based tools. They are internal tools in Dalkia. The basic purpose of these tools is to estimate how the heat production will be shared between various production units, given priority rules. P1-tool is simple and was developed several years ago. It has been adapted to new policies and is well-known at Dalkia Ile-de-France. SIME is a new tool, more complex, developed in another regional business unit. It is able to simulate various years and take more parameters as inputs.

The principle of both tools is to fulfill the cumulative load curve with the different production units. The load curve is drawn from meteorological data. From DD principle each temperature can be associated with one power consumption. The cumulative load curve can thus be drawn. Then the tool calculates how much energy is produced by each production unit, depending on pre-set priorities. Figure 21 shows an illustration of the calculation. The first production unit used is biomass and gas boilers are started only when biomass already works at full power (i.e. 7.5 MW in this example).
Figure 21: Illustration of P1-tool principle through the cumulative load curve over a year

Of course it may be a little more complex in reality. For instance cogeneration units are given priority from November to March because of feed-in tariffs. P1-tool is able to take into account cogeneration units. SIME is an advanced version of P1-tool. It can simulate various years from meteorological data, random failures of production units… P1-tool and SIME also give fuel consumptions (given efficiencies). To perform their calculations, both tools simulate each month of a year.
4 Methodology

4.1 How much energy is currently consumed in the network?

This first step consists in evaluating the annual consumption of each consumer in the network. In a substation, two types of heat are consumed: space heating and water heating. Water heating can be considered constant every month and never stops. Space heating only works between October and June and is highly dependent on the outside temperature (degree day). A valve is shut down to stop space heating consumption during summer. The date of opening and closing space heating is decided by inhabitants living on a same substation. Thus dates can vary from one substation to another.

Various data exists:

- From previous studies
- Recorded data used for billing
- Estimations based on type of households and surfaces

A previous study exists, based on years 2005 to 2010, but renovation works has been performed since. Isolation improvements have been made and consumptions should thus have decreased. This previous study is thus a good base for comparison, but cannot be used as a reference for future situations.

The recorded data is the best way to have the latest consumptions. Space heating consumption, hot water consumption, start date and stop date of space heating are extracted from an intranet platform at Dalkia. For each substation, degree days are calculated with meteorological data from a meteorological station near Sevran in Le Bourget, between start and stop dates. Finally space heating consumptions are corrected to fit with a 2300 DD level – the contract reference. Hot water consumption is supposed not to depend on external temperatures. The total consumption for a reference year is thus the sum of the corrected space heating consumption plus the water consumption.

\[
\text{Consumption in substation} = \frac{\text{Space heating consumption}}{\text{Degree days measurement}} \times \text{Degree days reference} + \text{Water consumption}
\]

For most substations the reference consumption is an average of the calculations for 2011-2012 and 2012-2013 seasons. Renovation works in some buildings leads to huge difference between years. Gathering information from the operational team on site is thus necessary. Based on this information source, it has been decided to count only the last year for recently renovated buildings. Some projections are also made to evaluate decrease in a few substations for which renovation is still in process.

It has been considered that 100 kWh of energy are required to heat up 1 m³ of water. Indeed, the sensible heat to heat up one cubic meter of water from 15°C (tap water from drinkable water network) to 60°C is around 50 kWh. But the distribution of hot water has a poor efficiency: in each building, it is mandatory to keep the whole hot water distribution warm (typically between 50°C to 60°C) both for comfort (so consumers do not have to wait for hot water to come) and sanitary reasons (to kill bacteria like legionella). This efficiency is around 50%, which leads to 100 kWh/m³ of water. It would be better to know this coefficient perfectly for each substation, but it was not possible to calculate it. Indeed it is necessary to compare hot water consumption with heat consumption on primary side, but the former is not measured in substations.

Details for substation 28 are presented in Table 7 and Table 8.

<table>
<thead>
<tr>
<th>N°</th>
<th>Client</th>
<th>Season</th>
<th>Start date</th>
<th>Stop date</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>FRANCE TELECOM</td>
<td>2011 - 2012</td>
<td>October 18th, 2011</td>
<td>May 21st, 2012</td>
<td>2087.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2012 - 2013</td>
<td>October 15th, 2012</td>
<td>June 11th, 2013</td>
<td>2515.8</td>
</tr>
</tbody>
</table>

Table 7: Meteorological data for substation 28
<table>
<thead>
<tr>
<th>N°</th>
<th>Client</th>
<th>Season</th>
<th>Space heating [kWh]</th>
<th>Space heating [kWh] at 2300 DD</th>
<th>Water heating [m3]</th>
<th>Total heat [kWh]</th>
<th>Total heat [kWh] at 2300 DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>FRANCE TELECOM</td>
<td>2011-2012</td>
<td>233 000</td>
<td>256 682</td>
<td>26</td>
<td>235 600</td>
<td>259 282</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2012-2013</td>
<td>225 000</td>
<td>205 700</td>
<td>39</td>
<td>228 900</td>
<td>209 600</td>
</tr>
</tbody>
</table>

Table 8: Consumptions for substation 28

In this case, the difference between the two last seasons is huge (around 20%) in this building office. The reason was given by exploitation team on site: a part of the building has been disconnected since summer 2012 and 2011-2012 season is not relevant anymore. The reference consumption taken for this substation is thus 209 600 kWh/year at 2300 DD. The same work has been performed for each substation.

The last method for evaluating consumption only concerns one substation recently built. There is thus neither recorded data nor previous studies for this substation. The assumptions taken for unknown buildings are the following:

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Space heating consumption</th>
<th>Hot water consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recently built buildings</td>
<td>6 MWh/households/year</td>
<td>3 MWh/households/year</td>
</tr>
<tr>
<td>20 year-old buildings</td>
<td>7 MWh/households/year</td>
<td>3 MWh/households/year</td>
</tr>
<tr>
<td>Social buildings</td>
<td>7 MWh/households/year</td>
<td>3.5 MWh/households/year</td>
</tr>
</tbody>
</table>

Table 9: Consumption assumptions for unknown buildings

These assumptions are based on Dalkia know-how. They are not very accurate but provide a quick evaluation of consumptions. It is possible to check that those values are reasonable. Recently built buildings must respect the last thermal regulation “RT2005” for buildings (Ministère de l'emploi, de la cohésion sociale et du logement 2006). This means a maximum consumption of 130 kWh of primary energy per square meter and per year in a building powered by fossil fuels. Assuming a typical accommodation of 75m² with an efficiency of 90%, a standard accommodation consumes 8.8 MWh of final energy which is coherent with the 6+3=9 MWh/households/year. The previous work on existing buildings revealed that hot water production accounted for about one third of the total consumption, which is coherent.
4.2 How many additional consumers can be connected?

In this part two matters are important for the future project: the renewable share and the technical feasibility. The aim is to provide an overview of the network before thinking of adding consumers. This work will reveal limits of the network.

4.2.1 Renewable share

How much energy can be delivered by the production units while respecting the contract requirement: the share of renewable energy should be at least 60% of the total annual production? To answer this question, simulations are performed with P1 and SIME tools for current consumption plus an extra consumption. The production share is thus calculated given the priorities in each consumption case. It is basically a sensitivity analysis to know which level of consumption can be reached while respecting the 60% share of renewable energy.

Space heating and hot water heating consumptions have been estimated in the previous section. A heat loss coefficient of 5% is taken for simulating losses in the network. This value is a typical value, but a more precise value will be calculated later. The purpose of this part is to evaluate a limit of extra-consumption, not to have a very accurate figure.

A sensitivity analysis is performed by adding consumption and studying the renewable share. The supplementary consumption is supposed to have the same ratio space heating/hot water heating as the existing network.

Meteorological data are used to compute the cumulative load curve.

![Figure 22: Frequency of outdoor temperature in hours/year at the meteorological station](image-url)
P1-tool then tries to fulfill the cumulative load curve with the production units. Figure 24 shows how biomass and cogeneration are running during the year. Cogeneration and biomass units cannot fulfill the peak demand; simple gas boilers are started to complete the production.

Figure 24 shows that cogeneration units are running at a constant power. Indeed cogeneration units are running first between November and March because of feed-in tariffs. The problem is then that biomass is not used at full power and the renewable share decreases. One solution is to set cogeneration units in dispatchable mode. This mode consists is letting the system operator of the electrical grid decide when to start the cogeneration unit for secondary frequency control. In this scenario it is thus not possible to rely on heat produced by cogeneration units; they are considered as stopped units. Dispatchable mode is possible every month between November and March. Three possibilities are studied: dispatchable mode in March, dispatchable mode in November, and dispatchable mode in both November and March. Other months are not studied because it will equal to starting a simple gas engine instead.
SIME tool takes more input data. Meteorological data are more accurate, failures are randomly simulated instead of just reducing the nominal power in average and various years are studied. In Figure 25, the cumulative load curve is represented with the share of each production unit: gas-cogeneration unit in red is working from November to March, the two biomass boilers in brown and green and gas-boilers in yellow. Failures are clearly visible.

![Figure 25: SIME cumulative load curve for season 1995-1996](image)

### 4.2.2 Technical feasibility

At this point of the study, the important thing to know is the state of the network in Sevran. The work consists thus in modelling the network on Termis software. Simulations provide knowledge of future constraints for extending the network: where can the network accept more flow? Where are the limiting branches?

#### 4.2.2.1 Pumping capacity

The pumping capacity depends on pumps models. Each branch has its own pump system, even if Perrin and Rougemont share one pump during summer to save electricity. It was possible to identify pump models on site and find characteristics on catalogues. However, Perrin’s pump was too old (1969, creation year of the network) and there were no catalogue for this pump. The nominal characteristics (flow and pressure difference) were fortunately available on identification tag.

<table>
<thead>
<tr>
<th>Branch</th>
<th>Number of pumps</th>
<th>Pump model</th>
<th>Nominal flow of one pump [tons/h]</th>
<th>Nominal pressure difference of one pump [meters of water]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perrin</td>
<td>2</td>
<td>Halberg Nowa 125/40</td>
<td>188</td>
<td>42</td>
</tr>
<tr>
<td>Rougemont</td>
<td>1</td>
<td>Grundfos NK 200-500 4-pole</td>
<td>400</td>
<td>60</td>
</tr>
<tr>
<td>Chanteloup</td>
<td>2</td>
<td>Salmson JRC 410-21/4</td>
<td>65</td>
<td>14</td>
</tr>
</tbody>
</table>

*Table 10: Pumps characteristics*
When several pumps are installed, it can be in parallel (Figure 27) or in series (Figure 28). Parallel pumps allow pumping twice the flow while pumps in series allow twice the pressure difference. Pumps are installed in parallel in Sevran.
Keeping pumping capacities in mind is only necessary to know if pumps have to be changed. It is not a strong technical limit, but it may increase investments.

### 4.2.2.2 Network simulation

Layouts had already been drawn on Autocad® software and much information can be gathered by exporting/importing those data. A first simulation was then performed. An important step consists then in checking data: orders of magnitude, pipes diameter in stressed points, typical values.

Sevran network is an old network. It is very difficult to know the exact characteristics of pipes. Most of them are made of black steel. A catalogue from Alstom® with such pipes was used in order to create the model.

<table>
<thead>
<tr>
<th>Pipe type</th>
<th>Internal diameter</th>
<th>Heat transfer coefficient [W/m/K]</th>
<th>Roughness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN80</td>
<td>82.5</td>
<td>0.29</td>
<td>0.04</td>
</tr>
<tr>
<td>DN100</td>
<td>107.1</td>
<td>0.31</td>
<td>0.04</td>
</tr>
<tr>
<td>DN125</td>
<td>132.5</td>
<td>0.37</td>
<td>0.04</td>
</tr>
<tr>
<td>DN150</td>
<td>160.3</td>
<td>0.43</td>
<td>0.04</td>
</tr>
<tr>
<td>DN200</td>
<td>210.1</td>
<td>0.47</td>
<td>0.04</td>
</tr>
<tr>
<td>DN250</td>
<td>263.0</td>
<td>0.47</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 11: Pipes catalogue

The first simulation revealed various stressed points. A visit on site allowed answering numerous questions about those results and corrections have been made: 2 diameters in Perrin and 2 diameters in Rougemont were corrected. One supplementary substation in Rougemont was revealed and one pipe route was slightly modified due to a building destruction.

The first simulation considered one unique return temperature for every substation: 55°C. The team on site read measurement instruments every weekday in order to control the production unit and records
values in a notebook: outside temperature, flows, powers, pressures... The notebook from May 2012 to April 2013 was used to control orders of magnitude. It would have been too long to perform an exhaustive statistical analysis from this hand-written notebook. Observations for low temperatures – 0°C to -7°C (nominal temperature) – gave typical values to check simulations’ inputs and outputs.

In a second simulation hypothesis from Table 12 were considered. Supply temperature is lowered at 100°C. This is because the 105°C is rarely reached in the notebook. Furthermore it guarantees a conservative hypothesis for future dimensioning. The Chanteloup branch has a different temperature mode. Return temperatures are set according to notebook observations.

<table>
<thead>
<tr>
<th></th>
<th>Rougemont</th>
<th>Perrin</th>
<th>Chanteloup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply temperature</td>
<td>100°C</td>
<td>100°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Return temperature at substation</td>
<td>55°C</td>
<td>60°C</td>
<td>50°C</td>
</tr>
<tr>
<td>External temperature</td>
<td>-7°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static pressure in return pipe</td>
<td></td>
<td>4.5 bars</td>
<td></td>
</tr>
</tbody>
</table>

Table 12: Reference hypothesis for Sevran network

In some points of Sevran network, mainly in Rougemont branch, some return flows are used to supply low temperature floor heater. Unfortunately Termis software is not able to simulate such flows and all substations were considered to work at the same supply and return temperatures. Those substations are nevertheless located on particular sub-branches and this approximation should not strongly impact the study.
4.3 Which consumers may be connected to the district heating system?

This part consists first in evaluating future needs of consumers who wish to be connected to the district heating network of Sevran. Then a secondary study is done to find other consumers that could be connected to the network.

For consumers who want to join the network, it is theoretically possible to get consumptions from past years, or at least a reference that can be used for simulations.

Finding other consumers is harder and requires finding interesting buildings close to the network, checking on site the type of building, finding the current heating installation and studying if it is possible to connect it to the network, and evaluating the consumption. The typical future client is a collective building near the current or future network, with a centralized heating system. Indeed, it is too expensive to connect a small house – compared to the consumption level – or to switch from an individual production (like electrical heaters) to a collective production. Ratios from Section 4.1 are used for this category of consumers.

4.3.1 Town centre

Sevran city asked for connecting its public buildings to the district heating network. City technical services provided consumptions. Unfortunately those consumptions were not linked with a degree day reference; it has been decided to use 2300 DD as a reference, because it fits with the 30 years-old reference.

Evaluating the heat power for public buildings is slightly different than for private apartments. Indeed during weekends and holidays, the temperature inside buildings is lowered. The number of degree day must be recalculated. Public buildings usually have a reduction of the inside temperature of 2°C during weekends and 4°C during holidays. A quick approximation consists in saying that its equals to a reduction of 4DD/day during holidays and 2DD/day during weekend. There are 6 weeks of holidays between October and May in France. This means 49 days of holidays (including weekends before and after) and 42 weekend days (excluding previous weekends counted as holidays): $49 \times (-4\, DD) + 21 \times (-2\, DD) = -280\, DD$. The base for computing the maximal power is thus reduced by 280 DD. Hot water production was estimated to work 6 hours per day.

4.3.2 Hospital

A hospital is located not far from the network. A connection may be possible. Gas consumption for space heating and hot water consumption were given. A comparison was performed with a previous study to check space heating consumptions. For power requirement, the reference temperature inside the hospital was considered to be 21°C and hot water production was estimated to work 6 hours per day.
4.4 How to connect those consumers to the network?

4.4.1 Drawing path to connect consumers

This step consists in imagining the future network given restrictions on the existing network.

4.4.1.1 City centre

The city centre is located at the end of an existing branch, the idea was thus to connect it to the closest point. Nevertheless, this point is made with a DN80 pipe (internal diameter around 80mm, the smallest size in Sevran network) and it was not possible to transfer all the power through this pipe. A DN150 pipe is located no far; the first scenario consists thus in connecting future consumers on this pipe. A DN200 pipe is also available a little further and will be studied if the DN150 pipe is not larger enough.

The city centre extension has been divided in 4 parts to evaluate how relevant each part is. Figure 30 shows the imagined network extension:

- Centre Ville 1 (CV1 – dark blue) includes all existing public buildings
- Centre Ville 2 (CV2 – light blue) includes future public buildings
- Privatifs 1 (PRIV1 – yellow) is a large condominium
- Privatifs 2 (PRIV2 – green) includes private buildings projects

![Figure 30: Planned extension in city centre (Geoportail n.d.)](image)

4.4.1.2 Hospital

Hospital situation was a little bit more complex due to restrictions on existing network. It is located at the end of Rougemont branch as shown in Figure 31. Flows circulating in this branch are already high and it is not sure that connecting the hospital is possible (see section 5.1.3.2.1).
Three pipes (see Figure 32) on the existing network are problematic:

- Just outside the boiler room (T1 – 50m long)
- Second pipe after the boiler room (T2 – 80m long)
- Reduction of diameter (T3)

T1 and T2 are strangely DN200 pipes, but the pipe following T2 is a DN250 pipe. Figure 32 shows pressure gradient in Rougemont branch. T1 and T2 have a high pressure gradient in comparison with the rest of the network.

Three connection points have been identified and a path has been drawn for each of them (see Figure 33):

A. Connection directly to the production unit, with a long path to the South
B. Connection on a DN200 pipe
C. Connection on a DN150 pipe
Connections to points B and C are also possible to the North, but were more expensive.

**Figure 33**: Possible connections to the hospital (hospital located at green point, with paths in light blue)

### 4.4.2 Simulating paths in Termis

This second step consists in evaluating each path technically. Termis software is able to determine the smallest diameter that can transfer the required flow without exceeding a friction loss of 10 mmwc/m (millimetres of water column per meter of pipe) and a flow speed of 3 m/s. This pipe sizing will allow evaluating investment costs.

Relevant results are friction losses in the considered branch and pump requirement. Friction losses are limited up to 10 mmwc/m when sizing new pipes, but it is also usual at Dalkia to accept 20 mmwc/m in existing pipes to allow extensions. A limit at 20 mmwc/m has thus been considered. Nevertheless the real problem with friction losses is the resulting pressure difference the pump should provide. If the pump is able to supply such pressure, friction losses are a secondary issue.

Simulation parameters are the following:

- Power factor on existing consumers: 1.00 or 1.15
- Power factor on future consumer in the town centre: 1.50
- Pressure in the pump = 1.15 x Friction losses

The power factor coefficient is just a security to avoid risks due to uncertainties on consumption evaluations.

For the hospital, the risk was high in some pipes as limits were reached and expensive operation to re-size the existing network on long distances would have been necessary. It has been decided to consider an alternative solution: proving heat to the hospital while the outside temperature is higher than 0°C and using a local gas boiler to supply the complementary heat when the outside temperature is lower than 0°C. Indeed hospitals always need back-up installations and gas boilers will be installed anyway inside the hospital. It is thus possible to use those boilers to heat-up the hospital when it is really cold outside.
4.5 At what price the future consumers will be connected?

This part consists in evaluating the price the consumer should pay so the investment is worth being done. Before evaluating prices, it is relevant to look at some indicators. An interesting one consists in calculating the ratio “maximal power requirement over network length”. It is usual to consider that a value under 3 or 4 kW/m means that the network is not worth being built (Narjot, Réseaux de chaleur - Chauffage urbain 1986).

For evaluating accurately if it worth investing, it is necessary to compare incomes and expenditures for the company. Incomes are fixed in the contract and apply for every consumer in the network (see section 0). They cannot be changed, even for a future consumer which is not connected yet. Costs are confidential so no detailed figures are presented here, but the principle for evaluating them is explained. There are various types of costs:

- Investment costs concerns pipes installation and substations construction. Pipes costs are evaluated with a price per meter considering the pipe diameter and the environment (road, sidewalk, grass...). A table with substation costs is used, providing a price for a given size (kW) of a substation. Investment costs may be reduced with subsidiaries (see Section 3.2.1).

- Operational costs concerns technicians who control installations. Some controls are mandatory by law (controlling water quality for instance) and others are performed to avoid larger costs later. Those costs were evaluated with an internal database at Dalkia based on return on experience. A list of material is needed to evaluate the required number of hours of technician per year and the compulsory controls (made by external companies). For instance, a typical substation includes:
  - two heat exchangers (space heating and hot water),
  - a hot water storage, pumps, water treatment equipment, controllers with 3-way or 2-way valves (to regulate the flow) and a backflow prevention assembly (to provide water without contaminating the drinkable water distribution network).

- Replacement of equipment when too old or when a failure happens. This cost is also evaluated with an internal database at Dalkia with the list of equipment and their age.

The last variable to fix is the price the consumer will pay for the connection to be made. This variable may be used to adjust the return on investment and reach the company criteria. One indicator is the Internal Rate of Return (IRR). Every year a balance is made, including all income sources, costs and investments. The balance at year 1 is negative due to large investments, but other years are positive due to incomes. The IRR is defined by the following formula:

\[ \sum_{i = \text{year 1 to } N} \text{Cumulative balance at year } i \ast (1 + \text{IRR})^i = 0 \]

The cumulative balance usually looks like Figure 34.

![Cumulative Cash Flow](image)

**Figure 34:** Example of cumulative cash flow
4.6 Summary of methodology

The methodology can be summarized according to Figure 35. The first step consists mainly in knowing the existing network. It is necessary in order to ensure that the future work will be relevant. The second step is to study future consumers that could be connected to the network and thinking of scenarios to connect them on the network. Those scenarios are finally simulated more precisely to provide results and decide which option is the best.

1. Existing network knowledge
   - Current consumption level
   - Renewable share
   - Technical aspects:
     - Pumping capacity
     - Critical points and branches

2. Connection options for future consumers
   - Future consumption vs. renewable share limit
   - Possible paths to connect consumers to the network

3. Best connection scenario
   - Technical feasibility
   - Friction losses
   - Pumping requirement
   - Economical feasibility

Figure 35: Methodology in brief
5 Results

5.1 Existing network

5.1.1 Consumption level

The previous study on Sevran network resulted in a total consumption of 50 213 MWh/year for 36 substations at 2300 DD. Renovations impacts was planned to lead to 46 120 MWh/year for 35 substations (one substation has been removed).

Nowadays the consumption is 45 254 MWh/year for 35 substations at 2300 DD, which is slightly less than the previsions. The hot water consumption accounts for 28%, similar to what gave the previous study (27%). The following table shows the share between branches.

<table>
<thead>
<tr>
<th>Network branch</th>
<th>Space heating [MWh/yr.]</th>
<th>Water heating [m3/yr.]</th>
<th>Total [MWh/yr.]</th>
<th>Equivalent power at -7°C [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perrin</td>
<td>10 689</td>
<td>28 476</td>
<td>13 536</td>
<td>5 708</td>
</tr>
<tr>
<td>Rougemont</td>
<td>18 008</td>
<td>80 838</td>
<td>26 091</td>
<td>10 617</td>
</tr>
<tr>
<td>Chanteloup</td>
<td>4 057</td>
<td>15 681</td>
<td>5 625</td>
<td>2 315</td>
</tr>
<tr>
<td>Total</td>
<td>32 754</td>
<td>124 994</td>
<td>45 254</td>
<td>18 640</td>
</tr>
</tbody>
</table>

Table 13: Reference consumption in Sevran network at 2300 degree-days

5.1.2 Renewable share

Table 14 shows the renewable share (biomass share) of yearly production depending on additional consumptions and running modes. Green cells highlight scenarios with more than 60% of renewable.

<table>
<thead>
<tr>
<th>Additional consumption [MWh]</th>
<th>Normal mode</th>
<th>Dispatchable mode in November</th>
<th>Dispatchable mode in March</th>
<th>Dispatchable mode in November and March</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>59,78%</td>
<td>64,89%</td>
<td>64,94%</td>
<td>70,06%</td>
</tr>
<tr>
<td>2 000</td>
<td>60,24%</td>
<td>64,84%</td>
<td>64,92%</td>
<td>69,52%</td>
</tr>
<tr>
<td>4 000</td>
<td>60,89%</td>
<td>64,91%</td>
<td>65,01%</td>
<td>69,03%</td>
</tr>
<tr>
<td>6 000</td>
<td>60,93%</td>
<td>64,50%</td>
<td>64,62%</td>
<td>68,20%</td>
</tr>
<tr>
<td>8 000</td>
<td>60,84%</td>
<td>64,02%</td>
<td>64,16%</td>
<td>67,34%</td>
</tr>
<tr>
<td>10 000</td>
<td>60,82%</td>
<td>63,56%</td>
<td>63,72%</td>
<td>66,46%</td>
</tr>
<tr>
<td>12 000</td>
<td>60,43%</td>
<td>62,84%</td>
<td>63,01%</td>
<td>65,42%</td>
</tr>
<tr>
<td>14 000</td>
<td>59,99%</td>
<td>62,12%</td>
<td>62,29%</td>
<td>64,42%</td>
</tr>
<tr>
<td>16 000</td>
<td>59,37%</td>
<td>61,25%</td>
<td>61,43%</td>
<td>63,30%</td>
</tr>
<tr>
<td>18 000</td>
<td>58,89%</td>
<td>60,49%</td>
<td>60,67%</td>
<td>62,26%</td>
</tr>
<tr>
<td>20 000</td>
<td>58,18%</td>
<td>59,59%</td>
<td>59,76%</td>
<td>61,17%</td>
</tr>
</tbody>
</table>

Table 14: Renewable share of heat depending on modes and additional consumption

The existing network does not allow a 60% share of renewable in “normal” mode with the current level of consumption (i.e. with 0 MWh of additional consumption), because of recent decrease in consumption due to renovation works. Keeping a non-dispatchable mode allows adding 12 GWh of consumers over a year. Assuming a dispatchable mode in November or March, it is possible to deal with around 18 GWh of extra consumption. The 12 GWh limit fits with the reduction of consumption due to buildings renovations (6 to 7 GWh in the contract base) plus the consumption of the hospital (around 6 GWh). Indeed the biomass boiler was designed considering the future hospital connection and old buildings in the network. Results are thus coherent.
SIME results are shown in Figure 36. The average renewable share is quite similar to P1-tool results. The limit in additional consumption is still about 12 GWh. Nevertheless SIME provides results on various years. Minimum and maximum values are represented and results revealed that there is a risk of having less than 60% biomass share. However, biomass share is always higher than 50%; this is a good point. Indeed VAT rate changes from 5.5% to 20% if the renewable share goes under 50%. There is thus no risk of paying the high VAT rate.

![Figure 36: Renewable share depending on additional consumption (SIME results)](image)

---

### 5.1.3 Today’s network analysis

#### 5.1.3.1 Power and temperatures

The network can be represented with the following curves. Figure 37 shows the required power for each branch in the network depending on the outside temperature. The power is considered linear with the outside temperature. At 18°C, space heating is no more necessary and there is only hot water production. Nevertheless, it is not just a sum of all power in substations because hot water production is not simultaneous in every substation. The power at 18°C is thus lowered according to notebook records.

![Figure 37: Required power in substations for each branch depending on outside temperature](image)
5.1.3.2 Simulations

Simulations were done without any margin coefficient to show the state of the current network. Calculated flows are coherent with notebooks records except for Chanteloup network where it is slightly higher than expected. It can be explained by the restrictive temperature regime of 65°C/50°C and the larger error made on this small temperature difference.

<table>
<thead>
<tr>
<th>Flow [tons/h]</th>
<th>Rougemont</th>
<th>Perrin</th>
<th>Chanteloup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure at production unit start [bars]</td>
<td>6.2</td>
<td>6.2</td>
<td>5.8</td>
</tr>
<tr>
<td>ΔP [bars] (without singular losses)</td>
<td>1.7</td>
<td>1.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Maximal regular friction losses [mmwc/m]</td>
<td>10.0</td>
<td>7.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 15: Hydraulic results of simulations

Network losses are slightly higher than expected (5% according to teams on site). It may be explained by heat transfer coefficients. Indeed they were taken from a pipe catalogue. Even if the material is the same, it is not sure that physical properties are exactly the same. Nevertheless the network is too old to get more accurate data. Furthermore heat insulators are old and damaged through the whole network. It is thus impossible to know how much the insulators are really damaged. Nevertheless simulations give coherent values compared with notebook records.

<table>
<thead>
<tr>
<th>Required power [kW]</th>
<th>Rougemont</th>
<th>Perrin</th>
<th>Chanteloup</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network losses</td>
<td>1.4%</td>
<td>2.3%</td>
<td>3.1%</td>
<td></td>
</tr>
<tr>
<td>Network length [ml]</td>
<td>2 545,87</td>
<td>1 941,12</td>
<td>1 267,36</td>
<td>5 754,35</td>
</tr>
<tr>
<td>Density [kW/ml]</td>
<td>4.23</td>
<td>3.01</td>
<td>1.89</td>
<td>3.30</td>
</tr>
</tbody>
</table>

Table 16: Thermal results of simulations

Network losses are lower in Rougemont due to higher density and higher velocities. The density in Chanteloup is low. Indeed there was a geothermal well some decades ago in Chanteloup; the main function of this network was to transfer heat from the well to the main production unit. Unfortunately the
well was closed for some reasons but the old long pipe is still there to transfer heat to consumers near the old well.

5.1.3.2.1 Rougemont

The minimal pressure difference (1 bar) is located in substation 13. Friction losses are important just after the production unit due to an old DN200 pipe. The second constraining pipe is located North-East just before a library (M). It is a DN100 pipe. The critical route5 goes from the production unit to substation 13 (SST13).

5 Critical route is the path with the highest pressure loss. It fits with the substation with the minimal pressure difference (set at 1 bar in the model).
5.1.3.2.2 Perrin

The minimal pressure difference is located in substation 27. Pressures and pressure gradients through the critical route is quite low with a maximal value of 5.3 mmwc/m. The maximal value on this branch (7.9 mmwc/m) only concerns substation 21 far from where the extension is imagined. The critical route goes from the production unit through substation 27.
5.1.3.2.3 Chanteloup

There is no particular restriction in Chanteloup branch. The old pipe to the closed geothermal well is large enough to transfer the heat. The critical substation is substation C3.
5.2 City centre extension

5.2.1 Consumption analysis

The following table shows the results of consumption calculations for each part of Sevran town centre.

<table>
<thead>
<tr>
<th>Extension partition</th>
<th>Space heating [MWh/yr.]</th>
<th>Water heating [MWh/yr.]</th>
<th>Total [MWh/yr.]</th>
<th>Equivalent power at -7°C [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV1</td>
<td>1 198</td>
<td>133</td>
<td>1 331</td>
<td>678</td>
</tr>
<tr>
<td>CV2</td>
<td>448</td>
<td>50</td>
<td>498</td>
<td>254</td>
</tr>
<tr>
<td>PRIV1</td>
<td>1 680</td>
<td>960</td>
<td>2 640</td>
<td>1 053</td>
</tr>
<tr>
<td>PRIV2</td>
<td>464</td>
<td>270</td>
<td>734</td>
<td>292</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3 790</strong></td>
<td><strong>1 413</strong></td>
<td><strong>5 203</strong></td>
<td><strong>2 277</strong></td>
</tr>
</tbody>
</table>

Table 17: Consumption in town centre at 2300 degree-days

5.2.2 Simulations

Two situations were studied: the first one includes only buildings given by Sevran city (CV1+CV2+PRIV2), the second one includes also the large condominium (PRIV1) (see section 4.4.1.1 and Figure 46). Simulations were done with a load factor of 1 for existing substations and 1.5 for the extension project. This allows a large technical margin.

5.2.2.1 CV1+CV2+PRIV2

The pressure profile and linear friction losses are reasonable. The latter never exceeds 10 mmwc/m; the highest value is 7.5 mmwc/m on 71 meters (see Figure 48). The critical route goes from the production unit toward the last building at the end of the extension (top right in green in Figure 46). In the extension part, diameters are calculated so the friction pressure gradient is kept under 10 mmwc/m. In Figure 48 it is possible to guess where the pipe diameter is changing. Pressure gradient decreases slowly when the pipe diameter remains the same, because substations are served one by one and the power in the branch
decreases. Friction losses increase quickly when the pipe diameter decreases due to higher flows (and speeds) in the pipe.

Figure 47: Pressure profile in the critical route (CV1+CV2+PRIV2)

Figure 48: Friction pressure gradient in the critical route (CV1+CV2+PRIV2)

Termis calculated the optimal diameters. Table 18 shows the calculated diameters. The main pipe is represented by bold and underlined values. Other values concerns pipes used to connect each building to the main branch. Thus the main branch needs DN125 pipes at the beginning to transfer enough power to all substations. The diameter then decreases along the main branch because there are fewer substations to serve (thus less power). The final pipe is a DN80 pipe, the smallest size available in the pipe catalogue for the software. In Figure 48, pipe reductions are clearly visible at point K06 (DN125 to DN100) and K28 (DN100 to DN80).

---

6 “K06” and “K28” are nodes name in Termis software. They are just used here to explain Figure 48 (nodes names are written on top of this figure).
Table 18: Optimal diameters (CV1+CV2+PRIV2)

Pressure difference due to linear friction losses accounts for 2.8 bars (see Figure 47). Including singular losses means a pump requirement of 3.2 bars. The calculated flow in production unit for Perrin branch plus the extension is 164.45 tons/h. The pumping capacity is 379 m³/h and 4.12 bars (Table 10), which is thus enough for this extension project.

Table 19 shows an overview of this extension. Power (with a 1.15 margin coefficient), consumption and network length is indicated for each part of the extension. This allows calculating ratios in kW/m and MWh/m. Density is very low with a maximum of 1.35 kW/m, far from the typical value of 4 kW/m.

Table 19: Results for CV1+CV2+PRIV2

5.2.2.2 CV1+CV2+PRIV2+PRIV1

Linear friction losses reach 14.2 mmwc/m in the existing network with this configuration. It is still acceptable. The critical route goes from the production unit toward the last building at the end of PRIV1 (top left in yellow in Figure 46). In the extension part diameters are calculated so the friction pressure gradient is kept under 10 mmwc/m. Pressures and flows are the same in the branch going toward CV1, CV2 and PRIV2 than in previous simulation (Section 5.2.2.1). Only common parts with PRIV1 are changed.
Figure 49: Pressure profile in the critical route (CV1+CV2+PRIV2+PRIV1)

Figure 50: Friction pressure gradient in the critical route (CV1+CV2+PRIV2+PRIV1)

<table>
<thead>
<tr>
<th>Zone</th>
<th>DN</th>
<th>Length [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common part</td>
<td>150</td>
<td>74.39</td>
</tr>
<tr>
<td>PRIV1 Cité Terre et famille 1</td>
<td>100</td>
<td>201.13</td>
</tr>
<tr>
<td>PRIV1 Cité Terre et famille 1</td>
<td>80</td>
<td>6.88</td>
</tr>
<tr>
<td>PRIV1 Cité Terre et famille 2</td>
<td>80</td>
<td>214.94</td>
</tr>
</tbody>
</table>

Table 20: Optimal diameters (PRIV1)

Pressure difference due to linear friction losses accounts for 3.5 bars (see Figure 49). Including singular losses means a pump requirement of 4.0 bars. The calculated flow in production unit for Perrin branch plus the extension is 198.66 tons/h. The pumping capacity is 379 m$^3$/h and 4.12 bars (Table 10), which is thus enough for this extension project.

Adding PRIV1 allows higher densities compared to previous case. Nevertheless it is not yet high enough. PRIV1 alone may be worth being connected because of the higher density (2.21 kW/ml), but it is still quite low.
<table>
<thead>
<tr>
<th>Zone</th>
<th>Consumption [MWh/yr.]</th>
<th>Power [kW]</th>
<th>Length [ml]</th>
<th>kW/ml</th>
<th>MWh/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIV1</td>
<td>2 640</td>
<td>1 210</td>
<td>547.1</td>
<td>2.21</td>
<td>4.83</td>
</tr>
<tr>
<td>PRIV1+CV1</td>
<td>3 971</td>
<td>1 990</td>
<td>1102.4</td>
<td>1.81</td>
<td>3.60</td>
</tr>
<tr>
<td>PRIV1+CV1+CV2</td>
<td>4 469</td>
<td>2 282</td>
<td>1420.9</td>
<td>1.61</td>
<td>3.14</td>
</tr>
<tr>
<td>PRIV1+CV1+CV2+PRIV2</td>
<td>5 203</td>
<td>2 618</td>
<td>1511.3</td>
<td>1.73</td>
<td>3.44</td>
</tr>
</tbody>
</table>

Table 21: Results for CV1+CV2+PRIV2+PRIV1

5.2.3 Economic feasibility

Investment to connect the city centre was evaluated at 1 100 k€ for 950 meters of network and eleven substations. The project is eligible to ADEME subsidiaries which can support 24% of this investment. Energy savings certificates can only support 8% of the investment. Only one of those two subsidiaries can be choose and ADEME is more interesting. It is nevertheless necessary to invest 840 k€ more for accomplishing this extension. This equals to spending 520 € per kW installed. This price can be compared with the contract limitations: 100€/kW. Those limitations do not apply in this case, but are a good reference. The investment is more than 5 time more expensive that what the contract advise.
5.3 Hospital extension

5.3.1 Consumption analysis

The following table shows the results of consumption analysis for the hospital.

<table>
<thead>
<tr>
<th>Space heating [MWh/yr.]</th>
<th>Water heating [m3/yr.]</th>
<th>Total [MWh/yr.]</th>
<th>Equivalent power at -7°C [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 933</td>
<td>9 361</td>
<td>5 869</td>
<td>2 930</td>
</tr>
</tbody>
</table>

Table 22: Hospital consumption at 2300 degree-days

Installed capacity is currently 3 100 kW in the hospital boiler room. Oversizing installations is normal and calculations are thus coherent with this value. Installed capacity was communicated lately and various powers were studied in order to evaluate sensitivity. Powers considered were: 2 930kW, 3500kW and 4000kW. Lately, 3100kW case was simulated (only for relevant scenarios).

5.3.2 Simulations

Before knowing the real installed power of the hospital, simulations were made for 2 930 kW, 3 500 kW and 4 000 kW. Network behaviour has been studied for a load factor on existing substations of 1.00 and 1.15. Given the high friction losses in the network, the possibility of not supply the hospital when the outside temperature is under 0°C was studied. In the following results tables friction losses over 20 mmwc/m are in red so it is easier to identify non-reasonable scenarios.

5.3.2.1 Results at -7°C

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>2 930</td>
<td>15 327</td>
<td>23.5</td>
<td>20.3</td>
<td>14.7</td>
</tr>
<tr>
<td>3 500</td>
<td>15 884</td>
<td>25.8</td>
<td>22.5</td>
<td>16.5</td>
</tr>
<tr>
<td>4 000</td>
<td>16 415</td>
<td>28.1</td>
<td>24.7</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Table 23: Results for hospital extension with a load factor of 1.15 on existing substations

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>2 930</td>
<td>13 735</td>
<td>19.3</td>
<td>16.8</td>
<td>12.3</td>
</tr>
<tr>
<td>3 500</td>
<td>14 292</td>
<td>21.4</td>
<td>18.8</td>
<td>14</td>
</tr>
<tr>
<td>4 000</td>
<td>14 822</td>
<td>23.6</td>
<td>20.8</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Table 24: Results for hospital extension with a load factor of 1.00 on existing network

5.3.2.2 Results at 0°C

Table 25 gives the equivalent powers at 0°C for simulations.
<table>
<thead>
<tr>
<th>Hospital power at -7°C</th>
<th>Equivalent power at 0°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 930 kW</td>
<td>2 304 kW</td>
</tr>
<tr>
<td>3 500 kW</td>
<td>2 753 kW</td>
</tr>
<tr>
<td>4 000 kW</td>
<td>3 146 kW</td>
</tr>
</tbody>
</table>

Table 25: Hospital powers at -7°C and 0°C

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>2 304</td>
<td>11 484</td>
<td>20.1</td>
<td>17.5</td>
<td>12.7</td>
</tr>
<tr>
<td>2 753</td>
<td>11 916</td>
<td>22.2</td>
<td>19.5</td>
<td>14.4</td>
</tr>
<tr>
<td>3 146</td>
<td>12 310</td>
<td>24.2</td>
<td>21.3</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 26: Results for hospital extension with a load factor of 1.15 on existing substations

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>2 304</td>
<td>10 309</td>
<td>16.6</td>
<td>14.6</td>
<td>10.8</td>
</tr>
<tr>
<td>2 753</td>
<td>10 741</td>
<td>18.5</td>
<td>16.3</td>
<td>12.3</td>
</tr>
<tr>
<td>3 146</td>
<td>11 133</td>
<td>20.3</td>
<td>18</td>
<td>13.8</td>
</tr>
</tbody>
</table>

Table 27: Results for hospital extension with a load factor of 1.00 on existing substations

### 5.3.2.3 Results with 3 100 kW

Finally the installed power in the hospital is 3 100 kW, which already includes an oversizing factor. Calculations were then made with 3 100 kW at -7°C.

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>3 100</td>
<td>15 515</td>
<td>24.2</td>
<td>21.04</td>
<td>15.26</td>
</tr>
</tbody>
</table>

Table 28: Results for hospital extension with a load factor of 1.15 on existing substations

<table>
<thead>
<tr>
<th>Hospital nominal power [kW]</th>
<th>Total power in Rougemont branch [kW]</th>
<th>Friction losses [mmwc/m]</th>
<th>Required pipe for the extension</th>
<th>Possible connection point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>3 100</td>
<td>13 923</td>
<td>19.96</td>
<td>17.5</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Table 29: Results for hospital extension with a load factor of 1.00 on existing substations
5.3.2.4 Pumping results
Simulations with 4 000 kW at -7°C with a load factor of 1.15 on existing substations and a connection in C (worst case because of higher friction losses) gave a total flow of 350 tons/h and pressure change of 5.4 bars (including +15% of singular losses). The installed pump is able to produce 400 m³/h and 5.89 bars, which is thus enough.

5.3.3 Economic feasibility
Investment for connecting the hospital was estimated at 497 k€ with the possibility of getting 176 k€ from energy savings certificates. This means a final investment around 100 €/kW. It is possible to make the hospital pay for this last investment because it is coherent with contract limitations. Changing pipes T1 and T2 will respectively cost 61 k€ and 91 k€. In the hospital context this extra investment is not necessary but will reduce pressure losses and thus the electricity consumption. The economic study showed that this extra investment is possible.
5.4 Tools comparison

Two types of tools were used for this master thesis. On one hand, P1-tool and SIME helped calculating the renewable share in the district heating network. One the other hand, versions 2 and 5 of Termis were used. This master thesis was the opportunity to criticize tools and compare them. The following conclusions are based on the experience I had using those tools.

P1-tool and SIME were strongly different but gave similar results. SIME has more parameters and gives more accurate results, with a sensitive analysis. P1-tools give simple results, based on reasonable simplifications, but it is hard to know the model limits. To the contrary, it is hard to get used to SIME, but it is easier to criticize results.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1-tool</td>
<td>• Only three meteorological data available</td>
</tr>
<tr>
<td></td>
<td>• Power requirement for sanitary hot water is</td>
</tr>
<tr>
<td></td>
<td>considered constant over a day</td>
</tr>
<tr>
<td>SIME</td>
<td>• Meteorological data can be set in</td>
</tr>
<tr>
<td></td>
<td>• Various consumers type</td>
</tr>
<tr>
<td></td>
<td>• Sensitive analysis year per year</td>
</tr>
<tr>
<td></td>
<td>• Simulate random failures</td>
</tr>
<tr>
<td></td>
<td>• More parameters to fit with the reality</td>
</tr>
<tr>
<td></td>
<td>• Hard to understand and to use</td>
</tr>
<tr>
<td></td>
<td>• Too many parameters that are not always</td>
</tr>
<tr>
<td></td>
<td>relevant</td>
</tr>
</tbody>
</table>

Table 30: Comparison of P1-tool and SIME

Versions 2 and 5 of Termis are based on the same solver engine, except for some bug-fixes and small improvements. In practice both versions gave same results in Sevran study case. Version 2 is very user-friendly and there is a graphical window for every parameter. This is a strong advantage for an occasional user. Nevertheless when it comes to a deeper use with many simulations, version 2 becomes long and heavy to use, while version 5 is quicker. Version 5 has also a lot of visualization possibilities that can be saved for a future use like presenting or checking results quickly.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Termis version 2</td>
<td>• One single license USB-key for one user at a</td>
</tr>
<tr>
<td></td>
<td>time</td>
</tr>
<tr>
<td></td>
<td>• Long importation procedure for network paths</td>
</tr>
<tr>
<td></td>
<td>• Limitations due to graphic interface</td>
</tr>
<tr>
<td>Termis version 5</td>
<td>• Complexity (various layouts, consumers</td>
</tr>
<tr>
<td></td>
<td>objects are difficult to understand</td>
</tr>
<tr>
<td></td>
<td>• Importations of network paths is incomplete</td>
</tr>
</tbody>
</table>

Table 31: Comparison of versions 2 and 5 of Termis
6 Conclusion

This master thesis work consisted in evaluating the feasibility of two extension projects on Sevran district heating network. The first work consisted in knowing the existing network before starting studying extension projects and gave a total consumption of 45.2 GWh/year of heat. The study with P1-tool and SIME revealed the possibility of adding new consumers up to 12 GWh/year while keeping a 60% renewable share. A technical analysis was then performed to understand the behaviour of the district heating network. This part was realized with Termis software to simulate hydraulic and thermal equations. The model was built from an old version of the network layout and corrected to fit with the current layout. Consumptions analysis and historical data of the production unit gave parameters for the model. A control was then performed to ensure that the model produced expected results according to historical data on site. The second work consisted in creating new extensions. This started with a consumption analysis. Then paths to connect future consumers were drawn and modelled in Termis. Simulations gave technical feasibility and investment requirements. Economical study could then be performed.

The two extension possibilities gave completely different results. If it is technically possible to connect the city centre, the return on investment is too low to make this operation profitable on a long term. Consumers should pay around 520 €/kW to make this profitable. To the contrary, hospital connection was more complex on a technical point of view with high friction losses up to 20 mmwc/m, but is economically feasible with an investment from the hospital of 100 €/kW.

Various approximations and simplifications were made to perform this work. The DD principle was the first simplification, introducing an error on consumptions and powers in the network. Then a pipe catalogue was used, considering new pipes even if the network is 45 years-old. Some renovations were made in the history of the network and it was not possible to exactly know pipes wear without performing a long and expensive measuring campaign. Furthermore single pressure losses in the network were approximated as a supplementary fraction of the linear pressure losses. Those approximations gave uncertainties but were necessary to save time in an industrial environment. In order to avoid risks in future investments, it was thus necessary to use safety coefficient to oversize equipment. Furthermore comparison with real data were made and provided a proof of reasonable results.

Results of this study were communicated to Sevran city and to the district heating owner. Connecting buildings in the city centre is now abandoned due to connection price. It has not been possible to densify the extension project with the surrounding buildings because they all have individual gas or electric heaters. Commercial relations have started with the hospital which is interested as it has to replace its boiler room soon. As Sevran network can accept more consumers while keeping a 60% renewable share, other projects are starting in order to benefit from the cheap price of heat in Sevran and to make the city more sustainable.

This work was also the opportunity to show the economic reality of the district heating industry. Gas-CHP units are working at full power from November to March, even if renewable resources are available and not fully used. Incentives play a significant role in economic feasibility of district heating networks. Finally I observed public concerns while meeting city services: noise, view, traffic perturbation.
7 Bibliography


Lazzarin, R., and M. Noro. “Local or district heating by natural gas: which is better from energetic, environmental and economic point of view?” Applied Thermal engineering, 2006, Elsevier Ltd. ed.


