The development of the urban heating sector in Romania

Master thesis

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Abstract

The transformation the energy sector is going through today cannot be achieved without major changes in the heating systems for urban areas. Since Romania has committed, along with the European Union, to reach specific energy targets by 2030, it is important that these targets are achieved in the most cost-effective way, by also bringing benefits to the society as a whole. Thus, this feasibility study analyses what is the most recommended heating solution to be adopted in three Romanian cities: Bucharest, Timisoara and Oradea, by comparing three scenarios based on individual heating and district heating. This resulted in the following research question:

What is the most feasible solution for improving the heating systems in the cities of Romania?

By matching the results obtained on a local level with the national level results obtained in another study, confirms that district heating, accompanied by heat savings is more cost-effective, energy efficient and environmentally friendly than individual heating solutions.

Provided that the results are confirmed locally and nationally, a set of recommendations for the Romanian authorities is established to help them develop new district heating strategies which empower the municipalities, help to retrofit, decarbonise and expand the existing systems, build new ones, and improve in general the image of this heating system to ultimately determine customers to reconnect to it.

List of abbreviations

ANRSC – The National Authority for Regulating Public Communal Administration Services

ANRE – The National Association for Energy Regulation

BAU – Business-as-usual

CHP – Combined heat and power

DHW – Domestic hot water

ECE – East and Central European

GIS – Geographical Information systems

GHG – Greenhouse gases

HoB – Heat only boiler

HRE – Heat Roadmap Europe

MSW – Municipal solid waste

OA – Owner Association

TEPP – Thermo-electric power plant

WTE – Waste-to-energy

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1. Introduction

At the COP 21 event in Paris, held at the end of 2015, the world state leaders from almost 200 countries, managed to reach an historic agreement to reduce the GHG emissions and their impact on climate change. One of the most important measures agreed at this event is related to the reduction of the GHG emissions to “less than 2°C” and to spending of $100 billion in developing countries for climate finance. However, the agreement was criticised for not having any binding measures (BBC News, 2015).

On a European level, the member states are together importing more than half of their energy needs, at a price of more than €1 billion each day. Out of this total energy, 40% is used to provide the heating, cooling and electricity needs of residential and service buildings (EC Europa, 2015). Since three quarters of this imports for the heating and cooling are in the form of fossil fuels, this indicates a high dependency on other countries outside the European Union, which could affect the security of supplies, especially for the countries where this comes from a single provider (European Commission, 2016).

On the other hand, much of the imported energy is wasted. Currently, on a European level, there is more wasted heat available then the heating demand (Connolly et al., 2012). Developing a strategy to make use of this wasted heat while also reducing the carbon emissions, increase efficiency and reduce the dependency on imports should be seen as a priority. Therefore, at the beginning of 2016, the European Commission (2016), through the Energy Union, released its first Heating and Cooling strategy.

The vision and goals of this strategy entail a renovation of the building stock and an increase its energy efficiency to decarbonise the whole sector. Among others, these objectives can be achieved through the use of district heating, automation and control systems which can better serve the occupants of the dwellings, but also provide flexibility for the electricity system through demand side management programs and thermal storage. The industry will need to make similar steps and increase the use of renewable energy, whilst the industrial processes which produce waste heat and cold should be reused in the buildings nearby through district heating (European Commission, 2016).

Many EU member states have a long tradition with district heating and in many countries it is seen as a good opportunity for business. However, in other countries, the district heating systems have shrunk, due to various reasons, but mainly related to the lack of investments, price regulations, low performance or negative image of the system (European Commission, 2016). Unfortunately, this describes the situation in Romania, where the district heating system is still rather extensive, but shrank by 78% in the period 1989-2014, from 315 municipalities served my district heating, to 70 today, and currently, only 22% of the municipalities of Romania are connected to the district heating (Government of Romania, 2015).

According to Leca (2015), the energy sector in Romania is separated in three strategic parts: electricity, natural gas and thermal energy. Out of these three, the thermal energy sector, is the most defective, due to the superficial treatment it received in the last 27 years after the Revolution. Thus, the business model of district heating in Romania is not seen as sustainable, given the large number of disconnections, the inefficient and old infrastructure, which was mainly developed in the 1970's prior to the oil crisis, and the subsidies for individual heating, all leading to high production costs and low revenues for the district heating operators.

The high number of disconnections and the lack of investments, with heat losses which can reach up to 30%, caused more than 80 boiler and TEPP to be decommissioned in the last 6 years. On the other hand, the co-generation plants are not receiving enough attention, and only 59 of them are in use, and 85% of them are used to supply heat in the district heating systems (Government of Romania, 2015).

The existing customers of district heating in Romania are the 7.6 mil. residents living in approximately 3 mil. flats spread in 83.000 blocks of flats, which represent the main type of dwellings in urban areas. These flats are the ones using 50% of the total energy produced, but at the same time is the sector with the highest energy losses, one which also is responsible for 40% of the GHG in the country (Leca, 2015).

The large number of blocks of flats in the urban areas of the country is a typical legacy of the communist regime, which included a rapid urbanisation process, and these determine the average size of a dwelling in Romania, which is 44,6 m², making it the country with the smallest sized dwellings in Europe (Eurostat, 2016).

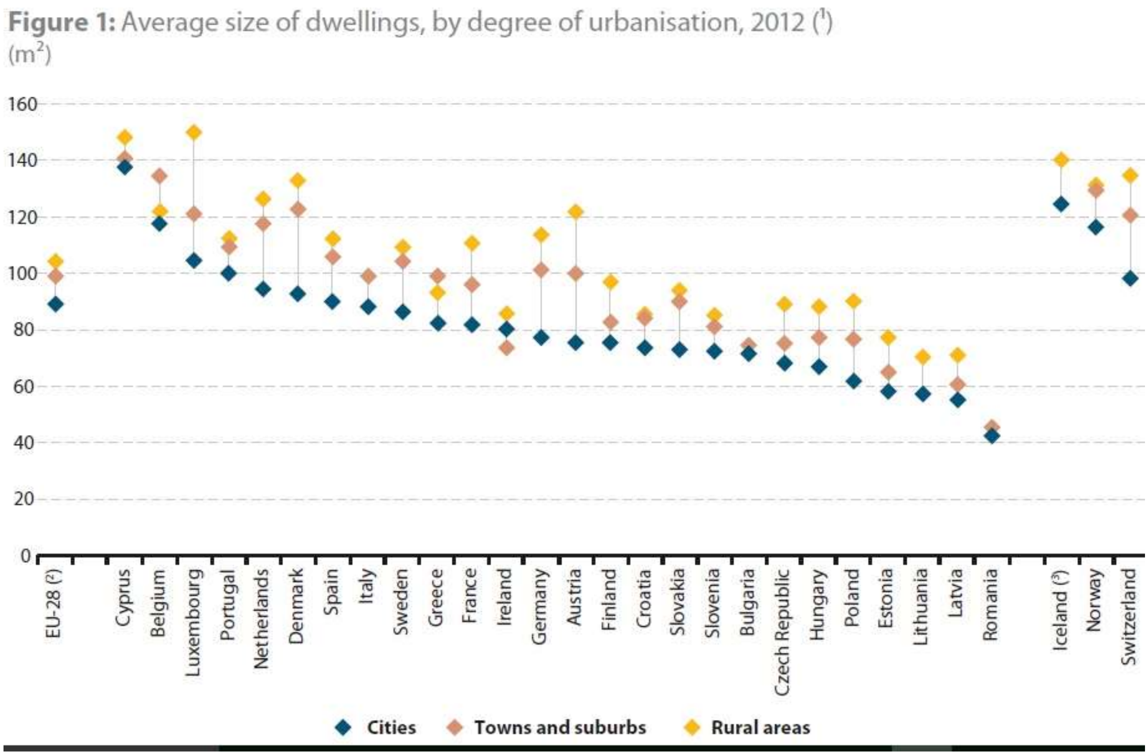


Figure 1 - Source: Eurostat

On a customer level, the average energy consumption in the Romanian dwellings accounts for 76% on heating and DHW use, and in some cases, the total energy demand can reach up to 250-300 kWh/m2/year (Leca, 2015). In the blocks of flats this translates in a heat demand of almost two times higher than the average in Europe, indicating an energy loss between 40-50% of the final energy consumption. This is related of the low level of insulation of the building envelopes, as 75% of the building stock was built at least 40 years old, when insulation was not a priority. Still, the retrofitting of the buildings is slowly progressing, and only 5-6% of the building stock has been retrofitted, due to inefficient retrofitting schemes or lack of funding from individuals, for which poverty is still a problem. Thus, the energy demand in the average non-retrofitted apartment is shown in Figure 1 (Petrescu, 2010).

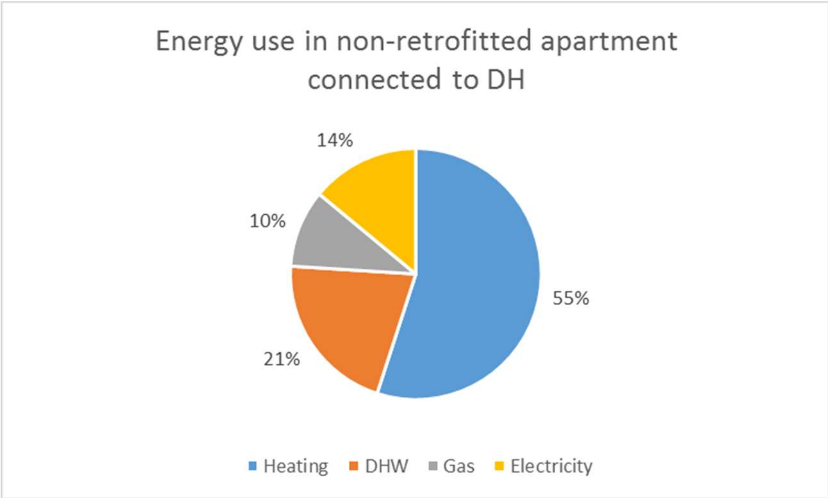


Figure 2 - Average energy demand in non-retrofitted flat

1.1 Problem formulation

Even though district heating in Romania confronts with a lack of interest from central and local authorities to be positioned as the main solution if providing heat in urban areas, the EU's acknowledgement of the importance of district heating through their recent Heating and Cooling Strategy (2016) should trigger more interest from the authorities on this sector.

Since many studies have emphasized the economic, environmental and social advantages of district heating (Chittum & Østergaard, 2014; Connolly et al., 2015; Persson & Werner, 2011), it is important to remember that the fundamental idea of district heating is to use local energy resources that otherwise would be wasted, in order to satisfy the local heat demand (Werner & Fredriksen, 2013).

District heating systems do not to use the same energy supplies as other individual heat only systems would do. Presently, Romania is still developing a dependency on natural gas, a natural resource of which Romania still benefits, but expected to deplete in less than 10 years at the current consumption rates, which will result in a future dependency on imports (this only includes the conventional natural gases, and not the ones obtained through fracking) (Spiridon, 2013). However, the country has vast potential for using renewable energy sources, and 52% of this potential is represented by biomass. This alone is enough to supply the current heat demands of the district heating systems in use today in Romania plus 10% of the electricity demand (Leca, 2015). It is also the country where the existing amounts of waste heat and renewable sources are more than enough to supply several times the district heating needs of the entire country, and where the heat demand is two times higher than the European average (Connolly et al., 2015).

The focus of the Romanian authorities should be on developing a functional and dedicated strategy for district heating, one which can reduce the dependence on natural gas, diversify the heat supply (Romania does not have waste-to-energy facilities and uses only 2% of its biomass potential), bust most importantly to increase the energy savings and overall efficiency of the district heating (Leca, 2015). However, in the recently issued *"Report on the assessment of the national potential to implement high-efficiency cogeneration and efficient district heating and cooling"*(Government of Romania, 2015), the ambitions are still unclear.

Romania's heating and cooling potential has been demonstrated and quantified within a Pan-European project named Stratego (Connolly et al., 2015), where five European countries, with particularities in the heating sector, were chosen to have developed heating and cooling plans made on a national level. These plans are intended to provide a tangible support and assist the local authorities to develop their heating plans, but also to find priority areas for intervention (Connolly et al., 2015).

After the publication of Stratego in 2015, Romania was provided with a choice for its future development of the heating and cooling sector. Since the national heating plans act as a guideline, many of its recommendations can be applied on a local/city level. Therefore, the aim of this feasibility study is to find out what is the most recommended heating solution on a city level, and make a connection between these results and the national level results, in order to raise the awareness of the local authorities about the importance of clear strategies for urban heating and proposing policy changes which will help develop this sector. Therefore, this provided the following research question and its sub-question:

What is the most feasible solution for improving the heating systems in the cities of Romania?

- *How do the results obtained on a local level compare with the national level results obtained in Stratego and how can these turn into recommendations for the thermal energy strategies of Romania?*

In order to provide an answer to these questions, it is relevant to first clarify which are the main points Romania should focus on in terms of urban heating, to show the direction the development of these systems should go towards. These are, in the following order:

Heat savings
- reduce the overall heat demand through building renovation
- synergy in reduction between the heat demand and heat supply to reduce thermal capacities

Heat efficiency
- district heating is more efficient in urban areas than natural gas networks and individual heating

Sustainable resources
- use the large amounts of available waste heat and renewable energy sources

2. Methodology and theory

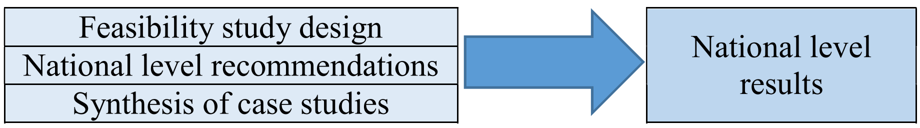
This chapter outlines the methods of analysis used to find the answers to the problem outlined in the problem formulation. The main component of this research are the case studies, based on a feasibility study design, where the national level plans are connected, directly or indirectly, to the plans on a city level. The case studies involve both qualitative and quantitative aspects within a real life context.

It is necessary to start with an introduction into the theory behind a feasibility study, and further continue with its design elements. The proposed study analyses the technical alternatives, with an evaluation of the economic, environmental and costs of these alternatives. Based on this, the feasibility study is constructed and conducted, in order to find out which are the necessary changes to be achieved in the Romanian regulatory and economic market, so that the interests of the society are compatible with the economic interests.

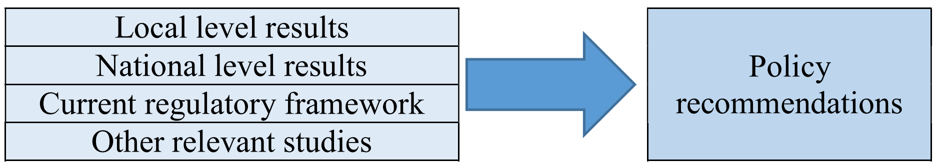
The next chapter continues with the description of the district heating situation in Romania, starting with the background of thermal heating in urban areas, since it was first implemented, followed by insights into the previous and present public regulation and energy strategies for district heating. This section continues with an introduction of the findings in Stratego (Connolly et al., 2015), a Pan-European project which analysed in detail the heating and cooling sectors of Romania and another four countries. With the all three perspectives, a set of recommendations is made for the district heating sector of the country. These recommendations are summarized to create a set of goals on a national level for Romania.

The goals presented on a national level provide the context for developing the three case studies, so the focus will switch from the national level to a city level, by analysing different scenarios in three Romanian cities: Bucharest, Timisoara and Oradea. The parameters assessed for the feasibility study are done quantitatively and/or qualitatively based on the availability of data. A more detailed presentation of the methodology for the case studies is available in Chapter 4.

The main findings in the three case studies are then synthetized, and the synthesis, along with the national recommendations and feasibility study design are used to create a set of national level results based on the results in Stratego (Connolly et al., 2015), in order to match the national level results with the local level ones.



The next chapter creates set of policy recommendations for Romania on how the improve the existing regulatory framework and better manage heating in urban areas. Insights from other relevant publications are included. Therefore, the policy recommendations result from:



2.1 Choice Awareness

Before starting the analysis of this study, it is important to create an overall theoretical framework for it, to better understand how the existing problems in the district heating sector can be overcame. The problems in question are related to the high reliance on fossil fuels, the lack of refurbishment of both the district heating networks and of the building stock, but also the lack of support for this sector on a political level. The Choice Awareness theory, which deals with the implementation of radical technological changes in the form of renewable energy systems, is providing itself as a useful tool to overcome these issues.

According to this theory, established organisations within existing institutions will influence the perception of choices for the society. The theory is based on the observation that existing organisations in the industry try to keep out new technology proposals, in order to keep their power and influence, by creating situations where no choices are provided, thus influencing the collective perception (Lund, 2014). The theory aims to make a clear distinction between choices, by categorising them in two types: true and false. A true choice is between several real options, whilst a false choice refers to a situation when the idea of choosing does not actually occur, as there is no real choice. This often happens in the political decision making processes, when the organisational interests try and eliminate the real choices (Lund, 2014).

Therefore, having the option to make real choices is a result of raising awareness in society that choices do exist (Lund, 2014). The heating and cooling sector makes no exception, as real choices do exist. In the case of Romania, a new choice has been made available after the publication of the Stratego project in 2015 (Connolly et al., 2015), offering a real alternative to the already established solutions for the heating and cooling sector. Therefore, by creating viable alternatives, the collective perception can be changed, and this can play an important role when making decisions on energy planning. The promotion of concrete technical alternatives through the identification of barriers becomes relevant for the future developments in the heating and cooling industry (Lund, 2014).

In the Romanian context, the high reliance on fossil fuels and an increasing focus on individual heating is not enough and well perceived by the society and politicians. Moreover, the existing organisations will not create by themselves alternatives to implement changes, and if they do, these are reliant on the same institutional setup. This could be explained through the discourse theory, which implies that various organisations represent different perceptions of reality with different views on what should be done to resolve the same problem. If a set of alternatives is promoted, others are not, because they would require an institutional setup change. For example, some politicians and industry associations might perceive the problem of refurbishing the aged district heating systems in a different way than environmental organisations (Lund, 2014).

Since the technological changes pose a threat for the existing technologies to be replaced, their representing organisations respond by eliminating the perception of choice and through discourse and public debate, in their attempt to protect their own interests (Lund, 2014).

According to the first thesis of the Choice Awareness theory, when society seeks to implement radical technological changes which imply a replacement of the already established technologies, the discourse of the existing organisations will affect the implementation, by hindering the development of new solutions, and eliminate certain alternatives, so that the society has no choice but to implement solutions that will save the existing organisations.

The second thesis of the Choice Awareness theory argues the benefit of raising awareness in society that alternatives do exist and that it is possible to make real choices. Such awareness can be promoted in various debates of new plans, through technical assessments demonstrating the new technologies comply with the regulations, or by designing feasibility studies which include relevant political objectives (Lund, 2014).

Therefore, the Choice Awareness theory and its two thesis focus on the decision-making procedures, emphasized as a conflict between different interests, influences and well-established organisations in a process over time, as developing policies, alternatives and proper methodologies for public regulation takes time.

2.2 Feasibility study design

This sub-chapter introduces the notion of feasibility study, which will be used as a guideline to assess thermal energy scenarios for three cities in Romania.

The feasibility study includes the design of what is feasible to be done from a technological point of view, along with an evaluation of the social, environmental and economic costs. These elements need to be overlaid with the institutional conditions that influence the implementation of alternatives. A feasibility study can be done in two ways: on a business-economic level, or on a socio-economic level. The first one analyses the perspectives from the enterprises' point of view, whilst the second is used to analyse if certain technical solutions are good to be implemented for the benefit of the society. Such studies are placed in a timeframe and include a reasoning of the consequences of such a change. That is as such changes cannot be implemented as '*end-of-pipe*' solutions, as the ones which only treat the emissions, or improve the efficiency, not even for the conservative countries which just want to have a functional energy system (Hvelplund & Lund, 1998). It is therefore necessary to focus on '*continuity'* and '*discontinuity'* strategies, where the entire system undertakes major changes, not relying on the conservative technical solutions which only treat the effects, but not the causes (Unruh, 2009).

Since single energy feasibility projects, such as for one heat plant, are not regarded anymore as relevant in today's context, the more relevant studies of this kind analyse the energy system as a whole, with its number of interrelations between different sectors of the system (Hvelplund & Lund, 1998).

The Choice Awareness theory can be regarded as the framework and starting point for analysing how radical technological changes can be implemented. The consequences for the environmental, social and economic costs of the technical alternatives need to be included in the design of a feasibility study. Such a feasibility study includes testing work to determine if such a project should or should not be implemented. It is also dependent on the accuracy of the data, which for this study is not always clear or available. Therefore, in the current report, the feasibility study is undertaken to verify if a fully documented feasibility study should be done. It is intended to provide a fast response of what is the best idea among several ones. Shortcut methods can be accepted at this stage, and such a study should be used to determine the guideline costs and consequences of using one technology or another (Hvelplund & Lund, 1998).

A well-known example, which received more importance in the last decade, is the connection between the heating and electricity sectors, where cogeneration, intermittent electricity and district heating are increasing their share of the market. As demonstrated in previous studies, (Connolly et al., 2012; Lund et al., 2011), district heating represents a liaison technology between the heating and electricity sector, and the studies which analyse the implementation of such a system are usually conceived for a long technical lifetime, of 20-30 years or even more. In such a long-term infrastructural study it is very likely that the institutional and technical conditions around the project will change, therefore making it relevant to analyse a broader area of consequences, without relying as if the legislation will not change (Hvelplund & Lund, 1998).

Therefore, any feasibility study should begin with an assessment of the historical, institutional and political context of the country analysed, and should not be done on the basis of an economically and institutionally optimal context. The changes in the systems will not occur in free-market situations, but must be placed in certain institutional and political frameworks. Such frameworks are created over time, by creating an inertia in the system, favouring the old technologies. Thus, when radical technological changes occur, the technologies must be developed and invested in while they compete with already established technologies. The introduction of such technologies require a careful examination of the system as a whole, as such systems are connected to a broader spectrum of objectives and conditions in society (Lund, 2014).

Such as, feasibility studies are more than a set of calculations which will lead to ideal situations, as the society never finds itself in an optimal situation. Such studies should be designed to identify the benefits for both the economy and the environment, as well as institutional policies which will make them possible to be implemented over time. Since these studies are subject of influences and pressures of the different actors involved, it is relevant to develop an innovative and transparent study to increase its chances to make a change. Feasibility studies are seen as tools to point the direction for the new technological changes and overcome the political and institutional barriers (Lund, 2014).

Therefore, this study is intended to help the actors involved in the heating sector of Romania to create, develop and improve their district heating strategies, by demonstrating the alternatives to the business-as-usual situation, currently based on fossil fuels, inefficient technologies and management. It is intended to be used as a blueprint to assess what are the alternatives, costs, benefits and consequences of retrofitting the district heating sector in Romania.

2.3 The critical and paradigmatic cases

The research design of this project is based on the idea of creating a set of case studies to increase the generalizability of a given subject, in this case of district heating. The objective is to achieve the greatest amount of information, as often, one representative case is not the most appropriate research strategy, due to its atypical or extreme characteristics, which do not reveal enough information (Flyvbjerg, 2006).

Therefore, the case studies in this project can be characterized as being both critical, of strategic importance to the general problem, and paradigmatic, which create a model.

The critical cases can be done either by looking into the ‘most likely’ cases, which clearly confirm that district heating can be replicated in other locations, or the ‘least likely’ cases, in other words, cases which demonstrate that such replication is not possible. It is necessary to mention though, even if some of the experiences can be transferred to other locations, these cannot be generally agreed as good practice for all the cases (Flyvbjerg, 2006).

Nevertheless, once the three cities are established as critical cases, by matching the city level results with the national level ones, the cases also become paradigmatic as they prove to highlight general characteristics over district heating. Such general characteristics are based on the validity claims made by researchers (Connolly et al., 2015) and do not follow a specific standard, but they set the standard (Flyvbjerg, 2006).

3. District heating in Romania

This chapter presents the status of district heating in Romania from several perspectives, starting with the background of the urban heating sector, followed by several insights into the most important changes in the regulatory framework. Since lately a high emphasis is put on district heating (Connolly et al., 2015; European Commission, 2016), it is relevant to look into the development of district heating in Romania, since its beginning, in the 1970's until today, as well into the legislative challenges encountered for regulating district heating in Romania. Finally, some of the recommendations of Stratego (Connolly et al., 2015) are presented to formulate a set of goals for district heating on a national level.

3.1 Background of district heating in Romania

A legacy of the communist regimes in ECE countries is the extensive infrastructure of district heating networks, which still function in many of these countries. The first centralised heating systems appeared in Romania in 1970's, within the process of rapid industrialisation and urbanisation of the country. The systems were all state owned, and managed within on large public company: S.C. Termoelectrica S.A. (Poputoaia & Bouzarovski, 2010). Later, in the 1980's, to respond to the expansion of district heating and the growing needs of heating for the population, the first TEPP plants were developed from the existing electrical power stations. Gradually, this type of systems extended, and most of them were almost exclusively dedicated to supplying the district heating needs (Iacobescu & Badescu, 2011). The construction of district heating systems was highly promoted at the begging of the 1980's, and at the end of the decade, up to 315 district heating systems were functional, spread in 251 settlements around the country (Government of Romania, 2015; Iacobescu & Badescu, 2011).

After the Romanian Revolution in December 1989, many social and political changes took place in the country, which affected the functioning of district heating. Many industrial consumers had to put a stop to their activities or decrease the production of goods, reducing the heat demand. Alongside, numerous residential consumers had chosen to disconnect from the centralized heating system, for various reasons such as the lack of trust in the district heating company, financial difficulties or opportunity for other types of heating. With the three combined, a massive misbalance affected the distribution of heat and DHW to the remaining customers, consequently resulting in a drop in the efficiencies of the whole system (Iacobescu & Badescu, 2011). This meant that district heating operators had to manage an oversized heat supply system facing a rapid decline in demand, with some operators having the ability to produce more than twice of the required heat. This affected especially the co-generation side, where the reduction in the demand could not be matched by a corresponding reduction in supply, leading to decreased revenues due to partial use of capacities. Since fixed costs represented a higher share than the total costs, the district heating operators could not respond to demand changes, adding to that the problem of overemployment, where 70% of the production costs were represented by salaries and pay-offs (Poputoaia & Bouzarovski, 2010).

The Romanian district heating system was also affected by a lack of credibility from the population, which was created by a faulty management. This began in 1985, when due to the decision of the authorities to pay the country's external debt, huge savings were made on the expense of the population. Therefore, the supply of heating and DHW only took place at peak hours, which were compressed, but not longer than 8 continuous hours of heat delivery per day. Besides this, between the years 1990-2000, no serious investments were made to maintain the existing infrastructure, resulting in often malfunctions and increases of losses, which determined the population to switch to individual heating. This was also helped by the low price of natural gas, which kept this level until 2001, when Romania started gradually equalising the price from the internal production with the import price, due to the commitments of the country before joining the EU. Therefore, by 2009, the price of natural gas increased by 400% (COGEN Romania, 2009). However, the price of natural gas was differentiated between residential and commercial consumers, the second ones having to pay substantial higher price than the first ones (Poputoaia & Bouzarovski, 2010).

This created a situation where individual heating became more advantageous than district heating. The suppliers of such systems used this opportunity to launch marketing campaigns exploiting the shortcomings of the district heating system. The acquisition of such systems required a consistent investment of time and capital, and this only resulted in a very low probability of these customers to return to the district heating system in a short or medium timeframe. On the other hand, the district heating regulators tried to counter-balance this by creating a bureaucratic maze, imposing numerous requirements for the disconnection from the centralized network. This only contributed to the negative image of the district heating in Romania (Poputoaia & Bouzarovski, 2010).

Today, the rate of disconnections has lowered, but the invested capital for modernising and maintaining the existing infrastructure in district heating systems is rather inexistent. This created the situation where only 70 municipalities still have functional district heating systems out of the 315 ones. This currently represents approximately 22% of the total number of municipalities in Romania (Government of Romania, 2015).

3.2 Policies

The Romanian authorities have been, and still are confronted with managing a post-communist district heating system. The difficult situation this sector finds itself, 27 years after the Revolution, has multiple causes, and among them could be mentioned:

- incoherency and lack of national strategies for district heating
- the problem of ownership for district heating
- the problem of ownership of residential buildings
- the lack of political will

The district heating sector in Romania has multiple actors involved, which have the roles to regulate, license and supervise the activities of district heating operators. The first and most important is the Government of Romania, which through the Ministry of Energy, Ministry of Regional Development and Public Administration and the Prime Minister, have established two regulators on the market: ANRSC and ANRE. The role of these bodies of administration is further explained.

Another important actor in the management of district heating is the associations of dwelling owners, the OA, as Romania is the country in the EU with the highest number of dwelling owners, with approximately 97% of apartments privately owned.

To begin with, it is relevant to mention that the Romanian authorities did not consider the energy sector as strategic infrastructure, and centralized heating systems as social priority for the population, until 2004. The agenda of the authorities has changed once it was clear that Romania was to join the EU in 2007. Therefore, a national strategy for district heating was issued in 2004, acknowledging the need for action in terms of environmental protection, decentralisation of public utility services, introduction of market mechanisms and the use of private funding for district heating refurbishment. Even though Romania engaged to achieve these objectives, the political will only acted on a declarative level, as the problems in this sector still exist. The district heating components form heat generation, transmission and distribution network and customer installations in many of Romania's cities have not been retrofitted and/or downsized. The restructuring of the district heating companies does not actively happen either, and in many cases, the problem of overemployment still exists, but is kept in this status due to political reasons (Poputoaia & Bouzarovski, 2010).

The regulating authorities in Romania were given separate roles, but their coordination and delimitation of responsibilities was not clearly determined. The ANRSC has the role of issuing licenses for district heating operators which function with HoB, supervising their compliance with the national legislation and issuing the secondary legislation. The other regulating authority, ANRE, is responsible with the co-generated heating systems. They were allocated with the responsibility of regulation, licensing and supervision of this type of systems (Poputoaia & Bouzarovski, 2010).

As mentioned previously, the ownership of district heating sector belonged to one public state owned company, named Termoelectrica. However, in 2002, the state eventually managed to transfer the ownership to the local authorities, to recognise their role self-organising and managing this service. With this transfer of ownership, the local authorities in the municipalities with more than 20.000 people were also given the responsibility of drafting energy efficiency programs in addition to their heat strategies. These requirements were part of the stipulations in the Energy Efficiency Law (Poputoaia & Bouzarovski, 2010).

The metering part of the heat deliveries was an important element in the regulation of district heating, which was made compulsory only in 2004, even though it was considered as having a primary role in modernising the district heating sector in Romania. This meant that the consumers did not have to pay anymore the losses in the network. However, the metering part was difficult to be implemented as this depended on overcoming a major flaw in the design on district heating infrastructure built during communist time. This is the "vertical distribution" on the radiators in the apartment block. Each radiator in each flat was connected to the radiator in the apartment above and/or bellow, not to the rest of the radiators in the apartment. This meant that the heat control at apartment level was not economically and technically feasible, as each radiator had to be metered individually. Therefore, the chosen solution was to meter collectively the building and to allocate costs to each apartment. This task is managed by the OA, which basically have to divide the bill from the district heating operator and invoice the respective apartment owners, according to their energy consumption, and then pay the district heating company. The problem with this process is that it is difficult to manage, bureaucratic and inefficient, and it often leads to non-payment. The district heating company also has to rely on the OA to deliver the information of the non-payers to recuperate the debts, which further burdens the recovery process, and creates financial difficulties for the district heating company (Poputoaia & Bouzarovski, 2010).

Another issue in the way of having a functional district heating system is related to the ownership of the apartments. This is also a legacy of the Communism, as after the fall of the regime, the tenants were offered to buy the apartments (previously owned by the state) for a price well-bellow the market one. This should have normally represented an advantage when it comes to retrofitting the apartment blocks, but given the generally low average incomes the Romanian population still has, has delayed many of the retrofitting plans.

The OA's also have a role the retrofitting of the apartment blocks, as they need the acceptance of the majority of dwellers to approve the retrofitting plans. However, in many small cities the OA's have disappeared along with the closure of the district heating operator. Since these OA's need to approve the retrofitting scheme, it is self-implied that this generates a problem. Between 2009 and 2015, since several national retrofitting schemes took place, only 1560 blocks of flats have been retrofitted in the whole, out of the total of 59.544 multi-story buildings. Since the retrofitting is made mainly on non-refundable funds, and the owner has to pay only 20% of the total costs, it is quite unclear why the retrofitting rate is slowly advancing. Nevertheless, this is mainly related to the bureaucracy and in some cases, to the inexistence of OA's (Poputoaia & Bouzarovski, 2010).

3.3 National level feasibility plans

In 2015, a project co-funded in the framework of Intelligent Energy Europe Programme, has been released by a group of researchers from Aalborg University and other institutes to support the local and national authorities in 5 EU countries to develop more efficient heating and cooling solutions.

The Stratego project is part of a series of other studies which share the same methodologies. The most recent ones, used in HRE I and II, released in 2012 and 2014 (Connolly et al., 2012, 2014), provided a new approach for the heating and cooling perspectives of the EU member states. Their approach was aimed at the expansion of district heating to a share of 50% by 2050, and the inclusion of higher amount of renewable energy. Based on this scenario, and compared to a similar project developed by the European Union, called Energy Roadmap Europe, the savings in the heating and cooling sector would be €100 bil. by 2050, and will also enable the creation of approximately 220.000 jobs in the implementation phase, among others.

In the Stratego project, which is the third in the HRE series, the focus was to develop plans on a national and regional level. In this case, a Business-as-Usual (BAU) scenario was used as a comparison model to the scenario proposed in this project. The BAU is based on a forecast of the European Commission for the year 2050 and represents the situation today, and the situation we are likely to end up with if we continue to use energy the same way as today (using 2010 as a reference year). Apart from this, a HRE scenario for each of the five countries is created, by adding energy efficiency measures in the heating sector. By comparing the two scenarios, the impact of the energy efficiency measures is quantified for 3 key metrics: primary energy supply, carbon emissions and total annual energy costs. The aim for creating these detailed measures was aimed to:

- Provide tangible support in developing National Heating and Cooling Plans
- Assist local authorities in evaluating their Heating and Cooling potential
- Find their priority intervention areas
- Identify concrete projects that should be implemented

In this project new methodologies and tools have been used to identify the potential of new energy solutions and to quantify the impact of implementing them for the energy system, economy and environment, all on a national level. Each of the new implemented solutions has an impact on a national level, and affect the overall performance of the energy system. The heat strategies used were a combination of heat savings, district heating in urban areas and individual heating in rural areas. It is relevant to mention that the study is based on GIS and energy system analysis, therefore even though it considers the national level, it does not lose the detail. The maps developed for the study have an accuracy per each km² (Connolly et al., 2015).

The five countries chosen to be analysed in Stratego are UK, Croatia, Italy, Czech Republic and Romania. These countries were chosen due to their particularities of the heating system, and to demonstrate that even when the backgrounds differ, district heating still proves as a technically and economically viable solution.

According to this study, Romania has the potential to reduce its energy demand by 40%, its CO_2 emissions by 75% and the costs with 15%, based on an investment of €125 bil. by 2050. Even though this is a high financial effort, the study accounts for important fuel savings of €5 bil./year due to the investments in energy efficiency compared to the BAU scenario. The most expensive part is represented by the investments in heat savings €80 bil., followed by the investment of €35 bil. for individual heat pumps mainly in rural area. However, only €10 bil. are accounted for the expansion of district heating, as Romania already has an extensive network of district heating infrastructure. Nevertheless, as it is further explained, the existing infrastructure needs extensive refurbishment, amount which is not included in the calculation of costs in Stratego (Connolly et al., 2015).

The primary changes in the HRE scenario were compared to BAU ones, and reflected in more heat savings in buildings, a replacement of natural gas in urban areas and a combination of heat pumps, solar-thermal and biomass boilers in the rural areas. More specifically, the heat demand in buildings is expected to reduce to 50% of today demands, whilst district heating should supply up to 40% of the total heat demand, from 20% today. The CO_2 emissions are expected to drop from almost 50 Mt/year to 13 Mt/year by 2050 (Connolly et al., 2015).

Within the same study, the potential for using waste heat was also analysed. This revealed a very high potential, as large amounts of unutilised waste heat are available from thermal and industrial plants, and by accounting renewable energy sources too, this indicated that there is three times the amount of waste heat in Romania than the required levels of district heating proposed in the study. Therefore, this emphasises again the need for developing the district heating grid, as this represents the only way to make use of these resources (Connolly et al., 2015).

The district heating networks should continue to represent the main type of heating in urban areas, since the current district heating grid is rather extensive and there is a high availability of waste heat and renewable energy sources in the country. District heating is technically and economically viable, and the cost of pipes only represents 5-15% of the annualised district heating system cost. This subsequently concludes that the use of natural gas and individual heating should gradually be reduced in urban areas (Connolly et al., 2015).

As part of the conclusion, the country report for Romania emphasizes on the need to reduce the heat density in residential and commercial buildings by 50% to a value of 60-70kWh/m2. These savings should be implemented with a long time span vision, in combination with building renovations. Not least, the heat savings can also be achieved through a reduction of the thermal capacity and varying the type of heat sources used in the district heating networks (Connolly et al., 2015).

3.4 National level goals

Given the different perspectives of the district heating in Romania provided by the historical background, policies and analysis made in Stratego, a set of recommendations for the national level can be extracted. The overview over these goals provides the reasons for assessing if the results found on a national level can be confirmed with ones on a local level. This is done through constructing and conducting a feasibility study on a city level, which will be further presented in the next chapter.

Therefore, by summarizing this chapter, and by using the recommendations in Stratego and "*Romania needs a strategy for thermal energy*"(Connolly et al., 2015; Leca, 2015), the main goals of the district heating sector in Romania should be:

- Reduce the heat losses in buildings to at least 50% of today's level
- Reduce the heat demand and improve in the heat supply to reduce thermal capacity
- Enable more waste heat and renewable energy sources to be used
- Retrofit and extend the district heating networks
- Discourage the disconnections from the district heating systems
- Create a clear designated authority in charge with district heating
- Switch from monomial to binomial tariff (payment of the bills in instalments, rather than only expensive bills in the heating season)

Once these national level recommendations have been addressed, the focus can switch to the local level, to eventually find out if the results match. In order to do this, three cities in Romania, with different heating strategies were chosen as case studies.

4. Case studies

This chapter describes the methodology used in the three case studies based on the feasibility study design presented in sub-Chapter 2.2. The same parameters are analysed for each of the three cities in order to better explain the results.

To start with, it is important to mention why these cities were chosen for this feasibility study. The main reason is rather simple, as these were the cities where most of the data was available. Nevertheless, this later proved as a relevant choice, as each of the cities has its own particularities, for example in area covered by district heating, heat density, population, access to renewable energy sources and different BAU strategies for the development of the thermal energy sector. Apart from this, there are also some similarities, as with all the other cities in Romania, such as: the reliance almost entirely on fossil fuels burned in TEPP, the partly refurbished transmission and distribution pipes, the general oversize of the system and the low level of thermal insulation of the existing building stock.

The structure of the case studies is further explained. The same parameters are analysed for all of the three cities, but given the lack and sometimes the incoherency of the data from some of the sources, the results for the parameters differ, especially for Scenario I. The parameters proposed in the three scenarios are quantitatively and qualitatively assessed based on the availability of data.

The same heat demand is used throughout the three main scenarios of each city, and it is calculated using the Pan-European Thermal Atlas (Stratego, 2015). Using the data in the atlas, the size of the building stock and the national average size of a dwelling in urban areas (44,6 m^2) the heat demand per/m^2 could be deducted.

In the heat savings section, the heat demand is reduced to the maximum recommended level (100 kWh/m^2/year), based on the size of the average size of urban dwellings in Romania, for all the three cities.

Scenario I

The first scenario considers that no changes will further occur in the district heating system, besides the ones which already started. The situation remains the same, as this scenario is considered to represent the Business-as-usual (BAU) one, and it reflects what has been happening in the three cities in the past 27 years since the Revolution. That means there are no major investments or changes in the heat supply or heat distribution, apart from the cases when these are mentioned specifically, and the investments made are usually just emergency ones, to keep the system functioning. The number of customers either stays at the same level or slightly decreases, depending on the context in each city.

The scenario starts with an assessment of the current heat demand, the heat production units, transmission and distribution pipes and infrastructure for the customers, to further continue with a qualitative assessment of the existing CO_2 emissions. The costs (technology costs and operation and management costs) are analysed mainly from a qualitative perspective, due to the lack of data.

The prices of heat paid by the customers in this Scenario are all subsidized by the state.

Scenario II

This scenario considers the development of individual (one heating unit/dwelling) and collective (for one or several blocks of flats or houses) heating solutions, to assess which would be the impacts of such a strategy, from a technical, economic and environmental perspective.

Section A of Scenario II starts with the outline of the types of heat supply. In this scenario the majority of the customers mainly use natural gas and electricity but also biomass, as each of the cities has important biomass resources, in the form of straws and woodchips.

The technologies to be used for the heat supply are: individual gas boilers, electric heating, collective gas and biomass boilers, existing substation boilers (in the case of Timisoara) and individual heat pumps.

The individual gas boilers considered in this study are the condensing ones, with an efficiency of 100%. This are the only type of boilers which can be commercialized now in Romania, as in the rest of the EU, since September 2015. The electric heating also has a 100% efficiency, and can include electric boilers or electric radiators. The collective gas boilers are expected to supply heat for a block or several blocks of flats, and are a common type of technology used in many urban dwellings in Romania, and in this study are expected to have a 100% efficiency. In the cases where some of the older heat production systems continue to be used, the efficiency of the gas boilers (after a certain level of retrofit) is 85%, whilst for the collective biomass boilers, which have the same destination as collective gas boilers the estimated efficiency is 90%. The heat pumps have a COP of 3.

There are different alternatives of distributing the different types of individual heating solutions, but in this study the following distribution was chosen: 50% individual gas boilers, 30% gas boilers and the rest of 20% is represented by the other heating solutions. The reason for such a high share of individual gas boilers is because these still represent the cheapest solution, from both an investment and O&M cost, to provide the necessary thermal comfort which lacks the existing district heating systems today. Natural gas still has an accessible price. Apart from this, there is a degree of scepticism for using other solutions than gas.

Electric boilers come second, as the technology is becoming more known and presents several advantages compared to gas boilers, as these do not require evacuation chimneys and special gas connection. Nevertheless, depending on the size of the flat, this equipment might require a three phase connection to electricity. Such a type of infrastructure also creates high peak loads, which can only be supplied by energy intensive power plants, therefore it is considered that 30% of the dwellings use it.

The other solutions represent either expensive or less known solutions, such as the heat pumps, or solutions using renewable energy sources, as the biomass boilers. These are intended to diversify the energy supply in the scenario, but only provide 20% of the total heat demand.

Section B estimates the CO_2 emissions using the estimations from: (Biomassenergycentre.com, 2011; EC Europa, 2011; SunEarthTools.com, 2016).

Section C analyses the costs of investment and O&M. These are further detailed in their respective appendix. The scenario also includes the costs of extending and reinforcing the gas and electricity networks. The costs used to calculate this scenario are based on the range of costs provided by the Danish Energy Agency (2014), and other sources, mentioned in the analysis.

Scenario III

This scenario proposes that the district heating expands to cover the entire heat demand. The current transmission and distribution pipes are to be refurbished, and even though the number of customer connections increases, the heat losses in the district heating system decrease due to the retrofit of the pipes.

Section A of the scenario provides an overview of the technical solutions proposed. There are several alternatives for developing a new production system. The idea behind the solution proposed is to reduce as much as possible the use of fossil fuels, utilise more renewable energy, reduce the amount of CO_2 emissions and reduce the amount of landfilled waste, as currently, all the cities in Romania have the problem with the management of waste. The distribution of these alternatives is also done in the idea of having the lowest investment cost.

The heat supply is sized including the losses in the networks, which are estimated to 18%, which is the approximate average of the district heating systems in Denmark. The following types of technologies are considered for the heat supply, depending on the case study:

- Waste-to-energy (WTE)
- Large scale heat pumps
- Geothermal plants
- Small and medium sized gas and biomass CHP
- Waste heat
- Peak load boilers

In the next part, of heat transport, the transmission and distribution systems are analysed in terms of technologies used, amount of heat losses in the pipes, and total length of the network. This also includes an estimation of the number of customer substations.

Section B estimates the CO_2 emissions using the estimations from:(Biomassenergycentre.com, 2011; Danish Energy Agency, 2014; EC Europa, 2011; SunEarthTools.com, 2016)

Section C of the scenario analyses the investment and O&M costs of the district heating system. The costs for technologies are extracted from the same source as in Scenario II, the Danish Energy Agency (2014), but also from a range of costs provided by Ene M. (email correspondence 19.04.2016):

Biomass CHP

- €3000/kW – price for greenfield development with all the connections to utilities (water, sewage, DH connection) available
- €5000/kW – price for brownfield development with no connections to utilities and which also requires on-site preparations

Gas CHP

- €800/kW - price for greenfield development with all the connections to utilities (water, sewage, DH connection) available

- €1200/kW - price for brownfield development with no connections to utilities and which also requires on-site preparations

Heat savings

The case study continues with a sensitivity analysis where heat savings are applied to both Scenario II and III. The total heat demand is reduced to a conservative level of 100 kWh/m²/year/dwelling for all the three cities, which is the maximum level recommended for existing buildings, after the retrofit, according to EPBD (Directive, 2010) and EED (Directive, 2012). The heat savings in buildings are achieved through the following means:

- Thermal insulation of exterior walls
- Replacement of doors and windows
- Thermal and hydraulic insulation of the roof
- Thermal insulation of the ground floor

With the reduction of the heat demand to maximum 100 kWh/m²/year the average heat demand for the dwellings in the three cities is estimated to 4.4 MWh/year.

Section A defines the new heat demand which allows for the redesign of the heat production and transport system. The outline for the production system is created for both Scenario II and III.

Section B defines the CO_2 emissions for both Scenario II and III.

Section C is related to the costs of heat savings. The thermal insulation of buildings and thus of the flats in Romania is done based on the surface of each flat, and not of its outside walls, as the exterior of the block is considered as being common space of all the inhabitants. The same applies for the ground floor and the roof, so the inhabitants at these levels do not have extra costs when it comes to paying for the thermal insulation. However, the windows are counted for each apartment. The costs for these elements have been provided on a country level in Stratego (Connolly et al., 2015), and have two levels. The first one represents the minimal type of insulation to be done, whilst the second cost if for the high efficiency retrofit, with minimal heat losses.

It is necessary to clarify that the costs of heat savings used in this study are only marginal ones, meaning that they are additional to the other maintenance or repairs works which should be done anyway. The costs of heat savings for each of the three cities are separated in standard costs, with the minimum level of insulation recommended, and high efficiency costs, which are intended to reduce even more the heat demand. Nevertheless, the costs considered in the calculation of the entire system are represented by the standard ones, as these should lower the heat demand to the expected level.

	Standard cost (€/m²)	**High efficiency cost (€/m²)**
Walls	17,5	39,1
Roof	15,1	38,1
Floor	18,2	40,2
Windows	187,5	222

Table 1 - Cost of heat savings (Connolly et al., 2015)

With the heat savings applied to Scenario II and III, the heat supply infrastructure is reduced to respond to the new heat demand. The same applies for the heat transport network, which can be reduced due to the lower heat demand. The costs for the two are calculated in their respective appendix.

As a side calculation, besides the costs of the conventional district heating system, a separate calculation is made for the new generation of district heating, which is using low supply and return temperatures. This is the 4th generation of district heating (4GDH), and is a coherent technological and institutional concept based on the concept of smart thermal grids. The smart thermal grid is usually regarded as being parallel to the smart electricity grids, as both focus on the coordination and integration with RES, as well a system which will include a certain degree of interaction with customers (Lund et al., 2014). Specifically, with the new generation of district heating, the losses in the transmission and distribution pipes decrease to an average of 14-16%, as the temperatures in the district heating network can be lowered to 50-55°C for the supply and 30-35°C for the return, also enabling a reduction of the demand in the buildings and in the costs of distribution. This allows for a more varied array of heat sources, compared to the current high exergy sources in use today.

Heat affordability

An important aspect, which always was considered as an issue in the post-communist Romania is the degree of supportability of the energy bill by the population. In the last years, the average income of the population has risen, but the prices of energy as well. Therefore, if the subsidies today would be eliminated, an important part of the population would have issues in paying the heating bills. This is an important parameter in this study, as the heating sector in Romania has always been affected by fuel poverty, and at the level of the year 2009, up to 11% of the annual income in a dwelling was spent on the heating bills (COGEN Romania, 2009).

Thus, based on the estimated price of heat in each scenario and the average income/dwelling/year, it can be assessed what is the percentage of costs for heating in all the scenarios, for each city.

Fossil fuel dependency

The next parameter assessed is the fossil fuel dependency, which analyses what is the difference in the amount of fuel used in Scenario II and III, with and without heat savings.

The importance of this parameter is related to the fact that Romania's conventional gas resources are expected to deplete at today consumption rates in 10 years. Any increase in the consumption of gas will determine a faster depletion of the resources and a rise in the amount of gas imported.

More than 50% of the electricity in Romania is also produced using fossil fuels, so even if the electricity mix will change in the future, having more electricity in the heat supply, for both scenarios, will put more stress on the existing infrastructure.

Results

Each case study ends with a short summary of the key results of the parameters analysed. First, the overall heat demand is discussed, for all the scenarios, with and without heat savings. Then

Scenario II and III are compared from the perspective of the technical solutions, the CO_2 emissions and costs for both the retrofit of the buildings and of the heating solutions proposed. The findings from the heat affordability and fuel dependency are used to confirm the results obtained and to create the conclusion and recommendation for each city.

Scenario I BAU	- Heat demand - Heat supply - Heat transport - CO_2 emissions - Costs
Scenario II Individual heating	- Heat demand - Heat supply - CO_2 emissions - Costs
Scenario III District heating	- Heat demand - Heat sources - Heat transport - CO_2 emissions - Costs
Heat savings Scenario II and III	- Heat demand - Heat supply - Heat transport - CO_2 emissions - Costs
Heat affordability	
Fossil fuel dependency	
Results	

4.1 Bucharest

The capital of Romania is located in the south of the country. It has a population of over 2 mil. inhabitants and overall expenses which reach up to €2 bil. each year, and one of the largest district heating systems in the world (Leca, 2012), as 41% of the total heat generated and sold in the country is in Bucharest. In terms of percentage of flats connected to district heating in Romania, 42% of them are located only in Bucharest (Government of Romania, 2015). The system covers the entire surface of the capital, with 987 km of transport pipes, 2964 km of distribution pipes and 1012 substations (RADET, 2016). Only 10% of the entire piping network has been refurbished, and the losses in the grid are estimated at 24% (Leca, 2012).

In 2015, approximately 565.000 consumers were connected to the district heating company out of the total of 804.300 dwellings. This accounts for approximately 70% of connections to the network out of the total possible ones, and the percentage remained unchanged over the last years. Today, approximately 1,25 mil. inhabitants are receiving heat from the centralised system (RADET, 2016).

According to the data in Stratego, the total heat demand for the reference year 2010 was 7735 GWh/year (Stratego, 2015). This includes however, several low density suburbs, which are currently not supplied by the district heating system.

The owner of the district heating network is RADET, a municipality owned company, which buys heat from ELCEN, owned by the Romanian government, and which has in administration 4 TEPP. The rest of the heat supply comes from other smaller producers, and together, in 2014, they generated over 6.345 GWh/year for the district heating system, out of which, only 4.920 GWh/year were invoiced (Government of Romania, 2015).

As for the thermal retrofit of the apartment blocks in Bucharest, only 35% of them have been insulated of the total of 8.300, leaving another approximately 5.300 blocks to be completed (Ivanov, 2015).

4.1.1 Scenario I - BAU

A. Technical assessment

<u>Heat demand</u>

The overall heat demand of the city is 7200 GWh/year, and it is projected that the existing customers will continue to gradually disconnect from the district heating network. Approximately 1000 customers disconnected each year until now, but the rate is expected to increase in the future, from 1% to 2 %, due to various reasons, such as the reduction of the subsidy offered by the state for district heating, lack of heat on demand, or the numerous interruptions in the heat supply. This can also be influenced be an increase in the living conditions, with people affording to install individual heating solutions. This projection is based on the data from Government of Romania (2015).

	2009	**2014**	**2019**	**2024**	**2029**	**2034**
Customers connected to district heating	569.768	564.440	553.152	542.089	531.248	520.624

Table 2 – Scenario I – Bucharest - Projected customer connections

The remaining customers either cannot afford to install other sources of individual heating, or they had their apartments already retrofitted and are satisfied with heating from RADET. However, the customers which disconnect from the network usually have a higher income and choose to switch to other sources of heating to increase the thermal comfort. If the level of maintenance for the district heating stays the same, the numerous break downs and lack of heat on demand will make more customers to disconnect.

Heat supply

In terms of heat supply, ELCEN continues to function with all 4 TEPP. The upgrades of the existing boilers and generators only follow the minimal legislation in place to continue operating, and they are replaced by case, where it is necessary. The following total installed capacity of the plants is:

Plant	Thermal output MW
Grozavesti	678
Bucharest South	1390
Bucharest West	1569
Progresu	871
Total	**4508**

Table 3 – Scenario I - Heat supply Bucharest

Heat transport

The main problems of the current piping system are its size, lack of maintenance, corrosion and high operation costs. The losses in the district heating network are 24% (Leca, 2012), for a system which was designed to deliver 12.500 GWh/year, a capacity which is double the size of today's needs. The pipes were built with the idea of being served by the centralized plants, which implies that heat always has to be transferred on long distances in non-retrofitted pipes.

The length of the transmission system is almost 1000 km, and only 10% of the pipes have been replaced so far causing losses of 1500 GWh/year (Government of Romania, 2015; Leca, 2012). Compared to other similar sized cities, such as Copenhagen's district heating systems, where the losses are estimated to be 15% (Harrestrup & Svendsen, 2014), these are not considered as alarming.

However, the main issue is with the 4-pipe distribution system, where the DHW and heat are supplied separately, in parallel pipes. These pipes are connected to more than 1000 substations spread across the city, connecting to the buildings via 1480 km of pipes for heating and the same for DHW, which actually defines the very large size of the network. Even though some of these pipes are already retrofitted, these still do not allow an efficient delivery of heat and DHW, because of the oversized system (Municipality of Bucharest, 2010).

The majority of pipes already replaced are outside the buildings, leaving the ones inside the buildings in a state of corrosion, which does not solve the issue of system losses, consequently implying the creation of make-up water from the substations (Municipality of Bucharest, 2010).

Currently, the strategies of the municipality for modernising the heat sources, pipes and increasing the thermal efficiency of the dwellings are rather conservative, and are usually characterized by emergency repairs only (Municipality of Bucharest, 2010).

Since many of the customers will choose to leave the district heating, the ones which will stay might be subject to higher bills and more thermal discomfort, as the hot water will have to travel more distances to reach the dispersed customers.

B. CO_2 emissions

According to a feasibility study made for Bucharest several years ago, the current CO_2 emissions have been estimated to 1.500.000 tCO_2/year, as an effect of burning fossil fuels in TEPP. Out of these, approximately 500.000 t/year are caused by the losses in the transmission and distribution networks (Municipality of Bucharest, 2010).

The reductions in CO_2 are expected to increase, as many of the disconnected flats will mainly switch the solutions based on natural gas.

C. Costs

The current thermal strategies for Bucharest found on the websites of ELCEN and RADET do not include any actual figures, but mention several measures for optimising the situation. Among these measures can be mentioned:

ELCEN:

- Retrofit the existing heat production facilities to reduce fuel consumption and emissions
- Increase in electricity production through cogeneration
- Increase the level of maintenance
- Decommission of the old, inefficient heat production units

RADET:

- Re-dimensioning and retrofit of the transmission and distribution system
- Modernise, retrofit and optimise the substations
- Encouraging customers to reconnect to the network
- Improve the control system of the network (i.e. automation)

Therefore, as no exact investments are planned for the future, it is relevant to find out how the operation and management costs were done in the last decade:

Year	Planned investment (mil. €)	% of completion	Subsidized heat price (€/MWh)
2015	2,18	18	44
2014	1,9	16	44
2013	3,6	30	44
2012	3,9	21	44
2011	2,88	38	44
2010	2	18	32
2009	2,56	20	30
2008	2.6	38	30
2007	0.57	100	27
2006	2.8	93	54
2005	1.45	100	47

Table 4 – Scenario I – Bucharest – O&M costs

According to the table above, the amount planned for investments was rarely used entirely. The average completion of the investments was 44%.

It can also be observed that in the years before 2007, the price of heat was fluctuant, being subsidized on the amount of generated heat rather than on the final user consumption. The subsidized price kept its ascending trend until 2011, being more stable since. However, it cannot be expected that subsidies will always pay for the heat.

4.1.2 Scenario II - Individual heating

A. Technical assessment

<u>Heat demand</u>

The heat demand used in this scenario is 7.200 GWh/year, whist the heat demand of a dwelling is 8.9 MWh/year, thus 200 kWh/m^2/year.

<u>Heat supply</u>

The efficiency of the heating solutions in Table 4 is 100%, except for the biomass boilers which have an efficiency of 90%. The available amount of biomass is 770 GWh/year (Stratego, 2015), so more biomass could be used, as the potential is available.

The distribution of the heating solutions is:

<table>
<tr><th>Type of heating</th><th>Heat demand/dwelling (MWh/year)</th><th>Primary consumption/dwelling (MWh/year)</th><th>Number of dwellings</th><th>Primary energy consumption (GWh/year)</th></tr>
<tr><td>Individual gas boiler</td><td rowspan="5">8.9</td><td>8,9</td><td>400.000</td><td>3.560</td></tr>
<tr><td>Electric heating</td><td>8,9</td><td>240.000</td><td>2.139</td></tr>
<tr><td>Heat pump</td><td>2,9</td><td>40.000</td><td>116</td></tr>
<tr><td>Collective gas boilers</td><td>8,9</td><td>80.000</td><td>712</td></tr>
<tr><td>Collective biomass boilers</td><td>9,9</td><td>40.000</td><td>396</td></tr>
<tr><td>Total</td><td colspan="3"></td><td>6.923</td></tr>
</table>

Table 5 - Scenario II – Bucharest - Production outline

The reason for a reduced energy consumption compared to the total heat demand is related to the use of heat pumps in 40.000 apartments. However, this solution would be highly theoretical, as heat pumps have a reduced penetration on the Romanian market. This is related to their high prices and lack of awareness of the population of such technologies even though the Romanian state subsidizes the installation of such equipment.

B. CO_2 emissions

	Unit	**tCO_2/year/dwelling**	**Total tCO_2/year**
Gas boiler	1 kWh gas=380g CO_2	3,38	1.352.000
Electric boiler	1 kWh=408g CO_2	3,63	871.200
Heat pumps	1 kWh=408g CO_2	1,18	47.200
Collective gas boiler	1 kWh gas=380g CO_2	3,38	270.400
Collective biomass boiler	1 kWh=18g CO_2	0,17	6.800
Total			**2.547.600**

Table 6 - Scenario II – Bucharest – CO_2 emissions

It can thus be seen that the CO_2 emissions caused by the extensive use of gas are almost as high as the total emissions of today caused by burning natural gas in the 4 TEPP, even though these would be the emissions from only 480.000 flats.

C. Costs

Opposite to the connection to district heating, where the costs are split between the utility company and the owners, the costs of installing individual heating solutions is mainly the responsibility of the owners of dwellings. They would also have to pay for the separate gas connection for heating (in case the building does not already have one) or for higher voltage electric connection, as the boilers using electricity need a different connection. There will be costs from the utility companies too, as they will need to increase the capacities of their gas and electric networks to supply the demand.

It this scenario, it is considered that even the customers which are currently using individual heating solutions will need to change at some point their equipment.

Since 400.000 apartments are considered to have individual boilers, the investment cost just for this technology is €1 bil. With the other heating solutions presented in the table below, the total investment cost is over €2 bil., with an annual investment of €121 bil. With the fuels included, the price reaches €650 bil. The detailed costs for this scenario ca be found in Appendix 1 – Scenario II - Bucharest.

Total costs	
Total investment all heating solutions (M€)	2029
Total annual investment all heating solutions (M€)	121,1
Total annual costs (M€/year)	215,2
Total fuel costs (M€/year)	435,0
Total annual costs with fuels (M€/year)	650,2

Table 7 - Scenario II - Bucharest - Total costs individual heating

4.1.3 Scenario III - District heating

A. Technical assessment

Heat demand

In this scenario, the district heating system is extended. Since this scenario focuses on the development of district heating, it is expected that the rest of the customers currently using individual heating based mainly on gas to be conditioned to join the future network or, if not possible, to use renewable energy sources. The amount of heat losses decreases, even with the expansion of the network, due to finalising the retrofit of the rest of the network. The total heat demand stays at 7200 GWh/year.

Heat supply

In this scenario, the proposed solution is represented by three WTE plants, which are expected to function most of year and are sized on the summer load along with the large scale heat pumps. The rest of the load is taken by the CHP plants, the waste heat, whilst the peak-loads are covered by the gas boilers, which supply the rest of the heat demand especially in winter time.

The outline for the production system is presented in Table 7. The reduction of the heat losses is included in the calculation at a value of 18% from the existing 24%, therefore the reduction of the heat losses is realistic, even though this might be lower in case of well-built district heating system.

For the sizing on the equipment an estimated heat load is used, based on the existing heat load in Bucharest (Government of Romania, 2015) of 235 MW. For the new production outline the summer load has been considered as increasing, to ensure that it can supply the DHW during the summer. This helped to develop the following production outline:

	Power (MW)	**Hours/year**	**Capacity (GWh/year)**	
Waste-to-energy	3x75	8000	1800	21%
Large heat pumps	2x50	8000	800	10%
Gas CHP	400	5000	2000	22%
Waste heat	580	5000	2900	34%
Gas peak boilers	660	1500	1000	13%
Total (including heat losses 18%)			**8500**	

Table 8 - Scenario III – Bucharest – Production outline

The outline of the production presented Table 8 is further explained:

Waste-to-energy (WTE)

There is no real experience in Romania with using WTE facilities, therefore the data for this type of energy conversion has been extracted based on the experiences from other countries and from a previous feasibility study made for Bucharest several years ago (Municipality of Bucharest, 2010). In the current situation of Bucharest, the WTE solution seems as the best possible, as the capital has a problem with the management of waste too, so developing such facilities would help the city reduce the impact of waste on the environment and make effective use of the energy stored in waste, as the WTE plants will be located in the city.

In general, the quantity of MSW is expected to increase over the time, due to the rise in the quality of life in Romania (Zhang, 2012). The quantities to be incinerated are expected to reach 1.5 mil. tonnes in the next years (Municipality of Bucharest, 2010).

Up to three such plants can be built in Bucharest. Two of them in the location of the existing TEPP, which are in Grozavesti and Progresu, providing the benefit of having the already built infrastructure for the new plant, with access to the necessary utilities. A third one can be built in the northern side of the city. Transport logistics will also need to be taken into consideration, as the lorries will need to have easy access to them.

The sizing of the new facilities has to be made based on the amount of MSW in the city and not by the heat demand. Therefore, it is assumed that the quantity of waste to be incinerated will have the values in the table below, but the total quantities of waste are actually expected to be higher in Bucharest. The incineration value of 60% is theoretical, as in Bucharest the waste is still not properly sorted, and the mixed waste ends up to be landfilled.

Total quantity (t/y)	2.500.000
Incineration (%)	60
Quantity (t/y)	1.500.000

Each of the three plants are able to burn up to 500.000 t/y. The heat recovery potential from waste in a WTE plant is expected to be 9.5 GJ/t (Warchter, Ionel, & Samuila, 2013), with an energy efficiency of 80%. The value is divided as:

- 50% heat
- 30% electricity
- 20% waste heat

In this situation, the three WTE plants are expected to produce 1800 GWh/year.

Large scale heat pumps

In this scenario, large scale heat pumps would be able to supply up to 10% of the total heat demand of Bucharest, and can be separated in two or more units, depending on the available heat sources. The following heat sources could be used:

- Sewage water: up to 380 GWh are available at the level of municipality of Bucharest. According to the heat pump manufacturer Ochsner (2012), approximately 5% of the heat demand of a city can be extracted from sewage water.

- River water: the river Dambovita and several lakes could prove as heat sources for the heat pump. The high availability of surface water is mentioned too in the Pan European Thermal Atlas (Stratego, 2015).

- Geo-thermal: Bucharest has an important geothermal potential. A geothermal basin is available underneath the capital, with temperatures of approximately 40°C, at a depth of 800-1000m, which could be used by the heat pumps as a heat source.

Gas CHP

Since the capital city has wide surface which has to be covered by district heating, one idea would be to decentralize the production with small scale CHP units spread in the city, in the areas with more heat density, to help the centralised system deliver the necessary heat and lower the heat losses in the transmission pipes. The availability of biomass, on a radius of 30 km around the city, is 770 GWh/year (Connolly et al., 2015), therefore some of the CHP engines can function on this type of fuel to reduce the dependency on natural gas.

The CHP stations should be built on the level of substations where possible, in order to take advantage of the already available infrastructure, but also to be able to take the load of the network before the WTE facility is built. This will allow the transmission networks to be redesigned and replaced in this time. The total power of these decentralized units is suggested to be of 400 MW, and the power for each unit can be between 10-20 MW, depending on the local heat density and distance from the transmission network.

Another option for the CHP is to work in connection with geo-thermal sources and heat pumps. Such projects could be built in key areas of Bucharest, more likely in the northern outskirts of Bucharest, where a geothermal reservoir is available, which extends below the capital. The temperature of the water has 40°C, at a depth of 800-1000m, which can be extracted and put into use by “Geo-thermal district heating modules”, which are based of geo-thermal heat pumps and a small to medium sized CHP engine to provide the electricity for the heat pump. These modules can be installed in key locations in Bucharest, specifically in the previous thermal points of the old network. There, these can be connected to the distribution network. According to Polizu and Haganu-Cucu (2015), the total capacity of such a system could reach 800 MWth and supply up to 3000 GWh/year (Polizu & Haganu-Cucu, 2015). Nevertheless, these values are theoretical, as these geothermal wells have not been fully tested yet.

Waste heat

According to the Pas European Heat Atlas (Stratego, 2015), there is currently a high amount of waste heat available in Bucharest coming from the existing TEPP producing electricity. The theoretical value is 4100 GWh/year, which represents more than two thirds of the total heat demand in Bucharest.

The use of waste heat requires the lowest investment cost, as essentially the heat only needs to be captured. This investment does not require any expenses with the fuels and has low O&M costs. Therefore, in this production outline, waste heat is expected to supply 2900 GWh/year.

Peak load boilers

The peak load boilers will supply heat in the coldest days, to supplement the existing CHP and the waste heat. These are oversized to be able to cover the low temperatures in the winter, which can sometimes reach -20°C. These can be built locally, with the CHP plants, in which case they can be downsized, as this way the losses in the transmission networks will not have to be accounted for. However, in order to reduce some of the capacity of these boilers, thermal storage units can be added alongside within the plants.

Heat transport

Since the current transmission system is designed to deliver double of the heat necessities in the city, this will have to be downsized for the future heat demand and redesigned to accommodate the new heat sources to be built.

One solution would be to rebuild the transmission network as a ring, which will connect the three WTE and the CHP plants. Such a system will provide the opportunity to reduce the number of branches in the transmission network. The branches should supply the most populated areas in the city, and in total, the length of the system can be considerably reduced (Municipality of Bucharest, 2010).

The advantage of such a system are represented by:

- Decrease of heat losses
- Less electricity used to pump the water
- Lower investment

The new network will allow the use of piping adapted to the new head demand, with diameters of up to 600 mm, unlike the actual network which uses piping of 1200 mm in diameter.

The delivery and return temperatures of such a future system should be kept on the lowest possible temperature in order to reduce the losses in the network and to increase the life time expectancy of the entire system. The losses in such a system are expected to be 18%, equivalent to 1300 GWh/year.

As part of the redesign, the distribution system has to be modelled on the decentralized production, by switching from the current 4-pipe system, a system based on centralised heat production, to the 2-pipe system, to reduce the heat losses. The centralized system cannot cope with the concept of heating and DHW on demand, as these take too much time until reaching the customer when needed.

The new system will have to enable the possibility of heat and DHW preparation via local heat exchangers. In this study, it is considered that no less than 8000 customer substations are built for the 8.300 blocks of flats, which will enable more accurate metering, an issue in many apartment blocks, and the availability of instant DHW which will be prepared locally.

The losses of the current system, in 2011, were almost 1650 GWh/year, the equivalent of 24% (Leca, 2015), in the new system these could have a level of 18%. Therefore, it can be observed that even though up to 30% more customers can be supplied with district heating, the heat losses in the system can decrease by approximately with 250 GWh/year. This translates into a less amount of fuel used for district heating, increasing the overall system efficiency.

	Present	Future
Flats supplied	564.440	800.000
Losses	24%	18%
Pipes (trans. + distrib.) km	987 + 2964	150 + 2000
Losses	1650 GWh/year	1300 GWh/year

Table 9 - Scenario III - Bucharest - Heat losses

B. CO_2 emissions

For the production system in this scenario, the CO_2 emissions are estimated in the table below. For the waste heat, the CO_2 emissions will be the ones for the existing infrastructure in place for producing electricity. Since these emissions are released in the atmosphere anyway, these are not considered in this scenario.

	Unit	Total tCO_2/year
WTE	1 GJ waste=37kg CO_2	527.250
Large scale heat pump	1 kWh=408g CO_2	108.528
Gas CHP	1 kWh gas=380g CO_2	1.520.000
Waste heat	no direct emissions	
Gas boilers	1 kWh gas=380g CO_2	464.360
Total		**2.620.138**

Table 10 - Scenario III - Bucharest – CO_2 emissions

Nevertheless, it can be observed that due to the use of waste heat, the total amount of CO_2 emissions for Scenario III are lower than for Scenario II, even though in Scenario III electricity is also produced.

C. Costs

The costs for reconstructing the district heating system in Bucharest have been estimated based on the data from the Danish Energy Agency (2012) and on the outline of the production system in this scenario.

Heat supply

The total investment cost in the production system is €866 mil. and the total annual cost of O&M of the production system and necessary fuel is €169 mil., as in the outline presented in the table below:

	WTE	LSHP	Gas CHP	Waste heat	Gas peak boilers
Investment cost (M€)	495	103,5	400	29	73
Annual investment (M€)	29,5	6,2	19,9	1	2,8
Fuel costs (M€)	0	33,2	120	0	36,7
Price of heat (€/GWh)	300	32.502	57.445	505	38.334

Table 11 - Scenario III - Bucharest - Costs of heat supply

The reduced price of heat from the WTE plant is adjusted this way as this facility is intended to be a non-profit one. The price of heat can either be adjusted through the gate fees of the MSW, or through the prices of the electricity it sells. In this scenario, the price of €55/t of MSW was chosen to obtain the minimal cost of heat above 0. Nevertheless, the price of MSW can fluctuate from €50 to €60/tonne, and this would be similar with the ones currently used in Denmark, which has the lowest fees in Europe for MSW (Kirkeby, Grohnheit, Møller Andersen, & Herrmann, Ivan Tengbjerg Karlsson, Bernard, 2014). The price estimated for electricity is €24/MW, but as mentioned before, it can also be adjusted.

The large scale heat pumps have high investment and O&M costs. Nevertheless, even though it is an efficient technology, it is still affected by the high price of electricity compared to the gas one.

The gas CHP plants have the highest investment cost as these also provide 30% of the city's heating needs. The costs in Table 11 are only for the gas CHP, but if some of the capacities would be shared with other biomass CHP, the price of heat would be higher.

The waste heat has the lowest investment costs as there are no additional fuels needed to produce it. It is considered that the price of investment cost for this type of heat supply is half the price of the cheapest technology. The waste heat mainly comes from the remaining infrastructure of the TEPP which will continue to produce electricity. In this scenario, more than 50% of the theoretical available amount of waste heat was included, but this should account for a higher share if other industries, besides the TEPP, which eliminate waste heat can be connected to the district heating network.

The gas peak load boilers have low investment costs compared to their capacities, but a high price for heat, thus they will be used only during the winter to supply the peak loads.

Heat transport and customer substations

The investment cost in the pipes considers the entire city network, including the areas which have the pipes replaced. The actual investment price in the pipes is estimated to €518 mil., but due the long technical lifetime of the pipes, the annualised investment costs are only €18 mil. With the O&M costs included, the price is €24,6.

The costs include the customer infrastructure too. The substations have been estimated to be built for each building apart, but in some cases, one substation can supply multiple buildings. Since the building stock in Bucharest is formed mainly by blocks of flats, the number of substations is estimated at 8000 units, indicating a total investment cost of €140 and an annual cost, with O&M costs included, of €9,6 mil.

Total costs

The detailed costs of the district heating network can be found in Appendix 2 – Scenario III – Bucharest, whilst the total cost is available in the table below:

Total costs	
Total investment (M€)	1.708,1
Total annual investment (M€)	83,1
Total fixed O&M ((M€/year)	90,4
Total annual variable O&M (M€)	5,0
Total fuel costs (M€/year)	178,7
Total annual costs-including fuel (M€)	218,8

Table 12 - Scenario III - Bucharest - Total costs

4.1.4 Scenario II and II with heat savings

This sensitivity analysis applies heat savings to scenarios II and III in Bucharest. These heat savings will have as an effect the reduction of the heat density and thus, of the heat demand. Currently, the average heat demand in Bucharest is 200 kWh/m²/year. These buildings will need to lower their heating demand to less than 100 kWh/m²/year, in order to comply with the existing European legislation. The district heating network is remodelled based on the new heat demand with the conventional 2-pipe system as in Scenario III, but as a side calculation, the new heat demand will also be supplied through a 4GDH system, to compare the costs.

A. Technical assessment

<u>Heat demand</u>

The majority of the building stock in Bucharest was built in the 80's, when there were no requirements for ensuring a certain level of thermal insulation, thus the existence of the oversized and centralized district heating system, created to generate great amounts of heat using fossil fuel sources. From the total of 8.300 apartment blocks in Bucharest, over 3.000 have already been retrofitted, while the 5.300 are due to be done (Ivanov, 2015).

In this analysis it is considered that all the building stock will all be retrofitted, and by estimating that some of the buildings have lower heat demands, the total heat demand is calculated to reduce to 3500 GWH/year.

<u>Heat supply – Scenario II</u>

The production outline is:

<table>
<tr><th>Type of heating</th><th>Heat demand/dwelling (MWh/year)</th><th>Fuel consumption (MWh/year)</th><th>Number of dwellings</th><th>Primary energy consumption (GWh/year)</th></tr>
<tr><td>Individual gas boiler</td><td rowspan="5">4,4</td><td>4,4</td><td>400.000</td><td>1760</td></tr>
<tr><td>Electric heating</td><td>4,4</td><td>240.000</td><td>1056</td></tr>
<tr><td>Heat pump</td><td>1,46</td><td>40.000</td><td>58,4</td></tr>
<tr><td>Collective gas boilers</td><td>4,4</td><td>80.000</td><td>352</td></tr>
<tr><td>Collective biomass boilers</td><td>4,88</td><td>40.000</td><td>195,2</td></tr>
<tr><td>Total</td><td colspan="3"></td><td>3.421,6</td></tr>
</table>

Table 13 - Scenario II with heat savings - Bucharest - Production outline

The total savings is terms of will be 3500 GWh/year of primary energy savings. Thus, the heat savings and individual and collective heating allow for important savings in terms of fuel. However, the individual heating solutions will still have to be installed in each of the dwellings, therefore the technology costs will stay, even though the amount and costs for fuels will decrease.

Heat supply – Scenario III

In this scenario, with heat savings, the reduction of the heat demand to 3500 GWh/year will allow the redesign of the production system. Thus, the savings for the heat produced would be reduced from 6350 Gwh/year (value 2014), to approximately 4150 GWh/year (heat losses included), even though the district heating covers the entire city.

	Power (MWth)	Hours/year	Capacity (GWh/year)	
Waste-to-energy	2x50	8000	800	19%
Large scale heat pumps	50	8000	400	9,5%
Gas CHP	200	5000	1000	24%
Waste heat	270	5000	1350	32%
Gas peak boilers	400	1500	600	14,5%
Total (including heat losses 18%)			**4150**	

Table 14 - Scenario III with heat savings - Bucharest - Production outline

The primary energy consumption in this scenario decreases by 2.689 GWh/year compared to Scenario II with no heat savings.

It can be seen that by implementing more heat savings, the overall size of the production system can be reduced. In such a scenario, there is no need for three WTE plants and two large scale heat pumps. The amount of MSW to be incinerated can decrease too, as there will not be the need for such high quantities. Since the WTE facility is recommended to have 15-20% of the total heat demand, the amount of waste to be incinerated in Bucharest with the heat savings is approximately 650.000 t/year. The expensive gas CHP units can be downsized too, as well as the peak load boilers.

B. CO_2 emissions

Scenario II

	Unit	tCO_2/year/dwelling	Total tCO_2/year
Gas boiler	1 kWh gas=380g CO_2	1,67	668.000
Electric boiler	1 kWh=408g CO_2	1,79	429.600
Heat pumps	1 kWh=408g CO_2	0,59	23.600
Collective gas boiler	1 kWh gas=380g CO_2	1,67	133.600
Collective biomass boiler	1 kWh=18g CO_2	0,08	3.200
Total			**1.258.000**

Table 15 - Scenario II with heat savings - Bucharest – CO_2 emissions

Scenario III

	Unit	Total tCO_2/year
WTE	1 GJ waste=37kg CO_2	228.475
Large scale heat pump	1 kWh=408g CO_2	163.200
Gas CHP	1 kWh gas=380g CO_2	760.000
Waste heat	no direct emissions	
Gas peak boilers	1 kWh gas=380g CO_2	228.000
Total		**1.379.675**

Table 16 - Scenario III with heat savings - Bucharest – CO_2 emissions

C. Costs

Heat savings

The size of the blocks in Bucharest is the largest in the country. The average size of such a block has been estimated though based on the building stock and the standard sizes of the 40 and 20 apartment blocks. For an apartment block with 90 flats the total estimated price for retrofitting it would be:

	Suface (m²)	Standard cost (€)	High efficiency cost (€)
Walls	5400	94.500	211.140
Roof	540	8.154	20.574
Floor	540	9.828	21.708
Windows	1700	318.750	377.400
Total		**431.232**	**630.822**

Table 17 - Cost of heat savings in Bucharest

The current level of insulation of the blocks of flats in Bucharest which have already been completed is considered to be the standard one. Since approximately 3.000 blocks have been retrofitted until today, the standard costs for the rest of 5.300 would reach €2,2 bil. However, in a high efficiency scenario, to reduce the heat demand to the lowest level possible in the capital city, for the entire building stock, the necessary costs are €5.2 bil.

Heat supply – Scenario II

When the heat savings are applied in Scenario II, the main reduction is with the cost of fuels. Thus, compared with Scenario II with no heat savings, the reduction with the cost of fuels is 50%. However, the overall total investment only slightly decreases to less than €2 bil, as the individual solutions will still have to be installed with similar capacities. The individual boilers, electric heating and heat pumps are sold in standard configurations, and there will be less savings in terms of capacity for the equipment used. However, the noticeable differences are with the collective gas and biomass boilers, whose capacities can be reduced.

The annual costs of this scenario are €215 mil., and with the fuels included this reach €407 mil. compared with €650 mil. in Scenario II. The calculations for this analysis can be found in Appendix 3 – Scenario II – Heat savings - Bucharest.

Total costs	
Total investment all heating solutions (M€)	1.755
Total annual investment all heating solutions (M€)	104,7
Total annual costs (M€/year)	192,8
Total fuel costs (M€/year)	215,0
Total annual costs with fuels (M€/year)	407,8

Table 18 - Scenario II - Heat savings - Bucharest - Total investment costs

Heat supply – Scenario III

With the heat savings applied to the entire building stock of Bucharest, the costs of the investing in a new production system will decrease too, as the capacities to invest in will be lower.

	WTE	LSHP	Gas CHP	Waste heat	Gas peak boilers
Investment cost (M€)	220	34,5	200	13,5	40
Annual investment (M€)	13,1	2,1	9,9	0,5	1,5
Fuel costs (M€)	0	11,1	60	0	20
Price of heat (€/GWh)	477,5	33.501	57.446	504,5	38.330

Table 19 - Scenario III with heat savings - Bucharest - Total costs

The investments in the production equipment have a cost of €508 mil., from the previous €1 bil. The costs of fuels are reduced by 50%.

Heat transport and customer substations

Due to the lower heat demands, the district heating pipes can also be resized. The costs are €252 mil. for the conventional 2-pipe network, with an additional €130 mil. for the substations. The same number of substations is considered in this scenario as in Scenario III.

Since all the buildings are considered to have the heat savings applied, the 4GDH can be considered as an option, but then the total investment in the heat transport infrastructure would reach €1,8 bil.

Total costs

Therefore, the investment costs in the production system, heat transport and customer installations in Bucharest is €890 mil., with an annualized cost of €44 mil. The calculations for this system can be found in Appendix 4.

Total	
Total investment (M€)	890,7
Total annual investment (M€)	43,8
Total fixed O&M ((M€/year)	40,6
Total annual variable O&M (M€)	2,5
Total fuel costs (M€/year)	91,0
Total annual costs-including fuel (M€)	115,8

Table 20 - Scenario II with heat savings - Bucharest - Total investment costs

4.1.5 Heat affordability

The situation in Bucharest is the most critical among the 3 cities, as the price of heat is 2.4 times higher than the price the population is paying. Therefore, the price paid for the subsidized heat is €44/MWh, whilst the real price today is €106/MWh. This mainly reflects the inefficiency of the district heating system, but even so, the price the population is currently paying for the heat is the lowest out of the three examples.

In terms of incomes per dwelling, Bucharest is the leader in the country, with an average income of €9.156/year. The table below estimates the prices of heat and what is their percentage of the current income/household in Bucharest (Scenario III includes the conventional district heating network. The heat savings are included in brackets):

	Income per dwelling (€/year)	Price of energy (€/MWh)	Energy consumption/ dwelling (MWh/year)	Price of heat (€/dwelling)	Percentage of current income
Scenario I	9.156	44	8.9	**391**	4,3%
Scenario II		91	8.9	**812**	8,9%
Scenario III		29	8.9	**261**	2,8%
Scenario II - Heat savings		115	4,4	**509 (+156)**	5,5%
Scenario III - Heat savings		27	4,4	**119 (+156)**	1,3%

Table 21 - Bucharest - Heat affordability

Thus, it can be observed that even with the investments in the heat supply, heat distribution and customer installations, with no heat savings, the price of heat will not be higher than it is today subsidized by the municipality.

The cost of heat savings was partly added in this calculation, as some of the retrofit has already been made, and these costs would have to be supported only by the home owners in the remaining 5.300 apartments. Nevertheless, the home owners would only have to pay 20% of this cost, benefit of the National Retrofit Program (Petrescu, 2010).

4.1.6 Fossil fuel dependency

The fossil fuel dependency is 100% in Scenario I. There is no other type of energy supply used by ELCEN besides natural gas, coal and heavy oil to supply the 565.000 apartments connected to the district heating system. The efficiency of the heat production facilities is unknown, but considering the old technologies in use, this is rather low. This does not account for the rest of the 240.000 flats which use individual solutions mainly reliant on fossil fuels, as many home owners in Romania prefer using gas to heat up their houses.

Even if the data about the amount of fuels used by the TEPP in Bucharest to produce heat is unknown, it is clear that the technologies used in Scenario II and III are more energy efficient and use less fossil fuels. Scenario III is based on the fundamental idea of district heating, of using local fuel and resources that otherwise would be wasted (Werner & Fredriksen, 2013), which is contrary to the way district heating is exploited today in Bucharest.

The table below makes a comparison between Scenarios II and III in terms of energy consumption. Electricity is included, as 50% of the electricity produced today comes from fossil fuel sources. Since the electricity can be produced in different ways and at different efficiencies, it is difficult to estimate what is the total primary energy supply in Bucharest for Scenario II, but the amount of fuel used is greatly reduced compared to Scenario I due to the more efficient technologies used.

(GWh/year)	Scenario II	Scenario II Heat savings	Reduction	Scenario III	Scenario III Heat savings	Reduction
Fossil fuels	4272	2112	50%	5222	2666	48%
Electricity	2255	1114	50%	266	133	50%

Table 22 - Bucharest - Fossil fuel dependency

With the heat savings, the amount of gas and electricity is significantly lower with the heat savings. However, the main difference is between Scenario II and III is that in the latter, besides heat, electricity is also produced, basically eliminating the electricity consumption in Scenario III. In Scenario II, all the individual or collective installations are heat only solutions.

4.1.7 Results and recommendations

The capital city of Romania is the largest city in Romania and has the highest heat demand out of all the cities of the country. This feature makes it very suitable for using district heating, as high heat densities also bring lower prices for the heat. The price of heat in Bucharest can be the lowest in the country, even if heat savings are applied or not. In this study, the price of heat is estimated at €261/year, even if no heat savings would be applied to the building stock, compared to €391/year paid today by the population, with the subsidy included. The condition is having an efficient heat supply and heat transport system, but none of these conditions are currently satisfied in the case of Bucharest.

The heat supply proposed for the district heating system makes more use of local resources and reduces the amount of fossil fuels needed, while also reducing the CO_2 emissions. In fact, the CO_2 emissions are in all cases equivalent between Scenarios II and III, with or without heat savings, but with the advantage of co-generation, electricity is produced, making the overall system more efficient.

By investing in a WTE facility the municipality gains on three important sectors of the city: heat, electricity and waste management, and even there is a financial effort to invest in such a facility, the future gains are numerous.

The investment in the waste heat infrastructure in Bucharest is one of the most low cost investments that can be done, and this type of heat source can cover an important part of the heat demand. Bucharest can make more use of renewable energy sources, such as biomass, or through using large scale heat pumps, which can use the sewage water or river water as heat sources.

The investment cost in the heat supply infrastructure is over €1 bil. in the case of Scenario III with no heat savings and half when heat savings are applied to the building stock. In both cases though, there is the advantage that some of the land to be constructed on is already available and infrastructure is already in place, with connections to national electrical grid, water, gas and other utilities, thus the investment cost should decrease.

As for the heat transport, the distribution system can change from the inefficient 4-pipe system to the standard 2-pipe one, so the heat can be produced locally. Even with the extension of the distribution system to all the dwellings, the losses in the pipes are should decrease by 250 GWh/year. Even though the size of the district heating system to be retrofitted is large, the share of costs for the pipes is only 10% of the total investment in the new district heating, due to the long lifetime of the pipes. This share of costs can even be reduced, as some of the pipes are already replaced, and some of the infrastructure is already in place.

In the case of the individual heating the total investment cost is over €2 bil., with over 50% of the total building stock dependent on natural gas. This is due to the cost/unit, which is difficult to be adjusted, as the individual equipment comes in standardized capacities, more difficult to be sized for the needs of real needs of each apartment. In this situation, the price of heat would eventually be higher than the price paid today, with €811/year for the scenario with no heat savings and €509/year with heat savings. Thus, this option proves as more expensive than district heating and also more polluting.

The heat savings are crucial to be done for Bucharest, as 65% of the existing building stock is not retrofitted, and this reflects in the highest heat demand per dwelling among all the three cities. The heat savings represent a high investment cost, higher than the investment in a new district heating network, and the total costs estimated for Bucharest would reach €5.2 bil., which would be almost 3 times higher than rebuilding the entire district heating network or more than two times in investing in individual only heating solutions. The standard, low investment option, also with marginal costs considers retrofitting the remaining 5.300 blocks in Bucharest and has an investment cost of approximately €2.2 bil. This measure is should reduce the heat demand to the required level.

Nevertheless, the heat savings bring the benefit of reducing in half the head demand, thus of the investment in high capacities for heat production and transport, as these reduce the energy consumptions and consequently the use of fossil fuels, create important reductions in the CO_2 emissions and also create now employment opportunities.

On an administrative level, the transfer of ownership of the district heating from the Romanian state to the municipality was only made for the piping network, by creating RADET, but not the heat production facilities, administered by ELCEN, which now created a situation of garnishment for RADET, not being able to pay its debts to ELCEN. However, plans to fusion the two are in development already in order to create an integrated management and use of resources to finally create the grounds to retrofit the old infrastructure.

4.2 Timisoara

The city of Timisoara is located in the west of the country, and it is the third in terms of size among the Romanian cities. It has 330.000 inhabitants, with over 50% of the population connected to the district heating system. The city has seen a high rate of disconnections form the grid, as in 2014 the number of connections to the district heating dropped by 26% compared to year 2009. This however covers more than 170.000 inhabitants (Government of Romania, 2015).

The total length of the network in the city has 340 km, out of which 73 km of transmission networks, and 210 km of distribution networks. The rate of refurbishment of the district heating network is rather low, and only 20% for the transmission and 40% for the distribution pipes were replaced (Municipality of Timisoara, 2014).

According to Stratego, the total heat demand for Timisoara is 1008 GWH/year, but this figure also includes areas outside the municipality. Thus, the estimated heat demand for the entire city is 1000 GWh/year. The average heat demand is 185 kWh/m²/year, and unlike Bucharest, out of the 122.000 dwellings, 87.000 are flats located in blocks of flats, whilst the rest is represented by 35.000 individual dwellings (houses).

The flats are located in 3.600 blocks, out of which only 300 were retrofitted by now, and 65.000 apartments are connected to district heating (Municipality of Timisoara, 2014). The local district heating network serves 170.000 people (Government of Romania, 2015).

The municipality of Timisoara is the owner of the district heating network, but unlike Bucharest, the public company Colterm also owns the heat supply infrastructure. The heating necessities in the city are provided by two TEPP plants: Timisoara Sud and Timisoara Centru, a CHP plant (Freidorf) and 11 small boilers adapted in the location of previous district heating substations. All the systems work with natural gas and coal. At the level of the year 2015, the generated heat was 980 GWh, but out of it, only 680 GWh was invoiced (Government of Romania, 2015). The heat losses in the system were, at the level of year 2011, of 20% (Municipality of Timisoara, 2014).

4.2.1 Scenario I - BAU

A. Technical assessment

<u>Heat demand</u>

In this scenario, the heat demand is 1000 GWh/year, and the customers are assumed to continue to disconnect from the network, but on a slower pace as until now, as the disconnection rate is expected to finally stabilize. The projection is based on the data from Government of Romania (2015):

	2009	2014	2019	2024	2029	2034
Customers connected to district heating	88.269	65.131	52.104	44.289	39.860	37.867

Table 23 - Scenario I - Timisoara - Projected connections to DH

The remaining customers either cannot afford to install other sources of individual heating, or they had their apartments already retrofitted and are satisfied with heating from Colterm. However, the disconnected customers usually have a higher income and choose to switch to other sources of heating to increase their comfort. The remaining customers will be the ones for which the district heating will still provide the necessary thermal comfort at an affordable price. For these customers the distribution pipes will be eventually retrofitted, along with some of heat production facilities.

Heat supply

In terms of the heat supply, Colterm continues to function with the 2 TEPP and with CHP Freidorf, which together have an installed capacity of 893 MW, and the decentralized boilers with an additional 48 MW. According to the company, the upgrades of the existing plants are represented by regular operation and maintenance works to improve their efficiency and reduce emissions, or replacement in case of necessity.

However, as the number of customers will decrease in this scenario, some of these facilities will need to be decommissioned. The municipality is also in advanced planning procedures for several years to build a WTE facility that will replace one of the TEPP, but the plans are yet to take shape. The WTE would have to be sized based on a decreasing heat demand, having multiple customers which keep on disconnecting, and this might create some problems in terms of sizing it.

Heat transport

The total length of the pipes in the city has 340 km, out of which 73 km are transmission networks, and 210 km distribution networks. The rate of refurbishment of the district heating network is rather low, and only 20% for the transmission and 40% for the distribution pipes were replaced (Municipality of Timisoara, 2014).

The main problems of the existing district heating system are the lack of refurbishment, but also the technologies used, with separate pipes for heating and DHW as in the case of Bucharest. Most of these pipes have between 10 and 30 years. The pipes were designed with the idea of using two main centralized plants, which implied that heat had to be transferred on long distances.

Their refurbishment can only be done to a certain level in some of the cases, as not all of them can be replaced with pre-insulated piping, many of the pipes being still above the ground. The current heat losses in the system are estimated to be 25%, indicating that for the whole district heating network these get to approximately 245 GWh/year (Government of Romania, 2015).

The main issue with the distribution networks is, as in Bucharest, the 4-pipe system, where the DHW and heat are provided separately. These pipes are connected to more than 118 substations spread in the city.

Currently, the municipality has a strategy for replacing more of the transmission and distribution pipes, but the progress is slow and no further information upon this subject is available from them.

B. CO_2 emissions

The municipality of Timisoara does not provide any exact information of how many CO2 emissions the existing district heating system is releasing in the atmosphere. Nevertheless, their target is to reduce the total heat demand by 69 GWh/year and the CO_2 emissions by 20.700t/year by the year 2020 (Municipality of Timisoara, 2014).

C. Costs

As in the case of Bucharest, Table 22 presents the amount of investments and their completion rate in the past years. Compared to Bucharest, most of the planned investment has been completed, which can indicate a higher level of maintenance.

Year	Planned investment (mil. €)	% of completion	Subsidized heat price (€/MWh)
2015	1,5	96	65
2014	1,67	90	65
2013	2,4	69	65
2012	2,55	79	65
2011	1,56	106	65
2010	1,58	93	65
2009	0,6	137	41
2008	0,6	100	38
2007	0,49	100	38

Table 24 - Scenario I - Timisoara – O&M costs

The prices for heat before 2007 are not available for the city of Timisoara. Nevertheless, it can be observed that the subsidized price of heat kept its ascending trend until 2011, being stable since. However, it might be expected that the prices of heat will rise, as subsidies cannot be expected to always pay for the heat.

4.2.2 Scenario II - Individual heating

A. Technical assessment

<u>Heat demand</u>

The heat demand in this scenario is 1000 GWh/year, thus 8.2 MWh/year/dwelling and 185 kWh/m²/year.

<u>Heat supply</u>

The efficiency of the heating solutions is Table 25 are 1:1, except for the existing boiler substations, which have an efficiency of 85%, after the retrofit. The losses in the pipes for this type of equipment are not considered in the table. The available amount of biomass is 910 GWh/year (Stratego, 2015), so even more biomass boilers could have been be considered for this scenario. These boilers, along with the gas ones, can be sized for some of the old substations, or for one or more apartment blocks.

The distribution of the heating solutions is intended to have a similar share as in the case of Bucharest:

Type of heating	Heat demand/dwelling (MWh/year)	Primary energy consumption/dwelling (MWh/year)	Number of dwellings	Primary energy consumption (GWh/year)
Individual gas boiler	8,2	8,2	61.000	500,2
Electric heating		8,2	36.600	300,1
Heat pump		2.7	4.000	10,8
Existing substation boilers		10,3	5400	55,6
Collective biomass boilers		9,6	15.000	144
Total				**1.010**

Table 25 - Scenario II - Timisoara - Production outline

The primary energy consumption in this Scenario is higher than the heat demand as some of the existing infrastructure was kept in order to reduce the investment costs.

B. CO_2 emissions

	Unit	**tCO_2/year/dwelling**	**Total (tCO_2/year)**
Individual gas boiler	1 kWh gas=380g CO_2	3,11	189.710
Electric heating	1 kWh=408g CO_2	3,34	122.244
Heat pump	1 kWh=408g CO_2	1,10	4.400
Existing substation boilers	1 kWh gas=380g CO_2	3,91	21.114
Collective biomass boilers	1 kWh=18g CO_2	0,17	2550
Total			**340.018**

Table 26 - Scenario II - Timisoara – CO_2 emissions

C. Costs

Opposite to the connection to district heating, where the costs are split between the utility company and the owners, the costs of installing individual heating solutions is mainly the responsibility of the owners of dwellings. They would also have to pay for the separate gas connection for heating (in case the building does not already have one) or for higher voltage electric connection, as the boilers using electricity need a different connection. There will be costs from the utility companies too, as they will need to increase the capacities of their gas and electric networks to supply the demand.

It is considered that even the customers which are currently using individual heating solutions will need to change at some point their equipment.

In the case of Timisoara, the total investment in the new heating solutions will be €329 mil., out of which the individual gas boilers have the highest share. The annualised cost is approximately €20 mil. With the prices of fuel included, the total annual costs with fuels included reaches €95 mil. The detailed input and calculations for this scenario can be found in Appendix 5 – Scenario II - Timisoara.

Total costs	
Total investment all heating solutions (M€)	329
Total annual investment all heating solutions (M€)	19,7
Total annual costs (M€/year)	34,3
Total fuel costs (M€/year)	61,1
Total annual costs with fuels (M€/year)	95,4

Table 27 - Scenario II - Timisoara - Total costs, individual heating

4.2.3 Scenario III - District heating

A. Technical assessment

Heat demand

In this scenario, the district heating system is extended. Since this scenario focuses on the development of district heating, it is expected that the rest of the customers currently using individual heating based mainly on gas to be conditioned to join the future network or, if not possible, to use renewable energy sources. The amount of heat losses stays decreases, even with the expansion of the network, due to finalising the retrofit of the rest of the network. The total heat demand is 1000 GWh/year.

Heat supply

Therefore, in this scenario a WTE plant and a large scale absorption heat pump are expected to supply the summer load in district heating system, by functioning most of the year. The rest of the heat demand will be gradually supplied by the existing CHP Freidorf (built in 2007) and another CHP plant based on biomass, which has a high potential in Timisoara. The peaks loads in the winter time are to be supplied by gas boilers. The heat losses are included in the calculation, at a value of 18%, from the existing 25%, therefore the reduction of the heat losses is realistic. For the sizing of the equipment the existing summer heat load in Timisoara is used, of 40 MW (Government of Romania, 2015).

	Power (MWth)	**Hours/year**	**Capacity (GWh/year)**	
Waste-to-energy	23	8000	180	15%
Geo-thermal plant	23	8000	180	15%
Existing CET Freidorf	10	5000	50	4%
Decentralised biomass CHP	80	5000	400	34%
Peak boilers	245	1500	370	32%
Total (including heat losses 18%)			**1180**	

Table 28 - Scenario III - Timisoara - Production outline

The outline of the production presented in Table 28 is further explained.

Waste-to-energy (WTE)

The municipality of Timisoara has been planning for several years to build a WTE plant, the first of its kind in Romania. However, even though this has been planned, the construction of the plant did not take place yet. The proposed size of the new plant is to deliver 180 GWh/year in the district heating of the city. The quantity of waste expected to be available in Timisoara is 150.000 t/year, thus the proposed quantity of waste to be burnt hourly is approximately 20 tonnes (Warchter et al., 2013).

According to the same study, the proposed location of the new WTE plant is in the location of the TEPP Timisoara Sud, since some of the infrastructure will already be in place, such as the connection to the electric network, the existing district heating transmission pipes, and the transport infrastructure for the lorries which will bring the MSW to the incinerator. This will also resolve the issue of waste management of the city.

The sizing of the new facilities has to be given by the amount of waste in the city and not by the heat demands. Therefore, it is assumed that the quantity of waste will have the following values in Bucharest:

Total quantity (t/y)	250.000
Incineration (%)	60
Quantity (t/y)	150.000

The heat recovery potential from waste in a WTE plant is expected to be 9,5 GJ/t, with an energy efficiency of 80%. Then, the final value is divided as:

- 50% heat
- 30% electricity
- 20% waste heat

The WTE plant is expected to produce 180 GWh/year.

Absorption heat pump

According to a study made by the institute of Fraunhofer in Stuttgart, over 50% of the county of Timisoara, especially its western part, has a high geo-thermal potential with temperatures reaching almost 100°C. This also includes the municipality of Timisoara. By having as a guideline the practices of the municipality of Oradea, it is expected that no less than 70 GWh of heat could be delivered in the district heating network (Municipality of Timisoara, 2014).

The new plant should be positioned possibly in the location of an existing substation, to make use of the existing infrastructure. Since no geo-thermal project are functional in Timisoara, the use of an absorption heat pump might prove as necessary to be able to reach the necessary output temperatures for the district heating.

Biomass CHP

The biomass potential of the areas surrounding Timisoara is high, as according to Connolly et.al., (2015), this reaches almost 1000 GWh/year in available wood and straw, in locations less than 30km away from the city. Therefore, to make use of this potential, several small CHP units, with capacities between 10 to 20 MW can be built around the city.

The efficiency of the biomass CHP is:

- 55% heat
- 25% electricity
- 20% waste heat

It is also necessary to mention that the existing CHP plant, CET Freidorf, built in 2007, continues to be used.

Peak boilers

The peak boilers will have an important role in supplying the heat in the colder periods. These are oversized to be able to cover the low temperatures in the winter, which can sometimes reach -20°C. The proposed number of operating hours is 1500 per year and their size is 245 MW and can supply 370 GWh/year. However, in order to reduce some of the capacity of these boilers, thermal storage units can be added alongside within the plants.

The building of the new facilities should start with the decentralised CHP, to take a part of the load of the existing facilities. Then, the WTE facility could be built in one of the locations of the existing plants, likely in the place of Timisoara Centru. The WTE and the decentralised CHP plants will take some of the production loads of the existing TEPP.

<u>Heat transport</u>

There is no exact information about the current capacities of the district heating system. The retrofit of the old network, from the heat supply to the consumer infrastructure will also imply a redesign of the distribution and transmission network.

First, the capacity of the transmission pipes will have to be reduced, as the only centralized production will be from the WTE plant and geo-thermal sources. Then, the new pre-insulated pipes will have to be buried, so a redesign of the transmission system would be seen as necessary. Since the WTE plant is expected to be placed in the location of CET Timisoara Sud, the largest pipes should connect it to the city. However, these should not be larger than 600mm in diameter.

The distribution system will need to be adapted to the decentralized production mode. The total length of the distribution system is currently 210 km, but it is expected to keep a similar size once the district heating will expand. The new distribution system will have to be able circulate the hot water in the summer, to ensure the base load, coming from the WTE and geothermal plants.

Also, it is expected that the new substations will enable the possibility of heat and DHW preparation via local heat exchangers. Some of the heat exchangers can be built in the old substations where necessary, and their capacities should be sized according to the heat demand, and not the DHW requirement, as that will be supplied from thermal storage units.

The losses in the existing system were 220 GWh/year in 2011, representing a value of approximately 25%. With the retrofit and the expansion of the system, these are expected to decrease to 18%, to 180 GWh/year. Therefore, the new system will supply almost 45% more customers, but the heat losses will be by almost 20% lower. This translates into a less amount of fuel used for district heating, increasing the overall system efficiency.

	Present	Future
Flats supplied	65.000	122.000
Losses	25%	18%
Pipes (trans. + distrib.) km	73 + 210	35 + 200
Losses	220 GWh/year	180 GWh/year

Table 29 - Scenario III - Timisoara - Heat losses

B. CO_2 emissions

	Unit	**Total tCO_2/year**
WTE	1 GJ waste=37kg CO_2	52.725
Geo-thermal plant	negligible; depending on the type of pump used	-
Existing CET Freidorf	1 kWh gas=380g CO_2	38.000
Decentralised biomass CHP	1 kWh=18g CO_2	12.096
Peak gas boilers	1 kWh gas=380g CO_2	150.600
Total		**235.421**

Table 30 - Scenario III - Timisoara – CO_2 emissions

C. Costs

The costs for reconstructing the district heating system in Romania have been estimated based on the data from the Danish Energy Agency (2012) and on the outline of the production system in this scenario.

Heat production

The total investment cost in the production system is €445 mil., whilst the total annual cost of O&M of the production system with the necessary fuel included is €61 mil. The outline bellow presents the broken down costs:

	WTE	**Geo-thermal plant**	**Existing gas CHP**	**Biogas CHP**	**Gas peak boilers**
Investment cost (M€)	59,8	41,4	0	320	24,5
Annual investment (M€)	3,6	2,1	0	19,1	0,9
Fuel costs (M€)	0	0	3	17,4	12,3
Price/GWh (€)	657	17.445	47.500	104.123	38.340

Table 31 - Scenario III - Timisoara – Cost of heat supply

The reduced annual costs of heat for the WTE are related to the price at the gate for the MSW, but also because the plant produces and sells electricity, prices which can be adjusted so the plant has no costs, nor profit. The price for MSW has been adjusted to €58/tonne, whilst the price for the sold electricity is €25/MWh.

The geo-thermal plant in Timisoara is has a relatively low investment cost, even with the absorption heat pump, can providing as much heat as the WTE plant with no carbon emissions.

The biogas decentralised CHP have an important role in the redesign of the future district heating network, but are also responsible for the highest price for heat. The existing co-generation plant, the CET Freidorf has no costs with the investment, only the O&M costs, and even though it is more polluting, it helps lowering the costs of the entire production system.

The gas peak boilers have the lowest investment cost, but they will only be used in the winter time to supply the peak loads.

Heat transport and customer substations

The investment cost in the transmission and distribution pipes considers the entire city network, including the areas which already have the pipes replaced. The investment price in the pipes is estimated to be €72 mil., but due the long technical lifetime of the pipes, the annualised investment costs are €3,4 mil. with the O&M costs included.

The costs include the customer infrastructure too. The substations have been estimated to be built for each building apart, but in some cases, one substation can supply multiple buildings. However, unlike Bucharest, the building stock in Timisoara also includes houses, for which separate substations have to be installed. For the 3600 blocks of flats in Timisoara, the investment costs in substations are €63 mil., and for the houses, the cost is €87mil.

Total costs

The detailed costs of the district heating network can be found in Appendix 6 – Scenario III – Timisoara. The total costs of the investment are:

Total costs	
Total investment (M€)	581,8
Total annual investment (M€)	36,3
Total fixed O&M ((M€/year)	24,5
Total annual variable O&M (M€)	0,1
Total annual costs-including fuel (M€)	32,8

Table 32 - Scenario III - Timisoara - Investment costs

4.2.4 Scenario II and III with heat savings

This sensitivity analysis applies heat savings to Scenarios II and III in Timisoara. These heat savings have as an effect the reduction of the heat density and heat demand. Currently, the average heat demand in Timisoara is 184 kWh/m²/year. These buildings will need to lower their heating demand to less than 100 kWh/m²/year, in order to reduce the amount of fuels used for heating, reduce CO_2 emissions and ultimately, comply with the European legislation. The district heating network is remodelled based on the new heat demand with the conventional 2-pipe system as in Scenario III, but as a side calculation, the new heat demand will also be supplied through a 4GDH system, to compare the costs.

A. Technical assessment

Heat demand

Like in Bucharest, the majority of the building stock is over 40 years old, and the dwellings in the city which have a high heat demand.

By today, only 300 of the total of 2900 dwellings were retrofitted leaving a lot of room for further improvements. This includes individual and collective buildings. Therefore, the retrofit this entire building stock will result in an important reduction in the heat demand.

With the heat savings applied to the entire building stock, the total heat demand is calculated to lower to 540 GWh/year, decreasing from the current level of 1000 GWh/year.

Heat supply – Scenario II

The production outline for this scenario is:

Type of heating	Heat demand/dwelling (MWh/year)	Fuel consumption (MWh/year)	Number of dwellings	Primary energy consumption (GWh/year)
Individual gas boiler	4,4	4,4	61.000	268,4
Electric heating		4,4	36.600	161
Heat pump		1,46	4.000	5,8
Existing substation boilers		5,2	5400	28
New biomass substation boilers		4,88	15.000	73,2
Total				**536,4**

Table 33 - Scenario II with heat savings - Timisoara - Production outline

The total savings is terms of fuel consumption are 573 GWh/year of primary energy savings. Thus, the heat savings and individual and collective heating allow for important savings in terms of fuel. However, the individual heating units still have to be installed in each dwelling, therefore the technology costs stay, even though the amount and costs for fuels decreases.

Heat supply – Scenario III

The production outline in this scenario is:

	Power (MW)	Hours/year	Capacity (GWh/year)	
WTE	13	8000	100	16%
Absorption heat pump	13	8000	100	16%
Existing CHP	10	5000	50	8%
Biomass CHP	42	5000	210	33%
Peak boilers	115	1500	170	27%
Total (including heat losses 18%)			**630**	

Table 34 - Scenario III with heat savings - Timisoara - Production outline

As for Scenario III, since the heat demand is expected to be 540 GWh/year, the total heat to be produced, with the 18% of losses, will be 630 GWh/year. First of all, this presents a reduction in the amount of heat generated by more than 100 GWh/year compared to the existing system, even though now it covers the entire city. Secondly, this will determine a new approach in the way the heat production facilities are sized and designed.

Therefore, with the reduction of the heat demand, the production system can be readjusted and the capacities of the production system can also be reduced. The WTE plant is expected to incinerate approximately 76.000 tonnes of MSW each year.

B. CO_2 emissions

Scenario II

	Unit	tCO_2/year/dwelling	Total (tCO_2/year)
Individual gas boiler	1 kWh gas=380g CO_2	1,67	101.870
Electric heating	1 kWh=408g CO_2	1,79	65.514
Heat pump	1 kWh=408g CO_2	0,59	2.360
Existing substation boilers	1 kWh gas=380g CO_2	2	10.800
New collective biomass boiler	1 kWh=18g CO_2	0.08	1.200
Total			**181.744**

Table 35 - Scenario II with heat savings - Timisoara - CO_2 emissions

Scenario III

	Unit	Total (tCO_2/year)
WTE	1 GJ waste=37kg CO_2	27.714
Geo-thermal plant	negligible; depending on the type of pump used	-
Existing CHP	1 kWh gas=380g CO_2	38.000
Biomass CHP	1 kWh=18g CO_2	3.780
Peak gas boilers	1 kWh gas=380g CO_2	64.600
Total		**134.094**

Table 36 - Scenario III with heat savings - Timisoara – CO_2 emissions

By comparing the two tables above it can be observed that the centralized type of heat production produces less CO_2 emissions, considering that the equipment in Scenario III also produces electricity.

C. Costs

Heat savings

The same national costs for the retrofitting the 3600 blocks in Timisoara is applied. Since very few have been retrofitted, in this case the retrofit will cover the entire building stock. The type of blocks of flats in Timisoara is different than in Bucharest, and the average number of apartments in a block is 18. The price for retrofitting a block of flats is €58.172 with the standard cost and €99.563 in the high efficiency version.

The building stock also includes 35.000 houses. Since the type of individual dwellings in Romania is varied, it is estimated that the cost for retrofitting a house is 5% of the costs for a 40 apartment block, resulting in a price of €9.775 for the standard cost and €13.364 for the high efficiency retrofit. Thus the cost of retrofitting in Timisoara are:

	Surface (m²)	Standard cost (€)	High efficiency cost (€)
Walls	1110	19.425	43.401
Roof	278	4.197	10.592
Floor	250	4.550	10.050
Windows	160	30.000	35.520
Total		**58.172**	**99.563**

Table 37 – Timisoara - Cost of heat savings

	Units	Standard cost (mil. €)	High efficiency costs (mil. €)
Blocks of flats	3.600	209	358
Houses	35.000	342	468
Total		**551**	**826**

Table 38 – Timisoara - Cost of heat savings for entire building stock

From the table above it results that there is a difference of €326 mil. between the two types of retrofit. As in the case of Bucharest, the standard level of insulation should prove enough to reduce the heating demand to the required level of 100 kWh/m²/year.

<u>Heat supply – Scenario II</u>

When the heat savings are applied in Scenario II, the main reduction observed is with the cost of fuels. Thus, compared with the Scenario with no heat savings, the reduction with the cost of fuels is more than 50%. However, the overall total investment is €291 mil., decreasing with €38 mil. compared to Scenario II, as the individual solutions will still have to be installed with similar capacities. The individual boilers, electric heating and heat pumps are sold in standard configurations, thus there will not be savings for this solutions. However, the noticeable differences are with the collective gas and biomass boilers, whose capacities can be reduced.

The annual costs for the heat supply are €17,4 mil., and with the fuels included this reach €27,7 mil. The calculations for this analysis can be found in Appendix 7 – Scenario II – Heat savings - Timisoara.

Total costs	
Total investment all heating solutions (M€)	270
Total annual investment all heating solutions (M€)	16,1
Total annual costs (M€/year)	30,7
Total fuel costs (M€/year)	32,6
Total annual costs with fuels (M€/year)	63,4

Table 39 - Scenario II - Heat savings - Timisoara - Total investment costs

Heat supply – Scenario III

When the entire building stock of Timisoara will be retrofitted, the costs of the investing in a new production system will decrease, as the capacities to invest in will be lower.

	WTE	**Geo-thermal plant**	**Existing CHP**	**Biomass CHP**	**Gas peak boilers**
Investment cost (M€)	33,8	23,4	0	168	11,5
Annual investment (M€)	2	1,2	0	7,2	0,4
Fuel costs (M€)	0	0	3	9,2	5,7
Price/GWh (€)	875,6	17.749	47.500	94.632	38.457

Table 40 - Scenario III with heat savings - Timisoara - Investment costs

In this calculation, the capacities of the production system are lower, thus the investment costs decrease. The existing CHP Freidorf has been this time included in the same category with the biomass CHP, providing the opportunity of lowering the total price of heat.

Heat transport and customer substations

Due to the lower heat demands, the district heating system can also be resized. The costs for it are €39 mil. for the conventional 2-pipe network, with an additional €56 mil. for the substations in the blocks of flats and €79 mil. houses. The same number of substations is considered in this scenario as in Scenario III.

As a side note, since all the buildings are considered to have the heat savings applied, the 4GDH can be considered as an option, but with a cost of €282 bil.

Total costs

Therefore, the investment costs in the production system, transmission and distribution networks and customer installations is €387, with an annualized cost of €49 mil. with the O&M costs and fuels included. The calculations for this system can be found in Appendix 8 – Scenario III – Heat savings - Timisoara.

Total costs	
Total investment (M€)	387,3
Total annual investment (M€)	20,3
Total fixed O&M ((M€/year)	14,6
Total annual variable O&M (M€)	0,9
Total fuel costs (M€/year)	17,8
Total annual costs-including fuel (M€)	49,4

Table 41 - Scenario III with heat savings - Timisoara - Total costs

4.2.5 Heat affordability

The subsidized price of heat in Timisoara is closer to the real price than in Bucharest. Nevertheless, the price is also higher than in the capital city. Thus, the price the population of Timisoara is paying for the heat supplied by Colterm is €65/MWh, whilst the real production price is €98/MWh.

The total incomes of the population are lower than in Bucharest, and the average income per dwelling is €577/month, therefore, there is a more concerning issue with the affordability of heat in Timisoara. The average price paid for heating a dwelling would be €862/year, which would represent more than 12% of the total annual income of the dwelling.

The table below estimates the prices of heat and what is their percentage of the current income/household in Timisoara (Scenario III includes the conventional district heating network. The heat savings costs are included in brackets):

	Income per dwelling (€/year)	Price of energy (€/MWh)	Energy consumption/ dwelling (MWh/year)	**Price of heat (€/dwelling/year)**	Percentage of current income
Scenario I	6.924	65	8,2	**533**	7,6%
Scenario II		95	8,2	**781**	11,3%
Scenario III		72	8.2	**507**	7,3%
Scenario II – Heat savings		118	4,4	**519 (+158)**	7,5%
Scenario III – Heat savings		70	4,4	**312 (+158)**	4,5%

Table 42 - Timisoara - Heat affordability

Thus, it can be observed that even with the investments in the heat supply, heat distribution and customer installations and the standard heat savings, the price of heat will not be higher than it is today as it is supplied and subsidized by the municipality.

Another observation is that the price of heat supplied through district heating without heat savings is still lower than the price of heat in Scenario II with heat savings, making the individual heating solutions an expensive alternative for both cases.

4.2.6 Fossil fuel dependency

The fossil fuel dependency is 100% in Scenario I as in Bucharest. There is no other type of energy supply used by Colterm besides natural gas, coal and heavy oil to supply the 65.000 dwellings connected to the district heating system. The efficiency of the heat production facilities is unknown, as in the case of Bucharest, considering the old technologies also in use in Timisoara. The rest of the 57.000 dwelling which use individual solutions are also mainly reliant on fossil fuels.

Even if the data about the amount of fuels used by the TEPP in Timisoara to produce heat is unknown, the technologies used in Scenario II and III are more efficient and use less fossil fuels.

The table below makes a comparison between Scenarios II and III in terms of energy consumption. Electricity is included as 50% of it is produced from fossil fuel sources. Since the electricity can be produced in different ways and at different efficiencies, it is difficult to estimate what is the total primary energy supply in Bucharest for Scenario II, but the amount of fuel used is significantly smaller than in Scenario I due to the more efficient technologies in use:

(GWh/year)	Scenario II	Scenario II Heat savings	Reduction	Scenario III	Scenario III Heat savings	Reduction
Fossil fuels	556	296,4	46%	100	100	0%
Electricity	311	166,8	46%	0	0	0

Table 43 - Timisoara - Fossil fuel dependency

With the heat savings, the amount of gas and electricity is several times lower with the heat savings. However, the difference between Scenario II and III is that in the latter, no electricity is used to produce heat besides heat, but electricity is produced in the WTE and biomass CHP, basically providing the opportunity of reducing the costs of heat. However, in Scenario II, all the individual or collective installations are heat only solutions with no possibility of producing electricity in co-generation mode, as in Scenario III.

4.2.7 Results and recommendations

The city of Timisoara is the second in size in this study, and has a population of 300.000. The heat density in its case is lower than in Bucharest, but in the case of Timisoara the final price of heat supplied through district heating in Scenario III is lower than the price of subsidized heat. The annual price of heat paid today by the population is €533, whilst the price paid with a retrofitted and extended district heating network is €507 and €319 when heat savings are applied. However, the price of individual heating is over €700 when no heat savings are applied and €519 with the heat savings.

The heat supply suggested in this case study for the district heating production is mainly based on using alternative fuels, such as MSW, geo-thermal and biomass, which have as an effect the reduction of the amount of CO_2 emissions compared to today's levels and compared to the scenario with individual heating. By also using co-generation units, electricity is available as a side product.

The investments in the heat supply for the district heating scenario have a total cost of €445 mil., and the highest investment is in the biomass CHP plants. The cost for these plants could be reduced by also building units based on gas, which are cheaper, but more reliant on fossil fuels and richer in CO_2 emissions. However, the city has a high potential for using biomass, which can be well exploited by such a plant. Nevertheless, the case of Timisoara has a particularity in terms of ownership, as Colterm owns the piping network and the heat production facilities as well, giving the municipality more flexibility when it comes to making investments in the infrastructure of the district heating.

An important part of the transmission and distribution pipes of the district heating network have been already retrofitted in proportion of 30%, so the total investment cost to retrofit the rest will be below the estimated €72 mil. in Scenario III.

In the case of individual heating, this investment cost is more expensive than in the case of district heating, but when the costs of both are annualised, district heating is less expensive, due to the longer technical lifetime of the heat supply and district heating pipes.

In terms of heat savings, less than 10% of the building stock in Timisoara is retrofitted, and the cost of retrofitting it would be approximately €518 mil. for the standard retrofit and €826 mil. for the high efficiency one. Nevertheless, the heat demand, as in the case of Bucharest, should be reduced to less than 100 kWh/m^2/year if a standard level of retrofit is applied to the entire building stock.

Therefore, even though the heat density in Timisoara in lower than in the capital city, the retrofit and expansion of district heating, accompanied by heat savings, proves as the most recommended approach for the future heat strategies of the city. The final price of heat with a new and extended district heating network plus the minimum level of heat savings is lower than the subsidized price of heat paid today by the population. The costs presented in this study represent the investment in a newly built district heating network, but an important part of the infrastructure for district heating is already in place, so the final price of heat should finally be lower than the one presented in this case study.

4.3 Oradea

The city of Oradea is located in the NW side of the country, at the border with Hungary. It has a population of 200.000 people a well-developed district heating system. Over 80% of the population is connected to centralized heating system, and is one of the few cities in Romania which experiences an increase in the of customers to district heating by 16%, between 2009 and 2014, to 65.000 customers today (Government of Romania, 2015).

The total length of the district heating system is 248 km, separated in 73 km of transport pipes, out of which only 10% have been retrofitted and 143 km of distribution pipes, with a 35% retrofitting rate. The losses in the transmission system are estimated to 26%, whilst the ones in the distribution one are lower, of only 13%, due to the existing retrofit measures (Proarcor, 2012).

According to the data in Stratego, the total heat demand for the reference year of 2010 was 687 GWh/year (Connolly et al., 2015). This includes however, several low density suburbs, which are currently not supplied by the district heating system.

Thus current heat demand for the entire city is approximately 650 GWh/year (Connolly et al., 2015). The average heat demand is 172 kWh/m²/year. No less than 65.000 dwellings are connected to the district heating system, out of the total of 84.000. These are separated in 44.000 flats and 40.000 houses, which are occupied by the 205.000 people living in Oradea. (Municipality of Oradea, 2014). Like in the majority of cities in Romania, the majority of the dwellings are represented by the apartment blocks. There are 1100 blocks apartment blocks, but only 77 of them have been retrofitted (Culiciu, email correspondence 09.05.2016).

The heating necessities are supplied by a newly installed CHP plant functioning on natural gas, belonging to the public company Termoficare Oradea. The rest of the heat supply comes from a geo-thermal heat plant with a capacity of 15 MW, operated by TRANSGEX, which sells its heat through several substations, but only to supply DHW, covering 7% of the necessities. The total heat generated by these two systems is 1110 GWh/year but out of which only 708 GWh/year were invoiced (Government of Romania, 2015).

4.3.1 Scenario I - BAU

A. Technical assessment

Heat demand

The estimated total heat demand of the city is 650 GWh/year. The customers continue to disconnect and reconnect to the grid, but this will not make a significant change in the number of consumers in the system, so the number is expected to stay the same in the future (Proarcor, 2012). The other customers prefer to stay with individual heating solutions.

Heat supply

The old TEPP in the city was built in 1966 and had a total power of 546 MW. It functioned with both gas and coal, but since no modernisation of the plant was made since it was built, its efficiency was low, of only 57%, and thus it used too much fuel.

Nevertheless, this year the municipality commissioned a new co-generation plant, sized on the summer heat demand, with a thermal output of 43 MW. This is accompanied by 4 gas boilers to supply the higher demand and heat storage unit of 300 MWh (Proarcor, 2012).

The geo-thermal capacities are planned to be increased too, as a new geo-thermal plant is planned to be commissioned in the next years. The new plant is expected to contribute with 15% to supplying the future heat demand, by supplying an extra of 50 GWh/year (Vasiu, 2015).

Heat transport

Like in many other Romanian cities where district heating was commissioned during communist times, the situation in Oradea is similar. Many of the pipes still in use today have been installed almost 40 years ago, and they have been dimensioned for different heat demands. However, some of these pipes have already been refurbished and replaced with pre-insulated ones. The total length of the district heating system is 248 km, separated in 77 km of transport pipes, out of which only 10% have been retrofitted and 143 km of distribution pipes, with a 35% retrofitting rate. The losses in the transmission system are 26%, whilst the ones in the distribution one are lower, of 13%, due to the existing retrofit works already done (Proarcor, 2012).

The municipality is planning to continue the retrofitting works to reduce the losses in the network. Some of the pipes will be replaced by pre-insulated ones, whist others will be kept in concrete ducts. The positioning of the transmission pipes will be underground and above ground, therefore the system will continue to keep most of its actual design. However, the system to be used for the distribution system will to be the standard 2-pipe one (Proarcor, 2012).

B. CO_2 emissions

The CO2 emissions of the previous TEPP power plant were considered to be 880.000 tCO_2/year. With the new system in place, the new system based on gas is expected to reduce the emissions by a third, to 320.000 tCO_2/year (Bihon, 2016).

C. Costs

The investments made in the grid in the last years are:

Year	Planned investment (mil. €)	% of completion	Subsidized heat price (€/MWh)
2015	1,4	38	62
2014	1,8	58	62
2013	0,59	34	53
2012	1,3	71	53
2011	0,35	250	53
2010	0,4	119	45
2009	0,47	75	37
2008	0,37	61	28
2007	0,37	99	28

Table 44 - Scenario I - Oradea – O&M costs

These investments were mostly done until 2012, when due to the plans to rebuild the production system, the investments decreased. On the other hand, it is visible that the price for heat grew almost every two years since 2007, when the subsidies for the final heat consumption were introduced. Nevertheless, even with the increasing price of heat, an important part of the population of Oradea reconnected to the district heating network.

The municipality has analysed, in a previous feasibility study, the reconstruction of the heat supply. The total cost of the investment to retrofit the district heating system is estimated to be over €50 mil.

By applying this investment, the population will be able to pay the real price of heat. Today, the price paid is €62/MWh with subsidy, but in the future the price will increase, mainly due to the increasing prices of gas, and the reliance of the system on gas, with the new investment in place.

4.3.2 Scenario II - Individual heating

A. Technical assessment

<u>Heat demand</u>

The total heat demand in this scenario is 650 GWh/year, whilst the heat demand for a dwelling is 7.8 kWh/m^2/year, the lowest in this study.

<u>Heat supply</u>

The technologies used allow a transformation of heat of 1:1, excepting the collective biomass boilers, which have an efficiency of 90%. The available amount of biomass is 848 GWh/year (Connolly et al., 2015), so more biomass boilers could have been considered for this scenario. These boilers, along with the gas ones, can be sized for some of the old substations, or for one or more apartment blocks.

The distribution of the heating solutions is:

<table>
<tr><th>Type of heating</th><th>Heat demand/dwelling (MWh/year)</th><th>Primary consumption/dwelling (MWh/year)</th><th>Number of dwellings</th><th>Primary energy consumption (GWh/year)</th></tr>
<tr><td>Individual gas boiler</td><td rowspan="5">7,7</td><td>7,7</td><td>42.000</td><td>323,4</td></tr>
<tr><td>Electric heating</td><td>7,7</td><td>25.200</td><td>194</td></tr>
<tr><td>Heat pumps</td><td>2,6</td><td>2.000</td><td>5,2</td></tr>
<tr><td>Collective gas boilers</td><td>7,7</td><td>8.000</td><td>61.6</td></tr>
<tr><td>Collective biomass boilers</td><td>8,5</td><td>6.800</td><td>57,8</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td>580,4</td></tr>
</table>

Table 45 - Scenario II - Oradea - Production outline

The reason for such a reduced energy consumption with individual and collective heating is related to the use of efficient technologies. This table above does not account for any heat losses in the piping networks for the collective heating solutions, as uses their theoretical efficiency to determine the amount of fuel used.

B. CO_2 emissions

	Unit	tCO_2/year/dwelling	Total (tCO_2/year)
Individual gas boiler	1 kWh gas=380g CO_2	2,92	122.640
Electric heating	1 kWh=408g CO_2	3,14	79.128
Heat pumps	1 kWh=408g CO_2	1,06	2.120
Collective gas boilers	1 kWh gas=380g CO_2	2,92	23.200
Collective biomass boilers	1 kWh=18g CO_2	0,15	1.020
Total			**228.108**

Table 46 - Scenario II - Oradea – CO_2 emissions

It can be thus seen that such a configuration of the energy system in the city would lower the CO2 emissions (due to the efficient and renewable technologies used) compared to the emissions of the heating plant commissioned by the municipality. However, such a deployment of heating technologies would not allow anymore the possibility of producing electricity in cogeneration mode.

C. Costs

Opposite to the connection to district heating, where the costs are split between the utility company and the owners, the costs of installing individual heating solutions is mainly the responsibility of the owners of dwellings. They would also have to pay for the separate gas connection for heating (in case the building does not already have one) or for higher voltage electric connection, as the boilers using electricity need a different connection. There will be costs from the utility companies too, as they will need to increase the capacities of their gas and electric networks to supply the demand.

It is considered that even the customers which are currently using individual heating solutions will need to change at some point their equipment.

In the case of Oradea, the total investment in the new heating solutions is €221 mil., out of which the individual gas boilers have the highest share. The annualised costs are €13 mil. and with the prices of fuel included, the total annual costs reach €63 mil. The detailed input and calculations for this scenario can be found in Appendix 9 – Scenario II - Oradea.

Total costs	
Total investment all heating solutions (M€)	221
Total annual investment all heating solutions (M€)	13,2
Total annual costs (M€/year)	23,5
Total fuel costs (M€/year)	40,6
Total annual costs with fuels (M€/year)	64,1

Table 47 - Scenario II - Oradea - Total costs individual heating

4.3.3 Scenario III - District heating

A. Technical assessment

Heat demand

In this scenario, the district heating system is extended. Since this scenario focuses on the development of district heating, it is expected that the rest of the customers currently using individual heating mainly based on gas, to be conditioned to join the future network or, if not possible, to use renewable energy sources. The amount of heat losses stays decreases, even with the expansion of the network, due to finalising the retrofit of the rest of the network. The total heat demand stays at 650 GWh/year.

Heat supply

In this scenario, the summer load is expected to be supplied by the newly commissioned CHP plant, whilst the rest of the demand can be supplied by the existing geo-thermal plant along with a newly built one, already planned by the municipality. The rest of the heat demand can be gradually supplied by a CHP plant based on biomass, which has a high potential in Timisoara. The peaks loads in the winter time can be supplied by gas boilers. The reduction of the heat losses is included in the calculation, at a value of 18%, from the existing 27%.

For the sizing on the equipment the existing summer heat load in Timisoara is used, of 60 MW (Government of Romania, 2015):

	Power (MWth)	**Hours/year**	**Capacity (GWh/year)**	
Existing CHP	43	8000	340	44%
Geo-thermal	13	8000	100	13%
Biomass CHP	25	5000	125	16%
Gas peak boilers	130	1500	200	27%
Total (including heat losses 18%)			**765**	

Table 48 - Scenario III - Oradea - Production outline

Existing CHP

A 43 MWth CHP was put in service at the beginning of 2016. Since it would not be financially and socially recommended to replace the newly installed unit, this takes part to this scenario. The new co-generation plant has already been sized for the summer load, but it has to be also supplied too by the existing and future geo-thermal facilities.

Geo-thermal

The geothermal capacities are already planned to be extended in the BAU scenario, and the same capacities are be kept in this scenario too.

The existing plant produces approximately 52 GWh/year, which are mainly used to provide the DHW. However, another extraction point for geo-thermal is planned to be built, and this will extend the capacities to approximately 100 GWh/year.

Biomass CHP

The biomass resources to be found in the proximity of the city of Oradea are estimated at over 800 GWh/year (Connolly et al., 2015), therefore much of the heating capacities could come from such renewable sources.

The new CHP unit can be built in the location of a substation, but it is recommended to have it built in areas further away from the existing plant, currently located in the NW of the city, or in areas of the city with higher heat densities, to decrease the heat losses in the pipes.

The efficiency of the biomass CHP is:

- 55% heat
- 25% electricity
- 20% waste heat

Gas peak boilers

The gas boilers will only supply heat during the peak loads. However, in order to reduce some of the capacity of these boilers, the existing thermal storage unit can be used. The units could be built in a centralized or decentralised mode, but such a deployment would need to alter their capacities. The proposed capacities in this case 200 MW.

<u>Heat transport</u>

The retrofit of the old network, the decentralisation of the heat supply with the new biomass CHP and the replacement of the consumer infrastructure will imply a redesign of the distribution and transmission network. The transmission network is likely to keep its existing length, but the diameter of the pipes will have to readapt.

The transmission networks should be redesigned in a manner which will decrease the heat losses, and this implies that the pipes will have to be buried in the ground, and all will need to be pre-insulated.

The distribution pipes will be replaced with the 2-pipe system in order to decrease the heat losses. Like in the other cases, the heat losses are estimated to be 18% in total, and the distribution system will need to be adapted to the new production. The total length of the distribution system is currently 143 km, but it already covers most of the city, so it is expected to slightly increase once the district heating will be expand. The new distribution system will have to be able circulate the hot water in the summer, to ensure the base load, coming from the existing CHP plant and geo-thermal heat sources.

The new system will enable the possibility of heat and DHW preparation via local heat exchangers. Some of the heat exchangers can be built in the old substations where necessary, and their capacities should be sized according to the heat demand, and not the DHW requirement, as that will be supplied from local thermal storage.

The losses in the existing system were 270 GWh/year in 2011, representing a value of approximately 27%. With the retrofit and the expansion of the system, these are expected to decrease to 18%, to 137 GWh/year. Therefore, the new system will supply almost 32% more customers, but the heat losses are expected to decrease by 50%. This translates into a less amount of fuel used for district heating, increasing the overall system efficiency.

	Present	Future
Flats supplied	65.000	84.000
Losses	28%	18%
Pipes (trans. + distrib.) km	77 + 143	77 + 150
Losses	270 GWh/year	137 GWh/year

Table 49 - Scenario III - Oradea - Heat losses

B. CO_2 emissions

	Unit	**Total tCO_2/year**
Existing CHP	1 kWh gas=380g CO_2	258.400
Geo-thermal plant	negligible; depending on the type of pump used	-
Decentralised biomass CHP	1 kWh=18g CO_2	4.086
Peak gas boilers	1 kWh gas=380g CO_2	84.360
Total		**348.846**

Table 50 - Scenario III - Oradea - CO emissions

C. Costs

The costs for reconstructing the district heating system in Oradea have been estimated based on the data from the Danish Energy Agency (2012) and on the outline of the production system in this scenario.

<u>Heat production</u>

The additional investment to be made in the production system for Oradea is €72 mil., as the city has a new CHP unit already installed. The total annual costs, the O&M of the production system with the necessary fuel included are €35 mil. The outline bellow presents the broken down costs:

	Existing gas CHP	**Geo-thermal plant**	**Biomass CHP**	**Gas peak boilers**
Investment cost (M€)	0	7	52	13
Annual investment (M€)	0	0,3	2,2	0,5
Fuel costs (M€)	20,4	0,3	5,4	6,7
Price/GWh (€)	47.500	10.091	57.082	38.204

Table 51 - Scenario III - Oradea - Investment costs heat supply

The main production of heat in Oradea is represented by the newly installed CHP plant, with a heat capacity of 43 MW. Since this plant has been put in service recently, it has been considered as part of this scenario, thus only the O&M and fuel costs have been considered for it.

A geo-thermal plant already functions for many years in Oradea, therefore this scenario accounts only for the new plant that the municipality is planning to build for several years, but which was never constructed. This plant is actually providing the lowest price for heat out of the 4 production systems.

The biogas CHP have an important role in the reduction of CO2 for Oradea, but also have the highest price of heat in this configuration of the production system.

The gas peak boilers have the lowest investment cost, but these will only be used in the winter time to supply the peak loads.

Heat transport and customer substations

The investment cost in the pipes considers the entire city network, including the areas which already have the pipes replaced. The investment price in the pipes is estimated to be up to €47 mil., but due the long technical lifetime of the pipes, the annualised investment costs are only €1,6 mil. With the O&M costs included, the total annual cost is €2,2 mil. Nevertheless, since almost 20% of the piping network has been retrofitted, this will lower these investment costs.

The substations have been estimated to be built for each building apart, but in some cases, one substation can supply multiple buildings. However, as Timisoara, the building stock in Oradea includes both houses and blocks of flats. Thus, the substations for the 1100 blocks have a cost of €17,5 mil., whilst the costs of the substations for the houses are €190 mil.

Total costs

The detailed costs of the district heating network can be found in Appendix 10 – Scenario III – Oradea. The total costs of the system are:

Total costs	
Total investment (M€)	226,3
Total annual investment (M€)	11,1
Total fixed O&M ((M€/year)	8,4
Total annual variable O&M (M€)	1,3
Total annual costs-including fuel (M€)	32,8

Table 52 - Scenario III - Oradea - Total costs

4.3.4 Scenario II and III with heat savings

This sensitivity analysis applies heat savings to Scenarios II and III in Oradea. These heat savings have as an effect the reduction of the heat density and heat demand. Currently, the average heat demand in Oradea is 195 kWh/m²/year. These buildings will need to lower their heating demand to less than 100 kWh/m²/year, in order to reduce the amount of fuels used for heating, reduce the CO_2 emissions and ultimately, comply with the European legislation in place. The district heating network is remodelled based on the new heat demand with the conventional 2-pipe system as in Scenario III, but as a side calculation, the 4GDH system is considered too, to compare the costs.

A. Technical assessment

Heat demand

Like the other cities of Romania, Oradea has a low level of retrofit for its existing building stock. This includes individual and collective buildings, which house over 200.000 people. Therefore, the retrofit of the entire building stock results in important reductions of the heat demand.

Nevertheless, like the previous scenarios, it is considered that all the building stock will be retrofitted, so the total heat demand is calculated to reduce to 370 GWh/year through heat savings, decreasing from the current level of 650 GWh/year, enabling a reduction by almost half compared to today's level.

Heat supply – Scenario II

The outline for the production equipment in this Scenario is:

Type of heating	Heat demand/flat (MWh/year)	Primary consumption/flat (MWh/year)	Number of dwellings	Primary energy consumption (GWh/year)
Individual gas boiler	4,4	4,4	42.000	184,8
Electric heating		4,4	25.200	110,9
Heat pump		1,46	2.000	2,9
Collective gas boilers		4,4	8.000	35,2
Collective biomass boilers		4,8	6.800	32,6
Total				**366,4**

Table 53 - Scenario II with heat savings - Oradea - Production outline

Heat supply – Scenario III

If the same heat savings would be applied to scenario III, the production system can be downsized and most of the expensive infrastructure can be reduced in size, thus reducing the costs. In this case, the outline of the production system presented in Scenario III is:

	Power (MWth)	**Hours/year**	**Capacity (GWh/year)**	
Biomass CHP	13	8000	100	23%
Geo-thermal	13	8000	100	23%
Existing CHP	31 (43)	5000	155	35%
Gas peak boilers	53	1500	80	19%
Total (including heat losses 18%)			**435**	

Table 54 - Scenario III with heat savings - Oradea - Production outline

In this scenario, the biomass CHP and geo-thermal plants are expected to deliver the summer load, whilst the existing CHP, even though it was recently installed, is expected to function at lower capacities, being considered as oversized for the new heat demand.

B. CO_2 emissions

Scenario II

	Unit	tCO_2/year/dwelling	Total (tCO_2/year)
Individual gas boiler	1 kWh gas=380g CO_2	1,67	70.140
Electric heating	1 kWh=408g CO_2	1,79	45.108
Heat pumps	1 kWh=408g CO_2	0,59	1.180
Collective gas boilers	1 kWh gas=380g CO_2	1,67	13.360
Collective biomass boilers	1 kWh=18g CO_2	0,08	544
Total			**130.332**

Table 55 - Scenario II with heat savings - Oradea – CO_2 emissions

Scenario III

	Unit	Total tCO_2/year
Biomass CHP	1 kWh=18g CO_2	3.276
Geo-thermal plant	negligible; depending on the type of pump used	-
Existing CHP	1 kWh gas=380g CO_2	117.800
Gas peak boilers	1 kWh gas=380g CO_2	33.774
Total		**154.850**

Table 56 - Scenario III with heat savings - Oradea – CO_2 emissions

By comparing the CO_2 emissions in the two scenarios with heat savings, these are higher in the case of the latter one, as the gas CHP is emitting more emissions in this distribution.

C. Costs

Heat savings

The same costs are applied for retrofitting the blocks of flats in Oradea, as in the case of Timisoara. There are 1.100 blocks of flats of which only 77 were retrofitted, therefore in this case too, the retrofit consider the entire building stock.

The building stock in Oradea is similar to the one in Timisoara, and also includes 40.000 houses. The type of individual dwellings in Romania is varied, so it is estimated that the cost for retrofitting a house is 5% of the costs for a 40 apartment block, resulting in a price of €9.775 with the standard cost and €13.364 with the high efficiency cost. Thus the price of retrofitting the whole building stock in Oradea is:

	Suface (m^2)	Standard cost (€)	High efficiency cost (€)
Walls	2.280	39.900	89.148
Roof	228	3.440	8.686
Floor	228	4.150	9.165
Windows	722	135.357	160.284
Total		**182.847**	**267.283**

Table 57 - Oradea - Cost of heat savings

	Units	Standard cost (mil. €)	High efficiency cost (mil. €)
Blocks of flats	1.100	201	294
Houses	40.000	391	534
Total		**592**	**828**

Table 58 - Oradea - Cost of heat savings for entire building stock

Heat supply – Scenario II

When the heat savings are applied in Scenario II, the main reduction observed is with the cost of fuels. Thus, compared with the scenario with no heat savings, the reduction of the cost of fuels is 50%. However, the overall total investment only decreases with €38 out of the total of €221 mil., as the individual heating solutions will still have to be installed with similar capacities.

The total annual costs of this scenario with the fuels included are €43 mil., compared with €64 mil. in Scenario II with no heat savings. The calculations for this analysis can be found in Appendix 11 – Scenario II – Heat savings - Oradea.

Total costs	
Total investment all heating solutions (M€)	183
Total annual investment all heating solutions (M€)	10,9
Total annual costs (M€/year)	21,3
Total fuel costs (M€/year)	22,4
Total annual costs with fuels (M€/year)	43,7

Table 59 - Scenario II with heat savings - Oradea - Total costs

Heat supply – Scenario III

When the entire building stock of Oradea will be retrofitted, the costs of the investing in a new district heating network will decrease, as the capacities to invest in will be lower.

	Biomass CHP	Geo-thermal plant	Existing CHP	Gas peak boilers
Investment cost (M€)	52	7	0	5,3
Annual investment (M€)	0	0,3	0	0,2
Fuel costs (M€)	4,4	0,3	9,3	2,7
Price/GWh (€)	60.775	10.091	47.661	38.298

Table 60 - Scenario III with heat savings - Oradea - Heat supply costs

Heat transport and customer substations

Due to the lower heat demands, the district heating system can also be resized. The costs for rebuilding the entire system would be €26,6 mil. for the conventional 2-pipe network, but with an additional €17,5 mil. for the substations in the blocks of flats and €90 mil. for the ones in the houses. The same number of substations is considered the same as in Scenario III.

There is also the option, since all the buildings are considered to have the heat savings applied, to upgrade the district heating system to 4GDH, but the investment costs is €193 mil.

Therefore, the investment costs in the production, the conventional district heating network and customer substations is €198 mil., with an annualized cost of €32 mil. including the fuels. The calculations for this system can be found in Appendix 12.

Total costs	
Total investment (M€)	198,4
Total annual investment (M€)	10,1
Total fixed O&M ((M€/year)	7,9
Total annual variable O&M (M€)	0,8
Total fuel costs (M€/year)	16,7
Total annual costs-including fuel (M€)	32,0

Table 61 - Scenario III with heat savings - Oradea - Total costs

4.3.5 Heat affordability

The table below estimates the prices of heat and what is their percentage of the current income/household in Oradea (Scenario III includes the conventional district heating network. The heat savings scenarios are included in brackets):

	Income per dwelling (€/year)	Price of heat (€/MWh)	Energy consumption/ dwelling (MWh/year)	**Price of heat (€/dwelling/ year)**	Percentage of current income
Scenario I	7.068	62	7,7	**477**	6,7%
Scenario II		99	7,7	**763**	10,8%
Scenario III		64	7,7	**495**	7%
Scenario II – Heat savings		118	4,4	**520 (+246)**	7,35%
Scenario III – Heat savings		75	4,4	**329 (+246)**	4,6%

Table 62 - Oradea - Heat affordability

The final price of heat in Oradea is similar to the one in Timisoara, being €62/MWh. However, it reflects more accurately the real price of heat, of €68/MWh, due to the recent investments in the infrastructure of the existing district heating network. The total income for each dwelling is also higher, so the issue of heat affordability does not affect the population in the same way, Oradea coming second after Bucharest with an average of €7.068/month.

Thus, in the case of Oradea, as in Bucharest and Timisoara, the investments in heat savings with the minimal heat savings would bring costs which will be higher than the price paid today for the heat. The most cost effective option in this situation would be the retrofit and expansion of the district heating network with no additional heat savings. However, heat savings are recommended to be done anyway, as these are good from an environmental and economic perspective too.

4.3.6 Fossil fuel dependency

Oradea is the only city among the three which is using other sources of energy for heating besides fossil fuels. Even though the current geo-thermal capacities are only used to provide DHW, these are supplying approximately 7% of the city needs. The local distribution company, Termoficare Oradea, has recently commissioned a new CHP unit, so the system still relies on fossil fuels to supply heat to the 65.000 dwellings connected to the district heating system. The rest of the 57.000 dwelling which use individual solutions are also mainly reliant on fossil fuels.

The table below makes a comparison between Scenarios II and III in terms of energy consumption. Electricity is included as 50% of it is produced from fossil fuel sources. Since the electricity can be produced in different ways and at different efficiencies, it is difficult to estimate what is the total primary energy supply, but the amount of fuel used is significantly smaller than in Scenario I due to the more efficient technologies in use:

(GWh/year)	Scenario II	Scenario II Heat savings	Reduction	Scenario III	Scenario III Heat savings	Reduction
Gas	384	220	42%	900	399	55%
Electricity	199	113,8	42%	0	0	

Table 63 - Oradea - Fossil fuel dependency

With the heat savings, the amount of gas and electricity used is half with the heat savings. However, the difference between Scenario II and III is that in the latter, no electricity is used to produce heat besides gas, but electricity is produced by the biomass and existing CHP, basically providing the opportunity of reducing the costs of heat. However, in Scenario II, all the individual or collective installations are heat only solutions, with no possibility of producing electricity in co-generation mode, as in Scenario III.

4.3.7 Results and recommendations

Oradea is the smallest city of the three presented in this study, thus it has the lowest heat demand and heat density. The district heating system of the city is already well developed, and 65.000 dwellings out of the 84.000 are already connected to district heating. The city has experienced a high rate a reconnections the district heating in the past years, and important investments have been made especially with the heat supply. A new CHP unit has been commissioned in at beginning of this year, replacing the old coal TEPP.

Nevertheless, the investments in the heat supply rely too on using fossil fuels, even though the efficiency of the system has increased with the new unit. In the district heating scenario with no retrofit a biomass CHP is added, but it is considered that the existing gas CHP and the geo-thermal plants supply the summer heat load.

The CO_2 emissions are considerably higher in Scenario III compared to Scenario II when no heat savings are applied, but these are lower and more levelled out when heat savings are applied. This is partly because it is considered that the CHP unit will not function at full capacity, giving priority to the biomass CHP. The gas CHP is however seen as oversized for Oradea when the heat demand is reduced to half due to heat savings.

The costs of rebuilding the entire district heating network is €46 mil. with the conventional piping system in Scenario III, but the costs are lower by €20 mil. when the heat demand is reduced. Since Oradea is the smallest of the three cities, the cost of investing in the 4GDH are the lowest here, and these could be done on an experimental to set up a precedent in Romania, but only if and when the heat demand/dwelling is reduced.

The retrofit of the buildings is however the most important issue in Oradea, as only 7% of the blocks of flats have been retrofitted. There is no information of how many of the houses have been thermally insulated, but since these represent almost half of the building stock, it is important that these are included as soon as possible in the retrofitting plans of the municipality. The responsibility of thermally retrofitting a house is on the owner directly, as well as the costs, and there is no scheme of subsidies of thermal retrofit for the houses, as it is for the blocks.

Nevertheless, the costs of heating an apartment are still lower than using individual heating solutions, as in the case of the other two cities. The price of heat supplied through district heating and no heat savings is lower than the price of individual solutions and heat savings, respectively €495/year and €520/year, giving the first one an advantage.

Therefore, the city of Oradea is recommended to continue its district heating strategies, but it needs to focus on attracting more customers, retrofit its aging network, but also to invest in heat savings, as these reduce the CO_2 emissions, the dependency on fuels and create more jobs.

5. Synthesis of case studies

The purpose of the present feasibility study is to examine which type of urban heating development is more feasible from the perspective of society as a whole. Such a study considers more aspects than just the economic part, but also evaluates social and environmental parameters. In other words, this feasibility study analyses the development of urban heating from the perspective of the three pillars of sustainability, which are overlapping each other: economic, social and environmental.

Economic

To begin with, the perspective presented in Scenario II, which proposes individual and collective heating solutions, presents a higher investment cost than the one for district heating. Up to 50% of this cost is for the investments in gas boilers, cost which increases its share of the total investment once the heat savings are applied. Even from the annual investment cost perspective, the costs do not decrease compared to district heating, as the technical lifetime of the boilers, 20 years, is shorter than the one of the technologies used for district heating. Nevertheless, this technical lifetime can be easily decreased, as other sources (Britishgas, 2016) are recommending a replacement every 10 or 15 years, which will increase the costs even more.

Since the technologies proposed in Scenario II are mainly reliant on gas, these are sensitive to any fluctuation in the price of this fuel. The price of gas used in this study comes from the data available from Eurostat (2016), but the costs are updated only for the first half of 2015. The price has constantly risen in the previous years, and the Government has postponed the liberalisation of the price for of gasses for individual consumers until 2021. Even so, the prices are still planned to have a yearly increase by 2021 (Mediafax, 2015).

On the other hand, the price of electricity is expected to have a small decline in the future, due to the integration of more renewable energy sources in the system, but also due to the low production price of electricity in the power plants, but in the last years the overall price of electricity increased in Romania too, being subject of the same liberalisation of prices as for the gas.

Nevertheless, when heat savings are applied to reduce the heat demand, the reductions in the investments for Scenario II with heat savings are small, because of the individual infrastructure which needs to be installed anyway, given the standardized sizes of the equipment. Even when the heat demand is halved, the price of the boilers only slightly decreases, therefore the savings are done more on the basis of the fuel saved, than on the reduced capacity of the equipment. Of course, since the collective (for one or several blocks of flats) heating solutions handle higher capacities, it is possible to adjust the installed power.

In Scenario III, district heating has a lower total investment cost due to a more adapted and more varied array of heat sources than the solutions presented in Scenario II. Besides this, even though the broken down prices of the technologies used are higher are more visible than for the individual solutions, the annualized cost is smaller, due to the longer technical lifetime of the equipment, specially of district heating pipes, whose lifetime can reach an average of 40 years.

The existing district heating systems in the three cities are functioning almost entirely on fossil fuels, so the investment in technologies such as WTE plants, biomass CHP, geo-thermal or waste heat will reduce the dependency on fossil fuels and their fluctuating prices and overall, will improve the security of supply of the country.

In the case of WTE plants and waste heat there are no costs with the fuels. The investment in such new types of technology will create a spill-over in the economy, and will breathe new life in some sectors of the economy which have been disregarded until now. The waste management sector has received little attention so far, and in Romania there are no waste incinerators, 99% of the waste being landfilled (Turton, 2014). Waste heat is available in high quantities in all the three cities, but none of them are using it, and such a type of investment can create a precedent in the country. The biofuel industry would also benefit if more of the heat production will be using this type of energy source.

Another type of spill over in the economy is on the customer side, as due to the reduced prices of heat provided by the use of district heating, the buying power of the population is increased. If individual heating would be used, the total percentage of the heating bill from the annual income can get up to 11%, in the cases of Oradea and Timisoara, where the income is lower than in Bucharest. With district heating, the percentage would only be 7% for both of them, and 3% in the case of Bucharest. If heat savings are added for all the cases, then the average cost of heat for the customer would be between 1.5 and 5%.

The heat savings account for the highest share of costs for all the cities, even with the lowest, standard costs for building insulation. These heat savings are seen as a necessity for the entire building stock of Romania, and currently the way these are done is with a direct cost, especially for the blocks of flats, which represent the majority of dwellings in all the three cities analysed, since no other maintenance or extensions works are done. However, since the annualised cost of these heat savings is spread over 40 years, due to their long technical lifetime, the costs are easier to be supported by the population.

Consequently, from an economic point of view, the development of district heating for all the three cities will bring important economic advantages. If there is the risk that heat savings will not be implemented, district heating will still provide a lower price than a heating system based on individual solutions. Therefore, since the investments in urban heating solutions ultimately affects the end consumers, the prices of heating up a dwelling, presented in Tables 20, 40 and 58 clearly show that it is cheaper to supply heat through district heating than through individual solutions.

Environmental

From an environmental perspective, the results obtained in the three case studies demonstrate that the use of district heating is more environmentally friendly than the individual heating solutions. The amount of CO_2 emitted in the atmosphere in Scenario III with district heating is, for Bucharest and Timisoara, bellow the emissions in Scenario II when only individual and collective heating solutions are used. The situation remains similar when the heat savings are applied, proving that the more customers are supplied by district heating, the less CO_2 emissions are released into the atmosphere. Nevertheless, even though in the case of Oradea the emissions of CO_2 are higher with district heating, it is important to remember that in case of district heating with CHP, electricity comes as a side product, still making the entire system more environmentally friendly than with the individual solutions.

Besides the CO_2 emissions, other harmful substances are emitted into the atmosphere when fossil fuels are burnt. Such substances are the SO_2, NOx, or fine dust particles. Since the amount of SO_2, NO_x and dust is unknown for the existing heat production outline presented in Scenario I, it is important to focus on the fossil fuel used in the other two scenario, which is natural gas. This fuel contains mainly methane, but also other hydrocarbons, as sulphur, radon, and a series of other impurities depending on the source of gas. As natural gas is burned in the air, which contains nitrogen as a main component, NO_x is formed. This type of burning includes tens if chemical reactions, many of them based on free radicals (Benga, Fowler, Haiduc, & Nastase, 2004).

Thus, from the fossil fuel dependency parameter it can be found out in which of the other two scenarios these substances are more likely to be found in higher quantities (Tables 21, 41, 59). In two of the three cases, Bucharest and Timisoara, district heating uses less gas and electricity than in the case of individual heating. For Oradea, the values for gas are slightly higher, as the newly installed CHP plant is still included in the production outline. With the heat savings applied, the values decrease in all scenarios, but in the case of Oradea, these still remain slightly higher than in the other cities, due to the presumably oversized CHP unit. However, this CHP could be adapted to use biofuels in the future.

However, this proves itself as less of a problem compared to Scenario II, where the installation of individual heating has other disadvantages compared to decentralized solutions. The burned gasses eliminated through the chimneys of individual boilers, located on the envelope of the blocks of flats, just next to the windows, terraces and other openings of the buildings can easily enter inside the flats. The emissions form the individual boilers are not to be compared with the limit values of emissions, as they would be eliminated though chimneys located above the roofs, but with the concentrations of the breathable air. The concentration of harmful emissions decreases 10 times at a distance equal to 30 diameters of the chimney. That is, through a 6 cm chimney, the emissions will reduce 10 times at a distance of 180 cm, close to the entrance of many windows or terraces. Therefore, 10% if the emissions are still above the accepted international values (Benga et al., 2004).

Consequently, the specially designed plants which can make a proper evacuation of the harmful gasses in controlled conditions bring more advantages than the, more or less, improvised individual heating solutions in dwellings which were not built to have evacuation chimneys. Such installations also increase the danger of fire and intoxication caused by the indoor connections to the natural gas network. Thus, district heating has the advantage over the individual solutions of reduced CO_2 and other harmful emissions, but also of increased indoor safety.

Social

Since the analysis of this study has been mainly aimed towards the economic and environmental perspective, it is important to bring forward the social perspective too, which actually overlaps with the other two pillars of sustainability.

The reduction of harmful emissions both through the use of district heating but also through the use of less fossil fuels, or more renewables, has an advantage over the social part, as the level of health is increased. The customers will also gain more floor space, which otherwise would be taken by the individual heating equipment.

Another parameter which overlaps the social and economic parameter is the creation of new jobs. The development of district heating will provide the opportunity of creating direct jobs, for the people employed in for the construction of the heat supply and heat transport system, but also indirectly, in the district heating sector and tertiary industries. A quantification of the number of future available jobs in each city is difficult to estimate, but by using some examples from other countries can create an idea over the scale of employment such an investment would have.

In the UK, the development of a 45 GWh district heating network in Stoke-on-Trent was expected to create at least 200 direct new employments, plus another 1350 in the related supply chain (Gov.uk, 2014). In Denmark, the expansion and improvement of the district heating networks has created 6000 new jobs in 2013 (District Energy, 2013). According to another publication, the expansion of a district heating network in Denmark from 64% to 70% can create up to 8000 permanent jobs every year and 18.000 temporary jobs in 10 years' time (The Green ThinkTank, n.d.).

On the other hand, the development of district heating will also create a share of unemployment, as the individual heating sector is likely to lose jobs if such a change is made. However, even though jobs are to be lost in this sector, more jobs can be created if the investment in district heating is accompanied by heat savings. It is difficult to quantify how many new jobs such an investment would create, but these would employ both qualified and unqualified work force. This has always proved as an issue in Romania, as workers often choose to leave the country in the search of employment. Therefore, by keeping this work force in the country would bring benefits on both the social, but especially on the economic side.

Finally, the overall conclusion over the case studies presented is that district heating bring more advantages than individual heating does, even if it is used in large cities with high heat densities, or small sized ones with lower densities. All three cities must focus on retrofitting their aging networks, diversify the heat supply using waste heat and renewable energy sources and most importantly, accelerate the retrofit of the building stock, as all these elements combined bring advantages on the economic, environmental and social sides.

6. Comparison with the national level results

Since on a local level it is demonstrated that district heating brings more benefits to the society than individual heat only solutions, the comparison with the national results for Romania obtained in Stratego (Connolly et al., 2015) becomes necessary, in order to confirm if the situation on the local level matches the situation on a national level, so that this finally creates the paradigmatic case of district heating in Romania (Flyvbjerg, 2006).

The key results obtained in Stratego (2015), are separated between '*Heat savings*' and '*District heating in urban areas*'. The results are based on the synthesis of the case studies, national level recommendations and the feasibility study design.

Heat savings

1. *Heat savings reduce the energy demand, carbon emissions and costs but eventually become more expensive than the cost of supplying sustainable heat*

There is always a positive impact of heat savings when applied to the energy system. These reduce the emissions, the amount of fuels used, the costs with heating and also create jobs. The jobs are created regardless of the type of retrofit done, being it the standard or the high efficiency one. However, the level of thermal insulation affects the rest of the parameters, thus in this study, the standard level of retrofit is considered as sufficient to reduce the heat demand to the maximum level recommended for existing buildings and to provide a more accurate idea of which are the minimal costs of applying this measure.

There is also the option to invest in the high efficiency retrofit for all the building stock, since the retrofit will be done anyway sooner or later and the retrofit works are expected to take several decades to be completed (result #3). The costs for the high efficiency retrofit would be in almost all the cases two or three times more expensive than investing in a new heat supply, distribution system and customer infrastructure. So the cost of these savings would eventually be higher than supplying sustainable heat. Apart from this, there is also the possibility that even though the high efficiency retrofit is applied, the final heat demand will not decrease to the expected level due to customer behaviour (Mathiesen et al., 2016).

2. *The average heat demand including space heating and hot water, should be reduced by approximately 50% in total*

Heat savings are one of the key measures to be adopted by Romania regardless of the type of heating used. Up to 75% of the building stock in the country was built 45-50 years ago, during the Communist regime, with no concern about thermal insulation (Leca, 2015). The average heat demand of the existing building stock for the three cities analysed is estimated to 185 kWh/m²/year.

By considering a maximum heat demand of 100 kWh/m²/year for all the case studies after the heat savings are applied, confirms the findings in Stratego (Connolly et al., 2015), of reducing the heat demand to 50% of the values today. However, the value suggested in the national study is 60-70 kWh/m²/year, which was considered as the most cost-efficient value of heat savings without making them more expensive than supplying sustainable heat.

Thus, the values estimated in the present study are more conservative, but the level of standard heat savings is considered as sufficient for reducing the heat demand to the maximum accepted. Nevertheless, by considering that the level of heat demand is not always dependent on the amount of heat savings applied, but also on the behaviour of the inhabitants of the dwellings (Mathiesen et al., 2016), the slightly oversized heat supply and heat distribution presumably make it more adapted to the situation on site.

3. *Heat savings should be implemented over a long-term time horizon, in combination with other building renovations*

The time horizon for implementing heat savings in this study is considered to be 40 years, as long as the lifetime of a district heating network, to better compare the results. The thermal retrofit should be done in combination with other building renovations, as the costs for this activity presented in this study only represent marginal ones. If the thermal insulation would be done separately, the costs would be higher than supplying sustainable heat.

However, since the average renovation rate in Romania is only 1,7% p.a. (Connolly et al., 2015), for example, in the case of Bucharest no less than 60 years would be necessary to complete the retrofit for the remaining blocks of flats. Thus, in the case of Romania, a high percentage of thermal insulation would most likely have a direct cost, if the 40 years' timeline is considered, thus increasing the standard level of cost presented in this study. Nevertheless, the heat savings should be implemented as soon as possible, so there will be sufficient time to implement them at the lowest price.

4. *There are synergies between the reduction of the heat demand and improvements in the heat supply, such as reducing the thermal capacity required and enabling more heat sources to be utilised on the district heating network.*

The gradual reduction of heat demand through heat savings will provide the possibility of replacing and reducing the capacity of the heat supply infrastructure. The heat sources to replace the old infrastructure should mainly avoid using gas, as this possibility is given when the heat demand is reduced, by a better employment of alternative fuels such as MSW, biomass, geo-thermal heat, or waste heat among others.

The reduction of the total heat demand will provide the possibility of gradually re-dimensioning and redesigning (when necessary) the pipes of the district heating system. The advantage of replacing pipes already in the ground is that much of the physical space for the infrastructure is already in place and can be reused.

Furthermore, a reduced heat demand will also provide the opportunity of shaving off the high peak loads the district heating system is experiencing today and would have to manage if no heat savings would be made.

District heating in urban areas

5. *District heating is more efficient and cost effective in urban areas than natural gas networks*

District heating is more recommended in high density areas due to the more varied types of heat sources it can use, thus reducing the amount of fossil fuels used. In all the scenarios of this study, district heating is using less gas than in the individual heating scenarios, and also less electricity, which in Romania is mainly produced through the use of fossil fuels. Thus, the costs with the fuels are lower.

The main advantage of district heating is that it eliminates the unit costs, by having several bigger units which can be better sized, operated and optimized, resulting in lower capacities and finally in lower heat prices for the end consumer.

6. *District heating can utilise very large amounts of excess heat and heat from renewable resources, which are wasted today in the energy system*

There are over 100 TWh/year of excess heat in Romania coming from thermal power generation, industry, geo-thermal and solar thermal, which represents three times more than the necessary to supply heat in all the proposed district heating systems of Romania (Connolly et al., 2015). In all three case studies such types of excess heat are included, and given the fact they do not use fuels (except for transporting the heat) they provide the lowest price of heat after the WTE plants.

If more waste heat would be used, such as the flue gas from the co-generation plants (approximately 20% of total fuel input), then this would further reduce the necessary capacities to be installed for these plants. However, if the district heating pipes would not be installed, then all these resources would be wasted.

7. *District heating pipes represent a relatively small fraction of the annualised district heating system cost (~5-15%)*

The initial investments in the new and extended district heating system are for the heat supply, the heat transport and the substation in the buildings. According to Connolly (2015), out of this cost, the district heating pipes have the smallest share of the total costs, of approximately 5-15%, depending on the heat density. This is confirmed in the case of all three cities, where the pipes have a share of the total costs between 4-11%, for both the scenarios without and with heat savings, confirming the low investment stated in the national study. This is mainly due to the long lifetime expectancy of pipes, estimated to be around 40 years, compared with the rest of the infrastructure which has a lifetime of up to 25 years. Consequently, the costs of the heat supply and substations are higher over the lifetime of the district heating system (Connolly et al., 2015).

The approximate costs for the heat production are estimated to be €50/MWh, based on the average costs in 20 district heating systems in Denmark (Connolly et al., 2015). In the case of the three cities analysed in this study, the average costs are estimated to be €56/MWh, with the lowest price of heat in Bucharest, demonstrating that a high density brings lower costs for the customers.

Consequently, the overall conclusion in Stratego (Connolly et al., 2015) establishes that a combination of energy efficiency measures in the form of heat savings and district heating in urban areas will reduce the total energy demand, the energy system costs and the carbon emissions. All the three benefits are achieved in all the three case studies, even though the cities are different in terms of size, heat density and background, confirming that the results obtained on a local level are confirmed with the ones on a national level, thus providing the possibility of extending the knowledge to other cities of Romania or Eastern Europe.

7. Recommendations

Romania is experiencing an urbanisation process, as the rest of Europe, and apart from the capital city, Timisoara and Oradea are experiencing a growing population, as many other large Romanian cities. Therefore, since the type of heating used in urban areas is critical for the sustainability of cities, and district heating has been confirmed as the recommended solution from both the city level analysis (Chapter 4 and 5) and the national level one (Connolly et al., 2015), it is relevant to find out how the policies for urban heating can adapt so that Romania can benefit from a high quality district heating system.

After the Revolution in 1989, district heating was largely disregarded by the authorities, which do not fully acknowledge its importance even today, even though Romania has a long tradition with district heating. Therefore, this chapter intends to provide several recommendations for the Romanian authorities on how to improve their district heating strategies. The recommendations are based on the existing regulatory framework, the case study results, the national level results in Stratego (Connolly et al., 2015), inspired by insights from the Danish communal heat planning, which over time has proven as a success model in terms of heat plans, heat distribution, maximisation of efficiency and using new resources for district heating (Chittum & Østergaard, 2014).

Thus, since the decision-making in energy planning has to be done with top-down and bottom-up policies, the same structure is applied across this chapter, with recommendations for the Romanian government, the municipalities, district heating companies and customers.

Government

The Romanian government is the main decision maker of the national energy market. One of the main changes it can make, through the prime minister, the delegated ministries and other actors in the energy market, is to adopt a *Strategy for thermal energy* (Leca, 2015). The strategy should maximize the development and use of CHP, renewable energy sources and district heating. This strategy is recommended to be included as part of the *Energy strategy for Romania*, which currently offers little attention to the heating part, mainly focusing on electricity.

Through such a strategy, the government can create a framework for the development of district heating, which can be used as a tool on a local level to create heat plans in connection with the national and European goals and targets for energy efficiency. The framework should be based on European (Connolly et al., 2012, 2014; European Commission, 2016), national (Connolly et al., 2015) and local feasibility plans and studies, which best serve the society as a whole.

As part of the changes at this level, the Romanian government is recommended to re-establish the regulatory authorities, which today are the ANRE, responsible with the co-generation district heating systems, and ANRSC, responsible with the HoB ones. In the future energy system, the role of the latter one turns to be unnecessary, as no district heating should function based solely on HoB, as this would contradict the fundamental idea of district heating, of using local resources and fuels that otherwise would be wasted (Werner & Fredriksen, 2013). By having two authorities with similar responsibilities, their strategies become confusing, and the roles undetermined.

Therefore, one of the two authorities is recommended to receive the role of single regulator, coordinator and license emitter for district heating. Another authority, currently named the Competition Council (CC), or another dedicated authority for district heating, can monitor the prices and monopoly of companies, consider the complaints from the customers and finally apply fines in case of failure to respect the strategies in place (Chittum & Østergaard, 2014).

Municipalities

Through a new thermal energy strategy, municipalities can be provided with high authority when it comes to self-organising themselves, from both heat savings to heat efficiency level.

One of the fastest and key actions to be taken by the municipalities is to improve the retrofitting rate of the buildings, and the existing thermal retrofit program is essentially well-intended, but badly employed. The existing program consists in an 80% subsidy out of the total retrofit cost from the Romanian state and local municipality, leaving the final consumer to pay the remaining 20%. The main actions to ease the implementation of this program would be a simplification of the bureaucracy, administrative process and the re-establishment of the OA or other a similar entity as a liaison between the local administration and consumers in the situations where the OA does not exist anymore.

Nevertheless, the majority of the funds for retrofit should be first intended for the most disadvantaged social categories and worst performing buildings.

Another important step made by the Government of Romania was in 2002, with the transfer of ownership of the district heating systems to the local authorities by allowing them to self-organise their heating strategies, but this transfer did not bring visible changes to the end consumer.

However, with a functional strategy for thermal energy in place, the municipalities can be required to conduct an analysis of their local resources and heat demand so they can develop new heat plans and undertake specific projects of developing and/or retrofitting the district heating networks. The municipalities should be the final arbiters when selecting the most cost-effective of the projects, and these should be done in the best interest of the communities (Chittum & Østergaard, 2014).

The municipalities should also find ways to limit the disconnections for the district heating network and increase the number of reconnections, in order to support the goals of achieving an efficient and cheap district heating system. For example, one tool to be used would be the establishment of unitary district heating areas, to limit the switch to individual heating solutions (Chittum & Østergaard, 2014).

However, such a measure should also be accompanied by high quality services and heat on demand, at competitive prices, elements currently missing in many of the existing district heating networks. As it could be observed in the case of Bucharest, by having a high heat density with numerous connections, the lower the price paid for heat is, the better leveraged the fuel costs or equipment failures are, along the other environmental and social benefits (Chapter 5).

As a particular situation in Romania, the aim of the municipality, with the help of the district heating companies, should be to improve the bad image district heating has in the country, and this can be done through several measures, such as:

- providing high quality heat and DHW at a competitive price;
- establishing the binomial tariff to eliminate the high costs of heat in the winter;
- allowing the end-consumers to take part in the decision-making processes;
- ensuring the transparency of the costs and actions for district heating development.

By using the example of the Danish communal planning (Chittum & Østergaard, 2014) municipalities should be provided with more possibilities of regulating the development of the district heating system. This ability of overseeing major aspects of the district heating development can help them to assess the future development but also how to interact with the heating systems of the neighbouring municipalities.

District heating companies

The district heating companies in Romania are owned by the municipalities but also by commercial companies. In case of the latter ones, the municipality should still retain a major part of the decision making processes to influence the activities of the companies. The type of ownership is not very important in this context as long as the municipalities and the consumers through the OA, are the final decisions arbiters, acting in the interest of the community and in protecting the unitary development of district heating.

District heating companies are recommended to be regulated as non-profit entities, as part the new strategy, so these will not have reasons to overlook the end-consumer interest for the interest of business. However, they should still find ways to self-finance themselves, so they can make the investments when they need to, not when there is enough capital. In this sense, for the major investments, municipalities can also act as a guarantor, to obtain reduced interest rates (Chittum & Østergaard, 2014).

On a practical side, the district heating companies, with the help of the municipalities and OA, should find a consensus in terms of correctly and efficiently metering the heat and DHW in the apartments with a vertical distribution of heat. The installation of individual substations in each building, as suggested in this study, should allow for a better distribution of the expenses.

Owner associations and end-consumers

The role of the OA as an intermediary between the district heating companies and end-consumers is essentially good, but the bureaucracy and lack of interest of the OA and end-consumers to collaborate with the district heating companies resulted in a deadlock in many situations. Thus, the OA should be reinstated in the cases where these do not exist anymore under a more efficient organisation, and should be given the right to take part in the decision-making processes through elected representatives. The customers should also be provided with access to the reports of the costs and investments made each year, to ensure the transparency of the decisions.

Whilst the municipalities are to be provided with the right of establishing unitary district heating areas, the customers, through the voice of the OA, should be consulted prior to the connection or disconnection to the system, in case they have the right to be exempted for connecting to district heating for a good particular good reason, such as an already installed heating system based on RES (Chittum & Østergaard, 2014).

The OA should also have a determining role for the retrofitting part, as a liaison between the owners and the authorities. The existing national program for retrofit relies on the cooperation with the OA, so the authority of this association is should be increased.

Since the retrofit programs are intended for the blocks of flats only, a similar type of association can be developed for this category of buildings, in the attempt to incentivize the frequency the retrofit measures are implemented. Compared to the blocks of flats, the renovations and modifications of the houses are presumably easier to implement, due to the existence of a single owner, but a national support scheme should be directed especially to the disadvantaged social categories.

To conclude the recommendations, it can be agreed Romania needs strong political support and consensus to promote district heating in urban areas. It is necessary that the decision makers recognise the importance of this sector in achieving the country's goals in terms of energy efficiency, security of supply and decarbonisation.

The main elements recommended for the development of this sector are represented by the establishment of a strong thermal energy strategy, the decentralisation of the power towards a local level, the transparency of the activities of both the municipalities and district heating companies, and the recognition of the importance of OA.

At the same time, the central government should reinforce and simplify the procedures for retrofitting the building stock and cooperate better with the municipalities and OA in order to accelerate the retrofit of the aging building stock.

8. Conclusion

The present feasibility study provides an analysis of different scenarios for heating in urban areas in three Romanian cities, Bucharest, Timisoara and Oradea, aiming to find out which solution, between the business-as-usual, individual heating and district heating is the most feasible from an economic, environmental and social point of view.

Since in all three case studies, district heating was demonstrated as the most efficient and cost-effective solution, with the results matching with the ones on a national level (Connolly et al., 2015), provides another confirmation for the Romanian authorities on the importance of focusing more on developing the thermal energy strategies in urban areas through building new district heating systems, modernising and extending the existing ones and focusing on using excess and renewable heat as a replacement for fossil fuels.

The strategies for heating in urban areas must be accompanied by a reduction of the heat demand in buildings to approximately 50% of today's levels, which can be accomplished by retrofitting the existing building stock, starting with the most energy intensive buildings and the most disadvantaged category of population.

In other words, the intent of this study is to reconfirm the relevance of using increased levels of district heating in urban areas, accompanied by heat savings, to provide a cost effective, low carbon solution, which can support the local economies, create local jobs and contribute to an increased level of health for the population. The country needs clear strategies and actions to be taken for this sector of energy (more than on a declarative level), and a decentralisation of power towards municipalities and end-consumers, to finally improve the image of district heating in Romania.

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Appendix 1 - Scenario II - Bucharest

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Collective gas boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-20	5	10	300-750	300-1000
Average heat production capacity for one unit (kW)	12,5	10	10	525	550
Total efficiency, annual average, net (%)	100	100	330	100	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	8,9	8,9	2,9	720.000	400.000
Specific investment (1000€/kW)	0,16	0,20	1	0,04	0,17
Specific investment (1000€/unit)	2	2	5	5-35	
Average specific investment (1000€/unit)	2	2	5	20	94
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,5	2	2
Fixed O&M (€/kW/year)	10,80	10,00	15,00	4,00	6,30
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/GJ)				2,00	
Variable O&M (€/MWh)				7,20	

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,5	2,5	5,5	22,0	95,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/MWh)	0,0	0,0	0,0	7,2	0,0
Number of units	400.000	240.000	40.000	3.000	1.500
Total Investment (M€)	1000	600	220	66	143
Annual Investment (M€)	59,7	35,8	13,1	3,9	8,6
Annual fixed O&M (M€/year)	54,0	24,0	6,0	4,6	5,2
Annual variable O&M (M€/year)				0,2	
Annual costs (M€/year)	113,7	59,8	19,1	8,8	13,7
Annual fuel costs (M€/year)	110,36	277,68	15,08	22,32	9,60
Annual and fuel costs (M€/year)	224,1	337,5	34,2	31,1	23,3

Total investment all heating solutions (M€)	2029
Total annual investment all heating solutions (M€)	121,1
Total annual costs (M€/year)	215,2
Total fuel costs (M€/year)	435,0
Total annual costs with fuels (M€/year)	650,2
Price of heat (€/dwelling)	812,8

Appendix 2 - Scenario III - Bucharest

Interest rate	1,75%				
	Waste-to-energy	**Large heat pumps**	**Gas CHP**	**Waste heat**	**Gas peak boilers**
Energy input price (€/MWh)	0,0	83,0	30,0	0,0	30,0
Heat efficiency %	50,0	300,0	50,0	100,0	90,0
Heat production capacity (MW)	225,0	100,0	400,0	580,0	660,0
Technical lifetime (years)	20,0	20,0	25,0	35,0	35,0
Annual heat production (GWh)	1.800,0	800,0	2.000,0	2.900,0	1.100,0
Annual fuel consumption (GWh)	0,0	266,0	4.000,0	0,0	1.222,0
Price of sold electricity (€/MWh)	24,0		25,0		
Sold electricity (M€)	26,0		30,0		
Specific investment (M€/MW)	2-2,4	0,54-0,84	0,8-1,2	0,03-0,07	0,07-0,13
Average spacific investment (M€/MW)	2,2	0,7	1,0	0,1	0,1
Fixed O&M (€/MW/year)	353.300	3700-7300	0,0	600,0	1200-6200
Average fixed O&M (€/MW/year)	353.300	5.500,0	0,0	600,0	3.700,0
Variable O&M (€/GWh)	0,0	0,0	2.500,0	0,0	0,0
Total investment (M€)	495,0	69,0	400,0	29,0	66,0
Annual investment (M€)	29,5	4,1	19,9	1,1	2,5
Annual fixed O&M (M€/year)	79,5	0,6	0,0	0,3	2,4
Annual variable O&M (M€)	0,0	0,0	5,0	0,0	0,0
Fuel costs (M€)	0,0	22,1	120,0	0,0	36,7
Total annual costs (M€)	0,5	26,7	114,9	1,5	41,6
Price of heat (€/GWh)	299,8	33.433,4	57.445,9	504,5	37.854,3

District heating network	
Net loss (%)	18,0
Pump energy (MWh/TJ/year)	0.2-4
Average pump energy (MWh/TJ/year)	2,1
Average pump energy (MWh/TWh/year)	7.560,0
Technical lifetime (years)	30-50
Average technical lifetime (years)	40,0
Investment costs (1000 €/TJ)	18-22
Average investment costs (1000 €/TJ)	20,0
Fixed O&M (€/TJ/year)	250,0
Average investment costs (1000 €/TWh)	72.000,0
Average fixed O&M (€/TWh/year)	900.000,0
Specific investment costs (1000 €/TWh)	72.000,0
Total heat demand (TWh)	7,2
Total electricity for pumps (TWh)	0,054
Total investment (M€)	518,4
Annual investment (M€)	18,1
Annual fixed O&M (M€/year)	6,5
Total annual costs (M€)	24,6

District heating substation	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	7.470,0
Total investment (M€)	130,7
Annual investment (M€)	7,8
Annual fixed O&M (M€/year)	1,1
Total annual costs (M€)	8,9

Total	
Total investment (M€)	1.708,1
Total annual investment (M€)	83,1
Total fixed O&M ((M€/year)	90,4
Total annual variable O&M (M€)	5,0
Total fuel costs (M€/year)	178,7
Total annual costs-including fuel (M€)	218,8

Price of heat	
Average price of heat (€/MWh)	25,9
Average price of heat/dwelling (€)	230,58
Distribution costs/dwelling (€)	30,76
Final price of heat (€/dwelling/year)	261,34

Appendix 3 - Scenario II - Heat savings - Bucharest

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Collective gas boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-15	5	8	200	250
Average heat production capacity for one unit (kW)	10,0	8	8	200	250
Total efficiency, annual average, net (%)	100	100	330	100	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	4,4	4,4	1,5	352.000	195.200
Specific investment (1000€/kW)	0,18	0,24	1	0,05	0,17
Specific investment (1000€/unit)	1,80	1,80	4,5	5-15	
Average specific investment (1000€/unit)	2	2	5	10	43
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,0	2	2
Fixed O&M (€/kW/year)	13,50	10,00	18,75	4,00	6,30
Fixed O&M (€/unit/year)	135,00	75,00	150,00	1.540,00	3.465,00
Variable O&M (€/GJ)				2,00	
Variable O&M (€/MWh)				7,20	

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,3	2,3	4,5	12,0	44,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	75,00	150,00	1.540,00	3.465,00
Variable O&M (€/MWh)	0,0	0,0	0,0	7,2	0,0
Number of units	400.000	240.000	40.000	3.000	1.500
Total Investment (M€)	920	552	180	36	67
Annual Investment (M€)	54,9	32,9	10,7	2,1	4,0
Annual fixed O&M (M€/year)	54,0	18,0	6,0	4,6	5,2
Annual variable O&M (M€/year)				0,2	
Annual costs (M€/year)	108,9	50,9	16,7	7,0	9,2
Annual fuel costs (M€/year)	54,56	137,28	7,59	10,91	4,68
Annual and fuel costs (M€/year)	163,5	188,2	24,3	17,9	13,9

Total investment all heating solutions (M€)	1.755
Total annual investment all heating solutions (M€)	104,7
Total annual costs (M€/year)	192,8
Total fuel costs (M€/year)	215,0
Total annual costs with fuels (M€/year)	407,8

Heat savings	**Standard***	**High efficiency**
Total investment (M€)	2.285	5.235
Total annual investment (M€)	79,91	183,08

Price of heat (€/dwelling)	509,8

* for the remaining buildings

Appendix 4 - Scenario III - Heat Savings - Bucharest

Interest rate	1,75%				
	Waste-to-energy	**Large heat pumps**	**Gas CHP**	**Waste heat**	**Gas peak boilers**
Energy input price (€/MWh)	0,0	83,0	30,0	0,0	30,0
Heat efficiency %	50,0	300,0	50,0	100,0	90,0
Heat production capacity (MW)	100,0	50,0	200,0	270,0	400,0
Technical lifetime (years)	20,0	20,0	25,0	35,0	35,0
Annual heat production (GWh)	800,0	400,0	1.000,0	1.350,0	600,0
Annual fuel consumption (GWh)	0,0	133,3	2.000,0	0,0	666,0
Price of sold electricity (€/MWh)	24,0		25,0		
Sold electricity (M€)	11,5		15,0		
Specific investment (M€/MW)	2-2,4	0,54-0,84	0,8-1,2	0,03-0,07	0,07-0,13
Average spacific investment (M€/MW)	2,2	0,7	1,0	0,1	0,1
Fixed O&M (€/MW/year)	344.500	3700-7300	0,0	600,0	1200-6200
Average fixed O&M (€/MW/year)	344.500	5.500,0	0,0	600,0	3.700,0
Variable O&M (€/GWh)	0,0	0,0	2.500,0	0,0	0,0
Total investment (M€)	220,0	34,5	200,0	13,5	40,0
Annual investment (M€)	13,1	2,1	9,9	0,5	1,5
Annual fixed O&M (M€/year)	34,5	0,3	0,0	0,2	1,5
Annual variable O&M (M€)	0,0	0,0	2,5	0,0	0,0
Fuel costs (M€)	0,0	11,1	60,0	0,0	20,0
Total annual costs (M€)	0,4	13,4	57,4	0,7	23,0
Price of heat (€/GWh)	477,6	33.501,8	57.445,9	504,5	38.330,1

District heating network	**Conventional**	**4GDH**
Net loss (%)	18,0	14,0
Pump energy (MWh/TJ/year)	0.2-4	1-4
Average pump energy (MWh/TJ/year)	2,1	2,5
Average pump energy (MWh/TWh/year)	7.560,0	9.000,0
Technical lifetime (years)	30-50	30-50
Average technical lifetime (years)	40,0	40,0
Investment costs (1000 €/TJ)	18-22	135-155
Average investment costs (1000 €/TJ)	20,0	145,0
Fixed O&M (€/TJ/year)	250,0	1.100,0
Average investment costs (1000 €/TWh)	72.000,0	522.000,0
Average fixed O&M (€/TWh/year)	900.000,0	3.960.000,0
Specific investment costs (1000 €/TWh)	72.000,0	522.000,0
Total heat demand (TWh)	3,5	3,5
Total electricity for pumps (TWh)	0,026	0,032
Total investment (M€)	252,0	1.827,0
Annual investment (M€)	8,8	63,9
Annual fixed O&M (M€/year)	3,2	13,9
Total annual costs (M€)	12,0	77,8

District heating substation	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	7.470,0
Total investment (M€)	130,7
Annual investment (M€)	7,8
Annual fixed O&M (M€/year)	1,1
Total annual costs (M€)	8,9

Total	
Total investment (M€)	890,7
Total annual investment (M€)	43,8
Total fixed O&M ((M€/year)	40,6
Total annual variable O&M (M€)	2,5
Total fuel costs (M€/year)	91,0
Total annual costs-including fuel (M€)	115,8

Heat savings	**Standard***	**High efficiency**
Total investment (M€)	2.285	5.235
Total annual investment (M€)	79,91	183,08

Price of heat	
Average price of heat (€/MWh)	26,1
Average price of heat/dwelling (€)	104,21
Distribution costs/dwelling (€)	14,95
Final price of heat (€/dwelling/year)	119,16

* for the remaining buildings

Appendix 5 - Scenario II - Timisoara

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Existing substation boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-20	5	10	4360	300-1000
Average heat production capacity for one unit (kW)	12,5	10	10	4360	650
Total efficiency, annual average, net (%)	100	100	330	85	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	8,2	8,2	2,7	55.000	145.000
Specific investment (1000€/kW)	0,16	0,20	1		0,17
Specific investment (1000€/unit)	2	2	5	35	
Average specific investment (1000€/unit)	2	2	5	35	111
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,5	0	2
Fixed O&M (€/kW/year)	10,80	10,00	15,00	4,00	6,30
Fixed O&M (€/unit/year)	135,00	100,00	150,00	15.910,00	3.465,00

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,5	2,5	5,5	35,0	112,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	100,00	150,00	15.910,00	3.465,00
Number of units	61.000	36.600	4.000	11	560
Total Investment (M€)	153	92	22	0,39	63
Annual Investment (M€)	9,1	5,5	1,3	0,0	3,8
Annual fixed O&M (M€/year)	8,2	3,7	0,6	0,2	1,9
Annual costs (M€/year)	17,3	9,1	1,9	0,2	5,7
Annual fuel costs (M€/year)	15,51	39,02	1,40	1,71	3,48
Annual and fuel costs (M€/year)	32,8	48,1	3,3	1,9	9,2

Total investment all heating solutions (M€)	329
Total annual investment all heating solutions (M€)	19,7
Total annual costs (M€/year)	34,3
Total fuel costs (M€/year)	61,1
Total annual costs with fuels (M€/year)	95,4
Price of heat (€/dwelling)	781,8

Appendix 6 - Scenario III - Timisoara

Interest rate	1,75%				
	Waste-to-energy	**Geo-thermal plant**	**Gas CHP**	**Biomass CHP**	**Gas peak boilers**
Energy input price (€/MWh)		83,0	30,0	24,0	30,0
Heat efficiency %	50,0		50,0	55,0	90,0
Heat production capacity (MW)	23,0	23,0	10,0	80,0	245,0
Technical lifetime (years)	20,0	25,0	25,0	20,0	35,0
Annual heat production (GWh)	180,0	180,0	50,0	400,0	370,0
Annual fuel consumption (GWh)	0,0	0,0	100,0	727,0	411,0
Price of sold electricity (€/MWh)	25,0		25,0	25,0	
Sold electricity (M€)	2,7		0,75	4,5	
Specific investment (M€/MW)	2-3	1,8	0,0	3-5	0,07-0,13
Average spacific investment (M€/MW)	2,6	1,8	0,0	4,0	0,1
Fixed O&M (€/MW/year)	345.600	47.000,0	0,0	120.000,0	1200-6200
Average fixed O&M (€/MW/year)	345.600	47.000,0	0,0	120.000,0	3.700,0
Variable O&M (€/GWh)	0,0	0,0	2.500,0	0,0	0,0
Total investment (M€)	59,8	41,4	0,0	320,0	24,5
Annual investment (M€)	3,6	2,1	0,0	19,1	0,9
Annual fixed O&M (M€/year)	7,9	1,1	0,0	9,6	0,9
Annual variable O&M (M€)	0,0	0,0	0,1	0,0	0,0
Fuel costs (M€)	0,0	0,0	3,0	17,4	12,3
Total annual costs (M€)	0,12	3,1	2,4	41,6	14,2
Price of heat (€/GWh)	657,4	17.444,7	47.500,0	104.123,0	38.320,4

District heating network	
Net loss (%)	18,0
Pump energy (MWh/TJ/year)	0.2-4
Average pump energy (MWh/TJ/year)	2,1
Average pump energy (MWh/TWh/year)	7.560,0
Technical lifetime (years)	30-50
Average technical lifetime (years)	40,0
Investment costs (1000 €/TJ)	18-22
Average investment costs (1000 €/TJ)	20,0
Fixed O&M (€/TJ/year)	250,0
Average investment costs (1000 €/TWh)	72.000,0
Average fixed O&M (€/TWh/year)	900.000,0
Specific investment costs (1000 €/TWh)	72.000,0
Total heat demand (TWh)	1,0
Total electricity for pumps (TWh)	0,008
Total investment (M€)	72,0
Annual investment (M€)	2,5
Annual fixed O&M (M€/year)	0,9
Total annual costs (M€)	3,4

District heating substation - blocks	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	1.250,0
Number of Units	3.240,0
Total investment (M€)	56,7
Annual investment (M€)	3,4
Annual fixed O&M (M€/year)	4,1
Total annual costs (M€)	7,4

District heating substation - houses	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	2.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	31.500,0
Total investment (M€)	78,8
Annual investment (M€)	4,7
Annual fixed O&M (M€/year)	4,7
Total annual costs (M€)	9,4

Total	
Total investment (M€)	581,8
Total annual investment (M€)	36,3
Total fixed O&M ((M€/year)	24,5
Total annual variable O&M (M€)	0,1
Total fuel costs (M€/year)	32,8
Total annual costs-including fuel (M€)	81,7

Price of heat	
Average price of heat (€/MWh)	41,6
Average price of heat/dwelling (€)	341,19
Distribution costs/dwelling (€)	166,21
Final price of heat (€/dwelling/year)	507,41

Appendix 7 - Scenario II - Heat savings - Timisoara

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Existing substation boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-15	5	8	4360	250
Average heat production capacity for one unit (kW)	10,0	10	8	4360	250
Total efficiency, annual average, net (%)	100	100	330	85	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	4,4	4,4	1,5	28.000	73.200
Specific investment (1000€/kW)	0,18	0,18	1		0,17
Specific investment (1000€/unit)	1,80	1,80	5	35	
Average specific investment (1000€/unit)	2	2	5	35	43
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,0	0	2
Fixed O&M (€/kW/year)	13,50	10,00	18,75	4,00	6,30
Fixed O&M (€/unit/year)	135,00	100,00	150,00	15.910,00	3.465,00

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,3	2,3	5,0	35,0	44,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	100,00	150,00	15.910,00	3.465,00
Number of units	61.000	36.600	4.000	11	560
Total Investment (M€)	140	84	20	0,39	25
Annual Investment (M€)	8,4	5,0	1,2	0,0	1,5
Annual fixed O&M (M€/year)	8,2	3,7	0,6	0,2	1,9
Annual costs (M€/year)	16,6	8,7	1,8	0,2	3,4
Annual fuel costs (M€/year)	8,32	20,94	0,76	0,87	1,76
Annual and fuel costs (M€/year)	24,9	29,6	2,6	1,1	5,2

Total investment all heating solutions (M€)	270
Total annual investment all heating solutions (M€)	16,1
Total annual costs (M€/year)	30,7
Total fuel costs (M€/year)	32,6
Total annual costs with fuels (M€/year)	63,4

Heat savings	**Standard**	**High efficiency**
Total investment (M€)	551	826
Total annual investment (M€)	19,27	28,89

Price of heat (€/dwelling)	519,3
Price of retrofitt/dwelling (€)	157,95

Appendix 8 - Scenario III - Heat savings - Timisoara

Interest rate	1,75%				
	Waste-to-energy	**Geo-thermal plant**	**Gas CHP**	**Biomass CHP**	**Peak boilers**
Energy input price (€/MWh)		83,0	30,0	24,0	30,0
Heat efficiency %	50,0		50,0	55,0	90,0
Heat production capacity (MW)	13,0	13,0	10,0	42,0	115,0
Technical lifetime (years)	20,0	25,0	25,0	30,0	35,0
Annual heat production (GWh)	100,0	100,0	50,0	210,0	170,0
Annual fuel consumption (GWh)	0,0	0,0	100,0	382,0	189,0
Price of sold electricity (€/MWh)	26,0		25,0	25,0	
Sold electricity (M€)	1,6		0,75	2,4	
Specific investment (M€/MW)	2-3	1,8	0,0	3-5	0,07-0,13
Average spacific investment (M€/MW)	2,6	1,8	0,0	4,0	0,1
Fixed O&M (€/MW/year)	310.000	47.000,0	0,0	120.000,0	1200-6200
Average fixed O&M (€/MW/year)	310.000	47.000,0	0,0	120.000,0	3.700,0
Variable O&M (€/GWh)	0,0	0,0	2.500,0	3.900,0	0,0
Total investment (M€)	33,8	23,4	0,0	168,0	11,5
Annual investment (M€)	2,0	1,2	0,0	7,2	0,4
Annual fixed O&M (M€/year)	4,0	0,6	0,0	5,0	0,4
Annual variable O&M (M€)	0,0	0,0	0,1	0,8	0,0
Fuel costs (M€)	0,0	0,0	3,0	9,2	5,7
Total annual costs (M€)	0,09	1,8	2,4	19,9	6,5
Price of heat (€/GWh)	875,6	17.749,2	47.500,0	94.632,4	38.457,0

District heating network	**Conventional**	**4GDH**
Net loss (%)	18,0	14,0
Pump energy (MWh/TJ/year)	0.2-4	1-4
Average pump energy (MWh/TJ/year)	2,1	2,5
Average pump energy (MWh/TWh/year)	7.560,0	9.000,0
Technical lifetime (years)	30-50	30-50
Average technical lifetime (years)	40,0	40,0
Investment costs (1000 €/TJ)	18-22	135-155
Average investment costs (1000 €/TJ)	20,0	145,0
Fixed O&M (€/TJ/year)	250,0	1.100,0
Average investment costs (1000 €/TWh)	72.000,0	522.000,0
Average fixed O&M (€/TWh/year)	900.000,0	3.960.000,0
Specific investment costs (1000 €/TWh)	72.000,0	522.000,0
Total heat demand (TWh)	0,54	0,54
Total electricity for pumps (TWh)	0,004	0,005
Total investment (M€)	38,9	281,9
Annual investment (M€)	1,4	9,9
Annual fixed O&M (M€/year)	0,5	2,1
Total annual costs (M€)	1,8	12,0

District heating substation - blocks	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	1.250,0
Number of Units	3.240,0
Total investment (M€)	56,7
Annual investment (M€)	3,4
Annual fixed O&M (M€/year)	4,1
Total annual costs (M€)	7,4

District heating substation - houses	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	2.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	31.500,0
Total investment (M€)	78,8
Annual investment (M€)	4,7
Annual fixed O&M (M€/year)	4,7
Total annual costs (M€)	9,4

Total	
Total investment (M€)	387,3
Total annual investment (M€)	20,3
Total fixed O&M ((M€/year)	14,6
Total annual variable O&M (M€)	0,9
Total fuel costs (M€/year)	17,8
Total annual costs-including fuel (M€)	49,4

Heat savings	**Standard**	**High efficiency**
Total investment (M€)	551	826
Total annual investment (M€)	19,27	28,89

Price of heat	
Average price of heat (€/MWh)	39,8
Average price of heat/dwelling (€)	159,37
Distribution costs/dwelling (€)	153,33
Final price of heat (€/dwelling/year)	312,70

Price of retrofitt/dwelling (€)	157,95

Appendix 9 - Scenario II - Oradea

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Collective gas boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-20	5	10	300-750	300-1000
Average heat production capacity for one unit (kW)	12,5	10	10	525	650
Total efficiency, annual average, net (%)	100	100	330	100	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	7,7	7,7	7,7	62.500	59.000
Specific investment (1000€/kW)	0,16	0,20	1	0,04	0,17
Specific investment (1000€/unit)	2	2	5	5-35	
Average specific investment (1000€/unit)	2	2	5	20	111
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,5	2	2
Fixed O&M (€/kW/year)	10,80	10,00	15,00	4,00	6,30
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/GJ)				2,00	
Variable O&M (€/MWh)				7,20	

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,5	2,5	5,5	22,0	112,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/MWh)	0,0	0,0	0,0	7,2	0,0
Number of units	42.000	25.200	2.000	600	255
Total Investment (M€)	105	63	11	13	29
Annual Investment (M€)	6,3	3,8	0,7	0,8	1,7
Annual fixed O&M (M€/year)	5,7	2,5	0,3	0,9	0,9
Annual variable O&M (M€/year)				0,0	
Annual costs (M€/year)	11,9	6,3	1,0	1,8	2,6
Annual fuel costs (M€/year)	10,03	25,23	2,00	1,94	1,42
Annual and fuel costs (M€/year)	22,0	31,5	3,0	3,7	4,0

Total investment all heating solutions (M€)	221
Total annual investment all heating solutions (M€)	13,2
Total annual costs (M€/year)	23,5
Total fuel costs (M€/year)	40,6
Total annual costs with fuels (M€/year)	64,1
Price of heat (€/dwelling)	763,5

Appendix 10 - Scenario III - Oradea

Interest rate	1,75%			
	Gas CHP	**Geo-thermal plant**	**Biomass CHP**	**Gas peak boilers**
Energy input price (€/MWh)	30,0	83,0	24,0	30,0
Heat efficiency %	50,0		55,0	90,0
Heat production capacity (MW)	43,0	7,0	13,0	130,0
Technical lifetime (years)	25,0	25,0	30,0	35,0
Annual heat production (GWh)	340,0	100,0	125,0	200,0
Annual fuel consumption (GWh)	680,0	4,0	227,0	222,0
Price of sold electricity (€/MWh)	25,0		25,0	
Sold electricity (M€)	1,7		1,4	
Specific investment (M€/MW)	0,0	1,0	3-5	0,07-0,13
Average spacific investment (M€/MW)	0,0	1,0	4,0	0,1
Fixed O&M (€/MW/year)	0,0	47.000,0	29.000,0	1200-6200
Average fixed O&M (€/MW/year)	0,0	47.000,0	29.000,0	3.700,0
Variable O&M (€/GWh)	2.500,0	0,0	3.900,0	0,0
Total investment (M€)	0,0	7,0	52,0	13,0
Annual investment (M€)	0,0	0,3	2,2	0,5
Annual fixed O&M (M€/year)	0,0	0,3	0,4	0,5
Annual variable O&M (M€)	0,9	0,0	0,5	0,0
Fuel costs (M€)	20,4	0,3	5,4	6,7
Total annual costs (M€)	19,6	1,0	7,1	7,6
Price of heat (€/GWh)	57.500,0	10.091,1	57.082,0	38.204,3

District heating network	
Net loss (%)	18,0
Pump energy (MWh/TJ/year)	0.2-4
Average pump energy (MWh/TJ/year)	2,1
Average pump energy (MWh/TWh/year)	7.560,0
Technical lifetime (years)	30-50
Average technical lifetime (years)	40,0
Investment costs (1000 €/TJ)	18-22
Average investment costs (1000 €/TJ)	20,0
Fixed O&M (€/TJ/year)	250,0
Average investment costs (1000 €/TWh)	72.000,0
Average fixed O&M (€/TWh/year)	900.000,0
Specific investment costs (1000 €/TWh)	72.000,0
Total heat demand (TWh)	0,7
Total electricity for pumps (TWh)	0,005
Total investment (M€)	46,8
Annual investment (M€)	1,6
Annual fixed O&M (M€/year)	0,6
Total annual costs (M€)	2,2

District heating substation - blocks	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	1.250,0
Number of Units	1.000,0
Total investment (M€)	17,5
Annual investment (M€)	1,0
Annual fixed O&M (M€/year)	1,3
Total annual costs (M€)	2,3

District heating substation - houses	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	2.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	36.000,0
Total investment (M€)	90,0
Annual investment (M€)	5,4
Annual fixed O&M (M€/year)	5,4
Total annual costs (M€)	10,8

Total	
Total investment (M€)	226,3
Total annual investment (M€)	11,1
Total fixed O&M ((M€/year)	8,4
Total annual variable O&M (M€)	1,3
Total fuel costs (M€year)	32,8
Total annual costs-including fuel (M€)	50,6

Price of heat	
Average price of heat (€/MWh)	40,7
Average price of heat/dwelling (€)	313,54
Distribution costs/dwelling (€)	182,01
Final price of heat (€/dwelling)	495,54

Appendix 11 - Scenario II - Heat savings - Oradea

Interest rate	1,75%				
Parameter	**Natural gas boiler**	**Electric heating**	**Heat pump**	**Collective gas boilers**	**Collective biomass boilers**
Heat production capacity for one unit (kW)	5-15	5	8	200	250
Average heat production capacity for one unit (kW)	10,0	10	8	200	250
Total efficiency, annual average, net (%)	100	100	330	100	90
Technical lifetime (years)	20	20	20	20	20
Primary energy consumption (MWh/year)	4,4	4,4	1,5	35.200	32.600
Specific investment (1000€/kW)	0,18	0,18	1	0,05	0,17
Specific investment (1000€/unit)	1,80	1,80	5,00	5-15	
Average specific investment (1000€/unit)	1,8	1,8	5,0	10	43
Connection to electricity and/or gas (1000€/unit)	0,5	0,5	0,0	2	2
Fixed O&M (€/kW/year)	13,50	10,00	18,75	4,00	6,30
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/GJ)				2,00	
Variable O&M (€/MWh)				7,20	

Fuel	Gas	Electricity	Biomass
Fuel price (€/MWh)	31	130	24

Specific investment (1000€/unit)	2,3	2,3	5,0	12,0	44,5
Technical lifetime (years)	20	20	20	20	20
Fixed O&M (€/unit/year)	135,00	100,00	150,00	1.540,00	3.465,00
Variable O&M (€/MWh)	0,0	0,0	0,0	7,2	0,0
Number of units	42.000	25.200	2.000	600	255
Total Investment (M€)	97	58	10	7	11
Annual Investment (M€)	5,8	3,5	0,6	0,4	0,7
Annual fixed O&M (M€/year)	5,7	2,5	0,3	0,9	0,9
Annual variable O&M (M€/year)				0,0	
Annual costs (M€/year)	11,4	6,0	0,9	1,4	1,6
Annual fuel costs (M€/year)	5,73	14,41	0,38	1,09	0,78
Annual and fuel costs (M€/year)	17,2	20,4	1,3	2,5	2,3

Total investment all heating solutions (M€)	183
Total annual investment all heating solutions (M€)	10,9
Total annual costs (M€/year)	21,3
Total fuel costs (M€/year)	22,4
Total annual costs with fuels (M€/year)	43,7

Heat savings	**Standard**	**High efficiency**
Total investment (M€)	592	828
Total annual investment (M€)	20,70	28,96

Price of heat (€/dwelling)	519,8
Price of retrofitt/dwelling (€)	246,47

Appendix 12 - Scenario III - Heat savings - Oradea

Interest rate	1,75%			
	Biomass CHP	**Geo-thermal plant**	**Existing CHP**	**Gas peak boilers**
Energy input price (€/MWh)	24,0	83,0	30,0	30,0
Heat efficiency %	55,0		50,0	90,0
Heat production capacity (MW)	13,0	7,0	31,0	53,0
Technical lifetime (years)	30,0	25,0	25,0	35,0
Annual heat production (GWh)	100,0	100,0	155,0	80,0
Annual fuel consumption (GWh)	182,0	4,0	310,0	88,8
Price of sold electricity (€/MWh)	25,0		25,0	
Sold electricity (M€)	1,1		2,3	
Specific investment (M€/MW)	3-5	1,0	0,0	0,07-0,13
Average spacific investment (M€/MW)	4,0	1,0	0,0	0,1
Fixed O&M (€/MW/year)	29.000,0	47.000,0	0,0	1200-6200
Average fixed O&M (€/MW/year)	29.000,0	47.000,0	0,0	3.700,0
Variable O&M (€/GWh)	3.900,0	0,0	2.500,0	0,0
Total investment (M€)	52,0	7,0	0,0	5,3
Annual investment (M€)	2,2	0,3	0,0	0,2
Annual fixed O&M (M€/year)	0,4	0,3	0,0	0,2
Annual variable O&M (M€)	0,4	0,0	0,4	0,0
Fuel costs (M€)	4,4	0,3	9,3	2,7
Total annual costs (M€)	6,2	1,0	7,4	3,1
Price of heat (€/GWh)	62.477,5	10.091,1	47.661,3	38.298,6

District heating network	**Conventional**	**4GDH**
Net loss (%)	18,0	14,0
Pump energy (MWh/TJ/year)	0.2-4	1-4
Average pump energy (MWh/TJ/year)	2,1	2,5
Average pump energy (MWh/TWh/year)	7.560,0	9.000,0
Technical lifetime (years)	30-50	30-50
Average technical lifetime (years)	40,0	40,0
Investment costs (1000 €/TJ)	18-22	135-155
Average investment costs (1000 €/TJ)	20,0	145,0
Fixed O&M (€/TJ/year)	250,0	1.100,0
Average investment costs (1000 €/TWh)	72.000,0	522.000,0
Average fixed O&M (€/TWh/year)	900.000,0	3.960.000,0
Specific investment costs (1000 €/TWh)	72.000,0	522.000,0
Total heat demand (TWh)	0,37	0,37
Total electricity for pumps (TWh)	0,003	0,003
Total investment (M€)	26,6	193,1
Annual investment (M€)	0,9	6,8
Annual fixed O&M (M€/year)	0,3	1,5
Total annual costs (M€)	1,3	8,2

District heating substation - blocks	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	17.500,0
Fixed O&M (€/unit/year)	1.250,0
Number of Units	1.000,0
Total investment (M€)	17,5
Annual investment (M€)	1,0
Annual fixed O&M (M€/year)	1,3
Total annual costs (M€)	2,3

District heating substation - houses	
Technical lifetime (years)	20,0
Average specific investment (€/unit)	2.500,0
Fixed O&M (€/unit/year)	150,0
Number of Units	36.000,0
Total investment (M€)	90,0
Annual investment (M€)	5,4
Annual fixed O&M (M€/year)	5,4
Total annual costs (M€)	10,8

Total	
Total investment (M€)	198,4
Total annual investment (M€)	10,1
Total fixed O&M ((M€/year)	7,9
Total annual variable O&M (M€)	0,8
Total fuel costs (M€/year)	16,7
Total annual costs-including fuel (M€)	32,0

Heat savings	**Standard**	**High efficiency**
Total investment (M€)	592	828
Total annual investment (M€)	20,70	28,96

Price of heat	
Average price of heat (€/MWh)	39,6
Average price of heat/dwelling (€)	158,53
Distribution costs/dwelling (€)	170,61
Final price of heat (€/dwelling)	329,14

Price of retrofitt/dwelling (€)	246,47