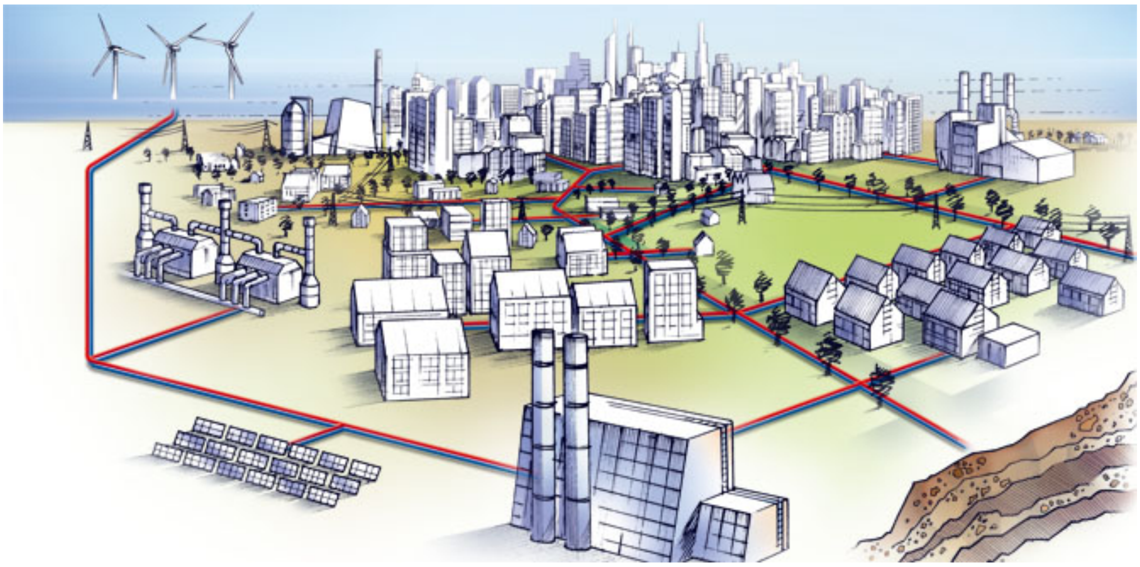

DISTRICT HEATING IN ROMANIA

An assessment of the district heating energy sector in Romania - A case study of Cluj-Napoca, Romania

Master's Thesis

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September 26, 2017

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Synopsis

An assessment of the possible technical solutions and policy recommendations for solving problems regarding the district heating sector of Cluj-Napoca were conducted in this thesis. An extensive literature review, data collection, and an EnergyPlan modelling have been carried out to present potential technical solutions. The thesis begins with a presentation of the current situation of Romanian DH sector, followed by the description of Cluj-Napoca heating sector.
It then changes focus on the methodology behind the modelling of the project and data collection. Using the simulation tool EnergyPlan, a reference scenario has been created based on the Cluj-Napoca heating sector, followed by three other alternative scenarios created to evaluate the most cost-effective solution of using renewable energy sources to fuel the Cluj-Napoca heating sector. The technical analysis is followed by a comparison between the future alternative scenarios and their results, emphasizing the benefits of using only renewable energy sources to fuel the DHS of Cluj-Napoca. Next, the most important Romanian laws regarding the national DHS are reviewed, and policy recommendations regarding the Cluj-Napoca district heating are presented. Finally, the assumptions, limitations, results and policy recommendations regarding the possible solutions for solving the problems of Cluj-Napoca district heating system are discussed.

Preface

Between July 26th, 2017 and September 26th, 2017, the project has been made. The project has been made in the last semester of the Master's degree Sustainable Energy Planning & Management at the School of Architecture, Design and Planning at Aalborg University.

Acknowledgement

I would like to express my sincere gratitude to my supervisor Prof. Dr. Herink Lund for his guidance and encouragement throughout this master thesis.
Also, I would like to thank all my family members and friends, who have been a continuous source of motivation throughout the whole education process.

Reading Guidance

In the report, several references have been used and organized with the Harvard approach, with authors and year of publication. If the year of publication is not included then the source will be written like this: "anre.ro, seen 2017". If the reference is after a dot in a section then it covers the whole section and if the reference is before the dot, then it only covers the line. For sources with the same author and year of publication there will be added an A, B or C to separate the reference. The text that is used directly from a source in the project has been made italic. All the references are gathered at the end of the project as a reference list with all the information about the sources.

Project Structure

The structure of the project's chapters and sections has been set up in numerical order with chapter as 1. XX and smaller sections as 1.1 XX or 1.1.2 XX. This order will also be used for figures, graphs and pictures that are being noted as "Figure 1.1" in the Chapter "1. XX" etc.

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Abbreviations and Acronyms

4GDH	4th Generation District Heating
BTU	British Thermal Units
CGB	Condensing Gas Boilers
CHP	Combined Heat and Power
CHPSS	Centralized Heat Power Supply System
CO2	Carbon Dioxide
DH	District Heating
DHS	District Heating System
EC	European Commission
EU	European Union
Gcal	Gigacalorie
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
IEA	International Energy Agency
IHS	Individual Heating Sector
IMHU	Individual Micro-Heating Unit
MWe	Megawatt electrical
MWh	Megawatt hour
MWt	Megawatt thermal
RATCJ	Autonomous District Heating Company - Cluj-Napoca
RE	Renewable Energy
RES	Renewable Energy Source
RON	Romanian Leu (Currency)

Measurement units

Measurement Unit		
MWh	GJ	Gcal
1	3.6	0.86
0.28	1	0.24
1.16	4.19	1

Based on information provided by (International Energy Agency, 2017)

1 Opening

Anthropogenic warming of the earth's climate system is now indisputable and its widespread effects are one of the biggest daunting problem nowadays. Global temperature rising, warming of the oceans, shrinking of the ice sheets, glacier retreat everywhere around the world, with sea levels rising, extreme events and ocean acidification are just some of the compelling evidence that the Earth's temperature is rising. Some of these effects and other associated impacts may continue for hundreds of years even after the complete stoppage of the anthropogenic carbon dioxide (CO2) emissions. (IPCC, 2014)

One of the largest contributors to global warming is the air pollution (IPCC, 2014), which is also the largest global health risk nowadays, since, annually, more than 6 million deaths are caused or related to poor air quality (World Health Organisation, 2005).
The key to solving this problem, which is also the underlying problem of air pollution is in the energy sector, which should be prioritized on the political agenda of each country, since it accounts for two-thirds of the Greenhouse Gas (GHG) emissions worldwide. (International Energy Agency, 2016) Numerous aspects have contributed to this situation, such as the lack of energy efficiency, the energy sources used in the energy generation such as fossil fuels and the amount of energy produced.

Moreover, the global population is growing significantly nowadays and it is expected that the trend will continue in the next decades (Global Health Observatory, 2017), which, of course, will lead to an increase in the energy demand across the globe.

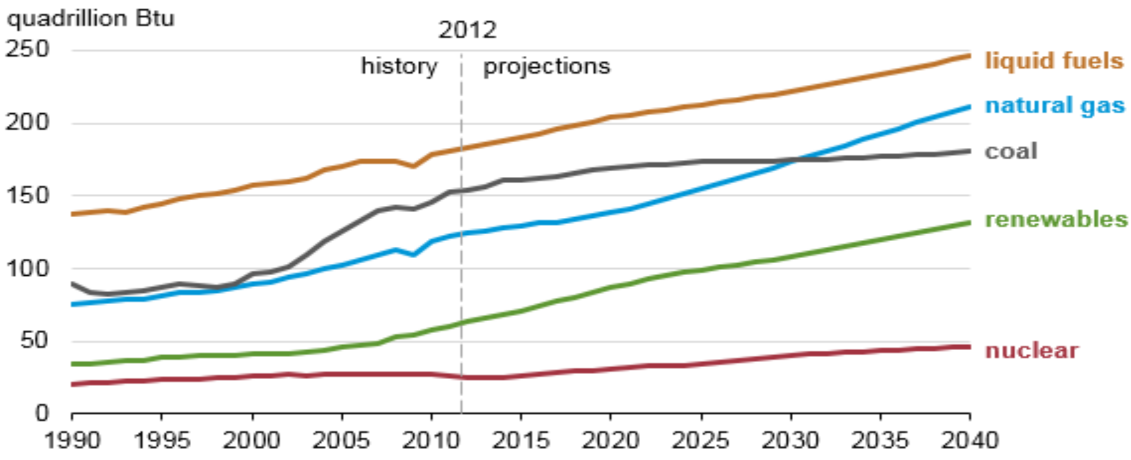


Figure 1.1: World Energy Consumption by source, 1990-2040, in quadrillion Btu.

The U.S. Energy Information Administration predicts that between 2012 and 2040, the world energy consumption will increase by 48%, as illustrated in Figure 1.1 above. (U.S. Energy Information Administration, 2016) This, certainly, will raise environmental concerns worldwide.

The global population growth is expected to affect Europe as well, of course, where the dependency on imported fossil fuels will increase too. In consequence, the need for change in the EU energy system is vital and unavoidable in order to secure a supply of energy in a sustainable way, without increasing the GHG emissions. (Østergaard & Andersen, 2016)

1.1 Towards an efficient and sustainable global energy system

At an international level, in December 2015, 195 countries represented by their state leaders, were united in Paris, France at The United Nations Climate Change Conference. The purpose of this Conference was singing the "Paris Agreement". Its primary aims were keeping the global temperature rise below 2°C above pre-industrial levels, reducing the GHG emissions and strengthening the ability of the countries to fight globally with the impacts of climate change. All the countries were demanded through nationally determined contributions to give all their interest in this issue in the years ahead. (United Nations, 2015)

In Europe, the European Union, with the 28 member states, has endeavoring goals regarding the climate change. The main objectives include decreasing the dependency of the EU on fossil fuel imports, reducing the use of its resources, bringing health benefits to the population by reducing air pollution and boosting its economy by using clean technologies and low- or zero-carbon energy. The European Commission has scheduled three steps in achieving these ambitious goals, by adopting targets and policy objectives for 2020, 2030 and 2050. (European Comission, 2011)
The first target is scheduled to be achieved by 2020 with a 20% cut in GHG emissions in comparison with the 1990 levels, a 20% improvement in energy efficiency and a 20% increase of the share of renewables in their energy consumption. The second target is set for 2030 with a cut of at least 40% in GHG emissions in comparison with the 1990 levels, a minimum of 27% improvement in energy efficiency and at least 27% of its energy consumption being covered by renewables. The last milestone, scheduled for 2050, aims on cutting the GHG with 80-95% in comparison with the 1990 levels. (European Comission, 2011)

To assure the achievement of these targets, a set of mandatory measures has been set by the EU.
One of the measures is the 2012 Energy Efficiency Directive, which imposes to all the EU countries using the energy as efficiently as possible, in all steps, from production to final consumption. (European Comission, 2012) Under the Article 7 of the Energy

Efficiency Directive, The European Commission binds each EU country to set up an energy efficiency obligation scheme (EEOS) or to create alternative measures to achieve a certain amount of energy savings. (European Commission, 2016)

Another Directive with the overall goal of producing and promoting energy use from Renewable Energy Sources, is the Renewable Energy Directive. Its main objectives are: minimum 10% of each country's transportation fuels originating from RES by 2020 and a minimum of 20% of total energy consumption of each EU country being produced by RES. (European Comission, 2009)

In February 2016 an EU Strategy on Heating and Cooling was released as part of EU decarburization strategy that aims to boost energy efficiency and renewable energy, and thus, create a more efficient district heating sector by combining the heating and electricity sectors and renovating the existing building stock. (European Comission, 2016)

In one of its reports, The International Energy Agency (IEA) states that energy efficiency policies among other measures have led to a total of 49% of the energy consumption between 1973 and 1998, in 11 European countries. Also, a further potential of 20% savings by the end of 2030 if all the measures imposed in the EC are respected is predicted. (International Energy Agency, 2006)

In Romania, the "Energy Strategy of Romania 2016 - 2030, with the perspective of 2050" has five fundamental strategic objectives aiming to create a more sustainable energy plan. (Ministry of Energy - Romania, 2016):

- The first objective is increasing the national energy security, which is the ability of a state to provide its energy needs uninterruptedly and at affordable prices. It will be based on the European approach to energy security policy, which, in turn, is based on rules of intra/extra-community cooperation, norms and institutions. (Ministry of Energy - Romania, 2016)

- Creating a competitive energy market represents the second objective, which will provide the consumers with the best quality/price ratio, and thus, supporting the country's economic competitiveness. In order to address this matter, an energy system based on free market mechanisms will be created, the main functions of the state remaining the policy maker, regulator, guarantor of the stability of the energy system and the investor. (Ministry of Energy - Romania, 2016)

- The third objective is creating clean energy, which will lower the GHG emissions and other noxious substances, thus contributing to mitigate climate change. Based on the principle of equitable participation in reaching national targets for 2020 and 2030, Romania will do its utmost to achieve its targets by investing effectively to increase the RESs. (Ministry of Energy - Romania, 2016)

- Modernizing the energy governance system is the fourth objective. Its purpose is increasing the quality of the energy governance system in Romania, which is the basis for all the other strategic objectives. (Ministry of Energy - Romania, 2016)

- The vulnerable consumer protection and the reduction of energy poverty (lack of access to modern energy services) are addressed by the last objective. It includes fundamental strategic objectives aiming to help the final consumer. Price accessibility is one of the most important challenges of the energy system. In addition, the objective aims to increase the communication quality between the energy suppliers and the consumers by continuing the installation of smart meters with remote reading and at the same time increasing the transparency of the final energy price. (Ministry of Energy - Romania, 2016)

Since there may be changes in the EU energy strategy in the following years, once every five years, the Romanian Energy Ministry intends on updating the system data and analysis, defining a new qualitative analysis of trends in the national energy system, and reviewing the targets as well as the priorities. (Ministry of Energy - Romania, 2016)

According to The European Commission, Romania is expected to achieve its 2020 renewable energy target since the share of renewable energy in Romania in 2013 was 23.9%. (European Comission, 2015)

1.2 European Union Energy System

In 2015, the production of primary energy in the EU totaled 767 million tons of oil equivalent (Mtoe) where only 72.4% of the total gross inland energy consumption was reaching the end users. (European Environment Agency, 2015)
The EU energy system is highly relying on fossil fuels with a share of 73.8% of the total energy consumption generated by burning fossil fuels in 2013, while renewable energy sources accounted for only 11.8%, and 13.6% nuclear power (European Environment Agency, 2015).

The EU dependency on energy imports from non-EU-member countries has increased significantly within all its energy sectors through the last two decades, from 40% in 1990 to 54% in 2015, meaning that more than a half of the gross inland EU energy consumption came from imported sources in 2015. (Eurostat, 2017)

Figure 1.2 illustrates the net imports of fuel types as a percentage of fuel-specific gross inland consumption from 1995 to 2013. The reader can notice, as pictured, that from 2005 to 2013 the import of all products remained approximately the same.

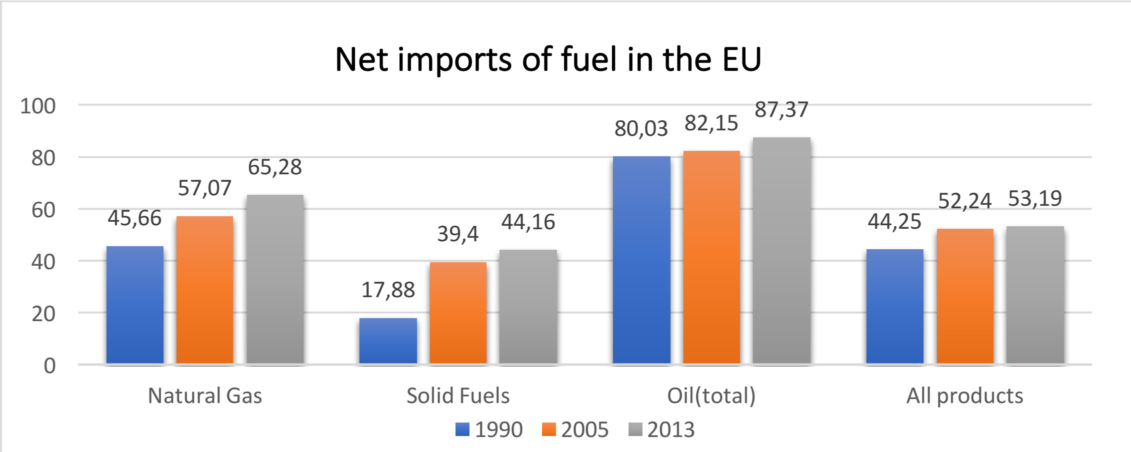


Figure 1.2: Net imports of fuel in the EU (European Environment Agency, 2015)

The Heating and cooling sector is using half of the EU final energy consumption and it accounts for approximately 68% of all oil and gas imports. The EC classifies this sector as being decisive in the EU's transition towards an energy efficient and decarbonized energy system. Moreover, this sector is essential in obtaining a long-term energy security. Considering that this sector is manly based on fossil fuel imports, it could be a potential thread for the European Economy since the security of supply is vital for it. The EU Strategy on Heating and Cooling proposed on February 2016 has as main objectives lowering the heating and cooling demand by renovating its buildings stock with high-performance insulation materials, increasing the energy efficiency in supply by using the latest technologies, increasing the use of renewable energy and reducing the cost of heating and cooling to an affordable level for the whole population. (European Comission, 2016)

The EU also plans to control the energy use with the help of intelligent thermostats, to upgrade the heating equipment to the most efficient technologies and to use biomass and solar heating systems to reduce the GHG emissions. In addition, other heating and cooling strategies are planned in the next years. (European Commission, 2017)

1.3 The current state of the Romanian Energy System

As depicted in the Figure 1.3, the primary energy consumption in Romania is diversified. In 2015, Romania's gross energy consumption was 377 TWh, while the final energy consumption was 254 TWh. The difference of 123 TWh came from the inherent losses of the transformation process in the thermoelectric power plants (66 TWh), the consumption of energy by the thermal power plants, refineries and extractive industries (28 TWh), the consumption of the raw material (17 TWh) and the losses in networks distribution of electricity, gas and thermal energy (12 TWh). (Ministry of Energy - Romania, 2016)

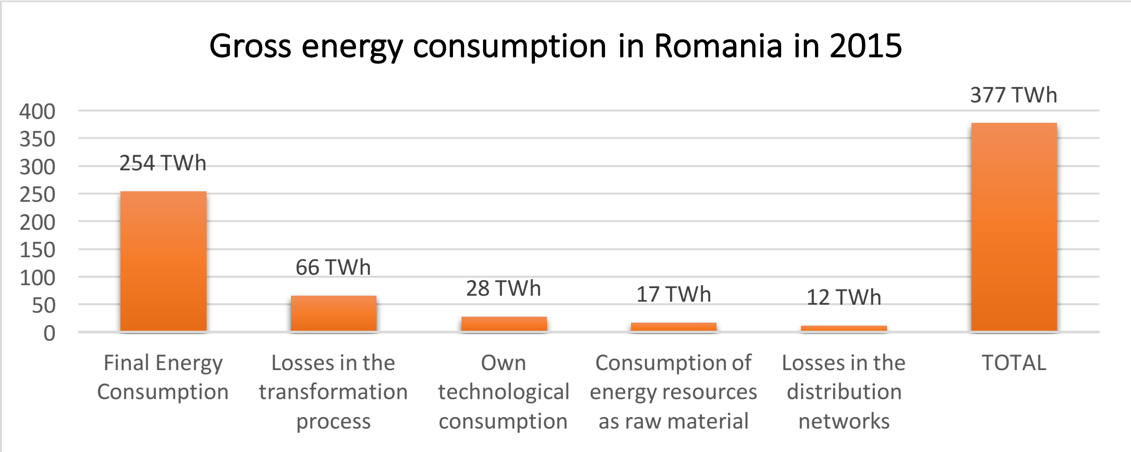


Figure 1.3: Gross consumption in Romania in 2015 (Ministry of Energy - Romania, 2016)

The analysis of final energy consumption in 2015 (total 254 TWh) by energy consumption, represented in Figure 1.4, shows that **the largest energy consumer in 2015 in Romania was the heating and cooling sector (97 TWh)**, with about 39% of the total consumption. The rest of the energy consumption was divided as follows: consumption in industrial processes (48 TWh), passenger transportation (48 TWh), other industrial energy consumption (27 TWh), freight transport (17 TWh), household and service electronics and home appliances (13 TWh), while the lowest energy consumer was the agricultural sector (4 TWh). (Ministry of Energy - Romania, 2016)

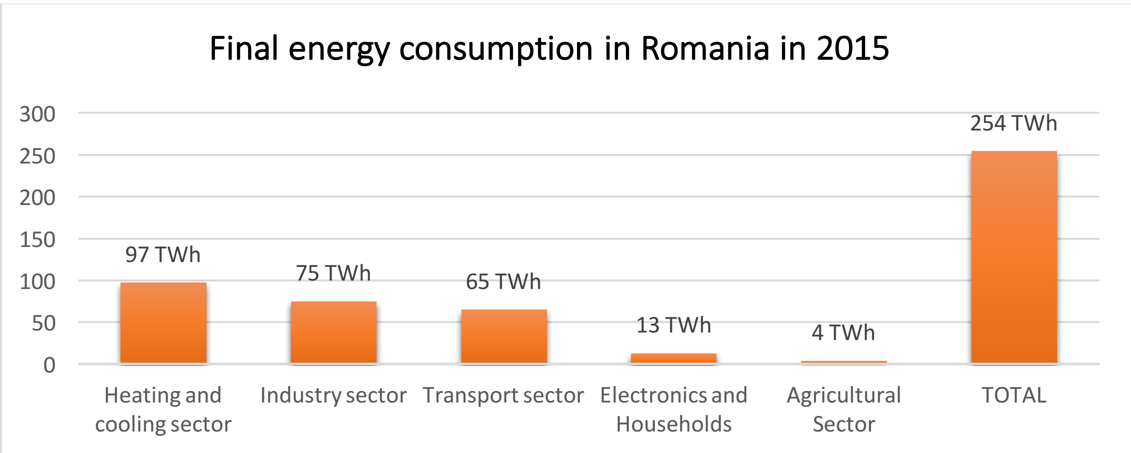


Figure 1.4: Final energy consumption in Romania in 2015 by sectors (Ministry of Energy - Romania, 2016)

1.4 District Heating in Romania

District Heating is a technical process of producing heat in different sources, transporting and distributing it through thermal networks (underground pipeline network). This technical process serves to supply heat efficiently to a large number of residential, public and private consumers. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)
The first district heating systems appeared in Europe in the late 19th century, while the first commercial district heating system was established in 1921 in Hamburg, Germany. (Euroheat & Power, 2005)
The District Heating Systems (DHSs) have proved to be a sustainable and low-cost method in all the densely populated urban areas and not only. Usually, both private and industrial consumers need electricity and thermal power at the same time. They can either be produced together in a Combined Heat and Power plant (CHP), with both electricity and heat being produced in a single process called cogeneration, or they can be produced separately. (Leca, 2012)

Romania is one of the 28 EU member states. It is situated in the South-East Central Europe, and its borders are as it follows: Republic of Moldova in the Northeast and East, Ukraine in the North and East, the Black Sea in the South-East, Bulgaria in the South, Serbia in the South-West and Hungary in the West. Romania is the 9th country in Europe by population, with over 21.000.000 people, and it is divided into 41 counties plus Bucharest, which is the capital city. (Ministry of Defense and Internal Affairs, 2008)
Depending on altitude and season, the temperature varies from - 38° C in winter and + 44.5° C in summer. The duration of the cold season varies from approximately 160 days/year in the South to 222-232 days in the North, with an average of 43.8% to 63.5% of a year. These climate conditions make the heating sector imperative in Romania. (The Government of Romania, 2004)

The first DHS appeared in Romania in the 1960s and all the systems were owned by the national company S.C. Termoelectrica S.A. (Vaida, 2014) During the communist regime, until 1989, 315 centralized district heating systems were built and 251 settlements across the country benefited from them. (Flavius Iacobescu, 2011)
After the overthrown of the communist regime in 1989, there have been many changes in Romania, among which, political and social changes that affected the functioning of district heating. The most damaging factor was that the industrial sector has shrunk much of its work after 1989. Alongside, numerous other causes have brought the urban energy in Romania in the serious situation today: buildings have large energy losses and thermal network structure is old and inefficient. Moreover, the legislation does not produce practical results, investments are absent and the national policy and regulations in this field are inadequate. (Leca, 2012)

According to the annual reports of public institutions in Romania, the number of localities connected to the DHS has been reduced by an average of 10% per year. Also, in approximately 40% of the urban localities, the public heat supply services provided in a centralized system were completely dismantled between 1997 and 2003. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

As shown in Figure 1.5, the number of localities connected to DHS dropped in Romania from 315 in 1989 to 61 in 2016, representing a decrease of 81.5%.

Almost all the consumers opting out to disconnect from the DHS are switching to IMHUs. (Ministry of Regional Development and Public Administration , 2013)

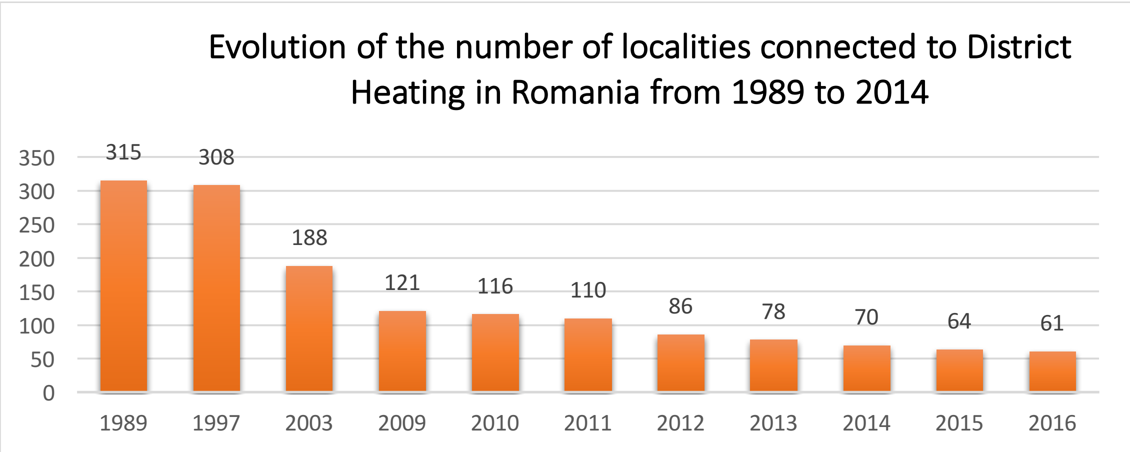


Figure 1.5: Evolution of the number of localities connected to DHS in Romania from 1989 to 2016. Figure created based on data from (National Regulatory Authority for Community Utilities Services, 2016) and (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

Figure 1.6 represents the number of flats and persons using the district heating system in Romania since 1992 until 2014.
The number of individuals using DHS dropped from 8.463.500 in 1992 to 3.822.000 in 2014.
The number of flats using DHS dropped from 2.885.012 in 1992 to 1.331.353 in 2014.

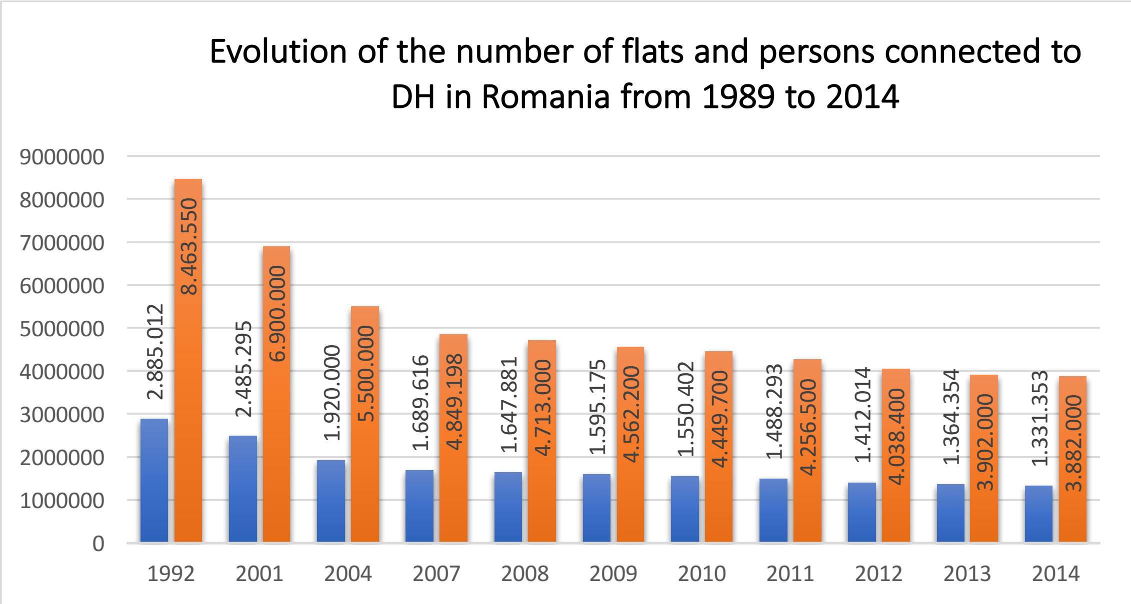


Figure 1.6: Evolution of the number of flats and persons connected to DHS in Romania from 1989 to 2016. Figure created based on data (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

Currently, only approximately 22% of the total number of cities and municipalities in Romania still have a DHS. If villages and communes are added to the total number of cities and municipalities and taken into account, the situation is even worse - only 0.43% of them are connected to DHS. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

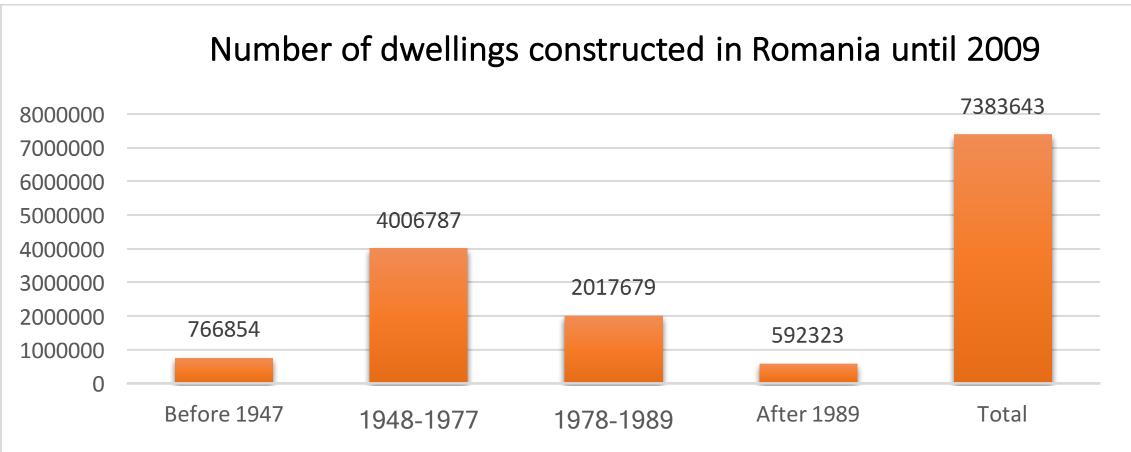


Figure 1.7: Number of dwellings constructed in Romania until 2009 (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

Moreover, as depicted in Figure 1.7, most of the **dwellings in Romania** were built prior to 1989, when there were no specific thermal requirements of the building elements that make up their tire, and for this reason the buildings in Romania have very high heat losses. The increase of urban consumption energy is therefore up to 25% compared to normal. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

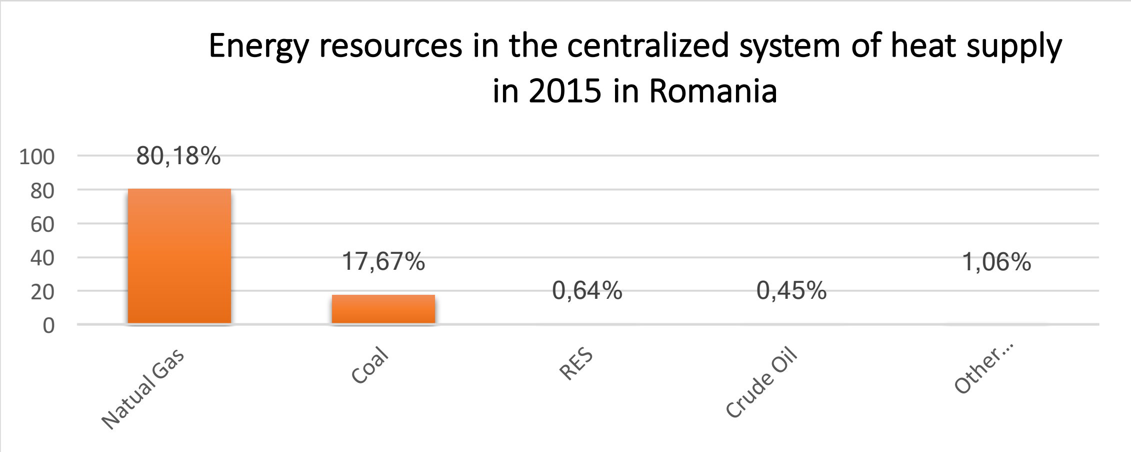


Figure 1.8: Energy resources in the centralized system of heat supply in 2015 in Romania. Figure created based on data from (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

The Figure 1.8 shows that natural gas is the most used energy resource in the DHS in Romania with a share of 80.18%, followed by coal – 17.67%, other resources such as combustible waste, etc. – 1.06%, renewable energy resources such as biomass, geothermal energy, solar energy – 0.64% and crude oil – 0,45%. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

In its mid-term and long-term development plan, Romania acknowledges the implementation of an energy strategy to capitalize on **the potential of renewable energy sources** (RES). The main renewable energy sources that can be used in Romania are biomass and geothermal sources - 66 geothermal water sources. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

1.5 Possibly wrong decisions of economic and energetic policy which affected the Romanian district heating

Romania’s **possible wrong economic decisions** in the last decades which affected the DHS in Romanian

Firstly, Romania hasn’t accepted to lower the Value Added Tax (VAT) for the district heating as many other “poor” countries of European Union. A lower VAT is applied for instance in The Czech Republic (20% normal VAT, reduced VAT for district heating 14%), Lithuania (21% and 9% respectively), Latvia (22% and 12% respectively).
Secondly, another possible issue was selling the national apartments to the tenants at the begging of the ’90s, and therefore, due to their low incomes, the owners cannot cope with the responsibilities they have for housing maintenance, such as energy upgrading of buildings.
Thirdly, the lack of a national economic strategy starting 1990 when the only structure specific to the centralized economy of Romania, the State Planning Committee, was dissolved was another possible problem of the country.
One last possible issue was that in ’80s, Romania paid entirely its external debt, and thus, hindered the economic and social development of the country for a long time. In ’90s, Romania requested assistance from the International Monetary Fund and the World Bank and therefore, during this long period of time, the technical and moral wear of the technologies and energy equipment has deepened, among which those specific to centralized heat supply systems. (Leca, 2012)

Romania’s possible wrong energetic decisions in the last decades which affected the DHS in Romanian

First of all, DHS have been involved in 4 ministries (Ministry of Administration and Interior, Ministry of Economy, Ministry of Labor and Social Protection, Ministry of Environment) and two regulatory agencies (National Regulatory Authority for Energy, National Regulatory Authority for Community Utilities Services). Of course, this has made coordination very difficult.
Secondly, the lack of interest and/or skills of the central and local authorities in finding financing solutions for the energy modernization of housing blocks has deepened the problem even more. As already stated, a lot of energy is lost due to the low energy performance of buildings, therefore making it of crucial concern.
Moreover, simple and ineffective solutions have always been adopted regarding the DHS, and this is one of the main reasons why today, the DHS represents the most deficit sub-sector in Romania. (Leca, 2012)

1.6 District Heating in Cluj-Napoca

Cluj-Napoca is one of the largest cities in Romania, situated in the north-west part of the country. (Autonomous District Heating Company Cluj-Napoca, 2017) The city's population doubled between 1960 and 1990, and this made the city grow with an incredible speed, which, triggered the construction of big districts and together with them, the development of the city’s district heating system. At the beginning of the

70s, the central heating supply and hot water supply were established in Cluj-Napoca. These services have been taken over in 1991 by the Autonomous District Heating Company of Cluj-Napoca (RATCJ) that is subordinated to the Local Council. (Autonomous District Heating Company Cluj-Napoca, 2017).

Currently, the city is an important university, cultural and industrial center, with a population of about 325,000 inhabitants. It is divided in 24 neighborhoods (Cluj-Napoca Municipality, 2015), of which, only 6 are currently connected to DHS. (Autonomous District Heating Company Cluj-Napoca, 2017)
The thermal energy production of the DHS of Cluj-Napoca has a total installed capacity of 556 MW, achieved by 2 CHPs with a total installed capacity of 13 MW, 76 thermal power plants with a total installed thermal output of about 400 MW and a district heating plant with 143 MW installed thermal output. (Autonomous District Heating Company Cluj-Napoca, 2017)
The transport of thermal energy of the DHS in Cluj-Napoca comprise 16.5 kms of thermal energy transport networks and **the distribution of thermal energy** is achieved through 128 kms of distribution networks of thermal energy. (Autonomous District Heating Company Cluj-Napoca, 2017)

The thermal energy production and supply system was renovated between 1991 and 2003 with investments of over 18,000,000 Euros. During this period 55.3 kms of thermal networks were rehabilitated, the equipment from 26 quaternary thermal power stations were modernized, 7 new thermal power stations and 8 new thermal power plants were built, 68 units were automated (both central and thermal) and the first CHP was constructed. (Autonomous District Heating Company Cluj-Napoca, 2017) But this fact didn't stop or lower the increasing number of consumers opting out to disconnect from the DHS in the next period.

The DH Company of Cluj-Napoca lost most of its clients, as people switched to IMHUs. (Ministry of Regional Development and Public Administration , 2013)

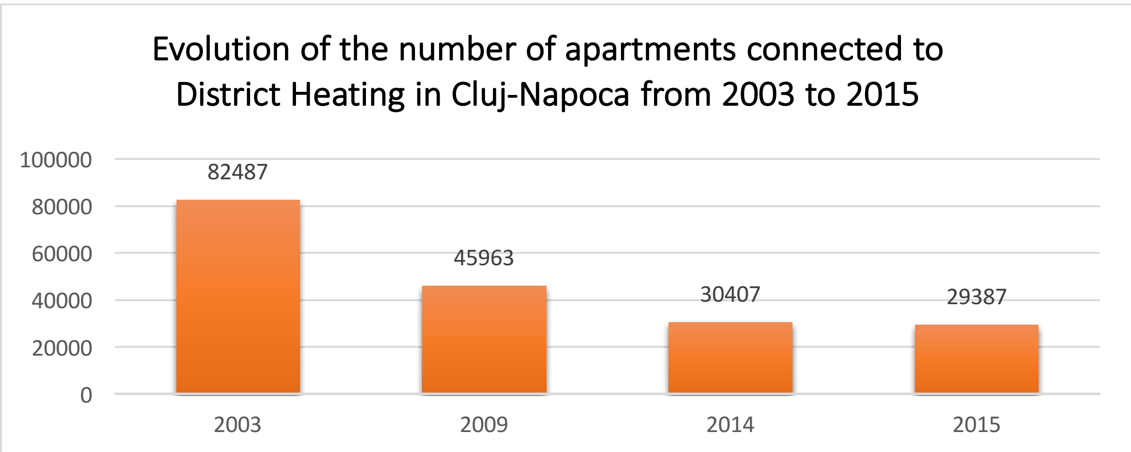


Figure 1.9: Evolution of the number of localities connected to District Heating in Cluj-Napoca from 2003 to 2015 (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015) (The Government of Romania, 2004)

Figure 1.9 illustrates the number of apartments connected to the DHS in Cluj-Napoca, that dropped from 82 487 in 2003 (The Government of Romania, 2004) to 29387 in 2015 (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015). The data shows a disconnection rate of about -64% from 2003 to 2015.

The main reason why RATCJ has lost most of its clients is the company's way of charging the customers. More exactly, the customers were being charged by the size of their apartment and not by the quantity of heat consumed. The hot water bills were emitted according to the number of people living in the apartment and not by the quantity of hot water consumed. For example, even when not being home, if you were to be their customer, you would have to pay high bills for heat and hot water. However, recently, the problem has been solved since RATCJ has introduced individual billing.

Moreover, part of the network transmission and distribution losses, which, for instance, in the winter of 2011-2012 accounted for 27.4% of the total heat, were incorporated in the final price paid by customers and in the subsidies borne by the local government.

To sum up, the dissatisfied customers of the poor quality of the network and the poor quality of the services, have decided to switch to Individual Micro-Heating Units (IMHU) and to only pay for what they actually consume. (Ministry of Regional Development and Public Administration , 2013)

2 Problem definition

The aim of the previous chapter is to describe the background of the Romanian urban energy sector, with a specific focus on the district heating system of Cluj-Napoca.
The aim of this chapter is to define the research problem and to present the context in which it will be analyzed. Also, an overview on the limitations and the structure of the project will be given.

2.1 Research Question

The Romanian energy system is facing changes in the coming years to improve its energy system by increasing the share of renewables in their energy consumption, improving its energy efficiency and reducing the GHG emissions on the road towards reaching the specific energy targets, to which, the country has committed to reach alongside the EU.
It is important that these targets are achieved in the most feasible way, district heating accompanied by heat savings representing now some of the most important priorities for the EU.

In Romania, the district heating sector is in a deplorable state where, because of the possible wrong energetic and/or economic decisions, the number of localities connected to the DHS is reduced annually by an average of 10%.
Out of total of 320 cities and towns in Romania, only 61 (19%) were still connected to DHS in Romania in 2016, compared to 315 (98,5%) in 1989.

In Cluj-Napoca, there is also a continuous trend of increasing the number of consumers opting out to disconnect from the DHS from different reasons such as: financial difficulties, opportunity for other types of heating, the lack of trust in the district heating company, the poor quality of the network or the poor quality of the services.
The number of apartments connected to the DHS in Cluj-Napoca dropped from 82.487 in 2003 to 29.387 in 2015. This represents a disconnection rate of about -64% in the period 2003 – 2015. If this trend will continue at the same extent in the next years, there is an imminent risk that the DHS of Cluj-Napoca will be lost.

The above facts have led to the following research questions, which define this thesis:

1. *<u>What caused the drop in the use of DHS in the city of Cluj-Napoca?</u>*

2. *<u>On a long-term period, what are the technical solutions so that the DH of Cluj-Napoca can offer a more feasible alternative to consumers which are using individual heating?</u>*

3. *What are the policy recommendations so that the actual situation of Cluj-Napoca DHS could be improved?*

This study focusses on DHS of the city of Cluj-Napoca, which is the second largest city population in Romania. The problems faced by the DH system of Cluj-Napoca are similar throughout the whole country and therefore, the analysis conducted in this study could be relevant to other DH systems in Romania.

2.2 Boundaries and limitations of the project

In this project, only the DHS of Cluj-Napoca city is analyzed, with it being the basis of the analysis. Other energy sectors such as industry or transport are not considered in the analyze, and therefore the data should be interpreted by taking this into consideration. The data used for the reference scenario is from 2012. The decision was taken considering the fact that this was the most recent year with a complete set of data available. The technological lifetime of the technologies considered in the project are 25 years. The price of gas used is the reference price published by the gas distributor of Cluj county. Some assumptions are being made for the report and discussed in the Chapter.

2.3 Project Structure

Figure 2.1 presents the structure of this master thesis report, with the grey sections illustrating the sections of the project, the blue boxes representing the chapters, and the orange one specifying the content of each chapter.

This project is divided in seven chapters, each of them containing sections and subsections.

Chapter 1 defines the background and the contextual information of the analyzed problem in this project, which led to the research question.

Chapter 2 introduces the research question, followed by a diagram of the project structure and explanation of each chapter. This chapter also provides information regarding the boundaries of this project.

Chapter 3 consists of the methods used in the report to answer the research question. The main subsections of the chapter represent the methodology and theory used in this project and the description of the EnergyPlan tool used to create the model for the scenario analysis.

Chapter 4 presents the background information for the analysis chapter, which is also the basis for the scenarios. Furthermore, it gives an overview of the DH feasible technologies that could be used in the DH system of Cluj-Napoca.

Chapter 5 presents the main analysis of this project, where scenarios are created and a detailed overview of the results of each scenario is provided. Moreover, a comparison between scenarios is conducted to explain the most effective solution for the DHS of Cluj-Napoca.

Chapter 6 is elaborates on the Policy Analysis regarding the District Heating Sector of Romania.

The results of the analysis and the solutions based on the problem definition are synthetized in Chapter 7.

In Chapter 8 the assumptions, the limitations and policy recommendations regarding the possible solutions for solving the Cluj-Napoca DHS problems are discussed.

Finally, the report ends by providing a list of the references cited throughout the project using the Harvard Referencing Style. In addition, the List of Tables, the List of Figures and the Appendix are provided with all the results of the scenarios created in EnergyPlan.

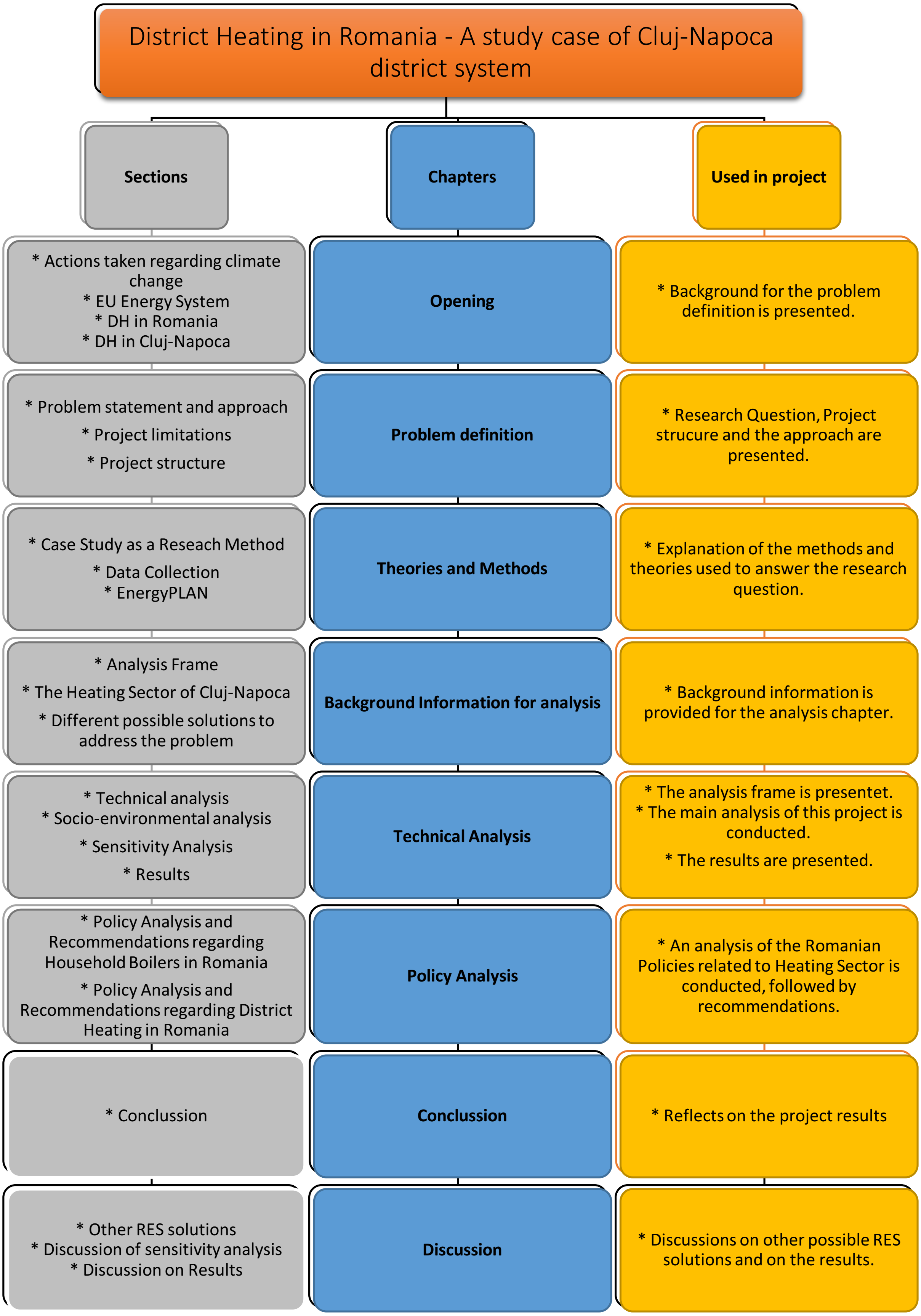


Figure 2.1: Thesis Structure

3 Theories and Methods

In order to provide the most conclusive results, a broad amount of methods and theories are included in this project. This chapter provides an introduction of all the methods and theories used in this project, followed by a detailed description of each of them.

This project is using different methods and theories in order to increment the veracity of the results. The idea behind it is that the results are more exact if different techniques lead to the same result. A very efficient way of getting results with high degree of accuracy, is the technique of cross verification of data from two or more sources (Bogdan & Biklen, 2006).
Besides that, the project is using different approaches such as quantitative, qualitative and pragmatic approaches. The quantitative approach is used in order to create conclusions and hypotheses about future energy systems, conclusions which can be made by making energy system analyzes, which involves various data based on measurements from the producers of energy and from the demand side, which is represented by the consumers.

The quantitative approach focused on collecting and converting data into numerical form so it can be used in statistics. The data from Cluj-Napoca city are collected, analyzed and verified followed by a validation of the data, which is made by comparing different documents, research articles programs and so on. The project also includes a quantitative approach because different types of tools such as EnergyPlan program are used to create, define and compare various scenarios. Objectivity is very important when a quantitative research is conducted and therefore the project scenarios are based only on reliable data from reliable sources without any personal interpretation. The validity of the conclusions drawn from the data and the hypotheses presented are based on one or more premises, such as different conditions and prior statements.
The qualitative approach is used in main the project as a tool for a better understanding of the underlying reasons, opinions and motivations of the analyzed problem.
As mentioned before, the EnergyPLAN program has been used to create a reference and other fictive alternative scenarios of the district heating sector of Cluj-Napoca city, and because the program works in the way that the developer has created it, it has some limitations such as: the user lacks flexibility in making different changes in the way it functions and mainly, because the program's theories are used as tools for making the analysis. Therefore, the approach used tends to be pragmatic. (A. Europe Office, 2009) Scenarios will be created to test the hypothesis that the new energy system is more feasible in comparison with the reference one. The analysis approach has the potential of being used in other DH energy system analysis in Romania.

3.1 Research method: A Case Study of the DHS of Cluj-Napoca

Case study research is a useful tool that allow deeply investigations of specific situations, offering a profound view of the research problem, facilitating the understanding and clarifying of the certain situation or research problem (Baškarada, 2014). The study case approach is a very useful tool that facilitates the analyze the researcher needs to conduct pointing exactly the information from a particular situation, such a small geographical area or a limited number of subjects. (Zainal, 2007) The approach can be used when multiple sources of evidence are taken into consideration (Yin, 2009), in order to ensure that a problem is not explored from only one point of view, but from a more angles (Zainal, 2007).

In this thesis, it is analyzed whether the DHS of Cluj-Napoca can offer a feasible alternative to consumers who are using individual heating.

Advantages of study cases

One of the advantages of using the study case approach is that data is examined depending on its context. This is different from an experiment, for instance, where the analyzed situation is isolated from the context. Another advantage of this approach is that both, quantitative and qualitative data can be collected. By using qualitative data in a study case alongside quantitative data, the real-life events can be better explained and understood in comparison to those situations in which only quantitative data are used such as experiments or survey research. (Zainal, 2007)

Disadvantages of study cases

One of the criticisms that are being made to this approach is that the author can intentionally omit certain facts or things to direct the outcome to a particular viewpoint, which he considers as viable. Another disadvantage of the case study approach is that it cannot be used for generalization of the quantitative data.

Study case approach

In each study case, the first step is the most important one, where the research problem and study objectives are clearly defined (Baškarada, 2014). In this case, the objectives of the study case analyzed is to find solutions and policy recommendations so that the DHS of Cluj-Napoca can regain its customers back.
Once the research question is set, the next step is the determination of the approach. The study case conducted could be: explanatory, exploratory, descriptive or a multi-case-study, etc. When a project analyses a problem related to only a certain area or a certain situation, the single case study approach is used, which is also the case in this thesis. Also, the research question has to be narrowed as much as possible to avoid excess of information (and unnecessary information), and the boundaries such as time and place must be well defined. (Jack & Baxter, 2008)

In the next steps data gathering and analysis techniques are determined, followed by their collection and analyze. The last step consists in the preparation of the results and their presentation. (Soy, 1997)
To sum up, the approach used in the project to answer the research question is the descriptive single case research, where the feasibility of a new energy system in Cluj-Napoca is analyzed. The boundaries are set in the problem definition chapter and data used in this project are explained so it can provide certainty that the project matches the real world as exactly as possible.

This study case was chosen for several reasons:

- The problems faced by the DH system of Cluj-Napoca are similar throughout the whole country and therefore, the analysis approach and solutions may be relevant for comparisons when other Romanian DH system analyses are conducted.

- As number of clients, the DH system of Cluj-Napoca suffered one of the largest customer losses in the whole country, with a disconnection rate of about -64% in the period 2003 – 2015.

- Data availability. Technical and statistical data can be obtained from the websites of European Commission, the Government of Romania and the RATCJ.

3.2 Data Collection

In the following section, the data collection methods are described. The data was gathered through literature review and through calculations in EnergyPlan program. The reference year for collecting data was chosen to be 2012 because of the data availability, as already mentioned, since it is the most recent year when all the necessary data for creating a reference scenario were available. The data can be found in **Appendix XX** – Data collection.

Literature study and data availability

Literature review forms the basis of the project, being the first phase of the project. The information was gathered from various sources: scientific reports such as ScienceDirect and ResearchGate where keywords relevant for this study were used, books, internet and public information provided by the Government of Romania and the RATCJ. The research was conducted in 2 languages, Romanian and English. A great part of data was gathered from official reports available only in Romanian language, while most of the research on the available literature has been conducted in English.

Energy System Analysis Tool – EnergyPlan

EnergyPLAN is an energy system analysis tool developed at Aalborg University. The aim of this tool is to simulate and optimize the operation strategy of a specified energy system on national, regional or even local level, such as towns or municipalities. The analysis of the energy system is carried out on an hourly basis during over a period of one year. It can also be used to create national energy planning strategies. (Lund H. A., 2014) EnergyPLAN will be used in this project to simulate the real existing heating energy system of Cluj-Napoca and to create possible future energy system as scenarios in order to find the most feasible solution for the DHS of Cluj-Napoca.

Analysis Approach

In EnergyPlan, four steps are necessary in order to complete an energy system analysis. The following section will describe each step of the analysis.

- Reference Energy Demand

To begin with, the user is requested to input the energy demand – electricity and district heating – for a period of one year, using an annual demand (TWh/year) and the distribution dataset which can be found in the database of the model. There is the possibility of adding two additional demands for transportation and for exports, but those are not used in this project. There is also the option of adding the individual heating sector (IHS) by including various solar thermal and micro-CHP systems. The heat demand section is divided into four different groups, namely group 1 to 4 (smaller heating plants, decentralized CHP plants, central CHP plants and individual demand). (Lund H. A., 2014) The reference year for the data used in the demand is 2012. The data was gathered mainly from the Romanian National Institute of Statistics and from the Municipality of Cluj-Napoca.

- Reference Energy Supply

The second step is defining the energy sources, the storage capacities and the energy conversion technologies. Capacities and the efficiencies of the DH power plants are divided in different groups. It is mandatory that the efficiency and the capacity of each energy production unit is defined. (Lund H. A., 2014) The efficiencies used in this project were obtained from the STRATEGO EnergyPLAN model for Romania.
Also, in this step, the installed capacity of each heat generation group and their annual production is specified, while a distribution dataset needs to be selected. For the RES used for heating purposes such as thermal plants, additional input such as distribution curves for the yearly calculation of the electricity and/or heat is needed.
The fuel types and the fuel consumption are also required. If the analysis includes the economic assessment, the price of the fuel has to be defined together with the taxes and the operation and maintenance costs. (Lund H. A., 2014) In this paper, the data was mainly collected from the Cluj-Napoca Municipality’s website. As a complement to the supply and demand, distribution curves can to be defined. The electricity demand curve used in this project was obtained from ENTSO-E. (European Network of Transmission System Operators for Electricity, 2017)

- Regulation of the Energy Supply System

At this point the user has to select one of the predefined general strategies: technical optimization or market-economical optimization, which will be later described in this section. Limitation and other additional options are also defined at this point. (Lund H. A., 2014)

- Alternatives

The last step consists of a comparison between the previous defined reference system and other alternative systems. These alternative systems are defined during this step. Also, the strategy and/or the technology can be changed during this step. (Lund H. A., 2014) In this project, the technologies will be changed by creating three new scenarios that will be later compared to the reference system in order to analyze the feasibility and the consequences of a new energy system for the city of Cluj-Napoca.

As mentioned before, the third step of the analysis - Regulation of the Energy Supply System - requires the selection of one of the predefined general strategies: technical optimization strategy or market-economic optimization.

The goal of the first optimization strategy – **technical strategy** – is to cut down the fuel consumption and to lower both the excess electricity production and the exports of electricity. Mainly, the excess energy is stored for later use and the exports are started only when there is no other use the electricity. The energy source, energy demands, production capacity and efficiency of the plants are required and the results include the annual energy production, fuel consumption, imports and exports and CO2 emissions. (Lund H. B., 2014)

Furthermore, this strategy is also divided into two other strategies. In the first one, only the heat demand is covered. For the centralized heat power supply systems with CHPs, the production units are prioritized as it follows: solar thermal, industrial CHP, CHP units, heat pumps, and peak load boilers. In the second strategy, both the electricity and the heat demand are covered. The electricity production decreases because the CHP production is reduced, while the overall electricity consumption increases, since the CHP heat production is replaced with heat pumps and boilers, which are using electricity for the heat production. (Lund H. A., 2014)

In the second strategy – **market-economic optimization** – it is assumed that each plant optimizes according to the business-economic profits. User inputs are used to determine the marginal production costs of the electricity production units and the market prices, depending on the imports and exports of electricity. (Lund H. B., 2014)

Another feature of EnergyPlan is the possibility of creating a **feasibility study** of a certain energy system. The analysis will calculate the socio-economic consequences of the production based on the investment costs, fixed operational and maintenance costs, lifetime of the technologies and the interest rate. The detailed results will show the costs, over a one year time period. They will be divided into 6 categories: fuel costs, investment costs, electricity exchange costs, fixed operational costs, variable operational costs and if there are any CO2 payments, these will be included too. (Lund H. B., 2014)

Lastly, the costs data have to be inputted in the EnergyPLAN. Costs of the energy systems are calculated in EnergyPLAN based on the discount rate and data inserted by the user. The costs are divided into four categories: fuel, operation, investment and additional costs. Fuel costs are used when the marginal productions costs are calculated, as well as in the feasibility study conducted at the end of the energy system analysis. The variable operational and the maintenance costs can be defined in the operation category, whereas the unit prices, lifetimes and fixed operation and maintenance costs can be specified in the investment costs category. The last category includes investments that are not directly connected to the production units. (Lund H. B., 2014)
The standard EnergyPLAN discount rate of 3% and the standard cost data of EnergyPLAN library have been used in this project. The costs are defined based on the Danish context and in this project, it is assumed that the costs data can be applied for Romania as well.

3.3 Summary of the theories and methods chapter

The above chapter aimed to present all the theories and methods used in this project, which represent the understructure of the project. Each theory and method is followed by a description. The first phase of the project consists of background information consisting of data that was gathered by literature study. The study case approach aims to investigate the specific situation of the DH system of Cluj-Napoca, by facilitating the understanding of the research problem. Lastly, the EnergyPLAN tool is presented, in order to simulate the reference scenario of the DH system of Cluj-Napoca. Two new alternative scenarios will be created using the EnergyPLAN tool, in order to evaluate the most cost-effective solution.

4 Background Information

This chapter presents the project's analysis frame, background information regarding the actual heating sector of Cluj-Napoca and, finally, a description and related planning considerations of other technologies and RESs which could improve the district heating system of Cluj-Napoca.

4.1 Analysis frame

The project’s main focus is the DH system of the Cluj-Napoca, a city located in the North-West region of Romania. The location of Cluj-Napoca city can be seen below on a national scale. (Google Maps, 2017)

Figure 4.1: Location of Cluj-Napoca in national context (Google Maps, 2017)

Cluj-Napoca is the 2nd city as population in Romania (Romanian National Institute of Statistics, 2015).

4.2 The Heating Sector of Cluj-Napoca (The Reference Scenario Basis)

The heating sector of Cluj-Napoca is divided in two categories:

- Centralized Heat Power Supply System (DHS), where the heat generation, transport and distribution, and the supply to end users is achieved in a centralized manner.

- Decentralized System of thermal energy generation and supply, which is also divided into two other categories:
    - Consumers without access to the DHS in areas where district heating systems have not been developed, using various IMHUs;
    - Consumers opted out from the DHS, now using various IMHUs.

(Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

4.2.1 Current costs of heating in Cluj-Napoca, 2017

Current cost of heating in Cluj-Napoca, 2017	
Current cost of heating in DHS	**Current cost of heating with IMHUs**
	1 Gcal = 1,29 MWh x 32,40 Euro
Price for 1 Gcal: **47,93 Euro**	Price for 1 Gcal = **42,14 Euro**

Table 4.1: Current cost of heating in Cluj-Napoca, 2017

As shown in Table 4.1, the price for 1 Gcal using a IMHU is 42,14 Euro, comparing to 47,93 Euro for 1 Gcal in the DHS of Cluj-Napoca. However, in addition to that, customers opting for IMHUs are also obligated to pay electrical power, periodic technical checks and ISCIR checks (Romanian State Inspection for Boiler Control, Pressure Vessels and Lifting Installations).

The local heating billing price to the population is 47,93 Euro / Gcal because the difference between the final price of thermal energy and the local heating billing price, which is 48,03 Euro, is borne by the Local Council budget.
If the price wouldn't be borne by the Local Council budget, the price of thermal energy in DHS in Cluj-Napoca would be **89,10 Euro / Gcal**. (Municipality of Cluj-Napoca, 2014)

The energy conversion rates used in the calculation were provided by RATCJ. Transformation ratio is 1Gcal = 1,163 MWh. IMHU average efficiency is 90% (1.29 MWh gas for 1 Gcal produced) (RATCJ, Seen 2017)

The price of the gas used in the calculations is the price displayed on the E.ON Gaz Romania's website, which is the gas distribution company of Cluj County. (1 MWh = 148,75 RON = 32.40 Euro) (E.ON Energy Romania, 2017)

The exchange rate - 1 Euro = 4.59 RON - was offered by the National Bank of Romania on September 8th, 2017. Romanian VAT 19% was included in the Price. (National Bank of Romania, 2017)

4.2.2 The Centralized Heat Power Supply System (DHS) of Cluj-Napoca

In comparison to 1996, when the total thermal energy distributed by DHS was 1.2 million Gcal, the production decreased approximately 4 times by 2013 when the amount of thermal energy distributed though DHS was only 260,000 Gcal (Ministry of Regional Development and Public Administration , 2013), and only 26% of the total buildings in Cluj-Napoca were still connected to the DHS. (Ministry of Regional Development and Public Administration & Ministry of Energy - Romania, 2015)

4.2.2.1 Production, transport and distribution of the thermal energy in DHS Cluj-Napoca

The thermal energy production in DHS in Cluj-Napoca is achieved by:

- 76 thermal power plants, equipped with approximately 300 boilers of various types that use natural gas as fuel and have a total installed thermal output of about 400 MW (The thermal agent used is hot water with parameters 90/70 degrees Celsius);

- 1 district heating plant with 143 MW installed thermal output that produces hot water with parameters of 110/60 degrees Celsius. The plant consists of an old hot water boiler of 116 MWt plus 3 new thermal motors with a capacity of 1,5 MWe each and 2 new hot water boilers (14 + 8 MWt).

- 2 interconnected CHPs with a total installed capacity of 13 MW;

Summed up, the total installed capacity in Cluj-Napoca is 556 MW. (Autonomous District Heating Company Cluj-Napoca, 2017)

The two CHPs were built in 1998 and 2001 respectively. The first CHP consists of 2 hot water boilers of 1160 kW each and a natural gas cogeneration unit equipped with a thermal motor of 210 kW electric and 350 kW thermal. The second CHP is connected to the old CHP and is composed of 3 boilers with a capacity of 3300 kW each and 2 natural gas cogeneration units of 300 kW and 450 kW each. (Autonomous District Heating Company Cluj-Napoca, 2017)

Cogeneration of Combined Heat and Power (CHP) is a process of simultaneous production of thermal and electrical energy with the same installation. Cogeneration plants have experienced a tremendous development over the last two decades due to existing energy crises. The operating principle is the conversion of the mechanical work produced by the engine into thermal and electric energy. Heat obtained during engine operation is delivered to the primary agent of the boiler through heat exchangers, thus achieving thermal energy. Also, a power generator is coupled to the motor shaft, that produces electric power. (Autonomous District Heating Company Cluj-Napoca, 2017)

Cogeneration plants are dimensioned in relation to the heat demand, the electricity being a "secondary" product, varying from the Classical Installations - Thermal Power Plants – are therefore sized for the electricity demand, the thermal energy being in this case the "secondary" product. (Autonomous District Heating Company Cluj-Napoca, 2017)

The implementation of the cogeneration system presents a number of advantages, among which the most important are:
- putting into practice the most modern energy solutions
- rational use of fuel
- low production and exploitation costs
- using electricity for own needs and pumping the surplus into the national energy system, thus becoming electricity producers, which leads to a more efficient investment. (Autonomous District Heating Company Cluj-Napoca, 2017)

Transport and distribution of thermal energy in DHS in Cluj-Napoca consists of:

- 16.5 kms of thermal energy transport networks (hot water network);
- 128 kms of distribution networks of thermal energy, out of which, 94 kms network of thermal power stations to consumers, 31 kms network from the thermal points connected to the district network plant to the consumers and 3 kms network from thermal points connected to thermal power plants to consumers. (Autonomous District Heating Company Cluj-Napoca, 2017)

4.2.3 Decentralized System of thermal energy of Cluj-Napoca

In the last 15 years, in Cluj-Napoca, like in other places in Romania, the number of apartments switching from DHS to IMHUs, has increased exponentially. (Ministry of

Regional Development and Public Administration , 2013) The main reasons for making this decision are listed below:

- The way of charging customers. More specific, the heat bills were charged by the size of their dwelling and not by the quantity of heat consumed. The hot water bills were emitted according to the number of people living in the dwelling and not by the quantity of hot water consumed. Even when they were not at home, they had to pay bills for heat and hot water. Now, the problem was solved since RATCJ has introduced individual billing. (Ministry of Regional Development and Public Administration , 2013)

- Network transmission and distribution losses, which were also charged mostly to the customers. (accounting for 27.4% in 2011-2012). (Ministry of Regional Development and Public Administration , 2013)

- The poor quality of the network and the poor quality of the services. (Ministry of Regional Development and Public Administration , 2013)

- The decreased number of customers connected to DHS determined also the reduced production of heat delivered. DHS equipment has been produced to cover a high level of production, and when the production volume has been reduced, the efficiency of this equipment has also decreased, which has increased the specific consumption of natural gas and electricity. By maintaining these fixed costs, this has led to increased production costs and, and therefore, to the rise in the price of thermal energy. (Benga, Fowler, Haiduc, & Nastase, 2004)

- The IMHU producers have advertised the IMHUs, presenting only the advantages, not the disadvantages of the IMHUs. (Benga, Fowler, Haiduc, & Nastase, 2004)

Moreover, in the early 2000s, Hungary restricted the micro-heating units on its territory, which led to an incredible increase in the imports of second-hand gas boilers in Romania. Besides that, new gas boilers could be found at a very reasonable price in Romania at that time, and the gas boiler producers were advertising them in Romania very intense, presenting only the advantages. (Ministry of Regional Development and Public Administration , 2013)
Thus, the gas boilers became the first choice of people when switching from the DHS to individual heating systems.

4.2.3.1 Condensing Gas Boilers as an Individual Heating Solution

Condensing gas boilers are water heaters fueled by gas, and are illustrated in the Figure 4.2 below. The water flows through a jacket which surrounds the combustion chamber where the fuel is burned. Thus, the energy generated by the combustion is utilized to heat the water. Compared to the conventional gas boiler, where energy is wasted by venting into the atmosphere the resulting flue gases, the CGB are utilizing the heat contained by the flue gases as well, transforming it into heat energy and feeding it into the heating circuit. Before passing into the primary heat exchanger, the cold heating water is preheated by the energy recovered by the secondary heat exchanger where the water vapor contained in flue gases is deliberately condensed, so hence the name of the CGB. (Group-Vaillant, 2017) An extra pipe to drain away the condensate liquid is required for CGB and in some cases where this is fitted externally, some problems may appear in the winter time when it freezes during very low temperature times when the coilers are shutting down for protection. (Baxi Heating UK Limited, 2017; Baxi Heating UK Limited, 2017)

Conventional gas boilers, illustrated in the Figure 4.2, use the same principle as Condensing gas boilers (CGB) to heat water by burning gas as fuel, with the only difference that the energy contained by the flue gases is not harvested and is vented into the atmosphere, thus, the efficiency is approximately 30% lower. (Group-Vaillant, 2017)

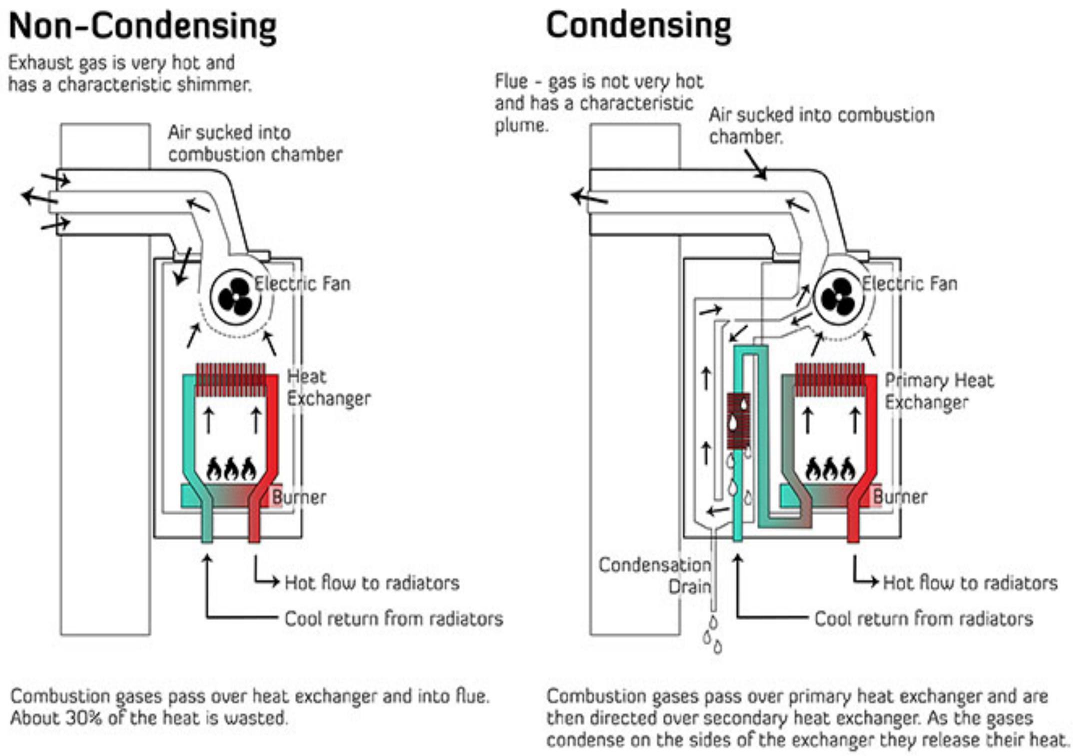


Figure 4.2: Simplified diagram of a condensing boiler vs. a non-condensing gas boiler (The Green Home, 2013)

4.2.3.2 Advantages of using household gas boilers

When it comes to using a household gas boiler, there are very few advantages and those are presented below. The CGB have an optimum energy efficiency of up to 98% - which means financial benefits for the apartment owners. (Group-Vaillant, 2017) Condensing boilers are fully room sealed and take air in directly from the outside through the chimneys, comparing to the conventional gas boilers. A good heating control can lead to an overall higher-efficiency of the CGBs if the following are associated with the CGB: Electronic timer or programmer that allows separate switching of heating and hot water, a room thermostat, thermostatic radiator control valves (TRVs), separate thermostatic control on the hot water system. (Baxi Heating UK Limited, 2017)

4.2.3.3 Disadvantages of using household gas boilers

Figure 4.3: Chimneys from individual micro-heating units, protruding through outer walls (Ministry of Regional Development and Public Administration , 2013)

The disadvantages of using household gas boilers are countless. The most important ones are presented below, in the following paragraphs.
In Romania, the exhausting of the flue gases of the household gas boilers is carried out by pipes which are protruding the exterior walls of the apartment blocks. As depicted in Figure 4.3, these baskets are located near the windows and balconies of neighbors or close to other openings in the blocks of flats and thus, all pollutants contained by the flue gases are brought into the respiratory area of people living in that building. These flue gases pipes are comparable with the gas discharge pipe of an automobile and they contain dangerous life-threatening compounds such as: Carbon dioxide,

nitrogen oxides, polyaromatic hydrocarbons, other polyaromatic compounds, volatile organic compounds, soot, particulate matter below 10 micrometers (PM10, PM2,5, PM1). (Benga, Fowler, Haiduc, & Nastase, 2004)
Since nowhere in the world, risk of gas installation is 0-degree risk, the danger of an explosion will always be present and that leads to a series of questions, such as: Are apartments and apartment blocks equipped with fire protection systems? In the case of earthquakes, what is the behavior of these IMHUs? (Benga, Fowler, Haiduc, & Nastase, 2004)
Also, the gases discharged by IMHUs damage the block facade mortar, in addition to the aesthetic pollution created by the gas evacuation pipes. (Benga, Fowler, Haiduc, & Nastase, 2004)
The increase in the number of IMHUs has also led to an increase in gas imports that have created unfavorable consequences for Romania's budget. (Benga, Fowler, Haiduc, & Nastase, 2004)
Based on the fact that only some of the neighbors are disconnected from the DHS and others are not, and because some neighbors are polluted by others, by the flue gases eliminated by the IMHUs of some tenants, social convulsions can be created. (Benga, Fowler, Haiduc, & Nastase, 2004)

4.3 Different RES as solutions for the District Heating System of Cluj-Napoca (an alternative scenario basis for DHS of Cluj-Napoca)

As is well known, the worldwide DHS are currently using mainly fossil fuels such as coal and gas. The DHS of Cluj-Napoca makes no exception to that, either.
Combining DHS with RES can bring various benefits, including increased energy security, improved system efficiency, improved local air quality and health, and reduced climate impact by reducing emissions. The most important RES that could improve the DHSs are solid biofuels, solar energy and geothermal energy. (International Renewable Energy Agency, 2017)

The renewable energy resources found in Romania are distributed throughout the whole country and they can be found in various forms, such as biomass, hydropower, geothermal potential, wind, solar and photovoltaic. (Ministry of Energy - Romania, 2016)

The RES in Romania have been increasingly promoted lately, but the main focus of the promotion was the production of electricity, especially through large projects. This promotion scheme immediately revealed its shortcomings in the fact that the economic effect of these large projects was low. These projects were implemented by foreign investors who created few job opportunities for the locals, while the profit had been externalized. The bigger problem, however, was that the thermal energy production sector has been neglected, even though it represents over one third of total final energy consumption in Romania. If the same efforts had been made in the case of sustaining the capitalizing of the RES potential through small or medium power projects, it would probably have resulted in a more positive social impact at the local level. Thus, jobs could have been created, gains could have been made in combating pollution, and the economic effects of these projects could have generated local benefits. (Center for Regional Development Agency - Romania, 2014)

The annual energy potential of Romania's RES is presented in the Table 4.1 below:

Renewable energy source	The annual energy potential	Equivalent economic energy (Millions toe)	Field of application
Solar energy: thermal	**60x10^6 GJ**	**1,423**	**Thermal Energy**
Solar energy: photovoltaic	1.200 GWh	0,132	Electricity
Wind Power	23.000 GWh	1,978	Electricity
Hydro Energy	40.000 GWh	3,440	Electricity
Biomass	**318x10^6 GJ**	**7,597**	**Thermal Energy**
Geothermal Energy	**7x10^6 GJ**	**0,167**	**Thermal Energy**

Table 4.2: The annual energy potential of RES in Romania (Center for Regional Development Agency - Romania, 2014)

Table 4.2 it illustrates that the renewable energy resources that can be mainly used in Romania in the production of thermal energy are:

- Biomass;
- Geothermal sources;
- Solar Energy.

Because no geothermal sources are present anywhere near or in the city of Cluj-Napoca, they will not be discussed in this section.
Next, biomass and solar energy will be presented as alternative sources of energy for the DHS of Cluj-Napoca.

4.3.1.1 Renewable Energy Source: Biomass

One of the strategy's priorities in “The Energy Strategy of Romania”, published in 2017, is increasing the biomass share in the Romanian energy mix. The most biomass could be used in the heating sector. It is also estimated that biomass could become Romania's main energy product by the year 2050 when total biomass production intended for energy production in the country could increase to 184 TWh. Currently, the total biomass production in Romania in 2015 was is 47 TWh. (Ministry of Energy - Romania, 2016)

The final energy consumption expected by the Ministry of Energy in Romania for 2020 in Romania is approximately 350 TWh. The target for the share of energy from renewable sources in Romania's gross energy consumption in 2020 is 24%. A small calculation shows that by multiplying the total energy consumption of Romania with the 2020 target, the amount of energy produced from renewable sources corresponding to the 2020 target in Romania is approximately 84 TWh. It can be observed from the above data presented in Table 4.1 that if the whole amount of biomass in Romania was used energetically, **only the biomass itself could meet the 2020 target**, since 7597 Mtoe equals 88.35 TWh. (Center for Regional Development Agency - Romania, 2014)

In the below Figure 4.4 the total annual potential use of wood biomass and plant biomass in Romania (318.000 TJ) is presented. It can be seen that biomass in Cluj County has a potential of 513,3 TJ, out of which wood biomass 29,98 TJ and plant biomass 483,32 TJ. (Ministry of Regional Development and Public Administration , 2013)

Figure 4.4: Total annual biomass potential in Romania (Ministry of Regional Development and Public Administration , 2013)

4.3.1.2 Renewable Energy Source: Solar Thermal Energy

Solar thermal technology collects solar energy and generates environmentally friendly thermal energy and/or electricity. The use of this technology is to generate hot water for use in homes, buildings, or swimming pools, heat the inside of homes, greenhouses, and other buildings and heat fluids to high temperatures in solar thermal power plants. The main limitation of the technology is that the amount of solar energy varies depending on location, time of day, season of the year, and weather conditions. **Invalid source specified.**

Solar District Heating (SDH) technology is a key step in fighting climate change nowadays. Its main advantage is that it can be used anywhere in Europe. SDH plants consist of large fields of solar thermal collectors where, the solar thermal energy is harvested for producing solar heat and later supplying it into district heating networks. The technology can be used together with other technologies for the heat production or/and with large heat storages. The most important advantages of SDH are that it is an emission-free technology, it is available everywhere in Europe and the costs are stable and known for the entire lifetime of the technology. At the end of 2015, in Europe 252 solar thermal plants were operating with more than 350 kW thermal nominal power. (Solites Germany, 2017)

Figure 4.5: Jelling, Danish district heating plant **Invalid source specified.**

Since the SDH technology is currently being used with feasible heating costs in Sweden and Denmark (Solites Germany, 2017), where the GHI has an annual average of 1000 kWh/m2/year or less, it can be concluded that SDH technology feasibility is worth being analyzed also in Romania, where the annual average of GHI is 1275kWh/m2/year.

Solar thermal technologies are used also for individual heating. A typical solar heating system consists of a collector and a fluid to absorb solar radiation, where the heat absorbing liquid is circulated by pumps through collector and then transferred to a room where the heat is needed or to a heat storage system and used later.**Invalid source specified.**

Figure 4.6: Typical Sun Collector used in Individual Heating Sector **Invalid source specified.**

In the following Figure 4.7 the Global Horizontal Irradiation (GHI) in Romania is presented. The GHI is the total amount of solar radiation incident received from above by a surface horizontal to the ground. The data presented were calculated based on the average annual sum GHI from 1994 to 2013. The reader can notice that more than half of the Cluj county area benefits from an average annual energy flow of 1275 kWh/m2. (Solargis, 2017)

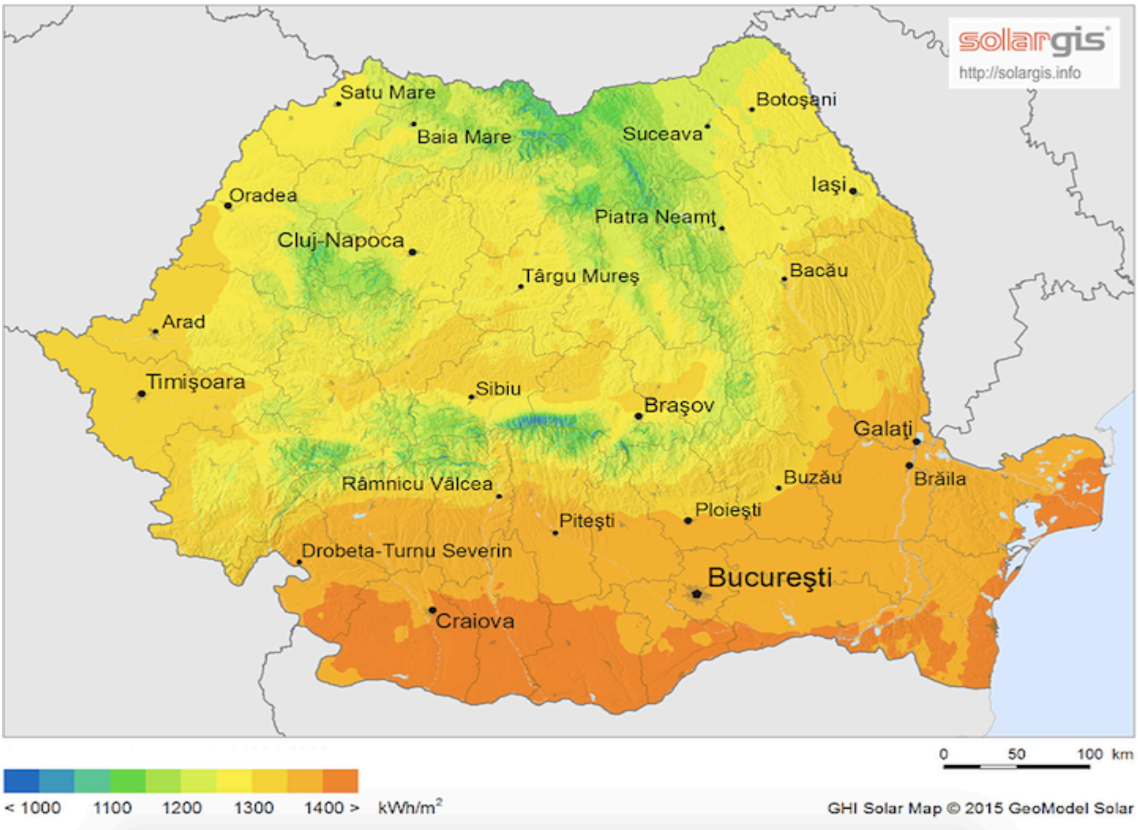


Figure 4.7: Annual Global Horizontal Irradiation (GHI) in Romania (Solargis Maps, 2017)

4.3.2 4th Generation District Heating (4GDH) (an alternative scenario basis for DHS of Cluj-Napoca)

Motivated by the global warming, the world is fast moving towards a transition of the energy systems where the primary energy supply has shifted to renewable energy sources. In this transition, the district heating has an important key role to play, and in order to play such a role, the actual generation of district heating technologies will require further development into a new generation, which will decrease grid losses and will increase the efficiencies of low-temperature production units in the system. (Lund, et al., 2014)

This section will present a new and sustainable generation of district heating systems, their implications and the changes needed in order to transform actual DHS of Cluj-Napoca into such a system.

Over time, three generations of DH have been differentiated. The main motivations of these first three generations of DH were the convenience, low costs and security of supply. A brief description of the technological differences used by the first three generations is presented below. The thermal agent used in the first generation of DHS was the steam. A typical system was consisting of steam pipes in concrete ducts, steam

traps, and compensators. This technology had several disadvantages such as heat losses and low energy efficiency. It was used up to 1930 when the second generation was introduced. Once with the introduction of the second generation of DHS, the thermal agent was changed to pressurized boiling hot water. A typical system of the second generation of DHS would consist of water pipes in concrete ducts, large tube-and-shell heat exchangers, and material-intensive, large, and heavy valves.
The third generation of DHS has grown in the 1980s and has been used worldwide ever since. The thermal agent is pressurized hot water, but with a temperature under 100 degrees Celsius. The components of a typical system have been changed to prefabricated, pre-insulated pipes directly buried into the ground, improved stainless steel heat exchangers and material lean components. Along with this generation renewable energy sources such as solar and geothermal heat, and other cheaper fuels that could found locally, such as coal, biomass and waste were introduced in the DH. (Lund, et al., 2014)

In the development of these generations of DHS over time, there is a tendency of using lower temperatures in installations. The components used are lean material and their prefabrication has reduced the number of workers at construction sites. These trends have built the basis of 4th Generation District Heating Technologies and Systems (4GDH). The new 4GDH differs from the first three generations in that its main goal is to transform the current energy system into a sustainable one. Change will not be easy and will encounter many difficulties along the way. It will involve the integration of new generations of DH into smart energy systems (), and thus, it will be necessary to create integrated smart electricity, gas and thermal grids. (Lund, et al., 2014)
A smart grid is an automated network consisting of controls and computers which can respond and react to fast changes in the usage of the network and thus, increasing its efficiency. (U.S. Department of Energy, 2017)

Integrating the new generation of DH into smart energy systems will make energy systems more efficient by using various industrial surplus heat sources, integrating geothermal and solar thermal heat into DHS and using CHP along with the use of heat from waste-to-energy. (Lund, et al., 2014)
The methods, techniques and technologies which are making the 4GDH an important pillar in the future sustainable energy systems will be presented next.

- Sustainable buildings have to be developed where low-temperature district heating for space heating and hot water could be supplied.

A sustainable building will not produce any CO_2 emissions either caused directly by the building, or indirectly by suppliers of energy to the building. (Srinivas, 2017)
In order to accomplish this, integrated building design features have to be used, as described in the following paragraphs.
First of all, since the energy needed during summer needs to be proportional to the one during winter, the aim is to reduce the total energy use for space heating in the new establishments so that it matches the energy use for domestic hot water heating. That in turn would lower the energy level and keep it at a constant level, allowing the

implementation of a heat recycling system or RES, that could finally reduce the overall costs. (Lund, et al., 2014)
Secondly, taking into account the existing buildings, other solutions could be implemented. More buildings could be connected to the same grid, if they were to be insulated, since its capacity and the production units would allow that. An option to be taken into consideration is using low-temperature space heating systems (e.g., floor heating, wall heating). On average, the difference between the water temperature and room temperature, doesn't have to be very accentuated. For example, temperatures of 40C could be enough. Furthermore, intelligent control of low-temperature domestic hot water (DHW) supply systems could be implemented in order to heat the buildings. Using this kind of systems would allow calculating and predicting the heat needed for each and every room, based on the weather forecasts. The concrete deck and its thermal capacity in such a system would have to work before an excess solar gain. (Lund, et al., 2014)

- Networks with low grid losses and heat distribution

If the network is composed of heating/cooling production units (e.g., individual contributions), smart thermal grids can be used. Their most important features will be described below.
Firstly, if normal distributions temperatures average 50C for the supply pipes and 20 C for the return pipes, per year, the overall network temperature will decrease.
Secondly, in order to reduce the heat losses, smaller pipes can be used. This wouldn't be possible if the peak flow rate didn't decrease.
Furthermore, intelligent control of the networks is recommended, with decentralised systems. Also, metering their performance is needed. For example, metering the sale of surplus heat to the grid from the solar thermal of the building, could be included. (Lund, et al., 2014)

- Low-temperature sources and their potential for renewable and recycled heat

The smart thermal grids aim both for a more efficient utilisation of the low-temperature sources as renewable and recycled heat systems, as well as CHP and large-scale pumps increasing their potential. The following aspects are of importance:
First of all, waste incineration and heat from CHP can be used. Being supplied throughout the whole year, waste incineration, as a district heating system option, is very useful. Also, waste from industrial processes and commercial buildings can be used in a higher proportion in low-temperature networks.
Secondly, making use of both the absorption heat pumps used in the geothermal heat systems as well as the steam production could make the overall process more efficient.
Another way in which the district heating system could be improved is using the seasonal storage of the central/local solar heating plants to supplement the heat supply.
Other benefits of these networks include increased use of geothermal and industrial heat sources, increased performance in the heat pumps and better heat recovery rates from gas condensation, increased performance of the central solar plants, as well as an increase in thermal energy storage. (Lund, et al., 2014)

- The integration of the DHS in the smart energy systems is essential

A challenge that can occur in the design of the future energy systems, is integrating on a large-scale the fluctuating power in the new energy systems in an efficient way. By finding solutions on how to integrate the RES with energy conservation and system efficiency improvements and creating the most optimal energy systems, an important step towards future renewable non-fossil energy systems will be achieved.
It has been shown many times that the DHS can improve the overall efficiency of energy systems by using CHP production and other renewable resources such as large-scale solar thermal. Also, the DHS can integrate the large heat pumps, geothermal heat, industrial surplus heat, and waste incineration to increase the overall efficiency. In order to integrate the DHS in the smart energy systems in a feasible way, the following elements need to be part of the development. The energy system should become more flexible so that changes in production and demand can be balanced out quickly, by involving flexible technologies in grid stabilization such as CHP, heat pumps, and the electrification of transport. This will reduce imbalances in the electricity system and the grid stability will be maintained. That will be of great importance since the share of energy from RES is growing day by day. For a better integration of the RES, large-scale heat pumps and heat storages capacities should be integrated in the CHP systems. Ground source heat pumps should also use individual heating when the energy density in the building stock is low. (Lund, et al., 2014)

- The planning, cost and motivation structures need to be implemented.

As mentioned before, 4GDH systems represent a great part of the transformation of the current energy systems into sustainable energy systems. An economic redistribution must be made by switching from nuclear and fossil fuel based energy systems to RE systems and by investing in energy conservation instead of construction of large power plants. Suitable planning will require tools based on geographical information system (GIS) and advanced energy system analysis. There will be different approaches to implement the new DH technologies into the future energy system, based on each country institutional framework and regulations, but the primary motivation in society will be the transformation of the current energy systems into future sustainable energy systems. The most important challenges which will be faced by the change are: decision of where the DHS should be placed or not, the decision on the capacity of the DHS versus the energy conservation, and the motivation of integrating of RES and other parts of the overall energy system. A change in the tariffs policies is also required along with the 4GDH, where the tariffs and cost principles are based on long-term marginal costs. (Lund, et al., 2014)

5 Technical Analysis

This chapter contains the modelling, results and outputs of 4 scenarios created in EnergyPLAN. Firstly, a reference scenario has been created, based on data from 2012, where the energy system of Cluj-Napoca is defined. Next, two alternative energy scenarios have been created and compared with the reference scenario. The purpose of the comparison between the alternative scenarios and the reference scenario was to find the most suitable solution to reduce the CO2 emissions, increase the energy efficiency and the share of RES in the energy system. In other words, the comparison has been made with the purpose of finding the most feasible long-term solution for the thermal energy system of Cluj-Napoca. The results are presented in the second part of this chapter. Lastly, a sensitivity analysis is presented to compare the price variation depending on different discount rates on the technologies and depending on the fuel price.

5.1 Scenarios Overview

SCENARIOS	FUEL	SHARE OF RES
Scenario 1 – Reference Scenario	NATURAL GAS	0%
Scenario 2 – Business-as-Usual Scenario 2050	NATURAL GAS	0%
Scenario 3 – BIO-SOL 2050	BIOMASS, SOLAR ENERGY	100%
Scenario 4 – BIO-SDH 2050	BIOMASS, SOLAR ENERGY	100%

Table 5.1: Overview of the Scenarios

The above table presents an overview of the scenarios, the fuels and the share of RES used in each of scenarios. Images during the modelling in EnergyPLAN can be seen in the print-outs in Appendix 2B.

5.1.1 Reference Scenario

In order to create a model which reflects the reality as best as possible, the year 2012 has been chosen as year for the reference scenario because it comprises the most complete set of data. The reference scenario description is divided in three parts: demand, supply and distribution curves. Each part contains a detailed description of data used in EnergyPLAN.

Demand Side

Data used in the demand side is compiled in the Table 5.2. The data regarding the heating sector of Cluj-Napoca was obtained by email from the Romanian National Institute of Statistics. The data include information regarding how many people are connected to the DHS of Cluj-Napoca, how many people are using individual heating systems and the fuel used by each category.
It needs to be emphasize that only natural gas is used as a fuel for the district heating production, which is also the most common choice of fuel for the IHS.
The data regarding the electricity production in Cluj-Napoca was gathered from Cluj-Napoca Municipality's website. The total electricity demand for Cluj-Napoca is 540 GWh. (Local Council of Cluj-Napoca, 2013)
The total individual heat demand for Romania was gathered from the STRATEGO model for Romania and then scaled down to the population of Cluj-Napoca. Their efficiencies were used also from the STRATEGO model for Romania. Total heat demand data were gathered from a report made by the Ministry of Regional Development and Public Administration. (Ministry of Regional Development and Public Administration , 2013)
Lastly, hourly heat demand in the IHS and district heating was obtained from the STRATEGO project for Romania and then scaled down by using the ratio of population. (Connolly, Hansen, & Drysdale, 2015)

<table>
<tr><th>Total no. of dwellings in Cluj-Napoca</th><th>Dwellings in Cluj-Napoca using DHS</th><th>Heat Demand of DHS of Cluj-Napoca</th><th>Heat Demand of IHS of Cluj-Napoca</th><th>Electricity Demand in Cluj-Napoca</th><th colspan="3">No. of dwellings in Cluj-Napoca using IHS</th><th></th></tr>
<tr><td rowspan="3">135419</td><td rowspan="3">39418</td><td rowspan="3">302.380 MWh</td><td rowspan="3">1.070.789 MWh</td><td rowspan="3">540.000 MWh/annual</td><td>Individual heating using Gas</td><td>Individual heating using Solid Fuel</td><td>Individual heating using Oil</td><td rowspan="3"></td></tr>
<tr><td>86100</td><td>408</td><td>228</td></tr>
<tr><td colspan="3">Total: 86.736</td></tr>
</table>

Table 5.2 Demand Side Data

As previously mentioned in the **Chapter 4.2.3**, it can be observed that Gas Boilers are the most common choice when it comes to individual heating systems.

Supply Side

On the supply side, the data regarding heating production of the DHS of Cluj-Napoca was obtained from the Autonomous District Heating Company of Cluj-Napoca. The data includes capacity of each plant and the fuel used by each of them. (Autonomous District Heating Company Cluj-Napoca, 2017)
The efficiencies are obtained from the STRATEGO EnergyPLAN model for Romania. (Connolly, Hansen, & Drysdale, 2015). Everything else is used as in the default version of EnergyPLAN.
Electricity within the municipal territory is mainly generated by two gas-operated municipal cogeneration power plants (37.5 GWh/a). No electricity is generated from hydropower, biomass or wind renewable sources. Data was gathered from Cluj-Napoca Municipality's website. The total electricity demand for Cluj-Napoca was 540 GWh in 2012. (Local Council of Cluj-Napoca, 2013)

<table>
<tr><td rowspan="3">Total electricity generation within the municipal territory – 2 CHP</td><td colspan="3">Thermal energy production capacity of Cluj-Napoca DHS</td></tr>
<tr><td>2 CHP</td><td>1 DH Plant</td><td>76 Thermal Power Plants + 300 Boilers</td></tr>
<tr><td>13 MWh</td><td>143 MWh</td><td>400 MWh</td></tr>
<tr><td>37500 MWh/a</td><td colspan="3">Total: 556 MWh</td></tr>
</table>

Table 5.3 Supply Side Data

Distribution Curves

As it was already explained in Chapter 3.3, distribution curves are used in the EnergyPLAN hourly based analysis. In this project two distribution curves have been used, one for electricity demand and one for heat demand.

Figure 5.1, presents the distribution curve of the electricity demand in Cluj-Napoca. It was obtained from the electricity demand distribution curve for the whole country, and then scaled down by using the ratio for the population. The distribution curve of the electricity demand for Romania was obtained from ENTSO-E. (European Network of Transmission System Operators for Electricity, 2017) It can be observed that the consumption alternates between day time and night time.

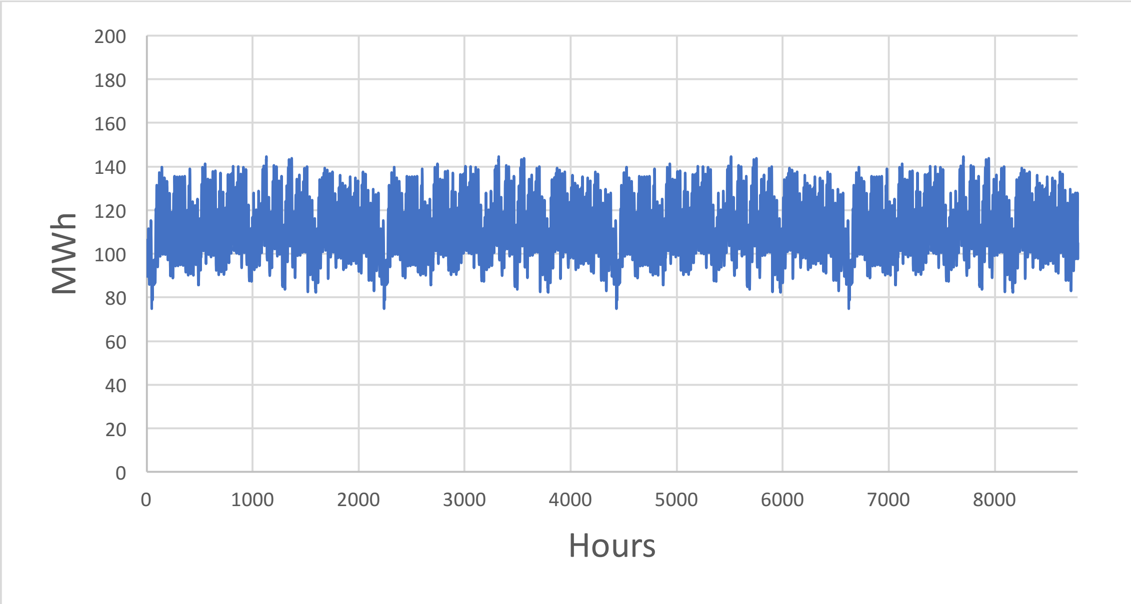


Figure 5.1: Electricity demand curve for Cluj-Napoca

Figure 5.3, presents the distribution curve for the heat demand of Cluj-Napoca. The hourly heat demand curve was obtained from the STRATEGO Project for Romania and then scaled down by using the ratio of population between Romania and Cluj-Napoca. It can be observed that heat demand is present only during winter times.

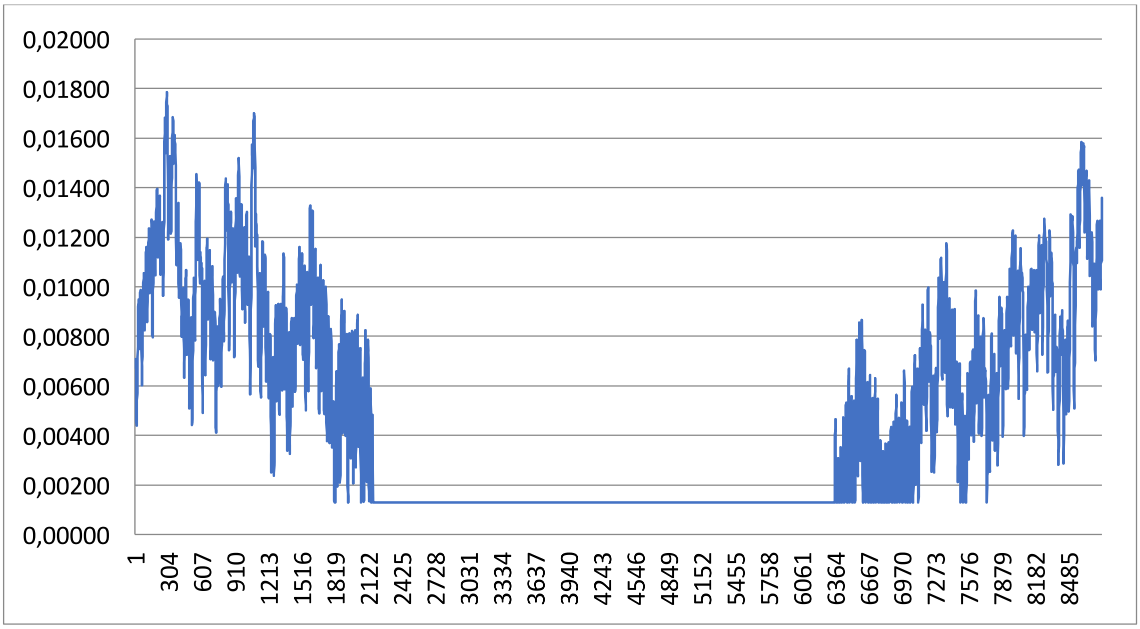


Figure 5.3: Head demand curve for INS Cluj-Napoca

5.1.2 Scenario 2: Business-as-Usual 2050 (BaU 2050)

Business-as-Usual-Scenario is an alternative future scenario with no major changes in technology, economics, or policies comparing to the reference scenario. It is based on a series of assumptions and projections that were made based on the on current trends and actual measurements of the reference scenario. Since there are no actual plans for future changing the actual structure of heat production in Cluj-Napoca, natural gas was still considered as the only fuel used in the heat production in Cluj-Napoca, but some assumptions needed to be made to drive the model for the year 2050.

The **Demand Side** in the BaU 2050 scenario was changed accordingly:

- The same share of district heating as in the reference scenario was maintained.

The DH Company of Cluj-Napoca declares on their website that there is a rhythm of decreasing disconnections from the centralized district heating network and stabilizing the number of customers they have. (RATCJ, Seen 2017)

- The annual electricity demand is assumed to increase by 1%.

Following the report by the European Bank for Reconstruction and Development it should be noted that the population of Cluj-Napoca has increased with 8.37% in the last 10 years. Moreover, we assume that the population living standard will also increase.
(European Bank for Reconstruction and Development, 2015)

- The oil boilers in individual heating will be replaced by CGB.

- The annual energy efficiency in the heating sector will increase by 0.3% each year.

This assumption was based on the achievements and projects realized in the heating system in Cluj-Napoca between the years 1991 and 2009. (RATCJ, Seen 2017)

Supply Side

On the supply side in the BaU 2050 scenario there was no need for decommissioning any heat or electricity plant since the demand is supposed to increase in the upcoming period. Also, any surplus of electricity produced can be exported to the national grid. Since the scenario is based only on Cluj-Napoca where the heat and electricity are produced almost only on natural gas, there was no change between fuel types used, e.g. switching from coal to natural gas. The heat demand will be increased by 1% annually on both district heating and individual heating.

- 2 CHPs - Total 13 MWh;
- 1 DH Plant - 143 MWh;
- 76 Thermal Power Plants + 300 Boiler - 400 MWh.

5.1.3 Scenario 3: BIO + SOL 2050

The third scenario - BIO + SOL 2050 - is an alternative future scenario where the DHS of Cluj-Napoca is based only on biomass and the individual heating is based on biomass, individual thermal systems and individual electric heating systems. That means that the system primary energy supply is shifted to 100% RES, which will be the first step in the transformation of the current energy system into a sustainable one, whose benefits are presented in the **Chapter 4**. The DHS efficiency is increased by 20% consisting in the renovation of the pipe in the distribution and transmission network. Also, the share of district heating is increased by 40%. Waste-to-energy and industrial surplus heat sources are not included in the project.
Technical details of the demand side of the scenario are presented next.

Demand Side

- The electricity demand is increased annually with 1%;
- The heat demand is increased annually by 1%;
- The efficiency is increased by 20% due to the renovation of the pipe network.
- The share of district heating is increased by 40%;
- All the individual heating systems based on natural gas are replaced by:
    - 55% - Biomass boilers
    - 25% - Individual solar thermal systems;
    - 20% - Individual electric heating systems.

Several assumptions are made in the supply side of the third scenario where production of heat is completely changed comparing to BaU 2050 scenario since only RES are used to fuel the heating sector of Cluj-Napoca. All the technical details of the supply side of the scenario are presented below.

Supply Side

- All thermal plants and boilers (400 MW) have been decommissioned;
- The thermal power plant (143 MW) have been decommissioned;
- 187 MW of CHP have been added (of which, 50 MW CHP back pressure mode with the thermal capacity of 64 MW).
- 50 MW of biomass boilers;

5.1.4 Scenario 4: BIO + SDH + SOL 2050

The fourth scenario - BIO + SDH + SOL 2050 - is another alternative future scenario, where the Cluj-Napoca District Heating is accomplished 80% by biomass CHP + 20% Solar District Heating. The individual heating sector is the same as in the third scenario, and is based on biomass, individual thermal systems and individual electric heating systems. The system primary energy supply of the fourth scenario is also based 100%

on RES. The DHS efficiency is increased by 20% consisting in the renovation of the pipe in the distribution and transmission network. Also, the share of district heating is increased by 40%. Waste-to-energy and industrial surplus heat sources are not included in the project. Next, technical details of the demand side of the scenario are presented.

Demand Side

- The electricity demand is increased annually with 1%;
- The heat demand is increased annually by 1%;
- The efficiency is increased by 20% due to the renovation of the pipe network.
- The share of district heating is increased by 40%.
- All the individual heating systems based on natural gas are replaced by:
  - 55% - Biomass boilers
  - 25% - Individual solar thermal systems;
  - 20% - Individual electric heating systems.

The supply side of the fourth scenario is changed to 80% Biomass CHP + 20% Solar District Heating. The individual and district heating is accomplished as presented:

Supply Side

- All thermal plants and boilers (400 MW) have been decommissioned;
- The thermal power plant (143 MW) have been decommissioned;
- District Heating is accomplished by 80% Biomass CHP + 20% Solar District Heating;
- 50 MW of biomass boilers;

5.2 Results

This section contains the validation of the reference scenario, followed by the EnergyPLAN analyses results of the above described scenarios. The results of the scenarios' analyses are then compared to each other in different figures and tables, created to emphasize the difference between them of CO2 emissions, share of RES, energy supply and the total costs of the modelled scenarios.

5.2.1 Validation of the Reference Scenario

In order to validate the accuracy of data used in the reference scenario, a validation of data followed by a CO2 emissions comparison has been made by comparing the value provided by the IEA and the value obtained in EnergyPLAN. This comparison can be seen in the Table 5.4. Since the difference is approximately 5%, it can be concluded that the reference scenario matches the official data offered by IEA.

The data used in this project was obtained only from official sources, such as: Romanian National Institute of Statistics, Ministry of Regional Development and Public Administration, Stratego Project and Cluj-Napoca Municipality. Since the data used to build the reference scenario were either offered by email upon request, either have been collected them from the official websites of the mentioned before sources, it can be concluded that the data is reliable. The costs of the scenarios are based on EnergyPLAN data costs library so the calculations are also assumed to be reliable.

Emission	EnergyPLAN	IEA	Difference EnergyPLAN-IEA
CO2	1,266 mil tons	1,341 mil tons	0,944

Table 5.4: Comparison of CO2 emissions for energy system of Cluj-Napoca

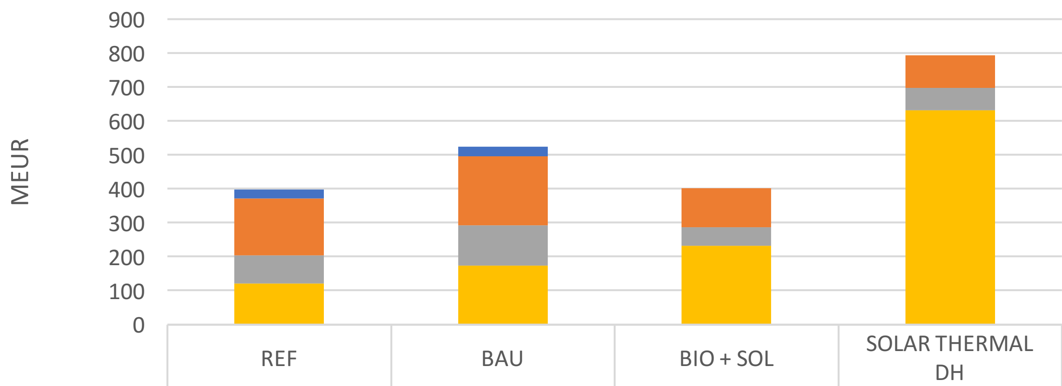
5.2.2 Scenarios Results and Comparison

In this section, the main results of the scenarios are compared in order to determine the most feasible one based on their most important characteristics:

- CO2 emissions;
- Primary Energy Production;
- Total Annual Costs.

COSTS

As specified in the **Chapter 3.3**, the costs of the energy system are calculated based on EnergyPLAN data costs library and based on the standard discount rate of 3%. The energy efficiency was inputted as additional costs and the operation and maintenance costs are the same in all scenarios.
As shown in Figure 5.3, from a financial point of view, BIO+SOL 2050 scenario is the most feasible one. While this scenario has almost the same annual costs as the reference scenario, it is the most feasible scenario from an environmental point of view, together with the last scenario, since there are only RES sources used and therefore the costs for CO2 emissions are 0. The last scenario BIO+SOL+SDH is the most economically unfeasible one due to the high costs of investment since SDH is a very expensive technology at the moment.



	REF	BAU	BIO + SOL	SOLAR THERMAL DH
CO2	25	29	0	0
Variable	169	203	114	97
Fixed O&M	82	119	56	65
Investment	121	173	231	632

Figure 5.2: Costs of scenarios

Primary Energy Supply

Figure 5.4 presents the Primary Energy Supply of each scenario created in this project. All three future scenarios have an increased electricity and heat demand since it was assumed that the electricity and heat production will have an annual increase of 1%. Since the system was completely changed to RES, the production based on natural gas has been phased out in both individual and district heating sectors in the last two scenarios. By the introduction of SDH technology with a share of 20% in the primary energy production, the biomass consumption was reduced significantly.
Since the SDH technology investment costs are so high at the moment, only 20% of the district heating production has been considered in the analysis, and even with that low percent, the investment costs in the last scenario BIO+SOL+SDH 2050 are much higher than in the third scenario BIO+SOL 2050.

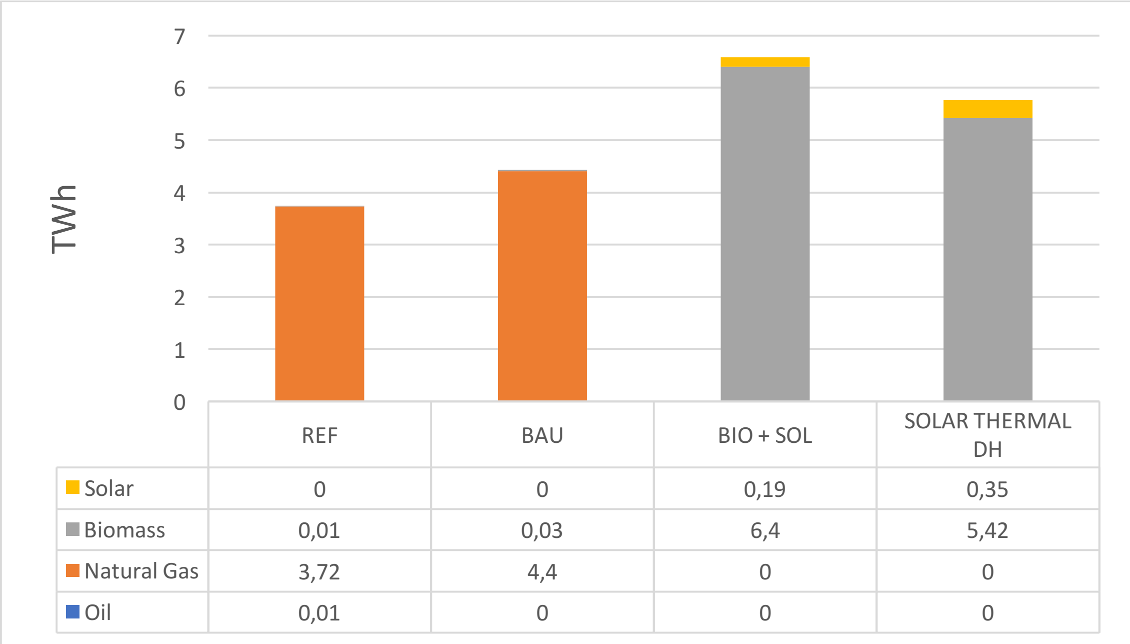


Figure 5.3: Primary Energy Supply

In Table 5.5 an overview of the scenarios main results is presented, where their most important characteristics are presented in three categories. The first one is the technical category where the primary energy supply of each scenario is presented, followed by the environmental category and the economic category. In the environmental category the CO2 emissions are presented, while the total annual costs are shown in the economic.

	REF	**BaU**	**BIO + SOL**	**BIO + SDH + SOL**
PES [TWh]	3,74	4,43	6,59	5,77
CO2 [Mt]	0,87	1	0	0
Total annual system costs [M EUR]	397	524	401	794

Table 5.5: Overview of the main results of scenarios

5.3 Sensitivity Analysis

The analysis was conducted to evaluate the feasibility of BIO+SOL scenario by implementing different possible future changes in the economy, such as different discount rates of the investment costs. In the EnergyPLAN model, the standard discount rate used is 3%. The discount rate offered by the Romanian National Bank is 1,75% starting with 2015, while in 2012 it was 5.25% (FocusEconomics, 2017). Discount rates from 1% to 15% for the investment costs of the alternative scenarios were considered in the analysis. The analysis was conducted by replacing the discount rate in EnergyPLAN with values from 1 to 15. The discount rates used are nominal discount rates, which are different from the real discount rates by the fact that inflation rate is included (Homer Energy', Seen 2017). Analyses will reveal the discount rates for which the BAU+SOL 2050 scenario will become more expensive then the BaU 2050 scenario.

In Figure 5.4 it can be observed that when a higher discount rate is applied to the investment costs, the value of the scenario is increasing. Also, it can be observed that when a discount rate greater than 12.8% is applied to the BIO+SOL 2050 scenario, this scenario is becoming more expensive then BaU 2050 scenario. From an economic point of view that means that the scenario BIO+SOL 2050 is no longer feasible.

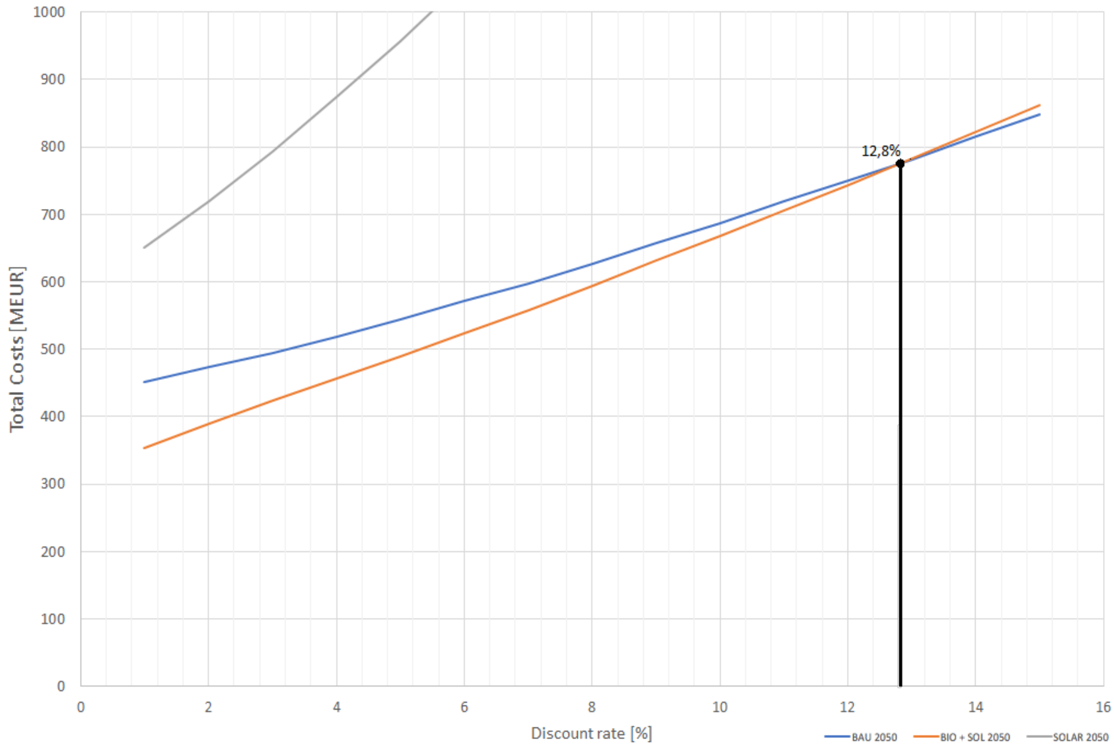


Figure 5.4: Sensitivity Analysis on different discount rates of investment costs

6 Policy Analysis

This chapter aims to investigate the ways in which the actual situation of the DHS of Cluj-Napoca can be improved in terms of policies. Also, this chapter contains a review of the Romanian laws related to district heating laws.

6.1.1 Policy Analysis and Recommendations regarding individual heating solutions

Since the gases emitted by the IMHUs are discharged very close to the breathable air of other tenants, the level of these gases should be compared to the concentration of pollutants in the breathable air, and not to the emission limit values of a central heating system which evacuation's baskets are located above the buildings high. As a result, the air inhaled by the tenants in blocks of flats where IMHUs were installed, violates the current rules on breathable air quality. (Benga, Fowler, Haiduc, & Nastase, 2004)
This situation can be regulated by laws which clearly stipulates the technical conditions under which an IMHU can be installed.

The installation of IMHUs in Romania is done in some cases without the consent of all building's condominium owners and violates at least two laws:

- Housing Law in Romania, no. 114/1996 with subsequent modifications stipulates in art. 14 of Annex 2: "no owner may violate or prejudice the right of joint or individual ownership". (The Romanian Parliament, 1996)

A law to tighten the technical conditions in which an IMHU could be installed so that other residents in the same building will no longer be affected by flue gas emitted by the IMHU could solve this problem. A technical solution would be to find a technical solution where the flue gases are discharged at the top of the buildings.

- Law 10/1995 on quality in construction in Romania, art. 5: "In order to obtain suitable quality constructions, the following requirements must be fulfilled and maintained throughout the lifetime of buildings: ... (d) hygiene, human health, restoration and protection of the environment; (The Parliament of Romania, 1995)

These breaches of laws could be prevented with an increased attention from the authorities.

Another right which is violated in Romania is the right to information, since the citizens were not and are not informed about the negative effects of the use of IMHUs.

- The right to information (Article 31 of the Constitution of Romania) foresees at paragraph 1: "The right of the person to have access to any information of public interest cannot be restricted" and at paragraph 2: "The public authorities, according to their competencies, are obliged to ensure that citizens are properly informed about public affairs and issues of personal interest." (Center for Constitutional Law and Political Institutions - Romania, 1991)

The Romanian State should start to inform its citizens about the harmful effects of IMHUs, by interviewing specialists and by providing detailed information through mass-media.

6.1.2 Policy Analysis and Recommendations regarding District Heating

The apartments which use IMHUs, save money by being part of a heated building with a DHS, because, during the cold season, their walls have an average temperature of +20 degrees Celsius and not equal with the outside temperature. This temperature difference is paid by the owners who are still connected to the DHS. (Benga, Fowler, Haiduc, & Nastase, 2004)
This could be solved by adding a tax, paid monthly by the apartment owners disconnected from DHS, depending on surface they share with the heated part of the building.

The Romanian authorities did not take into consideration the fact that the installation in mass of domestic boilers will lead to the destruction of the DHS, which is in contradiction with the policies and requirements of the European Union; (Benga, Fowler, Haiduc, & Nastase, 2004) The DHS is a public system and the decision to keep the DHS operating or not, should not entirely belong to the consumers, because by disconnecting the apartment from the DHS, the integrity of the DHS is jeopardized. This is mainly happening because at the moment, the disconnection from the DHS does not require the approval from all the apartment owners of the entire building or from the Romanian state.

Currently, the DHS in Romania is involved in 4 ministries (Ministry of Administration and Interior, Ministry of Economy, Ministry of Labor and Social Protection, Ministry of Environment) and 2 regulatory agencies (National Regulatory Authority for Energy, National Regulatory Authority for Community Utilities Services). Therefore, as already stated, this has made coordination very difficult. (Leca, 2012)
A better management could be achieved by modernizing the energy governance system.

Each year the municipality of Cluj-Napoca pays around EUR 15 million in heat subsidies, which is about 5% of the city budget, a figure that puts a big burden on the city's finances. (Municipality of Cluj-Napoca, 2014)

By investing in modernizing the distribution network and by creating a more efficient heat production, the subsidies can be reduced or even stopped, being no longer needed.

The 4th generation DHS should be strongly encouraged by the Government of Romania by subsidizing DH projects with high share of annual heat consumption from renewable energy sources or waste heat, as it is happening in other European countries such as Germany, where the German Ministry for Economic Affairs and Energy launched a new subsidy scheme for District Heating Pilot Projects. (Solites, 2017).

On top of the above-mentioned recommendations, the following can be added:

- The Value Added Tax (VAT) can be lowered for the district heating as it is happening in other European countries such as Czech Republic, Lithuania and Latvia;

- Interest of the central and local authorities in finding financing solutions for the energy modernization of building stock should be increased;

- The Energy Ministry should propose laws and come up with the fastest solutions to promote the restoration of DHSs in Romania in order to avoid a possible irreparable worsening of the situation.

6.1.3 Other laws related to District Heating Sector in Romania

- Law no.51/2006 on public services, addressing public services of lighting, waste, heat and water;

This law establishes the legal and institutional framework, the objectives, the competencies, the tasks and the specific instruments necessary for setting up, organizing, managing, financing, exploiting, monitoring and controlling the regulated supply / provision of community services of public utilities. (Romanian Parliament, 2006)

- Law no.325/2006 on the heating sector is the specific law for District Heating;

This law regulates the performance of specific public service activities for the supply of heat energy used for heating and hot water production, namely the production, transport, distribution and supply of district heating, under efficient conditions and quality standards, for using optimal energy resources and complying with environmental protection standards. This law applies to public service supply heat in a centralized system, established and organized in communes, towns, municipalities or counties, regardless of their size. (Romanian Parliament, 2006)

- GD (Government Decision) 1215/2009 on cogeneration support scheme.

This Decision establishes the legal framework necessary to implement a support scheme for the promotion of high efficiency cogeneration. (The Romanian Government, 2009)

- Law no.123/2012 on electricity and gas, also addresses cogeneration;

The purpose of this law is to regulate the development of activities in the electricity and thermal energy sectors produced in cogeneration in order to optimally use the primary energy resources under the conditions of accessibility, availability and affordability, and to respect the safety, quality and environmental standards. (Romanian Parliament, 2016)

- Law no.121/2014 on energy efficiency, transposing Directive 2012/27/EC;

The purpose of this law is to create the legal framework for the development and implementation of the national energy efficiency policy with a view to achieving the national energy efficiency target. (Romanian Parliament, 2016)

7 Conclusion

The previous **Chapter 4.2.3** and **Chapters 4.2.1** aimed to investigate what caused the drop in the use of DH, and thus to answer to the first research question:

What caused the drop in the use of DH in the city of Cluj-Napoca?

To sum up, it can be said that the major causes which lead to the drop of use of the DH of Cluj-Napoca were mainly related to the way of billing the customers, the poor quality of the network and the poor quality of the services offered by the RATCJ. The customers were charged according to the surface of their dwelling and not by the quantity of heat consumed, as previously stated. A similar principle was used on the hot water, where the customer was charged according to the number of people living in the dwelling and not by the quantity of hot was consumed. The transmission and distribution network used to have large losses of over 25%, which were mostly paid also by the customers. Therefore, the customers turned their attention to different individual heating sources where they could pay accordingly to their consumption. The IMHU producers have seen a great market opportunity in that and they started creating great offers and focusing on presenting the benefits of the IMHUs. In the last year major improvements to the transmission and distribution network of the DHS of Cluj-Napoca have been made, but the actual price offered by the RATCJ for 1 Gcal is higher comparing to the price paid by a customer using a IMHU such as condensing gas boilers. It is needed to be mentioned that customers opting for IMHUs have to pay electrical power, periodic technical checks, ISCIR checks (Romanian State Inspection for Boiler Control, Pressure Vessels and Lifting Installations) on top of the price paid for heating.

Chapter 5 aims to answer the second research question:

On a long-term period, what are the technical solutions so that the DH of Cluj-Napoca can offer a more feasible alternative to consumers which are using individual heating?

In the analysis of this project, three alternative scenarios of the Cluj-Napoca DHS have been created, analysed and compared to find a feasible long-term technical solution for Cluj-Napoca DHS. By finding and implementing this technical solution, the Cluj-Napoca DHS could be able to offer a feasible alternative for the individual heating consumers. Therefore, hopefully it could regain the customers who have opted out and got disconnected from the centralized heating system in the last few years.

Based on the actual Cluj-Napoca DHS, a reference scenario has been created in the first place. Afterwards, an alternative scenario for the year 2050, namely Business-as-Usual 2050, has been created based on a series of projections and assumptions made on the current trends and the actual measurements of the reference scenario. This scenario aimed to picture Cluj-Napoca DHS in 2050 if no modification will be made to its system. Two other alternative scenarios have been created starting from the assumption that only renewable energy sources were to be used to fuel the heating sector of Cluj-Napoca.

After the creation of the alternative scenarios was done, a comparison has been made between the Business-as-Usual 2050 scenario and the other two future alternative scenarios in order to analyze if a feasible solution can be found for Cluj-Napoca DHS. As previously mentioned, the feasible solution would aim to regain the individual heating consumers.

After comparing all scenarios, the first one - BIO+SOL 2050 – has been found to be a feasible solution for Cluj-Napoca DHS, due to its financial and environmental benefits. The annual costs in this scenario are much lower than Business-as-Usual 2050 scenario, while the production stays the same. Due to the exclusive use of the RES to fuel the DHS and fuel emissions being completely stopped, the scenario pinpoints numerous environmental benefits. These conclusions emphasize on the possibility for Cluj-Napoca DHS to offer a feasible solution to the consumers, by decreasing the prices and also contributing to the environment.

In the last scenario - BIO+SOL+SDH 2050 - fossil fuel emissions are completely reduced since, again, only renewable energy sources are used for the heat production. However, the annual costs are much higher than the Business-as-Usual 2050 scenario and double compared to the third scenario - BIO+SOL 2050 -.

In the future, renewable energy sources will clearly dominate the production of electricity and heat all over the world, due to the current environmental problems created by fossil fuels. This project shows that the implementation of a new DHS in Cluj-Napoca based solely on renewable energy sources would substantially reduce the annual costs of the DHS, thus becoming able to provide a feasible alternative solutions to the consumers using individual heating. Moreover, this could represent the first step towards a future sustainable energy system such as 4GDH systems. On top of that, the new defined DHS would bring enormous benefits to the environment, since fossil fuel emissions would be completely removed from the heat production process.

The previous **Chapters 6** aims to investigate in terms of policies what caused the drop in the use of DHS of Cluj-Napoca and how the actual situation can be improved, and thus to answer the last research question:

What are the policy recommendations so that the actual situation of Cluj-Napoca DHS could be improved?

It needs to be emphasized that the problems faced by the Cluj-Napoca DHS are similar throughout the entire country and therefore, the same recommendations could be made to any other Romanian DHS. Next, the most important policy recommendations that have been made following the policy analysis in Chapter 6 which could possible improve the actual situation of the Cluj-Napoca DHS, are presented below:

- Adding a regulating law which clearly stipulates the technical conditions under which an IMHU can be installed, including finding solutions the other residents in the same building to no longer be affected by flue gas emitted by the IMHU. A technical solution would be to find a technical solution where the flue gases are discharged at the top of the buildings;

- The Romanian State should start to inform its citizens about the harmful effects of IMHUs, by interviewing specialists and by providing detailed information through all the possible means;

- A monthly tax during the cold season could be added to the dwelling disconnected from DHS, depending on surface they share with the heated part of the building since they are also using the heat provided by the centralized heating power supply system;

- A regulating law could be made to tighten the conditions for disconnecting from the DHS since the disconnections are affecting the whole DHS. A possible solution would be that the disconnection to require the approval from all the dwelling owners of the entire building or from the Romanian state;

- A better management of the Romanian DHSs could be achieved by modernizing the energy governance system. A possible solution would be to designate only one ministry under which the Romanian DHSs is managed. Currently the Romanian DHSs are managed by four ministries;

- Instead of subsidizing the heat price with almost a half of its price, investing in modernizing the transmission and distribution network could lead to reduction or even a stoppage of this subventions by achieving a better overall efficiency of the DHSs;

- The Value Added Tax (VAT) can be lowered for the district heating as it is happening in other European countries such as Czech Republic, Lithuania and Latvia;

- Interest of the central and local authorities in finding financing solutions for the energy modernization of building stock should be increased;

- The Energy Ministry should propose laws and come up with the fastest solutions to promote the restoration of DHSs in Romania in order to avoid a possible irreparable worsening of the situation;

- The 4^{th} generation DHS should be strongly encouraged by the Government of Romania by subsidizing DH projects with high share of annual heat consumption from renewable energy sources or waste heat, as it is happening in other European countries such as Germany, where the German Ministry for Economic Affairs and Energy launched a new subsidy scheme for District Heating Pilot Projects.

8 Discussion

The outcome of the project is a result of calculations based on reliable data gathered from official sources combined with several assumptions and future projections of the Cluj-Napoca heating sector. In order to emphasize some methodological choices and the assumptions made in this project, a discussion will follow.

- EnergyPLAN regulation

The results of the project showed that it would be feasible to invest in a future energy system based 100% on renewable energy sources but it should be reminded that EnergyPLAN offers two different strategies for analyzing the energy system: Technical Strategy and Market-Economic Strategy. In this project has been used the first strategy, which is technical one. It is expected that a market economic simulation of the Cluj-Napoca would give a different outcome, leads to the question of what would have been the results if the second strategy would have been used in this project. The most important difference between the two strategies is that first strategy is based on the energy demand while the second one is based on the marginal costs and market price.

- Share of dwellings using DH

In the Business-as-Usual 2050 scenario created in EnergyPLAN, the share of DH has not been increased. It is expected that a bigger share in the use of DH would have increased also the DHS efficiency in this scenario and would have led to a different outcome but since the current trend is opposite, people currently disconnecting from the Cluj-Napoca DHS, it couldn't be considered that in the next period, the opposite will happen.

- Lack of data

One of the greatest challenges was the lack of data regarding the hourly electricity and heat demand distribution dataset. The distribution datasets were obtained from the Stratego Project for Romania and then scaled down by using the ratio of population, which may not be an accurate representation of the reality.

- Reference year

The results of the project are based on data from 2012 which defined the reference scenario. The year was used because is the most recent year which could offer official data on the real situation of the heating sector in Cluj-Napoca. It is not the most recent data and the energy system has undergone changes up to now in terms of electricity and heat demand and in the share of people using DH and maybe an implementation in the energy system of 2017 would have led to different results, but in principle, it can be assumed that the results follow the same trend.

- National Energy System Analysis

In this master thesis, it was chosen to answer the research question based on a case study. An alternative approach could have been to answer the question by using a national energy system analysis where more data could have been available and thus, it is expected that the results would have been more accurate. This does not necessarily mean, that the results of this project could not serve as an example case of the DHS of Romania.

- Costs used to calculate total system costs

The costs used in the energy system analysis were used from the EnergyPLAN library. The costs database which includes investments for RES, both fixed and variable O&M costs, fuel costs and other costs was created by the Danish Energy Agency and it fits the Danish context. It is expected that the results would have been more accurate if the actual costs for Romania would have been available.

9 List of Figures

10 List of Tables

11 Bibliography

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12 Appendix

12.1 A1. Reference Scenario – Cluj-Napoca

Input Reference Scenario.txt — **The EnergyPLAN model 12.0**

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	0,54	Fixed imp/exp.	0,00
Electric heating + HP	0,00	Transportation	0,00
Electric cooling	0,00	Total	0,54

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,37	0,01	0,00	0,38
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,37	0,01	0,00	0,38

Wind	0 MW	0,00	TWh/year	0,00	Grid
Photo Voltaic	0 MW	0	TWh/year	0,00	stabili-
Offshore Wind	0 MW	0	TWh/year	0,00	sation
River Hydro	0 MW	0	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		400		0,80	
Group 3:					
CHP	13	17	0,35	0,45	
Heat Pump	2	5			3,00
Boiler		143		0,80	
Condensing	13		0,45		

Heatstorage: gr.2: 10 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	300	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	1500	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	DKK/MWh
Multiplication factor	2,00	
Dependency factor	0,00	DKK/MWh pr. MW
Average Market Price	227	DKK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,01	1,25	0,01
Industry	0,00	0,00	0,00	0,00
Various	0,00	0,00	0,00	0,00

Output

District Heating

	Demand	Production								
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW
January	309	0	0	301	386	-369	0	8	0	-17
February	215	0	0	210	386	-369	0	6	0	-17
March	0	0	0	0	386	-369	0	0	0	-17
April	0	0	0	0	386	-369	0	0	0	-17
May	0	0	0	0	386	-369	0	0	0	-17
June	0	0	0	0	386	-369	0	0	0	-17
July	0	0	0	0	386	-369	0	0	0	-17
August	0	0	0	0	386	-369	0	0	0	-17
September	0	0	0	0	386	-369	0	0	0	-17
October	0	0	0	0	386	-369	0	0	0	-17
November	0	0	0	0	386	-369	0	0	0	-17
December	0	0	0	0	386	-369	0	0	0	-17
Average	43	0	0	42	386	-369	0	1	0	-17
Maximum	15789	0	0	15374	386	-369	0	400	0	-1
Minimum	0	0	0	0	386	-369	0	0	0	-17
TWh/year	0,38	0,00	0,00	0,37	3,39	-3,24	0,00	0,01	0,00	-0,15

Electricity / Exchange

	Consumption						Production							Balance					Exchange: Payment	
	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million DKK	Exp Million DKK
January	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	15
February	62	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	74	0	74	0	11
March	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	12
April	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	13
May	62	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	74	0	74	0	14
June	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	12
July	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	9
August	62	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	74	0	74	0	12
September	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	13
October	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	13
November	62	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	74	0	74	0	12
December	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	0	13
Average	61	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	75	0	75	Average price	
Maximum	79	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	95	0	95	(DKK/MWh)	
Minimum	41	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	57	0	57	-	227
TWh/year	0,54	0,00	-1,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,64	-2,52		0,00	0,65	0,00	0,65	0	149

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	Wind	PV	Offsh.	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt): Total	CO2 emission (Mt): Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,01	-	0,01	0,00	0,01	0,00	0,00
N.Gas	0,53	-	1,93	0,01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,25	-	3,72	-1,45	2,26	0,87	0,53
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,01	-	0,01	0,00	0,01	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
H2 etc.	-	-	5,60	0,00	-	-5,60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	0,53	-	7,53	0,01	-	-5,60	-	-	-	-	-	-	-	-	-	-	-	-	1,27	-	3,74	-1,45	2,28	0,87	0,53

Output specifications Reference Scenario.txt **The EnergyPLAN model 12.0**

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW
January	301	0	0	301	8	0	0	0	0	0	8	0	0	0
February	210	0	0	210	6	0	0	0	0	0	6	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	42	0	0	42	1	0	0	0	0	0	1	0	0	0
Maximum	15374	0	0	15374	416	0	0	0	0	0	400	0	0	16
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,37	0,00	0,00	0,37	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,00		0,00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage MW	Gr.3 Balance MW	RES1 Wind MW	RES2 Photo V MW	RES3 Offshore MW	RES 4-7 ind MW	RES Total MW	MW
January	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
February	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
March	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
April	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
May	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
June	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
July	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
August	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
September	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
October	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
November	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
December	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
Average	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
Maximum	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
Minimum	0	0	0	386	-369	0	0	0	0	-17	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	3,39	-3,24	0,00	0,00	0,00		-0,15	0,00	0,00	0,00	0,00	0,00	0,00

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million DKK)	
Total Fuel ex Ngas exchange =	37
Uranium =	0
Coal =	0
FuelOil =	0
Gasoil/Diesel=	0
Petrol/JP =	0
Gas handling =	36
Biomass =	0
Food income =	0
Waste =	0
Total Ngas Exchange costs =	107
Marginal operation costs =	0
Total Electricity exchange =	-149
Import =	0
Export =	-149
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	25
Total variable costs =	20
Fixed operation costs =	100
Annual Investment costs =	199
TOTAL ANNUAL COSTS =	320

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	440	219	0	327	0	0	986	0	0	0	0	0	0	986	986	0
February	306	219	0	291	0	0	817	0	0	0	0	0	0	817	817	0
March	0	219	0	201	0	0	421	0	0	0	0	0	0	421	421	0
April	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
May	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
June	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
July	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
August	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
September	0	219	0	56	0	0	275	0	0	0	0	0	0	275	275	0
October	0	219	0	126	0	0	346	0	0	0	0	0	0	346	346	0
November	0	219	0	206	0	0	426	0	0	0	0	0	0	426	426	0
December	0	219	0	304	0	0	523	0	0	0	0	0	0	523	523	0
Average	62	219	0	142	0	0	423	0	0	0	0	0	0	423	423	0
Maximum	22463	219	0	552	0	0	23234	0	0	0	0	0	0	23234	23234	0
Minimum	0	219	0	40	0	0	259	0	0	0	0	0	0	259	259	0
Total for the whole year TWh/year	0,54	1,93	0,00	1,25	0,00	0,00	3,72	0,00	0,00	0,00	0,00	0,00	0,00	3,72	3,72	0,00

RES Share: 0,3 Percent of Primary Energy 0,0 Percent of Electricity 0,0 TWh electricity from RES

12.2 A2. Scenario 2: Business-as-Usual 2050

Input BAU 2050.txt **The EnergyPLAN model 12.0**

Electricity demand (TWh/year):			
Fixed demand	0,80	Flexible demand	0,00
Electric heating + HP	0,00	Fixed imp/exp.	0,00
Electric cooling	0,00	Transportation	0,00
		Total	0,80

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,54	0,01	0,00	0,55
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,54	0,01	0,00	0,55

Wind	0 MW	0,00 TWh/year	0,00	Grid
Photo Voltaic	0 MW	0 TWh/year	0,00	stabili-
Offshore Wind	0 MW	0 TWh/year	0,00	sation
River Hydro	0 MW	0 TWh/year	0,00	share
Hydro Power	0 MW	0 TWh/year		
Geothermal/Nuclear	0 MW	0 TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		400		0,90	
Group 3:					
CHP	13	17	0,35	0,45	
Heat Pump	2	5			3,00
Boiler		143		0,90	
Condensing	13		0,45		

Heatstorage: gr.2: 10 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	300	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	DKK/MWh
Multiplication factor	2,00	
Dependency factor	0,00	DKK/MWh pr. MW
Average Market Price	227	DKK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	1,83	0,03
Industry	0,00	0,00	0,00	0,00
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW
January	447	0	0	439	386	-369	0	8	0	-17
February	312	0	0	306	386	-369	0	6	0	-17
March	0	0	0	0	386	-369	0	0	0	-17
April	0	0	0	0	386	-369	0	0	0	-17
May	0	0	0	0	386	-369	0	0	0	-17
June	0	0	0	0	386	-369	0	0	0	-17
July	0	0	0	0	386	-369	0	0	0	-17
August	0	0	0	0	386	-369	0	0	0	-17
September	0	0	0	0	386	-369	0	0	0	-17
October	0	0	0	0	386	-369	0	0	0	-17
November	0	0	0	0	386	-369	0	0	0	-17
December	0	0	0	0	386	-369	0	0	0	-17
Average	63	0	0	61	386	-369	0	1	0	-17
Maximum	22853	0	0	22437	386	-369	0	400	0	-1
Minimum	0	0	0	0	386	-369	0	0	0	-17
TWh/year	0,55	0,00	0,00	0,54	3,39	-3,24	0,00	0,01	0,00	-0,15

Electricity

	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Electrolyser MW	EH MW	Hydro Pump MW	Production: Turbine MW	RES MW	Hydro MW	Geothermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million DKK	Exchange Payment Exp Million DKK
January	89	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	47	47	0	0	9
February	92	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	44	44	0	0	7
March	91	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	45	45	0	0	7
April	90	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	46	46	0	0	8
May	92	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	44	44	0	0	8
June	90	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	46	46	0	0	7
July	90	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	46	46	0	0	5
August	92	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	44	44	0	0	7
September	90	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	46	46	0	0	8
October	90	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	46	46	0	0	8
November	92	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	44	44	0	0	7
December	91	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	45	45	0	0	8
Average	91	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	45	45	0	Average price	
Maximum	116	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	76	76	0	(DKK/MWh)	
Minimum	60	0	-123	0	0	0	0	0	0	0	0	300	-287	333	0	20	20	0	-	227
TWh/year	0,80	0,00	-1,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,64	-2,52		0,00	0,40	0,40	0,00	0	90

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioConversion	Synthetic Fuel	Wind	PV	Offsh.	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt): Total	CO2 emission (Mt): Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	0,64	-	1,93	0,01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,83	-	4,40	-0,89	3,52	1,00	0,80
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,03	-	0,03	0,00	0,03	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
H2 etc.	-	-	5,60	0,00	-	-5,60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	0,64	-	7,53	0,01	-	-5,60	-	-	-	-	-	-	-	-	-	-	-	-	1,86	-	4,43	-0,89	3,55	1,00	0,80

Output specifications BAU 2050.txt **The EnergyPLAN model 12.0**

District Heating Production

Gr.1	District heating MW	Solar MW	CSHP MW	DHP MW
January	439	0	0	439
February	306	0	0	306
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	61	0	0	61
Maximum	22437	0	0	22437
Minimum	0	0	0	0
Total for the whole year TWh/year	0,54	0,00	0,00	0,54

Gr.2	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW
January	8	0	0	0	0	0	8	0	0	0
February	6	0	0	0	0	0	6	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	1	0	0	0	0	0	1	0	0	0
Maximum	416	0	0	0	0	0	400	0	0	16
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,00		0,00

Gr.3	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW
January	0	0	0	386	-369	0	0	0	0	-17
February	0	0	0	386	-369	0	0	0	0	-17
March	0	0	0	386	-369	0	0	0	0	-17
April	0	0	0	386	-369	0	0	0	0	-17
May	0	0	0	386	-369	0	0	0	0	-17
June	0	0	0	386	-369	0	0	0	0	-17
July	0	0	0	386	-369	0	0	0	0	-17
August	0	0	0	386	-369	0	0	0	0	-17
September	0	0	0	386	-369	0	0	0	0	-17
October	0	0	0	386	-369	0	0	0	0	-17
November	0	0	0	386	-369	0	0	0	0	-17
December	0	0	0	386	-369	0	0	0	0	-17
Average	0	0	0	386	-369	0	0	0	0	-17
Maximum	0	0	0	386	-369	0	0	0	0	-17
Minimum	0	0	0	386	-369	0	0	0	0	-17
Total for the whole year TWh/year	0,00	0,00	0,00	3,39	-3,24	0,00	0,00	0,00		-0,15

RES specification	RES1 Wind MW	RES2 Photo \ MW	RES3 Offshoı MW	RES 4-7 ind MW	Total MW
January	0	0	0	0	0
February	0	0	0	0	0
March	0	0	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	0	0	0	0	0
July	0	0	0	0	0
August	0	0	0	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
Average	0	0	0	0	0
Maximum	0	0	0	0	0
Minimum	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million DKK)		
Total Fuel ex Ngas exchange =		48
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	0	
Gas handling =	47	
Biomass =	1	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		127
Marginal operation costs =		0
Total Electricity exchange =		0
Import =	0	
Export =	-90	
Bottleneck =	90	
Fixed imp/ex=	0	
Total CO2 emission costs =		29
Total variable costs =		203
Fixed operation costs =		119
Annual Investment costs =		173
TOTAL ANNUAL COSTS =		495

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	526	219	0	478	0	0	1223	0	0	0	0	0	0	1223	1223	0
February	366	219	0	426	0	0	1011	0	0	0	0	0	0	1011	1011	0
March	0	219	0	294	0	0	514	0	0	0	0	0	0	514	514	0
April	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
May	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
June	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
July	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
August	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
September	0	219	0	82	0	0	301	0	0	0	0	0	0	301	301	0
October	0	219	0	185	0	0	404	0	0	0	0	0	0	404	404	0
November	0	219	0	302	0	0	521	0	0	0	0	0	0	521	521	0
December	0	219	0	445	0	0	664	0	0	0	0	0	0	664	664	0
Average	74	219	0	208	0	0	501	0	0	0	0	0	0	501	501	0
Maximum	26841	219	0	808	0	0	27869	0	0	0	0	0	0	27869	27869	0
Minimum	0	219	0	58	0	0	278	0	0	0	0	0	0	278	278	0
Total for the whole year TWh/year	0,65	1,93	0,00	1,83	0,00	0,00	4,40	0,00	0,00	0,00	0,00	0,00	0,00	4,40	4,40	0,00

RES Share: 0,7 Percent of Primary Energy 0,0 Percent of Electricity 0,0 TWh electricity from RES

12.3 A3. Scenario 3: Biomass + Solar 2050

Input BIO-SOL 2050.txt — The EnergyPLAN model 12.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	0,80	Fixed imp/exp.	0,00
Electric heating + HP	0,30	Transportation	0,00
Electric cooling	0,00	Total	1,10

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	0,80	0,80
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	0,80	0,80

Wind	0 MW	0,00	TWh/year	0,00	Grid
Photo Voltaic	0 MW	0	TWh/year	0,00	stabili-
Offshore Wind	0 MW	0	TWh/year	0,00	sation
River Hydro	0 MW	0	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	2	3	0,35	0,45	
Heat Pump	2	5			3,00
Boiler		50		0,90	
Condensing	200		0,45		

Heatstorage: gr.2: 10 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	300	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	DKK/MWh
Multiplication factor	2,00	
Dependency factor	0,00	DKK/MWh pr. MW
Average Market Price	227	DKK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	

CAES fuel ratio: 0,000

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	0,82
Industry	0,00	0,00	0,00	0,00
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

	District Heating: Demand Distr. heating MW	Production Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million DKK	Exp Million DKK
January	651	0	0	0	386	-382	0	0	0	647	89	0	-103	0	64	0	0	0	0	0	0	300	-100	333	0	150	150	0	0	30
February	453	0	0	0	386	-382	0	0	0	449	92	0	-108	0	57	0	0	0	0	0	0	300	-100	333	0	159	159	0	0	24
March	0	0	0	0	386	-383	0	0	0	-2	91	0	-115	0	39	0	0	0	0	0	0	300	-100	333	0	185	185	0	0	31
April	0	0	0	0	386	-383	0	0	0	-3	90	0	-126	0	8	0	0	0	0	0	0	300	-100	333	0	229	229	0	0	39
May	0	0	0	0	386	-383	0	0	0	-3	92	0	-126	0	8	0	0	0	0	0	0	300	-100	333	0	227	227	0	0	42
June	0	0	0	0	386	-383	0	0	0	-3	91	0	-126	0	8	0	0	0	0	0	0	300	-100	333	0	228	228	0	0	36
July	0	0	0	0	386	-383	0	0	0	-3	90	0	-126	0	8	0	0	0	0	0	0	300	-100	333	0	229	229	0	0	26
August	0	0	0	0	386	-383	0	0	0	-3	92	0	-126	0	8	0	0	0	0	0	0	300	-100	333	0	226	226	0	0	36
September	0	0	0	0	386	-383	0	0	0	-3	90	0	-125	0	11	0	0	0	0	0	0	300	-100	333	0	223	223	0	0	39
October	0	0	0	0	386	-383	0	0	0	-2	90	0	-119	0	25	0	0	0	0	0	0	300	-100	333	0	205	205	0	0	37
November	0	0	0	0	386	-383	0	0	0	-2	92	0	-113	0	40	0	0	0	0	0	0	300	-100	333	0	181	181	0	0	30
December	0	0	0	0	386	-383	0	0	0	-2	91	0	-105	0	59	0	0	0	0	0	0	300	-100	333	0	155	155	0	0	28
Average	91	0	0	0	386	-383	0	0	0	88	91	0	-118	0	28	0	0	0	0	0	0	300	-100	333	0	200	200	0	Average price	
Maximum	33241	0	0	0	386	-377	0	49	0	33233	116	0	-71	0	107	0	0	0	0	0	0	300	-100	333	0	260	260	0	(DKK/MWh)	
Minimum	0	0	0	0	386	-383	0	0	0	-5	60	0	-128	0	8	0	0	0	0	0	0	300	-100	333	0	56	56	0	-	227
TWh/year	0,80	0,00	0,00	0,00	3,39	-3,36	0,00	0,00	0,00	0,78	0,80	0,00	-1,04	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	2,64	-0,88		0,00	1,76	1,76	0,00	0	398

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	Wind	PV	Offsh.	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biomass	-	-	5,58	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	0,82	-	6,40	-3,90	2,50	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,19	-	-	-	0,19	0,00	0,19	0,00	0,00
H2 etc.	-	-	1,95	-	0,00	-1,95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	-	7,53	-	0,00	-1,95	-	-	-	-	-	-	-	-	-	-	0,19	-	0,82	-	6,59	-3,90	2,69	0,00	0,00

Output specifications BIO-SOL 2050.txt — The EnergyPLAN model 12.0

District Heating Production

	Gr.1 District heating MW	Solar MW	CSHP MW	DHP MW	Gr.2 District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

	Gr.3 District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	RES specification RES1 Wind MW	RES2 Photo V MW	RES3 Offshore MW	RES 4-7 ind MW	Total MW
January	651	0	0	386	-382	0	0	0	154	647	0	0	0	0	0
February	453	0	0	386	-382	0	0	0	167	449	0	0	0	0	0
March	0	0	0	386	-383	0	0	0	388	-2	0	0	0	0	0
April	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
May	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
June	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
July	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
August	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
September	0	0	0	386	-383	0	0	0	388	-3	0	0	0	0	0
October	0	0	0	386	-383	0	0	0	388	-2	0	0	0	0	0
November	0	0	0	386	-383	0	0	0	388	-2	0	0	0	0	0
December	0	0	0	386	-383	0	0	0	388	-2	0	0	0	0	0
Average	91	0	0	386	-383	0	0	0	351	88	0	0	0	0	0
Maximum	33241	0	0	386	-377	0	49	0	583	33233	0	0	0	0	0
Minimum	0	0	0	386	-383	0	0	0	0	-5	0	0	0	0	0
Total for the whole year TWh/year	0,80	0,00	0,00	3,39	-3,36	0,00	0,00	0,00		0,78	0,00	0,00	0,00	0,00	0,00

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million DKK)		
Total Fuel ex Ngas exchange =		114
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	0	
Gas handling =	0	
Biomass =	114	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		0
Marginal operation costs =		0
Total Electricity exchange =		0
Import =	0	
Export =	-398	
Bottleneck =	398	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		114
Fixed operation costs =		55
Annual Investment costs =		231
TOTAL ANNUAL COSTS =		401

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

RES Share: 100,0 Percent of Primary Energy -2372,1 Percent of Electricity 2,0 TWh electricity from RES

12.4 A4. Scenario 4: Biomass + Solar + Solar District Heating 2050

Input SOLAR THERMAL 2050.txt — The EnergyPLAN model 12.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	0,80	Fixed imp/exp.	0,00
Electric heating + HP	0,30	Transportation	0,00
Electric cooling	0,00	Total	1,10

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	0,80	0,80
Solar Thermal	0,00	0,00	0,16	0,16
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	0,64	0,64

				Grid stabilisation share
Wind	0 MW	0,00	TWh/year	0,00
Photo Voltaic	0 MW	0	TWh/year	0,00
Offshore Wind	0 MW	0	TWh/year	0,00
River Hydro	0 MW	0	TWh/year	0,00
Hydro Power	0 MW	0	TWh/year	
Geothermal/Nuclear	0 MW	0	TWh/year	

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	Efficiencies COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	13	17	0,35	0,45	
Heat Pump	2	5			3,00
Boiler		50		0,90	
Condensing	150		0,45		

Heatstorage: gr.2: 10 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2
KEOL regulation	00000000
Minimum Stabilisation share	0,30
Stabilisation share of CHP	0,00
Minimum CHP gr 3 load	300 MW
Minimum PP	0 MW
Heat Pump maximum share	0,50
Maximum import/export	0 MW
Distr. Name :	Hour_nordpool.txt
Addition factor	0,00 DKK/MWh
Multiplication factor	2,00
Dependency factor	0,00 DKK/MWh pr. MW
Average Market Price	227 DKK/MWh
Gas Storage	0 GWh
Syngas capacity	0 MW
Biogas max to grid	0 MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	0,82
Industry	0,00	0,00	0,00	0,00
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

District Heating (MW):

	Demand: Distr. heating	Solar	Waste+ CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba-lance
January	651	141	0	0	386	-368	0	0	0	492
February	453	72	0	0	386	-368	0	0	0	363
March	0	0	0	0	386	-369	0	0	0	-17
April	0	0	0	0	386	-369	0	0	0	-17
May	0	0	0	0	386	-369	0	0	0	-17
June	0	0	0	0	386	-369	0	0	0	-17
July	0	0	0	0	386	-369	0	0	0	-17
August	0	0	0	0	386	-369	0	0	0	-17
September	0	0	0	0	386	-369	0	0	0	-17
October	0	0	0	0	386	-369	0	0	0	-17
November	0	0	0	0	386	-369	0	0	0	-17
December	0	0	0	0	386	-369	0	0	0	-17
Average	91	18	0	0	386	-369	0	0	0	56
Maximum	33241	31546	0	0	386	-364	0	50	0	33219
Minimum	0	0	0	0	386	-369	0	0	0	-19
TWh/year	0,80	0,16	0,00	0,00	3,39	-3,24	0,00	0,00	0,00	0,50

Electricity (MW) and Exchange:

	Cons.: Elec. demand	Flex.& Transp.	HP	Elec-trolyser	EH	Hydro Pump	Prod.: Tur-bine	RES	Hy-dro	Geo-thermal	Waste+ CSHP	CHP	PP	Stab-Load %	Imp	Exp	CEEP	EEP	Payment Imp (Million DKK)	Payment Exp (Million DKK)
January	89	0	-99	0	64	0	0	0	0	0	0	300	-150	333	0	96	96	0	0	19
February	92	0	-103	0	57	0	0	0	0	0	0	300	-150	333	0	105	105	0	0	16
March	91	0	-110	0	39	0	0	0	0	0	0	300	-150	333	0	130	130	0	0	22
April	90	0	-121	0	8	0	0	0	0	0	0	300	-150	333	0	174	174	0	0	30
May	92	0	-121	0	8	0	0	0	0	0	0	300	-150	333	0	172	172	0	0	32
June	91	0	-122	0	8	0	0	0	0	0	0	300	-150	333	0	173	173	0	0	27
July	90	0	-122	0	8	0	0	0	0	0	0	300	-150	333	0	174	174	0	0	20
August	92	0	-121	0	8	0	0	0	0	0	0	300	-150	333	0	172	172	0	0	28
September	90	0	-120	0	11	0	0	0	0	0	0	300	-150	333	0	168	168	0	0	30
October	90	0	-114	0	25	0	0	0	0	0	0	300	-150	333	0	150	150	0	0	27
November	92	0	-108	0	40	0	0	0	0	0	0	300	-150	333	0	126	126	0	0	21
December	91	0	-100	0	59	0	0	0	0	0	0	300	-150	333	0	100	100	0	0	19
Average	91	0	-113	0	28	0	0	0	0	0	0	300	-150	333	0	145	145	0	Average price	
Maximum	116	0	-67	0	107	0	0	0	0	0	0	300	-150	333	0	205	205	0	(DKK/MWh)	
Minimum	60	0	-123	0	8	0	0	0	0	0	0	300	-150	333	0	2	2	0	-	227
TWh/year	0,80	0,00	-1,00	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	2,64	-1,32		0,00	1,27	1,27	0,00	0	289

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	Wind	PV	Offsh.	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biomass	-	-	4,60	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	0,82	-	5,42	-2,83	2,59	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,35	-	-	-	0,35	0,00	0,35	0,00	0,00
H2 etc.	-	-	2,93	-	-	-2,93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	-	7,53	-	0,00	-2,93	-	-	-	-	-	-	-	-	-	-	0,35	-	0,82	-	5,77	-2,83	2,94	0,00	0,00

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District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age MW	Gr.2 Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age MW	Gr.3 Ba-lance MW	RES1 Wind MW	RES2 Photo Voltaic MW	RES3 Offshore MW	RES 4-7 ind MW	Total MW
January	651	141	0	386	-368	0	0	0	150	492	0	0	0	0	0
February	453	72	0	386	-368	0	0	0	145	363	0	0	0	0	0
March	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
April	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
May	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
June	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
July	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
August	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
September	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
October	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
November	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
December	0	0	0	386	-369	0	0	0	363	-17	0	0	0	0	0
Average	91	18	0	386	-369	0	0	0	327	56	0	0	0	0	0
Maximum	33241	31546	0	386	-364	0	50	0	541	33219	0	0	0	0	0
Minimum	0	0	0	386	-369	0	0	0	0	-19	0	0	0	0	0
Total for the whole year TWh/year	0,80	0,16	0,00	3,39	-3,24	0,00	0,00	0,00		0,50	0,00	0,00	0,00	0,00	0,00

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million DKK)		
Total Fuel ex Ngas exchange =		97
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	0	
Gas handling =	0	
Biomass =	97	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		0
Marginal operation costs =		0
Total Electricity exchange =		0
Import =	0	
Export =	-289	
Bottleneck =	289	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		97
Fixed operation costs =		65
Annual Investment costs =		632
TOTAL ANNUAL COSTS =		794

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

RES Share: 100,0 Percent of Primary Energy -3932,5 Percent of Electricity 1,6 TWh electricity from RES