Master's thesis

Cogeneration and District Heating in Greece

Opportunities and Barriers for Development

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Abstract:

This Master thesis examines the sectors of Cogeneration and District Heating in Greece with the purpose to identify opportunities and barriers for further development.

The methods that are used are a literature study concerning the existing installations, the legislative framework and the pricing for the cogenerated electricity, as well as a case study of a Greek industry, as industrial sector is the sector that appears to have the higher potential for CHP development in Greece. Different scenarios of the operation of the industry are simulated in the software of energyPRO and their results are analysed and discussed.

The main findings are that there are opportunities for development of the sectors, however primarily there are important barriers that need to be overcome.

Preface

This M.Sc. thesis was written during the 4th Semester of the study programme Sustainable Energy Planning and Management of the Department of Development and Planning of Aalborg University, in the period from February to June 2015.

References and Appendixes

Concerning the references in this report, the Chicago Fifteenth Edition is used. According to this style, the author's name and the publication year is referred to in the text in the form of: (Author Year). When there are two or more references with the same author's name and year, then there is a distinction between them by using the letter a, b etc., for instance (European Commission 2014a), (European Commission 2014b). If the name of the author is not given, then the publication organisation is mentioned instead. As for the figures and the tables, these are numbered according to the number of the corresponding chapter with a continuous numbering.

The report has three Appendixes, and it is complemented by one CD containing all the simulations of the report.

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Zaklin Dasyra

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Abbreviations

ADMIE	Independent Power Transmission Operator
BAT	Best Available Techniques
CCS	Carbone Capture and Storage Technologies
CFSR	Climate Forecast System Reanalysis
CHP	Combined Heat and Power
DH	District Heating
EEC	European Economic Community
EMY	Greek National Weather Service
FEK	Greek Government's Newspaper
FIT	Feed-in Tariff
GHG	Greenhouse Gas Emissions
HACHP	Hellenic Association for Cogeneration of Heat and Power
HDD	Heating Degree Day
HECHP	High Efficiency Combined Heat and Power
HRE	Heat Roadmap Europe
IPCC	Intergovernmental Panel on Climate Change
LAGIE	Hellenic Operator of Electricity Market
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
NSRF	National Strategic Reference Framework
PPC	Public Power Corporation
RAE	Greek Regulatory Authority of Energy
RE	Renewable Energy
TEE	Technical Chamber of Greece
TIC	Techno-Institutional Complex
YPEKA	Ministry of Environment, Energy and Climate Change

1 Introduction

Nowadays, one of the most crucial problems that humanity is called to face is climate change. Especially during the last 30 years, temperature on Earth's and oceans' surface has continuously been increasing, glaciers in Greenland and the Antarctic area have been becoming smaller and precipitation as well as sea level has been rising. All these changes influence both the natural and human systems and various impacts are noticeable, such as population changes of living species, negative impacts on crops and extreme weather events. (Core_Writing_Team, Pachauri and Meyer 2015)

The main reason for these phenomena seems to be greenhouse gas emissions (GHG). As the Intergovernmental Panel on Climate Change (IPCC) states in its Fifth Assessment Report (AR5): "*Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history*." According to different scenarios that have been developed to estimate the concentration of the CO_2 emissions up to year 2100, the global mean surface temperature develops almost linearly in regards to CO_2 emissions. (Core_Writing_Team, Pachauri and Meyer 2015) Therefore, a key factor for the moderation of climate change is the mitigation of CO_2 emissions.

Looking more closely to the increase of CO_2 emissions, it can be seen that it is related to the primary energy consumption and the economic growth worldwide. However, a recent study, called "*The Climate Change Performance Index*", results that there is a global tendency, particularly for the primary energy consumption to be decoupled from the emissions. This can be justified by the constant development of use of renewable energy (RE) among the 58 studied countries, with an average rate of RE development equal to 15% over the last years.

The same study highlights that the biggest effort should be made towards the elimination of the use of coal, because this is the fossil fuel causing the most pollution and it is projected that the following years will be really challenging for the global coal industry. Concerning the two largest emitters, USA and China, it seems that they have already designed anti-coal policies, such as the measures of some of the Chinese provinces to diminish the coal power plants. (Burck, Marten and Bals 2014)

On the other hand, European Union has updated its climate policy and has set new targets to be fulfilled by 2030; 40% decrease of the greenhouse gas emissions compared to 1990 levels and an increase of the share of renewable energy and energy efficiency by at least 27%. (European_Commission(a) 2015) European Union is on track to meet the previous targets set under the Kyoto Protocol second commitment period (2013-2020) and under the Europe 2020 Strategy and probably this is one of the reasons it appears more ambitious about its 2030 Strategy. (European_Commission(b) 2014) The policy measures through which it intends to achieve its future targets include the EU Emission Trading System, Directives for the development of the sectors of renewable energy and energy efficiency of the Member States, research on carbon capture and storage (CCS) technologies and other actions. (European_Commission(c) 2015)

A parameter that is included not only in the most recent EU Directives, but also in the energy policies of other regions worldwide, as a contributing way towards the decarbonisation of the energy system, is cogeneration technologies and district heating and cooling networks. In EU Directive 2009/28/EC, under Article 13, district heating and cooling is encouraged to be used for the construction of new industrial or residential buildings or for the renovation of the old ones (European_Commission 2009), while, in EU Directive 2012/27/EU, under Article 14, it is stated that: *"By 31 December 2015, Member States shall carry out and notify* *to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration*[1] *and efficient district heating and cooling*[2] *[...]*" (European_Commission 2012)

Concerning other policies around the globe, there is a 2012 US Executive Order on "*Accelerating Investment in Industrial Energy Efficiency*", where a target of extra 40 GW of industrial cogeneration is set to be achieved in the United States by 2020 (Obama 2012). In China, Chinese government encourages the expansion of gas-fired cogeneration plants and aims to reach a capacity of 50 GW by 2020 (Kerr 2012), whereas in Japan, as part of the Energy and Environmental Strategy of the Japanese government, there are also supportive measures for the deployment of cogeneration, which is estimated to reach 25 GW by 2030 compared to 9 GW of installed capacity in 2010 (Government_of_Japan 2012).

These provisions encourage the use of district heating and cogeneration, as one of the measures to be adopted in order to achieve energy savings. But, what exactly are cogeneration and district heating and why is it beneficial to deploy these technologies? The following section tries to briefly answer these questions.

1.1 Cogeneration and District Heating

In thermodynamics, a *Heat Engine* is a mechanism where supplied heat energy is converted partially to mechanical energy. There are different kinds of heat engines; those operating in a cycle and those that are not. In heat engines operating in a cycle, the supplied heat energy, coming from e.g. fuel combustion, is transferred usually from a hot reservoir to a working fluid. The working fluid of the system follows then a cycle process, through which heat is dumped into a cold reservoir (losses) and work is done. The other category of heat engines includes gas turbines and internal combustion engines, such as car engines. In this case the working fluid (the combustion gases) does not follow a whole cycle process. The combustion gases are not cooled, but they are discarded and replaced by a new mixture of air and fuel.

Efficiency of the heat engine is defined the ratio of the available work to the supplied heat energy. According to the Second Thermodynamics Law, it is impossible to construct a heat engine with efficiency equal to one, i.e. it is impossible to convert all the amount of the supplied heat energy into work without having any losses. The maximum efficiency of an ideal cyclic heat engine was defined by Sadi Carnot as:

$$\eta = 1 - \frac{Tc}{Th} = \frac{Th - Tc}{Th} \quad (1)$$

where:

- Th is the temperature of the hot reservoir, expressed in Kelvin

- Tc is the temperature of the cold reservoir, expressed in Kelvin

[1] "*High efficiency cogeneration shall result to primary energy savings of at least 10% compared to the references for separate production of heat and electricity [...]*" (European_Commission, Directive 2012/27/EU 2012)

[2] "*Efficient district heating and cooling means a system using at least 50% RE, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat.*" (European_Commission, Directive 2012/27/EU 2012)

In the Carnot Cycle the working fluid is an ideal gas and the efficiency is only dependent on the temperatures of the hot and cold reservoirs. The wider is the difference $Th-Tc$, the higher is the efficiency of the engine. As it is seen from equation (1), in order to achieve efficiency equal to one, it should be $Tc=0K$ which is impossible, so it is always $\eta<1$. As cold reservoirs, are usually used the atmosphere, oceans or rivers. (Cengel and Boles 1998)

Nowadays, the operation of all the conventional power plants is based on the above described thermodynamics principles, and this is why power production involves a lot of losses and power plants have a limited efficiency. *Cogeneration (or Combined Heat and Power or CHP)*[3] *,* which is defined as the process where electricity and heat is produced at the same time, appears as a way to increase the overall efficiency of a system and to diminish the losses. The main advantage of this mechanism is based on the fact that when there is a heat demand, such as an industry, a hotel, or a number of residences, connected to the cogeneration system, then the total efficiency can reach up to 90%. This is much bigger compared to the efficiency achieved by conventional power stations producing only electricity, as it is seen in Figure 1.1, and it allows for energy savings varying between 15-40%. (COGEN_Europe(b) 2015)

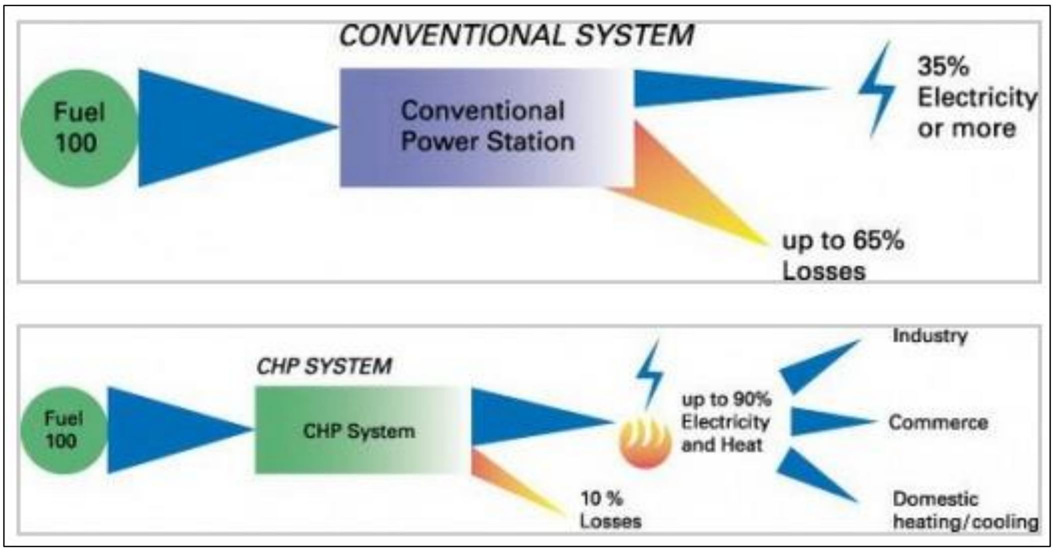

Figure 1.1: Conventional system vs. CHP system, Source: (COGEN_Europe(a) 2015)

On the other hand, *District heating (DH)* is a term used to describe the infrastructure that provides heat for space and water heating to a network of end-users. Heat can be produced from different sources, namely it can be recovered heat from electricity production and cogeneration sites, waste heat from industrial processes or heat produced from exclusively heat plants. The overall amount of heat is distributed through pipes in the form of hot water or steam from a central point to the final consumers which can be residential, commercial, public and industrial ones. (IEA 2013, COGEN_Europe(c) 2015, DHC+ Technology 2009)

Apparently, district heating and cogeneration are two linked concepts: when cogeneration sites are placed close to a final heat demand, then DH provides the network needed to distribute the generated heat from the CHP plants to the final end-users. The benefits from the deployment of these technologies are multiple. Starting with the principle of DH to use the surplus heat that else ways would be thrown away in the environment, primary energy

[3] Especially in this report, the word "cogeneration" is used to refer to the process of simultaneous production of electricity of heat, while the world "CHP" is used to refer to the technology of serving this process.

consumption is reduced and so are the greenhouse gas emissions. Cogeneration results also to less fuel consumption and together with the fact that usually local resources are preferred to be used instead of depending on imported fuels, security of energy supply is increased. (COGEN_Europe(b) 2015, DHC+ Technology 2009)

Moreover, DH and CHP appear as quite flexible systems that allow for higher deployment of locally available renewable energy sources and facilitate their integration into the energy system. Some forms of renewable energy, such as geothermal, are difficult to handle and they do not offer the same value for money to individuals compared to the one offered by a centralised energy production unit. In addition, DH and CHP could help the balancing of the fluctuating renewable energy sources, taking into account some characteristics of their operation. An advantage of CHP is that the ratio of power to heat output can be regulated according to the energy demand, while both DH and CHP can make use of storage capacity during periods of excess electricity in the system. (COGEN_Europe(b) 2015, IEA 2014)

The utilisation of DH and CHP is also related to the creation of socioeconomic benefits. Some of them are: fewer costs for producing energy and therefore affordable prices for consumers, decentralised electricity generation adapted to the local demand, contribution to the energy market liberalisation, increase of competiveness among the producers, and creation of jobs for the local societies. (COGEN_Europe(b) 2015, DHC+ Technology 2009)

From the above, it seems that CHP and DH are very useful for a sustainable energy system, while being beneficial for the economy and the society, as well. Having defined these two concepts and the major benefits of their deployment, the following section describes the current situation in Europe and it discusses the potential of expanding district heating networks.

1.2 Potential of District Heating in Europe

Today, around 5,000 operating district heating networks in Europe cover a percentage of more than 9% of the total heat demand. However, the development of these networks is not the same between the EU countries. There are countries where the development of the sector is almost zero and others where the share of DH in the heat market is up to 70%. Countries with high development of DH networks are mostly those in North-, Central and East-Europe, with Poland and Germany distributing the biggest volume of district heat. Good examples of urban district heating networks are the cities of Copenhagen, Helsinki, Warsaw, Vilnius and Riga. (DHC+ Technology 2009) In the case of Copenhagen, 98% of the city's heat demand, corresponding to 500,000 inhabitants, is covered by district heating, taking advantage of the CHP technology and utilising RE fuels, such as renewable waste and biomass (ARUP 2012).

As far as CHP in Europe is concerned, according to Eurostat data, 11.7% of gross electricity generation was attributed to CHP units in 2010. As it is the case with district heating, there are big differences in the shares of CHP between the EU countries. In 2010, the biggest share of cogeneration was found in Denmark (49.2%), following by Latvia (45%) and Finland (36.2%), while the lowest percentages were found in Malta with no cogeneration at all, in Norway (0.2%) and Cyprus (1%). (Eurostat(a) 2015)

Generally, there are different heat demands among the different sectors in Europe. An amount of heat is used to cover the needs of the industrial processes, while another one is used for space and water heating in buildings of the public, residential, commercial (services) and industrial sector. Figure 1.2 below illustrates the sources used for the heat supply of buildings of the residential and services sector in EU-27, in 2010:

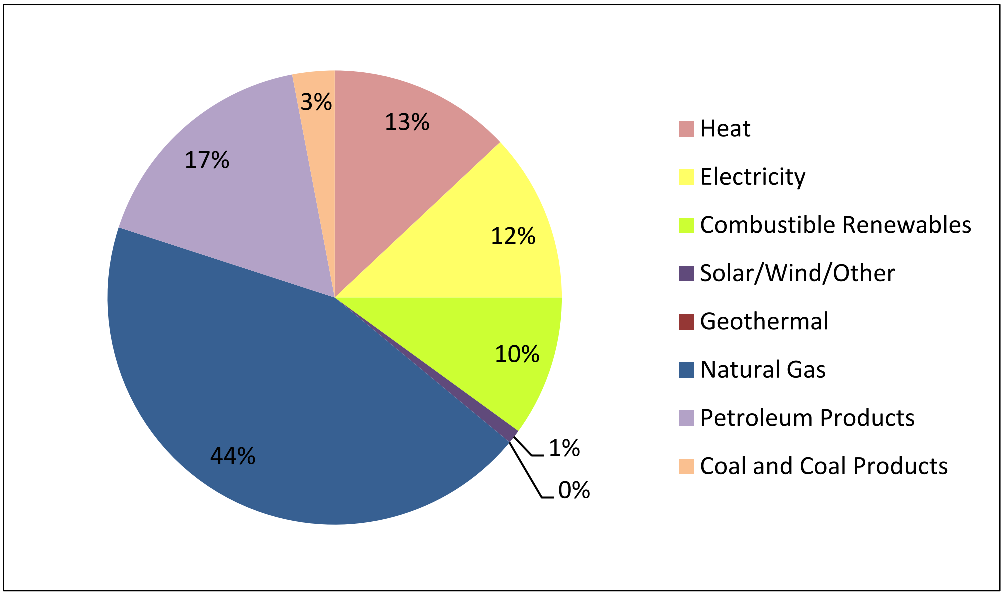

Figure 1.2: Heat supply sources for residential and services buildings in EU-27 in 2010, Source: (IEA 2012, Connolly, et al. 2014)

As it can be seen, the biggest percentage of heat supply (64%) was made through the use of fossil fuels, namely natural gas (44%), petroleum products (17%) and coal and coal products (3%), whereas only 13% was provided by district heating, called as "heat" in the graph. Despite this low percentage of DH in 2010, it seems that there is a good potential for expansion of the current district heating networks resulting to multiple benefits for the EU energy system. (Persson, Möller and Werner 2014, Connolly, et al. 2014)

According to (Persson, Möller and Werner 2014), now in EU, there are available excess heat resources that if they are recovered and used for the heat supply, the general efficiency of the energy system will increase. The methodology used in order to come to this conclusion is based on the assessment of the surplus heat resources coming from the combustion of fuels in the energy and industrial sector. Due to the fact that data on the annual excess heat of these sectors are currently unavailable, excess heat is calculated based on the annual CO_2 emissions coming from the combustion and on the characteristic CO_2 emission factors by country. The results show that there is a relationship between the surplus heat resources and the high-density populated areas and that the strategy for development of district heating should be build upon the unique characteristics of the areas.

This study was conducted within a broader project called Heat Roadmap Europe (HRE). Heat Roadmap Europe is a project that studies the perspective of the heating sector in Europe until 2050. The research team, consisting of experts from various countries, i.e. Denmark, Sweden and Germany, suggests a scenario for expanding district heating together with heat savings, utilisation of renewable energy sources and taking advantage of the wasted heat that exists today in the energy system. (Research_Team 2014) The goal is to achieve the 80% reduction of GHG emissions by 2050 (compared to 1990 levels), that is indicated in the report "*Energy Roadmap 2050*" conducted by European Commission (European_Commission 2011). Using as methodology the mapping of the European heat demand and the energy modelling of different scenarios, it is resulted that the heating and cooling costs are lower by the proposed scenario of the Research Team compared to the one developed by the

European Commission, which does not emphasize district heating so much. (Research_Team 2014)

Overall, district heating arises as a solution for the improvement of the efficiency of the EU energy system and it has probably been neglected so far, considering the low percentage of deployment that was presented before. Europe could take advantage of all the benefits that DH offers, as long as a variety of suitable strategies is developed, such as modernisation and expansion of the existing networks (DHC+ Technology 2009).

1.3 The case of Greece

Greece, as one of the EU Member States, in order to implement European Commission's Directives, has designed its own energy policy. Information is found in the National Renewable Energy Action Plan (NREAP), the National Energy Efficiency Action Plan (NEEAP), in the website of the Ministry of Environment, Energy and Climate Change (YPEKA) and in the document "*Energy Roadmap for 2050*", submitted in 2012 by the National Energy Planning Committee . The following section is a short description of the Greek energy policy, the national energy targets and the current situation of the Greek energy and heat supply sector.

The basic elements of the Greek energy policy can be summarized below as:

- Target to make use of various energy sources
- Construction of interconnection networks for the oil and natural gas markets
- Major exploitation of the domestic energy sources
- Decoupling from the imported energy sources
- Development of the RE sector and provision of incentives towards this direction
- Use of "clean" and efficient technologies
- Elimination of the monopoly and creation of a free and competitive electricity and natural gas market
- Provision of incentives to individuals and industries for the generation of electricity
- Energy savings in the sectors of industries, transport, buildings and dwellings
- Setting of national targets for the increase of the RE share in the primary energy production, the decrease of the greenhouse gas emissions and the increase of the energy savings (Ministry of Environment 2014)

Explaining the last point of the national targets, in the Greek NREAP, Greece has set a target of 18% share of renewable energy in the gross final energy consumption by 2020. There are also individual targets concerning the share of RE in the heating and cooling sector, the electricity, and the transport sector, namely a share of 19.7%, 39.8% and 10.1% respectively. (National_committee and CRES 2009) Moreover, in the Greek NEEAP, there is a description of the targets for the overall primary and the final energy consumption by 2020. For the primary energy consumption the target is set to 24.7 Mtoe by 2020, which is a reduction of about 19.5% compared to the levels of 2007, while for the final energy consumption the target is set to 18.4 Mtoe. (CRES(a) 2014)

The analysis of the final energy consumption in Greece shows that it has followed an increasing trend from 1990 levels (14.7 Mtoe) until 2010 (19.4 Mtoe) with a peak of consumption appearing in 2007. However, the period 2008-2010 was a declining one, mainly due to the economic recession and the application of energy efficiency measures. As it can be seen in Figure 1.3 below, the biggest share of energy supply for all the final consumers is made through oil products, although the share was reduced by 4.9% between 1990 and 2010, mostly because of the introduction of the natural gas in the Greek market. The next biggest share is the one of the electricity, which increased by 6.9% between the studied years. RE and natural gas appear to cover a rather small percentage of the Greek energy demand, while coal's share has declined a lot during the 20-year period. District heating, called as "heat" in the graph, appears with the smallest share of 0.2% in 2010. This is due to the fact that district heating was applied in a large scale in Greece only in 1993, i.e. in towns close to thermoelectric power production stations, and it is not yet a developed sector. (Odysee-Mure and CRES 2012, Γιακουμή and Ιατρίδης 2009)

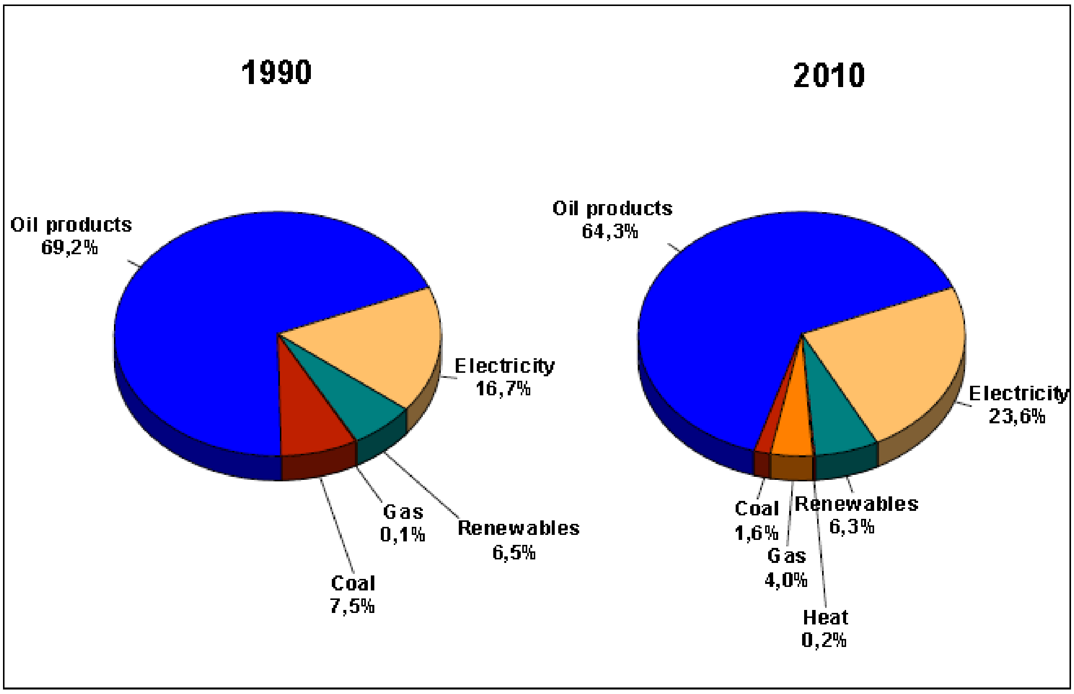

Figure 1.3: Energy supply by fuel for the final energy consumption in Greece (years 1990 and 2010), Source: (Odysee-Mure and CRES 2012)

Concerning the categories of consumers, transport seems to be the biggest energy consumer, followed by the residential and the industrial sector, while the rest of the consumption is made by the tertiary and the agriculture sector. It is worth to mention, that the tertiary share has increased considerably between 1990 and 2010, which indicates the change of the Greek economy towards a more service-oriented one. (Odysee-Mure and CRES 2012) Before moving any further, it is useful to describe how electricity is generated in Greece, because as it was said before it has the second biggest share of energy supply after oil products.

1.3.1 The Greek electricity sector

The Greek electricity system is divided into two parts: a) the interconnected system of the mainland, and b) the autonomous system of the islands, as it is illustrated in Figure 1.4. Electricity generation is made through lignite power plants (56%), combined cycle natural gas power plants (18%),oil products (13%) and RE (13%). Lignite is the only domestic fossil fuel resource and it will continue to be the basic resource for electricity generation for the following years. It is estimated though that it will be affected by the integration of the costs for GHG emissions and the price of natural gas and its use will gradually be reduced after 2020.

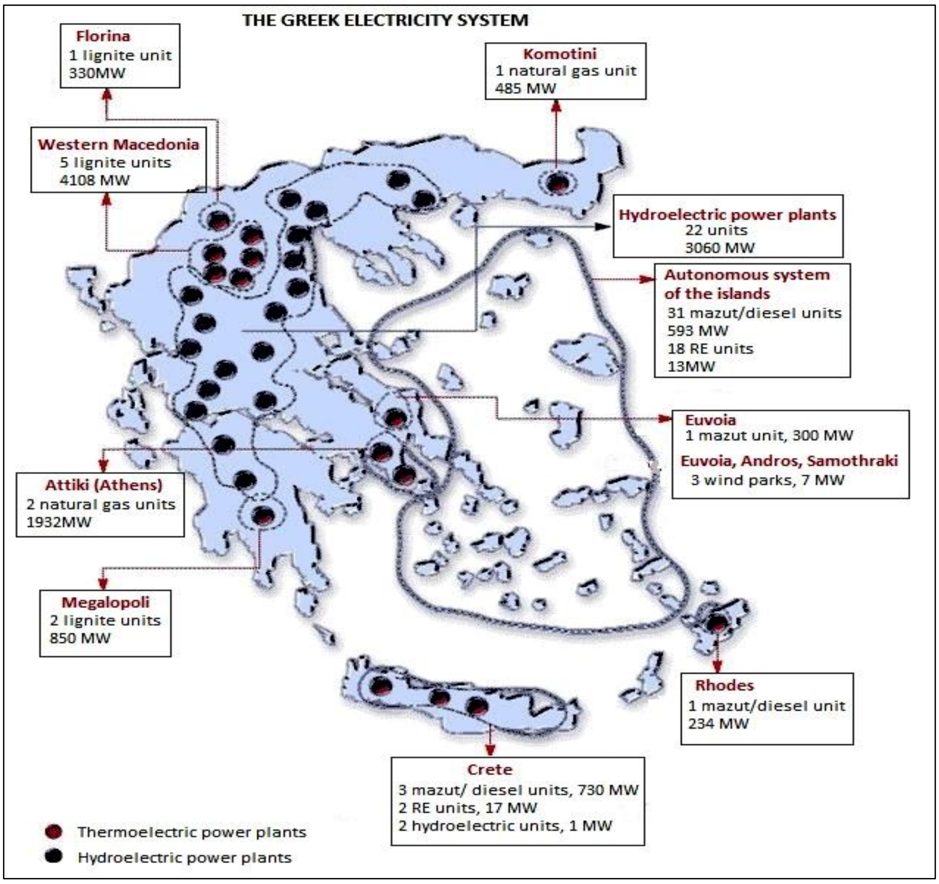

Figure 1.4: Map of the Greek Electricity System indicating the location and the type of the power production units by 2007 (PPC 2013)

In addition, there is a low development of CHP units and district heating networks. The biggest part of the installed capacity of CHP is found in the industrial sector (industrial CHP), especially in refineries and food processing industries, and in big power production units with the purpose to cover the heat demand of neighbouring urban areas, as it was said before. More information concerning the sector of DH and CHP in Greece is given in Chapter 4.

As for the locations where electricity is generated, the biggest power plants, i.e. lignite and hydroelectric power plants are located in Northwestern Greece, where also the largest lignite resources are. However, the highest electricity consumption is in Southern Greece (Attiki), where the capital and the most population are. This is one of the reasons that electricity generation from natural gas power plants located closer to the capital has grown recently.

The majority of Greek islands remain isolated and not connected to the mainland's electricity grid, except of Euvoia, Andros and Samothraki, and the electricity generation is made mainly by oil products, diesel and mazut[4], and a small share of RE. In the future,

[4] "*Mazut is a heavy, low quality fuel oil, used in generating plants and similar applications. Due to increased refining costs and high sulfur content, heavy crude oils are often priced at a discount to lighter ones.*" (Coastal_Petro_LLC 2010)

islands will gradually be connected to the mainland's grid, starting with the biggest island, Crete, and continuing with the rest until 2025. The goal of this interconnection is to cut down the use of oil products and to exploit renewable energy resources' full potential. (National_Planning_Committee 2012)

1.3.2 The Greek heating sector

Having described how electricity is generated in Greece, it is useful to examine the Greek heating sector, concerning the existing heat demand and the resources that are used to cover it. A valid indicator for the evaluation of the heating requirements of an area is the Heating Degree Day (HDD). HDD indicates the energy needed for the heating of a building, when the outside temperature is below a basic temperature. While heating demand is also affected by other factors, such as wind speed, the energy performance of a building, the fuel prices and the habits of the users, the external temperature is a factor closely related to the climate. When there is climate change, this is reflected to the external temperature and therefore to the number of HDDs of an area. (EEA 2013) With the aim to examine the heat demand in Greece in relation to the climate of the country, this indicator is chosen to be examined further.

Figure 1.5 gives a comparison of the HDDs in Greece and the average HDDs from all 27 EU countries. This data coming from Eurostat is on a monthly basis, over a time period from January 1980 until May 2010, and the basic temperature is chosen equal to 15 °C. As it can be seen, during the whole period, HDDs in Greece are lower than the EU average, while there are also months in Greece with HDDs=0 °Day, i.e. the HDDs of the months of June, July, August and September for almost every year. As an example in order to understand better the difference is chosen the month of January 2010: HDDs in Greece are equal to 319.81 °Days, while the average HDDs in EU are 624.23 °Days, which is almost 50% more. (Eurostat 2013)

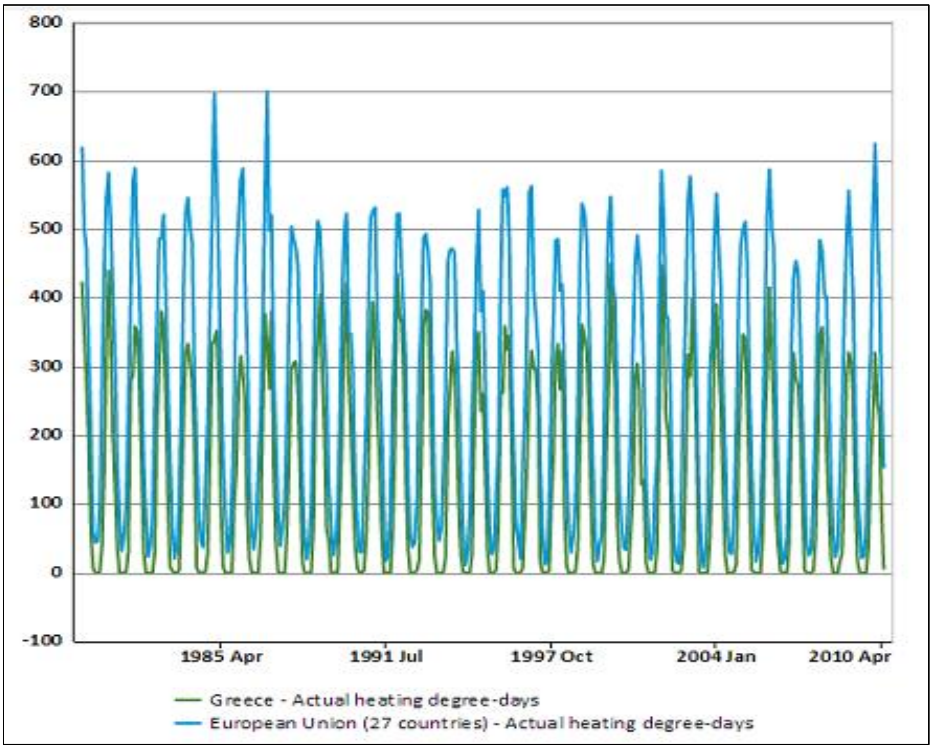

Figure 1.5: Monthly data of Heating Degree Days in Greece vs. EU-27, Source: (Eurostat 2013)

As it was said previously, the overall heat demand of a country is affected also by other factors, but it is chosen here to focus on the HDDs as an indicator of the climate of the different regions in the Greek territory. A study which was made by two Greek researchers for the purpose to define the heat demand of the different Greek regions and to indicate the time periods when the imported heating oil shall be available in the market showed that there is a big variation in the climate of the country (Ματζαράκης and Μπαλαφούτης 2002).

In this study, the calculation of the HDDs for the different regions was based on the maximum and minimum daily external temperature collected from 40 different meteorological stations by EMY (Greek National Weather Service) over the coldest eight-month period from October till May and for five consequent years. The basic temperature was chosen equal to 14 °C, following the method of trial and error. The results showed that the average HDDs vary a lot between the different regions. The highest number of HDDs is found in the town of Florina (Northwestern Greece) and is equal to 1,748.4 °Days. This is nine times higher than the lowest number of HDDs which is found in the island of Rhodes (Southeastern Greece) which is equal to 195.4 °Days and it is an indicator of the different climatic zones existing in Greece, which are four according to YPEKA (see Figure A.1 in Appendix A. (Ματζαράκης and Μπαλαφούτης 2002, Greek_Government(a) 2010)

High HDDs are also noticed in other Greek towns and cities, such as in Kozani (Northwestern Greece) with 1,629.4 °Days and in Orestiada (Northeastern Greece) with 1,481.1 °Days, but also in Tripoli (Southern Greece) with 1,300.3 °Days, because of the altitude of the region (661m), and in Kavala (Northern Greece), where despite the fact that the city is located close to the sea HDDs reach the value of 1,197.3 °Days. Concerning the Greek islands, Limnos is the one with the highest heat demand, with HDDs equal to 872.7 °Days, whereas Santorini and Crete present some of the lowest values equal to 200-300 °Days. A map of Greece illustrating the HDDs of the different regions and all the towns/cities and islands mentioned before is found in Appendix A (see Figure A.2).

Another analysis in the same study was made referring to the duration of the heating period expressed in days per year (see Figure A.3, Appendix A). The biggest heating period (more than 220 days per year) is found in Northwestern Greece and in other regions of the mainland having high altitude or other special topographic characteristics in Northeastern, Central and Southern Greece. For the rest of the areas in the mainland and the Northern islands, this period varies between 190-210 days and 170-190 days. Finally, the shortest period is found in the Southern islands of the country (S. Kyklades, Crete, and Rhodes) with 150-160 days per year. (Ματζαράκης and Μπαλαφούτης 2002)

After the description of one of the factors influencing the heat demand in Greece, it is useful to see how this demand is covered focusing on the energy consumers of the residential sector, as potential customers to be connected to a district heating network. In 2010, the energy supply was made by: Oil products (42.6%), Electricity (33.8%), RE (16.9%), Natural gas (5.5%), Heat (District heating) (1%) and Coal (0.1%). The sectors where the provided energy was utilised were: Space Heating (64.6%), Electrical Appliances (21.4%), Cooking (7.3%) and Water Heating (6.7%). (Odysee-Mure and CRES 2012)

These figures can be explained by the way that the Greek society is structured. During the past years, the population of the urban areas has increased and people tend to live in apartments with central heating systems, based mainly on oil boilers. After the introduction of natural gas in the Greek market in 1995, a lot of central heating systems have gradually been converted and oil boilers are replaced by natural gas boilers. (Γιακουμή and Ιατρίδης 2009) At the moment, there are only three providers of natural gas for the counties of Attiki (Southern Greece), Thessaloniki (Northern Greece) and Thessalia (Central Greece), but three more providers are expected to work in order to cover the rest of the geographical areas. (RAE(a) 2015) Space heating in cities is also made by using other supplementary sources, such as electrical radiators and air conditioning systems or biomass that is burnt in stoves and fireplaces. Especially because of the fluctuations of the oil price the last two years and the economic crisis, a significant part of the heat consumers in cities have chosen these alternatives as a cheap solution, a fact that is verified by the recently increased biomass use (mainly burning wood) and electricity demand. (Λιάγγου 2015) Finally, most of residences in rural areas remain using wood for space heating, but there are cases of central heating systems with oil boilers and electrical heating systems, as well (Γιακουμή και Ιατρίδης 2009).

As for water heating, this is mainly done by the use of solar thermal collectors. Despite the financial crisis that does not allow for new housing constructions and therefore new installations of collectors, the market in 2013 showed an increase of the installed capacity by 1.4% due to the replacement of the old solar thermal systems (ESTIF 2014). During the winter period, when the sun radiation is low, heat exchangers in combination with the central oil and natural gas heating systems are used instead. Electrical water heaters are also installed in all residences, as part of the basic electro logical equipment, but their use has been reduced and it is only supplementary during the past years. (Γιακουμή και Ιατρίδης 2009)

1.3.3 Challenges in the Greek energy system

From all the above, it can be concluded that Greece is a carbon-intensive country that is heavily dependent on fossil fuels, concerning both the electricity and the heating sector. This appears to be a twofold problem: one on a short-term perspective and one on a longer one. On a short-term perspective, Greece imports all the oil and natural gas that is used, because it doesn't have its own resources. After the embargo that European Union decided against Iran for the oil transactions, almost half of the oil is imported from Russia and the rest comes from Libya, Kazakhstan, Saudi Arabia, Egypt and other countries participating in the market (Χατζηϊωάννου 2013). Natural gas is also 100% imported from Russia, Algeria and Turkey (RAE(b) 2015). The problem to be dependent on these countries is related to the power that the governments controlling the resources like to demonstrate and the political unstable situation among these regions. Examples can be taken from history, such as the oil crisis in the 1970's (Lund 2010), which influenced oil prices across the globe, and the ongoing crisis between Russia and Ukraine, which resulted in a cut off of the natural gas supply through Ukraine in 2006 and 2009; a really risky situation for whole Europe, as half of Russia's gas exports to Europe pass through Ukraine. (Gloystein 2014)

Looking at the problem from a longer term perspective, it is a fact that fossil fuels will deplete in time, either they are domestic (in this case: lignite), or they are imported (oil and natural gas). Often scenarios and policies are designed without having that in mind and climate change is faced without the factor of fossil fuel depletion (Höök and Tang 2013). This is an issue that should not be ignored and in order to mitigate the risk of being left without energy resources, alternatives and sustainable solutions for the Greek energy system should be found before it is too late.

1.4 Problem Formulation

As it is discussed before, nowadays, there is more than ever the need to tackle the climate change and to implement measures that will reduce the primary energy consumption and especially the use of fossil fuels. District heating and increase in the use of CHP units appear to be a potentially attractive solution for the reduction of the GHG emissions and the improvement of the overall efficiency of the energy system, while creating at the same time a lot of environmental, social and economic benefits.

A lot of countries worldwide are aware of this option, as it is concluded by the study of their recent policies, where targets for further development of DH and CHP in the future are set. It is indicative, that EU Member States are encouraged by European Commission to make an assessment of the potential for efficient district heating and cooling and high efficiency cogeneration and to notify it to the Commission by the end of 2015 (European_Commission, Directive 2012/27/EU 2012).

Greece, as one of the EU Member States, has set targets for the reduction of the energy consumption and the associated GHG emissions. In addition, there is an increasing penetration of renewable energy sources and an ongoing promotion of energy efficiency measures in the Greek energy market. (CRES(a) 2014)

However, the study of the energy sources that are used to cover the Greek energy demand proves that there is a significant issue in the energy sector, both in the electricity and the heating sector, which is the heavy dependency on fossil fuels. This is not only negative for the economy, regarding the imported resources, but also for the security of supply now and in the future. District heating, which, as it is said, is at an early stage of development in Greece, and CHP units could contribute to the solution of this problem.

Therefore, the research question of this study is:

What is the current situation of District Heating and Cogeneration in Greece and what are the opportunities and barriers for development?

The first part of the research question will be answered based on a literature review of the status of the existing Greek DH and CHP systems. This study will continue for the second part of the question as well, in order to find out the existing regulatory framework and the incentives or the barriers that it poses to potential developers. In addition, a case study of a Greek industry is chosen to be made, including scenarios for installation of CHP and development of a small-scale district heating network, examining both the costs and the benefits of these investments.

After a short investigation, it was found out that sector with the highest potential for CHP development in Greece is the industrial one (see also sub-Section 7.2.1), so this is the reason why a case study about an industry was found interesting by the writer and relevant for answering the RQ. Although it is affected by the specific regional characteristics of the area where the industry is located and the energy demand of the industry, the purpose of this study is to recognise and understand better the complexity of the reality and to provide a model for other industries with similar characteristics which are potentially interested in Cogeneration and District Heating.

The extent of this research is limited by the following aspects:

1. The focus of this study is the District Heating and Cogeneration sectors. Only a small part of the Electricity sector is examined, i.e. the legislative framework referring to the electricity cogenerated by CHP.
2. The possibility of application of energy saving measures before the development of CHP and DH systems is not studied.

1.5 Structure of the Report

This section explains the structure of the report, providing an overview of the written chapters together with a short description of their contents.

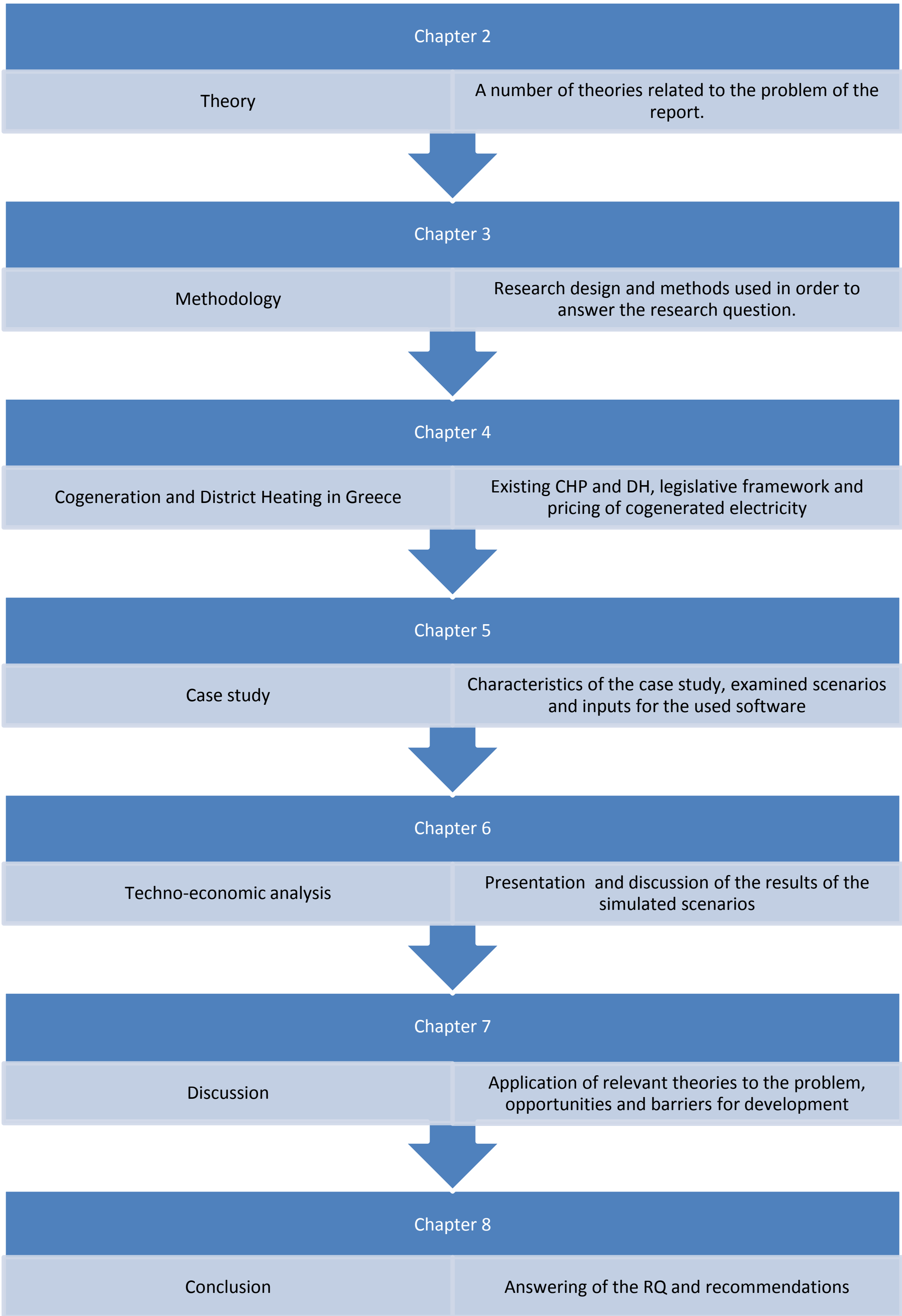

Figure 1.6: Structure of the report

2 Theory

This Chapter is a description of the theoretical background of the project, i.e. it presents a number of theories that are related to the problem of this report. As it is discussed in the Introduction, the problem is the heavy dependency of the Greek energy sector on fossil fuels. The presented theories try to elaborate on the reasons of this dependency and on the approach that shall be followed in order to mitigate it. All the following concepts agree on the fact that it is difficult to change the structure of a market that is well-established and that societies are influenced by the power of the existing institutions.

2.1 Concrete Institutional Economics

One principle idea of the Neoclassical Economy is the "*free market*". A market is regarded free when there is a variety of suppliers and buyers of products which act independently, there is complete awareness concerning the quality and the prices of the products and both goals for the maximisation of the profits and the maximisation of the utility are achieved. Concerning regulations, no private regulation is made, while public regulation is neutral to the market.

On the other hand, the Institutional Economy claims that the "*real market*" is different than the concept of the free market. In reality, there are special conditions in each market regarding the type of the existing institutions and the interaction between them, while private regulation does exists and public regulation is not neutral to the market. Private regulation can mainly be seen in the organisation of the energy systems, which are often based on monopolies or oligopolies. Moreover, the existing energy supply companies usually have financial and political power which prevents the development of other technologies. (Hvelplund and Lund 1998)

The theory of the "*Concrete Institutional Economics*" is related to the conducted feasibility studies when the aim is to achieve technological innovations and institutional changes in a real market, while taking into consideration the environmental and energy security issues. It provides a methodology for potential sustainable energy investments that can stimulate the employment and the growth of the industrial sector, as a solution to the current recession in the economy of many countries. The theory is not limited to the approach of the classic cost-effectiveness and cost-benefit analysis, as it gives a big emphasis on examining the existing institutions of the market of each country and the need for designing new policies that can ease the institutional changes. (Lund and Hvelplund 2012)

In general, two different kinds of feasibility studies can be identified: the *social economic* and the *business* economic *feasibility studies*. The first category of studies concerns the assessment of the feasibility of a project for the entire society, whereas the second concerns a more narrow scope of assessing the feasibility for a business. There is also the concept of "*socioeconomic analysis*", which includes both an economic analysis and an assessment of the impacts on the society, for instance the examination of the job creation factor, and it can be applied in both cases of public and private investments. (Hvelplund, Lund and Sukkumnoed 2007)

2.2 Choice awareness

Choice awareness is used to describe "*the collective perception of having a true choice*". The collective perception refers to the general perception of the society, who is called to make a decision after evaluating all the presented options. When the presented options are two or more real ones, then the choice is considered true. On the other hand, when the decision is based on only one alternative, which is often a deception of the reality, then the choice is considered as false. (Lund 2010)

This theory is also related to the concept of the "*radical technological change*" and on how to achieve such a change. Technology can be described by five factors: Technique, Knowledge, Organisation, Products and Profit. As radical is called the change when more than one of the above factors are influenced, for instance when a fossil fuel based system changes to a renewable energy based one. According to Hvelplund, societies should aim for similar radical technological changes, because economic and environmental benefits, as well as, benefits for the energy security are involved. (Lund 2010, Hvelplund 2005)

The theory of Choice Awareness has two main theses:

1. When a radical technological change is to happen, the existing institutions will resist and they will try to convince the society that there is no other choice than the use of the technologies that will retain their existing status.
2. It is beneficial for the society to be aware that there are more than one alternative in order to make a true choice.

In addition, a general methodology including four different steps is proposed to be used when examining individual cases. The first step is about recognising and analysing the existing technical alternatives. This is connected to the energy policies and the economic goals that a government already has or to other new targets being proposed. The second step is referred to the need for socioeconomic feasibility studies, in order to evaluate the alternatives and it is linked to the previously described concept of the Concrete Institutional Economics (see Section 2.1). The third step is about business - economic feasibility studies and the obstacles that might exist in the market and the purpose is to suggest regulation changes, such as changes in the tax system. Finally, the fourth step is referred to the recognition of institutional obstacles that might delay the implementation process and it suggests long-term institutional changes. (Lund 2010)

2.3 The Carbon Lock-in concept

The concept of "*Carbon Lock-in*" is used by Unruh to describe those energy systems of the today's societies which are based on fossil fuels or in other words are "locked into" fossil fuels. According to the writer, these systems are represented by established markets that tend to be stable and hinder the development of alternative technologies being carbon-saving. He claims that there is a Techno-Institutional Complex (TIC) consisting of technologies and institutions, either public or private, which influence and control the energy system. In the past, this complex was helpful for the evolvement of the different technologies, such as for those utilised during the development of the electricity networks. However, today, this tendency has changed and TIC appears to delay the evolution of the alternatives, despite the recognition of the threat of the climate change. Some of the barriers are organisational, such as the existence of legislations that favour the development of the carbon based systems, while others are related to the resistance demonstrated by the fossil fuels industries whenever a policy seems to harm their activities. (Unruh 2000)

The same writer in another article discusses the ways of escaping from this Carbon Lock-in. It is argued that it is difficult to promote the alternative technologies even if they are cost effective because it is an issue influenced by the prevailing institutions. It is believed though that this process can be facilitated if there is support coming from the society. For this reason, proper educational programmes should be developed and scientific research should be made. It is also concluded that policy makers should apply such policies together with the appearance of extreme climate events, as this the time when they will probably be more effective. The exact time of these events is usually unexpected therefore policy makers should be ready for any occasion. (Unruh 2002)

3 Methodology

The purpose of this Chapter is to describe the research design and the methods used in the project in order to answer the research question. In the research design, a theoretical approach is made, defining all the parameters that need to be examined during the analysis of the problem. Afterwards, a description of the chosen methods is given, together with the reasons that lead to their choice.

3.1 Research Design

After a literature study presented in the Introduction, it is found out that the problem of this report is the heavy dependency of the Greek energy system on fossil fuels. The goal is to escape from this situation through the deployment of CHP technologies and DH networks and to draw conclusions on the potentials of the sectors. The technological characteristics of these sectors are chosen not to be analysed in depth, as it is assumed that there are already available and developed technologies. On the other hand, more significance is given to the examination of the opportunities and the barriers concerning the development of the sectors and especially the development of the industrial CHP in Greece. For this reason, a case study about a Greek industry is chosen to be made, including a techno-economic analysis of different scenarios.

Moreover, as basic parameters that need to be taken into consideration are deemed the market legislation and the involved actors. By market legislation is meant the Greek energy policy, found through the study of the national plans and the goals of the relevant Ministries, as well as, all the established laws that provide regulations for the sectors of CHP and DH, such as the FIT scheme being analysed in Chapter 4. As involved actors are considered all those players that might influence or be influenced by the development of CHP and DH. These are: a) potential users, such as local communities and industries, b) actors contributing to the implementation of relevant projects, such as engineers, planners, technical companies, banks and ESCOs, c) actors providing regulations, such as EU, the State, municipalities and other authorities, and d) other players, such as universities, media and NGOs who might be seen as external, but they can also play a crucial role concerning the promotion of the sectors.

Apart from the case study, the methods used for the examination of these parameters are a literature study, communication with selected actors and an energyPRO modelling, described in more details in Section 3.2. Figure 3.1 illustrates the components of the research design and the research methodology:

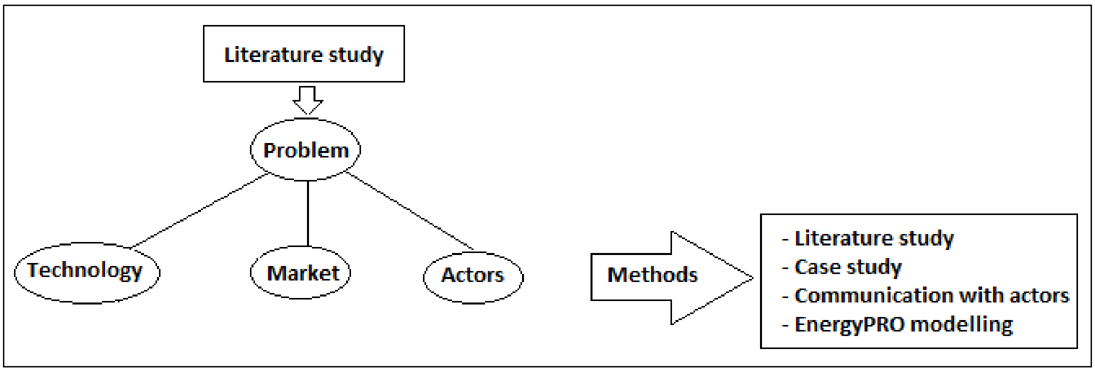

Figure 3.1: Research Design and Methodology

3.2 Methods

3.2.1 Literature study

First of all, the literature study is found useful for the Introduction of this report, and it also leads to the realisation of the problem. Afterwards, it is used mainly in Chapter 4, where the current situation of CHP and DH is described, but it can be said that it provides the background knowledge for almost all of the chapters in the report and a better understanding of the discussed topics. The sources that are used are scientific articles, reports and books of researchers, as well as data from websites and news, especially concerning the investigation of the energy topics in Greece.

In order to improve the validity and the reliability of the data collected through this study, the sources are chosen with cautiousness, especially if they are web-sources. Data found in websites are always double-checked and only trustful and official websites are used, such as the website of the Greek Regulatory Authority for Energy (RAE). Moreover, when another writer is mentioned in an article, then the original source is used as a reference. Based on the nature of the used sources, it can be said that the collected information is accurate and close to the reality, and if another researcher repeats the same study, he will come up with the same findings.

3.2.2 Case study

"*A case study is a detailed examination of one setting, or one single subject, or one single depository of documents, or one particular event.*" (Bogdan and Biklen 1982) There are different techniques to perform a case study, such as observation, interview or use of documents and records. The findings of a case study can be seen as the starting base for further research of a matter, or they can be used as a learning tool for similar problems. (Wellington and Szczerbinski 2007)

In this report, a case study is chosen to be made for a Greek industry, i.e. the "*Elina-Komotini Paper Mill*". This case is chosen based on the potential interest of the owners to invest in a CHP unit and because of the topographical characteristics of the area where it is located. It is about an industrial area including a number of various operating industries, while at the same time there are small neighbouring villages (see Chapter 5). Apart from the installation of a CHP unit in the examined industry, the purpose is to investigate whether there is a possibility to develop a district heating network in order to cover the heat demand of one of the nearby communities. The model used for the simulation of the different scenarios is the energyPRO, which is presented in Sub-section 3.2.4.

3.2.3 Communication with selected actors

The communication with selected actors can be seen both as a technique for the case study and as a separate method itself useful for the whole project. The selected actors are four and the communication took the form of email correspondence, except of one case being a telephone interview.

The first contact person was Efterpi Lampaditou, a Senior Energy Analyst, working at the Power Exchange Division of the Hellenic Operator of Electricity Market (LAGIE). She is the one offered inspiration for the project by bringing the writer in touch with the examined industry. Moreover, she provided the data about the Greek electricity spot market price.

The next contact persons were two actors involved in the examined industry: Paras Gravouniotis, who is the General Manager of Elina-Komotini Paper Mill, and Christos

Papageorgiou, who is the Production Manager of the industry. P. Gravouniotis provided information concerning the existing production unit and helped to form the idea of developing a CHP unit. C. Papageorgiou provided the technical data of the existing unit, such as the current capacity, the fuel consumption and the heat demand of the industry.

Finally, the Municipality of Komotini, where the examined industry and the nearby communities are located, was contacted by phone in order to collect information on the way that the heat demand of the area is covered. The interview took the form of an informal conversion and it was chosen not to be recorded.

All data received from the above mentioned communications are presented in detail in Chapter 5.

3.2.4 EnergyPRO modelling

EnergyPRO is a software package for examining and optimising energy projects both technically and economically. It gives the user the possibility to simulate projects including different kind of power plants, as well as projects for cogeneration and tri-generation combined with storage options.

Some of the advantages of the software are:

- It allows the user to define a lot of input data concerning energy demand and external conditions, like wind speeds and ambient temperatures, the operation of the different plants and the priority between them, various costs and tariffs etc.
- When a change is made in the characteristics of a plant or its operation, the user can directly see how this change affects the economic analysis of the project.
- The operation of the various plants can be optimised daily against fixed tariffs or spot market prices. (EMD(a) 2014)

In addition, it is trusted as a valid software package. There is written documentation about performed studies during the last two decades and many companies worldwide use it every day. The consultancy team of the company is internationally recognized and works for private companies, banks and other institutions. (EMD(b) 2014) For all the above reasons, energyPRO is found suitable for the case study of this report and it is chosen for the simulation of the different scenarios.

The software gives the user the possibility to choose between four different modules when simulating an energy project: a) the DESIGN module, b) the FINANCE module, c) the ACCOUNT module, and d) the OPERATION module. The DESIGN module is suitable when the energy conversion and the cash flow are studied for one year of operation of the project. The FINANCE module is chosen when apart from the calculations of the DESIGN module, an investment and financing analysis is desirable to be done. The planning for more than one year is also possible through this module. The ACCOUNT module is similar to FINANCE module, but it also offers the possibility for depreciation and taxation inputs and income statements and balance sheets as outputs. Finally, the OPERATION module is suitable for optimisation of a project for a short period. (EMD(a) 2014) For the case study of this report the FINANCE module is chosen, because it is desirable to analyse the operation data and the investment of the project for more than one year.

Moreover, the user is able to decide between two different operation strategies: a) "*Minimizing net production costs*" and b) "*User defined*". If the first strategy is selected the software automatically calculates the priority of the existing production units based on the revenues and operation expenditures inputs. The highest priority is given to the unit/tariff period with the least production cost, followed by the unit/tariff period with the second least production cost, etc. until all the demands are met. In the "*user defined"* strategy the user has the opportunity to design its own strategy and to define the priority of the units based on the criteria that he/she wishes. In the simulation of the scenarios of this report, there are two energy conversion units, where one of them is always considered as the primary one and the other as a backup capacity. For this reason it is decided to choose the "*user defined*" strategy.

More details about the input data used while modelling are found in Chapter 5.

4 Cogeneration and District Heating in Greece

This Chapter is a detailed description of the existing CHP units and district heating networks in Greece. Starting with the first section, it is given information concerning the historical development of cogeneration and the existing installed capacity of CHP units. The second section analyses the Greek district heating sector, i.e. it provides information about the existing and planned networks. Afterwards, in the third section, the Greek legislative framework for cogeneration is discussed together with the adapted or planned policies for the development of the sector. Finally, in the fourth section, the pricing of cogenerated electricity is analysed, providing information on the past and current methods of estimation of the prices.

4.1 Historical development of CHP capacity

Most of the following data is found through the Hellenic Association for Cogeneration of Heat and Power (HACHP) and the Hellenic Operator of Electricity Market (LAGIE):

In Greece, cogeneration started almost 40 years ago, i.e. in the early 70's, in the industrial sector and it developed gradually. At that time, all industries with CHP units were characterised as auto-producers of electricity. Although the term of *auto-producers* was used since then, its definition and the difference from the *independent producers* were established later in Law 2244/1994. As *independent producers* are called the producers that inject all the generated electricity into the grid, whereas as *auto-producers* are called the producers that generate electricity in order to cover their own needs and they can be grid connected or not (Greek_Government 1994).

The first CHP units were oil-based, because of the unavailability of natural gas at that time and they did not receive any subsidy. In 1985, the total installed industrial CHP capacity was 346.3 MW_e distributed between: Refineries (27%), Steel (23.1%), Food processing (16.17%), Chemical (13.8%), Pulp & paper (12.43%), Textile (4.14%) and Aluminium (3.35%). Around 1985, cogeneration applied also in the tertiary sector with the aim of EEC[5] funding. There were two projects at that time: a) the Solar Village in Athens with a capacity of 67 kW_e and 72 kW_{th}, using diesel as fuel and b) the American College of Athens, which was the first tri-generation[6] unit in Greece, with a capacity of 320 kW_e, 380 kW_{th} and 265 kW_{cool} – operating as diesel unit, as well.

In 1995, though, a reduction in the industrial CHP capacity was noticed. During that period, new circumstances appeared inside and outside the country, such as the development of Eastern European and Asian companies against the Greek ones, or the moving of Greek companies to other countries for lower taxation. For these reasons, the number of the operating industries was affected and the total installed capacity of industrial CHP decreased to 116.1 MW_e, distributed among the sectors of Refineries (80.53%), Aluminium (9.99%), and Chemical (9.47%). (HACHP 2014)

[5] European Economic Community

[6] "*Tri-generation is the simultaneous production of power/electricity, hot water and/or steam, and chilled water from one fuel.*" (COGEN_Europe(d) 2015)

Moving to the early 2000's, industrial CHP capacity had developed again, reaching a total capacity of 137.05 MW_e, after the publication of the Law 2773/99 concerning the electricity market liberalisation, which is described more analytically in Section 4.3 (Greek_Government 1999). In addition, through co-financing by EU funding, new cogeneration units with a capacity of 5.20 MW_e emerged in the tertiary sector and there were also CHP installations of 25.91 MW_e in six municipal water companies, using mainly landfill gas. (HACHP 2014)

Figure 4.1 below illustrates the development of the installed industrial CHP capacity between the years 1985-2005:

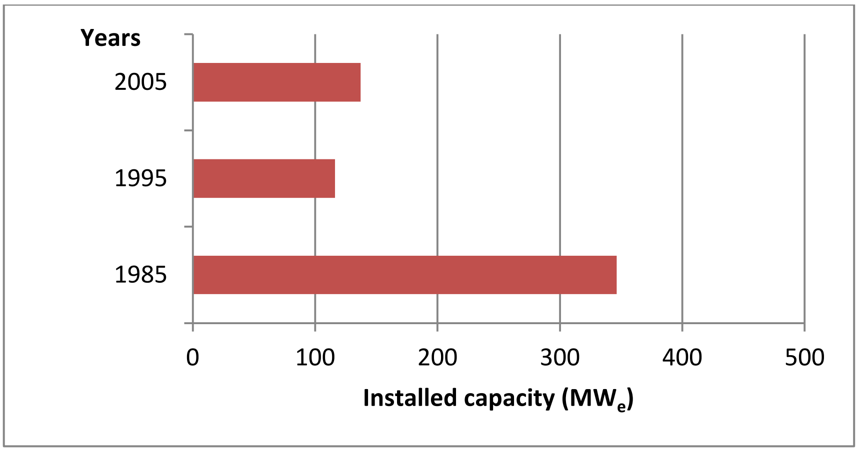

Figure 4.1: Industrial CHP capacity for 1985-2005, Source: (HACHP 2014)

Nowadays, natural gas is available in Greece allowing for natural gas CHP units and there is a guaranteed feed-in-tariff, FIT, for the generated electricity by High Efficiency CHP (HECHP) units, which is analysed in a Section 4.4. However, it is noticeable that a lot of natural gas CHP units have been shut down since 2010. This is explained by the recent economic crisis: LAGIE who is responsible for the compensation of the cogenerated electricity that is fed into the grid, delays to remunerate the producers, with a delay of up to eight or even more months, having as a result the failure of the producers to pay the natural gas providers and their decision to close the installations. (HACHP 2014)

The development of CHP among all sectors, between the years 2006-2012 is shown in Table 4.1. As it is seen, during the seven-year period, with an exception of the years 2007 and 2008, most of the producers were auto-producers.

Year	Installed capacity (MW_e)	Share of CHP in total electricity generation (%)	Independent producers (%)	Auto-producers (%)
2006	250	1.7	20	80
2007	220	1.6	100	0
2008	400	1.9	100	0
2009	510	3.0	10.1	89.9
2010	590	4.3	6.8	93.2
2011	590	4.5	11.6	88.4
2012	570	3.9	6.9	93.1

Table 4.1: CHP capacity in all sectors for 1985-2005, Source: (HACHP 2014, Eurostat 2015)

Moreover, in 2011, after a registration conducted by HACHP, all the HECHP installations above 50 kW_e had a total capacity of 101.07 MW_e, of which 90.59 MW_e came from the industrial sector and the rest 10.48 MW_e from the tertiary sector. All the registered units referred to independent producers that might or might not function at that time. (HACHP 2014)

In Appendix B, there is a detailed list of all the CHP units of the industrial sector that are registered by LAGIE, including information on the name of the industry, the area of installation and the installed capacity. No information is available though, whether these units currently operate or not. (LAGIE 2015)

A case worth mentioning from the list is the one of the "Agritex Energeiaki A.E", an agriculture industry located in Alexandria Imathias (Central Macedonia, Greece). The industry has a greenhouse of 100000 m^2 and a CHP unit based on natural gas with electrical capacity of 4.8 MW_e and thermal capacity of 6 MW_{th} operating since 2007. The maximum annual electricity generation injected into the grid is 32,000 MWh, while the thermal production covers more than 85% of the heat demand of the greenhouse. Particularly interesting is the fact that the installation is also connected with a flue gas treatment unit, where the flue gases coming from cogeneration process are converted into clear CO_2 through catalysis. CO_2 which is essential for the growth of the plants is then lead into the greenhouse. The potential for CO_2 production is 1.5 ton per hour. (Agritex_Energeiaki 2009)

4.2 Greek DH networks

After the description of the CHP capacity in Greece, this section gives information on the existing DH networks. All the names of the towns/cities that are mentioned in this section are found in Figure A.2 in Appendix A. As it is said in the Introduction, district heating is not considered as a developed sector. The first small scale installation applied in the small community of *Eordaia* (Northwestern Greece) in 1960, but the first large scale district heating network appeared only in 1993, in order to provide heating for the urban population of the town of *Ptolemaida* (Northwestern Greece). The fact that the town is located close to the lignite power plants operated by the Public Power Corporation (PPC), together with the conversion of some of the units into cogeneration allowed for the development of a DH network that covers currently a number of 12,900 households. The system operates for the period of 15^{th} October to 15^{th} May, when the average outdoor temperature is 6.7 °C. After a recent extension in 2012, it includes: CHP units with a total capacity of 175 MW_{th}, a 25 MW_{th} back-up oil boiler, total thermal storage of 25 MW_{th}, transmission and distribution pipelines, and thermal substations for the connections of the buildings. (DETIP 2011)

During the same decade, district heating grew in three more towns: *Kozani* and *Amyntaio* in Northwestern Greece and *Megalopoli* in Southeern Greece. These towns have the same characteristics as Ptolemaida concerning the proximity of the towns to PPC lignite power plants. In *Kozani*, the DH system started its operation in 1993. Currently, it has a capacity of 140 MW_{th}, through which space and water heating is offered to almost 25000 apartments. (DEYAK 2015)

In *Amyntaio*, DH appeared in 2004-2005, with the first year of operation being a trial period (DETEPA 2011). The initial capacity of the system was 25 MW_{th} and later it was upgraded to 40 MW_{th} (ANKO_S.A. 2000). At present, around 1,500 households of the municipality are heated, and there is a plan to extend the existing network through the use of local biomass from agriculture residues and local biogas from livestock units. The project, which is part of the Operational Programme 2014-2020 and it will be financed with a share of 80% by EU and with a share of 20% by Municipality of Amyntaio, will have as a result the connection of 4,000 more households. (Macedonia's_journalists 2013)

In *Megalopoli*, there is also a DH network that offers heat to 2,500 residences through CHP operating in one of the existing PPC lignite power units (255 MW_e), while 1,500 more customers are planned to be connected in near future. Moreover, there is a ready-constructed biomass plant with a capacity of 21 MW_{th} that is planned initially to work as supplementary unit and later on to replace the lignite power unit concerning heat production. Part of the project is the production of local biomass through the cultivation of a land of 718,000 m^2, which was offered to the Municipality of Megalopoli by the Ministry of Rural Development following the activities for restoration of the area after the disastrous fires in 2007. However, it is noticed a delay concerning the implementation of the whole project, probably due to administrative issues, and there is no concrete information about the current stage of development. (Μαρτίκας Σ. 2009, ADMIE 2015, AKTOR 2014)

All the previously described DH networks are under the responsibility of municipal companies, but since 2007 there is also a private DH company operating in *Serres* (Northern Greece). The installations include a CHP unit with a total capacity of 16 MW_e and 92 MW_{th}, based on natural gas and oil boilers, and the district heating network has a connection of over 10,000 buildings. The benefits for the city of Serres are less CO_2 and SO_2 emissions of about 14,000 tons/year and 40 tons/year respectively. (Thermie_Serrwn 2014, Techem 2007)

Another town that is going to cover its heat demand through district heating is the town of *Florina* (Northwestern Greece). This is one of the measures mentioned in NEEAP for the promotion of efficient district heating and cooling systems in Greece. Florina is the Greek town with the coldest winter, characterised by high precipitation and snowfall levels, and an average annual temperature of 12.1 °C. The lowest temperature ever recorded by EMY was minus 25.1 °C, in 17th January 2012 (EMY(a) 2015).The DH network will be connected to a neighbouring PPC lignite power unit with a maximum capacity of 70 MW_{th} and it will cover a number of 2300 households. The total cost of the project is estimated €86.4 million, of which 80.44% will be financed by EU and the rest by the Municipality of Florina, which will be responsible for the operation as well. At the moment, there is a setback in the timetable of the construction activities, because of legal issues and delay in the subsidising of the project. The construction of the transmission and distribution pipelines have started, but it stopped about a month ago, due to extreme weather conditions. (CRES and YPEKA 2014, Municipality_of_Florina 2015)

Finally, a few months ago, the Municipality of *Alexandroupoli*, which is a city in Northeastern Greece, received license for a natural gas CHP unit. The generated electricity will be sold to the grid and the produced heat will be used to cover the heat demand of the indoor swimming pool of Alexandroupoli and probably the needs of other municipal buildings. The high efficiency unit will be installed in the boiler house of the swimming pool and it will have an electrical capacity of 0.8 MW_e and a thermal capacity of 0.825 MW_{th}. During summer, an absorber chiller and one or more cooling towers with minimum capacity of 0.5 MW will work for the cooling of the pool. The Municipality of Alexandroupoli is the first municipality in Greece for receiving such license and similar decisions could ease the development of small scale DH networks. (Energypress 2015, Παπαδόπουλος Α. 2014)

Table 4.2 summarizes the name of the Greek towns/cities with existing or future DH networks, providing information on the thermal capacity and the type of fuel used by the CHP units. It is concluded that there are no operating DH networks based on RE, except of a pilot geothermal project on the island of Lesvos (National_committee and CRES 2009).

	Name of town/city	Type of CHP fuel	Thermal capacity (MW_{th})
Existing networks	Ptolemaida	lignite	175
	Kozani	lignite	140
	Amyntaio	lignite	40
	Megalopoli	lignite[7]	21
	Serres	natural gas and oil	92
Future networks	Florina	lignite	70
	Alexandroupoli[8]	natural gas	0.825

Table 4.2: Thermal capacities and fuels used in Greek DH networks (based on sources mentioned in main text)

4.3 Legislative framework and related policies

This section presents briefly the existing Greek legislation concerning cogeneration and district heating, and the measures that have been adopted or planned in order to promote the development of the sectors. All the relative Laws have been published in the Greek Government's Newspaper (FEK) and in the website of the Greek Regulatory Authority of Energy (RAE) (Greek_Government 2015, RAE(c) 2015). The legislative framework starting from the early '90s is summarised below:

➢ Law 2244/1994, entitled: "*Regulation of issues regarding electricity generation from RE sources and other conventional fuels, and other provisions*"

This Law establishes industrial CHP with the use of natural gas. Independent producers are allowed to install combined cycle natural gas CHP units with a maximum capacity equal to the heating and cooling needs of the industries where the systems will be installed. Auto-producers are allowed to install conventional fuelling CHP with a maximum capacity equal to the heating and cooling needs of the industries, but if it is a CHP unit utilising the residual heat or other non-toxic residues coming from the production process of the industry, then there is no limit concerning the maximum CHP capacity. The Law includes also regulations for the licensing process of installation and operation of CHP and the remuneration of the independent producers for the cogenerated electricity fed into the grid. (Greek_Government 1994)

➢ Law 2273/1999, entitled: "*Liberalisation of the electricity market - Regulation of issues regarding energy policy*"

According to this Law, LAGIE shall give priority to independent producers for the cogenerated electricity by CHP units with a capacity up to 35 MW_e. In addition, priority shall be given to auto-producers for the excess electricity that is fed into the grid and is cogenerated by CHP units with a capacity up to 50 MW_e. The Law introduces also new regulations concerning the pricing of the cogenerated electricity. (Greek_Government 1999)

➢ Law 3175/2003, entitled: "*Exploiting the geothermal potential, regulation of district heating networks and other provisions*"

This Law establishes the obligation to acquire license by RAE, called "*License of distribution of thermal energy*", in order someone to install and operate a district heating or cooling network. This license describes the time period of its validity, the characteristics of the area

[7] to be replaced by biomass
[8] It is assumed that a small scale DH network will be applied in the future

where the DH network will be installed, the technology that will be used, the timetable of the construction activities, and the conditions for the distribution of the produced heat to the final consumers. If heat is produced by CHP systems, then the *License of distribution of thermal energy* is given together with the *License of electrical energy generation* by RAE. (Greek_Government 2003)

- Law 3468/2006, entitled: "*Electricity generation from RE sources and HECHP, and other provisions*"

This Law introduces the license for installation and operation of HECHP units and it simplifies the previous established process. HECHP units are defined according to the definition given in the Directive 2004/8/EC, i.e. HECHP are called those CHP units that result to primary energy savings of at least 10% compared to the separate production of electricity and heat. Moreover, the supportive scheme of "Feed-in Tariff" or FIT regarding the pricing of the cogenerated electricity is established with the purpose to promote the security of the investments. (Greek_Government 2006, European_Commission 2004)

- Law 3734/2009, entitled: "*Promotion of cogeneration two or more useful forms of energy, and other provisions*"

This Law is the transposition into national legislation of the EU Directive 2004/8/EC. It describes the method of calculation of the electricity from cogeneration, the types of CHP technologies and the methodology for determining the efficiency of the cogeneration process. In addition, CHP units are categorised based on their capacity: to small scale installations if the capacity is ≤1 MW_e, and micro scale installations for CHP units being ≤50 kW_e and FIT is applied only to HECHP units and not to all CHP, as a measure to promote energy efficiency. (Greek_Government, Law 3734/2009 2009)

- Law 3851/2010, entitled: "*Acceleration of the development of RE for tackling climate change and other provisions*"

Law 3851/2010 sets again new pricing of the cogenerated electricity, which is analysed in details in Section 4.4, and facilitates the installation of CHP units ≤1 MW_e, as for these units an electricity generation license is not required. Moreover, an important provision of the Law is the fact that by 31.12.2019, all new buildings are required to cover their primary energy demand by utilising only RE sources, CHP, district heating systems on a large area scale or block scale and heat pumps. Regarding new public buildings the deadline for this obligation is set earlier, i.e. by 31.12.2014. (Greek_Government(b) 2010)

- Law 3908/2011, entitled: "*Support of the private investment for economic growth, entrepreneurship and regional convergence*"

According to this Law, support is offered for the investment costs of HECHP units. This can take the forms of: tax exemption to the income of the businesses that invest in HECHP installations, free of charge state subsidy in order to cover part of the investment costs, and financial lease state subsidy in order to cover part of the instalments paid for the procurement of mechanical and other equipment. (Greek_Government(a) 2011)

- Law 4001/2011, entitled: "*For the operation of the electricity and natural gas energy markets, for the research, production and transmission networks of carbon resources [...]*"

The most important provision of this Law is that priority for cogenerated electricity shall be given by LAGIE to all HECHP units, regardless of their installed capacity, which means that the threshold of the 35 MW_e set by a previous Law is cancelled for both the independent and the auto-producers. (Greek_Government(b) 2011)

- Law 4254/2014 entitled: "*Measures to support and develop the Greek economy* [...]"

This Law sets again changes in the pricing of the cogenerated electricity, see Section 4.4. In addition, the threshold of 35 MW_e regarding the maximum HECHP capacity that is prioritised in the electricity market is reset and HECHP units are divided into categories based on the type of technology and their installed capacity. (Greek_Government(a) 2014)

From the above mentioned framework it can be concluded that the provisions concerning cogeneration and district heating sector have been improved through time with the purpose to support the development of these sectors. With an exception probably of the most recent Law that brings back a barrier regarding the maximum capacity of CHP units that are prioritised into the electricity market, the rest of the legislation is seen as necessary and helpful for the potential investors.

An important document for someone willing to invest in CHP is considered also the document entitled "*Technical guidance: CHP installations in buildings*" written by the Technical Chamber of Greece (TEE). This report focuses on the benefits of cogeneration and provides information on the available CHP and tri-generation technologies, as well as the required infrastructure in order to connect with the electricity distribution network. It is considered very useful for all the engineers, as it gives examples on the methodology used in order to design a CHP installation for the covering of the needs of a hotel and a hospital. (TEE 2012)

The importance of the cogeneration and district heating sectors is recognised in the documents of the Greek NREAP, NEEAP and the Energy Roadmap for 2050, as well. By 2020, it is estimated that 13.271 GW of RE will be installed for the covering of the electricity needs, of which 40 MW will be CHP units (National_committee and CRES 2009). The supportive measures include the creation of an online tool with statistical data and planning for energy savings and HECHP, which will be useful for businesses, ESCOs and engineers working on these fields (CRES and YPEKA 2014).

4.4 Pricing of electricity generated by CHP

Concerning the pricing of electricity generated by cogeneration, it is an issue that is established legally for the first time by Law 2244/1994. However, the currently applied supporting scheme of "*Feed-in Tariff*" or "*FIT*" was introduced twelve years later by Law 3468/2006. FIT refers to the electricity cogenerated by independent producers or auto-producers, which is injected into the Grid or the System, including the Grid of Non-Interconnected Islands. The subsidising is based on the special RE fee paid by the electricity consumers through their electricity bills, on the NSRF[9] funding and the state funding foreseen by Law 3908/2011. (Greek_Government 2006, CRES and YPEKA 2014)

The following definitions are useful to understand better the definition of the term of "*FIT*":

"Grid is the PPC-owned electricity distribution network that is installed in the Greek territory and it consists of medium and low voltage lines and distribution installations, including those high voltage lines and installations which are connected to it."

[9] The "*National Strategic Reference Framework"* is a document for the national programming of European Union Funds. (Ministry_of_Economy 2015)

"*System is defined as the high voltage lines, the installed interconnections of Greek territory and all the installations, equipment and control units which are necessary for the smooth, safe and continuous provision of electrical energy from a power production unit to a substation, from a substation to another, or from and towards every interconnection. The System does not include the power production units and the high voltage lines and installations which belong to the Grid, neither the Grid of the Non-Interconnected Islands.*"

"Non-Interconnected Islands are the Islands of Greek territory, of which the electricity distribution grid is not connected to the System and the electricity distribution grid of the mainland." (Greek_Government 1999)

The pricing is expressed in €/MWh, based on the electricity injected into the System or the Grid, including the Grid of Non-Interconnected Islands. In 2006, the price of cogenerated electricity by all CHP units and by all fuels was 73 €/MWh, if it was fed into the Interconnected System and 84.6 €/MWh, if it was fed into the Grid of Non-Interconnected Islands (Greek_Government 2006). However, after publication of Law 3734/2009, FIT for cogenerated electricity is referred only to electricity generated by HECHP units, as it is said in Section 4.3 (Greek_Government, Law 3734/2009 2009).

Later on, the publication of Law 3851/2010 brought more changes. Starting with the selling contract between CHP producers and PPC, its duration extended to 20 years from ten years that it was before, with the possibility to further extend it in case that the license of electricity generation was up to date (a provision that is still on today). The price of cogenerated electricity by HECHP units and by all fuels except of natural gas became 87.85 €/MWh, if it was fed into the Interconnected System and 99.45 €/MWh, if it was fed into the Grid of Non-Interconnected Islands. Concerning natural gas HECHP units, the price was increased for the first time by a clause coefficient (CC), i.e. it became 87.85*CC for the Interconnected System and 99.45*CC for the Grid of Non-Interconnected Islands. The clause coefficient could not be less than one and it was defined as:

$$CC = 1 + (ANG - 26) / (100 \times \eta el) \qquad (1)$$

where:

- ANG is the average monthly price, in €/MWh, of gross calorific value natural gas sold for cogeneration to natural gas users in Greece, excluding electricity generation customers.

- ηel is the electrical efficiency of HECHP operating with gross calorific value natural gas and it is equal to 0.33 for HECHP units ≤1 MW and equal to 0.35 for units >1 MW.

This pricing of cogenerated electricity by natural gas HECHP units was made every month based on the ANG of the previous 3-month period. (Greek_Government 2010)

After RAE decision 435/2011, CC was increased more, but only for cogenerators that had made or planned to make investments in flue gas treatment units for the enrichment of cultivations with CO_2 in greenhouses (RAE 2011):

$$CC = 1.18 + (ANG - 26) / (100 \times \eta el) \qquad (2)$$

Moving on to the current pricing method, which is described in Law 4254/2014, one could say that pricing is made now in a more complicated way. First of all, there is a distinction for the prices between: a) the HECHP units which were in operation, a normal or a trial one, when the Law came into force and b) those which are going to operate in future, after publication of the Law. Moreover, HECHP units are categorised to those that received a subsidy for the investment, i.e. *"with subsidy (WS)*", and those that they did not receive one, i.e. "*without subsidy (WoS)*". As subsidy is meant a state subsidy with a share of greater than 20% of the investment cost that is given to facilitate the investment and it can either be direct subsidy, or it can take other forms, such as tax exception, interest rate subsidising etc. In addition, natural gas HECHP units are divided into different categories depending on their capacity and used technology, which are seen in the following tables. (Greek_Government(a) 2014) Here, only the pricing for the HECHP units which are activated after Law 4254/2014 is presented, see Table 4.3 below:

HECHP units activated after Law 4254/2014			
Types of units		**WoS**	**WS**
HECHP units with natural gas	Capacity of ≤1 MW_e for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	88+ADP	76+ADP
	Capacity of ≤1 MW_e for all remaining categories	92+ADP	80+ADP
	Capacity of >1 MW_e up to ≤5 MW_e for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	80+ADP	70+ADP
	Capacity of >1 MW_e up to ≤5 MW_e for all remaining categories	84+ADP	74+ADP
	Capacity of >5 MW_e up to ≤10 MW_e for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	74+ADP	65+ADP
	Capacity of >5 MW_e up to ≤10 MW_e for all remaining categories	78+ADP	70+ADP
	Capacity of >10 MW_e up to ≤35 MW_e for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	68+ADP	62+ADP
	Capacity of >10 MW_e up to ≤35 MW_e for all remaining categories	72+ADP	66+ADP
	Capacity of >35 MW_e for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	61+ADP	57+ADP
	Capacity of >35 MW_e for all remaining categories	65+ADP	60+ADP
Rest of HECHP with all other fuels	Connected to Interconnected System	85	80
	Connected to Non-Interconnected Islands	95	90

Table 4.3: Pricing of HECHP units activated after Law 4254/2014, Source: (Greek_Government(a) 2014)

ADP is referred to the adaptation of price of natural gas, in order to include the fluctuations of its cost and it is defined as:

$$ADP = \left(\frac{\dfrac{\left(1-(\eta-\eta e)\right)}{\eta hr}}{\eta e} \right) \times \left(ANGt - 26 \right) \qquad (3)$$

where:

- ηe is the electrical efficiency of the HECHP unit

- ηh is the thermal efficiency of the HECHP unit

- $\eta = \eta e + \eta h$ is the total efficiency of the HECHP unit

- ηhr is the reference value of the efficiency for the separate heat production

- $ANGt$ is the average monthly mixed price of natural gas in €/MWh that includes the selling price together with the transport costs and the special tax for consumption, called as $ANGm$ or $ANG\eta$, to which is added the average CO_2 cost ($AveCO_2$), corresponding to electricity generation.

- $ANGm$ is the average monthly selling price of gross calorific value natural gas for cogeneration, expressed in €/MWh, that is applied to natural gas users in Greece except of electricity generation customers. This price is defined monthly by YPEKA and it is announced to LAGIE.

- $ANG\eta$ is the average monthly selling price of gross calorific value natural gas expressed in €/MWh, that is applied to those natural gas users being electricity generation customers. This price is also defined monthly by YPEKA and it is announced at LAGIE.

- $AveCO2(€/MWh) = 0.37 \times AveCO2rights(€/ton) \times \eta e$ (4)

- $AveCO2rights$ is the average monthly price of CO_2 rights expressed in €/ton, as it results from the European Energy Exchange (EEX) data. This price is calculated by YPEKA and it is announced to LAGIE.

The values of efficiencies at gross calorific value for the different natural gas units are illustrated in Table 4.4 below:

Natural gas HECHP units	Efficiencies
Capacity of ≤1MW$_e$ for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	η=72%, η_e=33%, η_{hr}=81%
Capacity of ≤1MW$_e$ for all remaining categories	η=67%, η_e=33%, η_{hr}=81%
Capacity of >1MW$_e$ up to ≤5MW$_e$ for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	η=72%, η_e=35%, η_{hr}=81%
Capacity of >1MW$_e$ up to ≤5MW$_e$ for all remaining categories	η=67%, η_e=35%, η_{hr}=81%
Capacity of >5MW$_e$ up to ≤10MW$_e$ for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	η=72%, η_e=35%, η_{hr}=81%
Capacity of >5MW$_e$ up to ≤10MW$_e$ for all remaining categories	η=67%, η_e=35%, η_{hr}=81%
Capacity of >10MW$_e$ up to ≤35MW$_e$ for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	η=72%, η_e=35%, η_{hr}=81%
Capacity of >10MW$_e$ up to ≤35MW$_e$ for all remaining categories	η=67%, η_e=35%, η_{hr}=81%

Capacity of >35MW$_e$ for: a) Combined cycle gas turbines with heat recovery b) Condensate steam turbine	η=72%, η_e=35%, η_{hr}=81%
Capacity of >35MW$_e$ for all remaining categories	η=67%, η_e=35%, η_{hr}=81%

Table 4.4: Efficiency values for gross calorific value natural gas HECHP units activated after Law 4254/2014, Source: (Greek_Government(a) 2014)

In case that the heat produced through a HECHP unit of this category is used for the production of agricultural products and this is the main activity of the producer, or it is utilised through urban district heating networks, then the constant factor in the price of Table 4.3 is increased by a percentage of 20%, e.g. if it is (80+ADP), it becomes (96+ADP). In addition, in case that the flue gases from cogeneration are treated and utilised in the agricultural sector, then the constant is increased by 20% and this is an extra increase apart from the previous described one. (Greek_Government(a) 2014) It should be mentioned that with the provisions of Law 4273/2014 these percentages were replaced by 45% and 17% respectively. (Greek_Government(b) 2014)

As far as the cases of biomass or biogas HECHP units are concerned, new cogenerators which are willing to invest in such a project appear to have two options. According to the above presented data, see Table 4.5, this type of unit belongs to the "Rest of HECHP with all other fuels", except of natural gas. The prices applied are: 85 €/MWh for the Interconnected System and 95 €/MWh for the Non-Interconnected Islands if the investment is made without a state subsidy or 80 €/MWh for the Interconnected System and 90 €/MWh for the Non-Interconnected Islands if the investment is made with the aim of a state subsidy. It seems though, that is more profitable for a new cogenerator to apply for a biomass or biogas unit as an RE project, because in this case FITs are higher, as it is illustrated in Table 4.5. The situation was similar in the previous Laws providing for the pricing of cogenerated electricity, but here only the most recent prices for biomass/biogas units are presented:

Types of RE units		**WoS**	**WS**
Biomass units applying thermal processes (combustion, gasification, cracking)	Capacity of ≤1 MW	198	180
	Capacity of >1 MW up to ≤5 MW	170	155
	Capacity of >5 MW	148	135
Biogas units applying anaerobic digestion of biomass	Capacity of ≤3 MW	230	209
	Capacity of >3 MW	209	190

Table 4.5: Pricing of biomass and biogas units activated after Law 4254/2014, Source: (Greek_Government(a) 2014)

4.5 Conclusion

This Chapter is an answer mainly to the first part of the research question, i.e. "*What is the current situation of District Heating and Cogeneration in Greece [...]*". It provides information concerning the installed CHP capacity, the existing DH networks, as well as the legislative framework and the methodology of pricing of the cogenerated electricity.

The most recent data about CHP refers to the year of 2012, when the installed capacity of CHP was equal to 570 MW_e, representing a share of 3.9% in the total electricity generation. Although this is an increased number compared to the previous years, the sector has been affected by the recent economic crisis, especially the capacity of the CHP installations based on natural gas.

The developed DH networks are few having a total capacity of 468 MW_{th} and covering the heat demand of only five Greek towns/cities. Most of them are based on lignite fuelled CHP units operated by PPC, under the responsibility of municipal companies, except of one network which is based on a natural gas/oil CHP and it is operated by a private company. In the future, there are plans for two more town/cities to install similar applications.

The established legislation providing for cogeneration and district heating networks appeared for the first time in 1994. Today, the supportive schemes in force are the FIT for the cogenerated electricity by HECHP units, the possibility to install a CHP unit ≤1 MW_e, without the requirement of an electricity generation license and the financial support offered for the installation of HECHP units. Concerning DH networks, in order someone to install and operate such a network, he/she shall acquire a *License of distribution of thermal energy* by RAE.

For the pricing of the cogenerated electricity, it is examined if the HECHP unit is activated before or after the publication of the most recent Law, if the unit has received or not a subsidy and if it is operated on natural gas or on another fuel. If it is a natural gas HECHP unit, taking into consideration also the capacity and the utilised technology, the price consists of a constant factor plus a variable one representing the adaptation of the price of natural gas. If it is a HECHP unit based on a different than natural gas fuel, then the price consists exclusively of a constant factor, depending on whether the unit is connected to the Interconnected System or to the Non-Interconnected Islands.

5 Case study

This Chapter describes the case study of the report. It presents the selected industry and the characteristics of the area where it is located. Afterwards, it discusses the three different scenarios that are decided to be simulated using the energyPRO software. The inputs used in the scenarios are also described in the final section.

5.1 The case of Elina-Komotini Paper Mill

Elina-Komotini Paper Mill was founded in 1979. It is a Greek industry producing tissue paper in the form of semi-finished industrial rolls that are sold afterwards to tissue paper converters not only in the Greek territory, but also in Turkey, Bulgaria, FYROM, Albania, Cyprus and Romania. It specialises in napkin grades and it has a production of 18,000 tons in two production lines. (Komotini_Paper_Mill 2015)

It is located in the Industrial area of Komotini, in North-eastern Greece, as shown in Figure 5.1. The original planning of the area included the installation of 100 industries, however today only 48 companies from different sectors are operating (Thrace_online_news 2013). Moreover, in the same area, a natural gas power plant owned by PPC is installed with a capacity of 485 MW_e (PPC 2013).

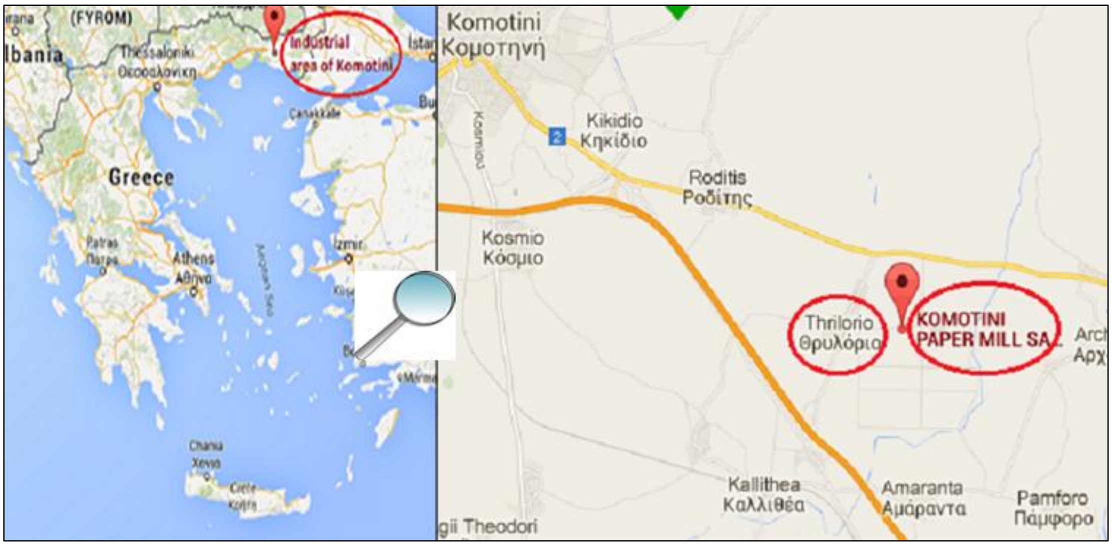

Figure 5.1: Map of the Industrial area of Komotini, Source: (Google_maps 2015)

What makes *Elina-Komotini Paper Mill* special not only in the area, but also among other industries in the whole of Greece is its environmental policy. Five years ago, it decided to reduce the CO_2 footprint of the industry and to make use of sustainable solutions, reducing at the same time the production costs. Currently, it reuses all the needed water for the production, utilising only 12 m^3 of water per ton of produced paper, which is the lowest threshold according to the European Directives of Best Available Techniques (BAT). Concerning waste disposal, there is a central biological treatment unit in the industrial area together with a waste management system that is implemented individually by the industry.

In addition, in June 2012, the industry made an innovative investment in cooperation with Greek boiler manufacturers. It installed a biomass (pellet) boiler with a capacity of 7,560 kW_{th}, replacing in this way the heavy fuel oil (mazut) boiler that it used before for the production of steam which is necessary for the drying process of the paper. The biomass boiler covers the overall heat demand of the industry with almost zero emissions of greenhouse gases, compared to the 11,000 tons of CO_2 equivalent that it emitted annually in the past because of the mazut consumption (11 tons/day). This application can be characterised as unique in Europe among the paper production sector and it was awarded with the first Greek award "*Ecocity- Environmental Investment*" in 2012 and the third Greek award for the Environment in the category "*Process award*" in 2014. The industry also has ambitious goals for the future, i.e. to study the potential of tri-generation (electricity, steam, diathermic oil) and the potential of cogeneration with biomass gasification. (Komotini_Paper_Mill 2015, Gravouniotis 2015) For all the above reasons, this specific industry attracts the interest of the writer and it is decided the examination of different scenarios which are presented in Section 5.2.

Moreover, as it is seen in Figure 5.1, near Komotini Paper Mill there are several small communities-villages with a population of less than 1,000 inhabitants, while the biggest town of *Komotini,* with a population of 43,326 inhabitants, is located at distance of around 9 km away. *Thrilorio*, encircled in Figure 5.1, is the village located closest to the industry (1.2 km away), having a population of 620 inhabitants according to the latest census conducted in 2011 (Greek_Government 2012). Because of the proximity of the village to the chosen industry, it is chosen to focus on Thrilorio with the purpose to examine the potential of a future small –scale district heating network which will utilise excess heat produced by the industry.

Examining the heat demand of the area, it is a fact that it belongs to Climatic Zone C, which is the second coldest zone in the country (see Figure A.1, Appendix A). In 2010, the average annual temperature was 14.5 °C, and the average annual wind speed 3 m/s. (YPEKA and TEE 2010) The HDDs, calculated with a temperature base of 14 °C, are equal to 1131 °Days which is considered a rather high number compared to other Greek regions (see sub-Section 1.3.2). (Ματζαράκης and Μπαλαφούτης 2002) Concerning the energy performance of the buildings, in order to come up with safe conclusions the ideal approach would be to visit the area and to create an inventory of all buildings including the collection of data, such as the construction materials, the existence or not of insulation, the used heating systems etc. Because of time limitations of the project though, this method is chosen not to be followed and assumptions are made based on literature study and communication with the Municipality of Komotini which the village of Thrilorio belongs to.

An investigation of the Greek building stock by Balaras et al. showed that the majority of the buildings, with a percentage of around 75%, are not insulated and are constructed before 1980 (Balaras, et al. 2007); therefore the same hypothesis is made for the buildings of Thrilorio. In addition, they are assumed to be single dwellings and not apartments, as it is the case with most of the buildings of the Greek villages. According to the data given by the Municipality, the heat demand of the community is covered either by individual oil boilers and/or by stoves and fireplaces. The Introduction of the report discussed the increased use of burning wood during the past two years, which is also the case for the community of Thrilorio. In the past, there was also a discussion in about the possibility of a district heating network in the broader area, when the PPC natural gas power plant was installed, but nothing ever happened since then. (Municipality_of_Komotini 2015) In fact, the Ministry of Development has studied the potential of applying a DH network by modifying the PPC power plant for the communities located at a distance of 25km. The production cost has been found satisfactory; however in order the existing plant to provide for the thermal load, the electricity capacity should be decreased by 16.5 MW_e which is not technically acceptable by PPC. (Writing_team 2008)

5.2 Description of scenarios

For the examination of the case, different scenarios were modelled in energyPRO, but finally three were decided to be presented here:

Scenario 1

In the Scenario 1, the current operation of the industry is modelled, i.e. the operation of the biomass boiler together with a mazut boiler of the same capacity is simulated. The mazut boiler is used as a backup for the periods of maintenance and unavailability of the first. The used data comes from the email correspondences with the two contact persons of the industry, i.e. P. Gravouniotis and C. Papageorgiou (see Section 5.3 for numerical inputs).

Scenario 2

In Scenario 2, a biomass CHP unit is introduced. It is assumed that this is the main unit for the process heat demand of the industry and that the current biomass boiler works as a backup, while the mazut boiler is decommissioned. The industry is assumed to work as an independent producer concerning the electricity generation, which means that all the cogenerated electricity is fed into the grid (see Section 4.1).

Scenario 3

Scenario 3 is basically an alternation of Scenario 2. The units that are included are the same, i.e. a biomass CHP and a biomass boiler, but in this case it is assumed that the heat produced by the flue gas condenser of the CHP unit is utilised through a district heating network in order to cover the heat demand of the neighbouring community of Thrilorio. It is assumed that the Municipality of Komotini will be interested for the development of a DH network in the area and it will take over all the installation and operation expenditures which are chosen not to be assessed in this report. In practice, the future network will be under the responsibility of the Municipality and the industry will sell the produced heat to it. As in Scenario 2, the industry is deemed to be independent producer concerning the electricity generation by the CHP unit.

5.3 EnergyPRO inputs

This section is a description of the inputs used in energyPRO in order to simulate the scenarios of the project. The structure of the presentation is according to the structure of the environment that a user meets when using the energyPRO software. Most of the technical data are taken from a Danish catalogue for energy plants published by the Danish Energy Agency and an American Biomass CHP Catalogue published by the U.S. Environmental Protection Agency.

Project identification: The calculation mode is set on FINANCE (see sub-Section 3.2.4), as it is desirable to plan more than one year and to receive results on the investment of the project, apart from the production data of the conversion units. The software gives the option to analyse the financing of the project as well, however this is chosen not to be made, as the economic situation and the intention of the owners of the industry are unknown. The planned years are chosen based on the technical lifetime of the energy conversion units, which is equal to 20 years for a biomass CHP and the same for a biomass boiler (DEA and Energinet.dk 2012, EPA 2007). However, due to the fact that the biomass boiler has already been operating for three years (installation in 2012), the planning period is taken equal to 17 years.

Time series: The time series used in the project is the ambient hourly temperatures of the specific region for one year. The data is accessed through the Climate Forecast System Reanalysis (CFSR), and the year 2010 is chosen, because it includes the most recent and complete data. The temperature is chosen to develop over the years according to an index of temperature increase (see below). The time series concerning the electricity price of the Greek spot market in 2010 is also available, but is not used as whenever an amount of electricity is exported to the grid is remunerated on a fixed-tariff basis described later in this section.

Indexes: Two indexes are included in the scenarios referring to the temperature increase and the inflation. The projections of IPCC concerning the global mean surface temperature over the next 20 years are about a temperature raise in the range of 0.3-0.7 °C (Core_Writing_Team, Pachauri and Meyer 2015). Here it is assumed that the overall increase will be 0.5 °C by the end of the planning period. Concerning the inflation index, because of the current economic situation of the country, it is decided to take the average European one which in 2014 was equal to 0.6% (Harmonised Indexes of Consumer Prices- HICP for EU-28) (Eurostat(b) 2015)

Fuels: The fuels tested are three different types of biomass fuels, which are indicated by the contact persons of the industry. These are sunflower pellet, woodchips with 20% humidity content and cotton straw, which is locally produced, as well as mazut (heavy fuel oil), which is used only in Scenario 1. The calorific value of the sunflower pellet is deemed equal to 17.3 MJ/kg and of the cotton straw equal to 18 MJ/kg, both found in a study on biomass potential in Greece (Γεμτός 2012). The used woodchips are assumed to be beech woodchips. The calorific value for beech woodchips with humidity content of 20 % is calculated equal to 13.2 MJ/kg, after a linear interpolation between the 15% and 30% values which are found in an Italian wood fuel handbook (Francescato, et al. 2008). The calorific value of mazut is taken equal to 40.68 GJ/ton, found in an oil information report which is published by International Energy Agency (IEA 2010).

Demands: Two individual demands are simulated in the scenarios; the industry heat demand (process heat demand) and the community heat demand (district heat demand) including the district heating network losses. The industry heat demand is equal to 52,980.5 MWh/year, calculated based on data given by the contact persons; the needed steam for the drying process of the paper is 8 tons/hour (base load) and the Paper Mill works on a 24/7 basis.

Concerning the heat demand of the community of Thrilorio, as it was said before, it is based on assumptions and not on real data. It is assumed that the village has around 155 single-family dwellings, and that an average house has a total floor area of 80 m^2. The average annual final heat demand is taken equal to 107.7 kWh/m^2. This is a figure calculated for residential buildings in Climatic Zone C by Balaras et Al. based on estimation of various factors, such as the efficiency of the installed heating systems, the available building audits and the actual data taken from YPEKA, concerning the annual final energy consumption and the total floor area of the different climatic zones. (Balaras, et al. 2007) It is also assumed that 60% of the demand is used for space heating, 20% for domestic hot water and the rest of 20% is network losses in transmission and distribution pipes (EMD(a) 2014). The described assumptions result in a district heat demand of 1,602.6 MWh/year. The 60% of the demand is set to depend linearly on the ambient temperatures for the period from October till May and the reference temperature is chosen equal to 20 °C (Writing_team 2008).

Energy conversion units: The energy conversion units simulated in the scenarios are a biomass boiler, a mazut boiler and a CHP unit. The biomass boiler has a capacity of 7,560 kW_{th} and an efficiency ranging from 86-93%, according to the data given by the contact persons. It has an availability of approximately 94% (or 8,256 hours of operation per year) because of outages for maintenance operations. Moreover, it is sized at approximately 120% of the base load and it can reach a peak production of 10 tons of steam per hour. As it was said before, the mazut boiler is used as a backup for the periods when the biomass boiler is maintained, and it has the same characteristics as the biomass boiler. (Gravouniotis 2015, Papageorgiou 2015)

As for the CHP unit, it is assumed to be a "*direct-fired*" system. This is one of the two most common technologies for biomass conversion to power and heat, with the other one being "*gasification*" systems. A direct-fired system consists of a boiler where biomass is burnt in order to produce high pressure steam, which is lead to a steam turbine connected to a generator. In the Scenarios, it is assumed that the CHP unit includes also a flue gas condenser, which is used in Scenario 2 in order to increase the efficiency of the unit and in Scenario 3 in order to deliver district heat. (EPA 2007, DEA and Energinet.dk 2012)

In Scenario 2, the overall efficiency of the unit is set equal to 103% (with flue gas condensation) and the sizing is done so that the process heat demand of the industry is met (heat match). Moreover, it is assumed that the production of the Paper Mill and therefore the process heat demand will remain stable for the following years. As it is seen as a priority to produce process heat, the electrical efficiency is chosen to be 20% and the process heat efficiency 83%. The availability of the unit is set to approximately 94%. In Scenario 3, the size of the CHP unit remains the same, but the efficiencies are set to 76% process heat efficiency and 20% electrical efficiency, because the flue condenser is utilised as a separate unit. The sizing of the condenser is set equal to 120% of the peak heat demand of the community, i.e. at 672 KW_{th} (EPA 2007, DEA and Energinet.dk 2012)

Electricity market: In Scenario 2 and 3, a fixed tariff market is defined. This market represents the fixed biomass FIT that is paid to the industry expressed in €/MWh for the amount of electricity that is fed into the grid (see Table 4.5). This price is valid for all year long and for all hours and the selling contract made with PPC has duration of 20 years with possibility of extension (Greek_Government(b), Law 3851/2010 2010).

Operation strategy: The operation strategy is set as "*user defined*" in all cases. In Scenario 1, the biomass boiler gets the highest priority and the mazut boiler the lowest, while in Scenario 2 and 3, the CHP unit and the flue gas condenser get the highest priority and the biomass boiler the lowest. All units in all scenarios are allowed to work on partial load.

Economy: This is the section of energyPRO where all the economic data are set. The currency for the calculations is set to Euro, the inflation is connected to the inflation index that was described before, and the nominal discount rate is taken equal to 6% based on the recommendation by European Commission for all cohesion countries[10] (EIB_Projects_Directorate 2013). The Net Present Value (NPV) and the Internal Rate of Return (IRR) are taken as output from the software.

Revenues: The revenues of the analysis are connected to the sale of electricity and to the sale of heat. As it was said before, the electricity exported to the grid is remunerated by a

[10] The EU countries under the Cohesion Fund for the years 2014-2020 are: Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia. (European_Commission(b) 2014)

fixed biomass FIT. It is assumed that the project will apply as an RE project and not as a HECHP unit (see Section 4.4.) and it will not be granted a subsidy, so the price is taken equal to 170 €/MWh from Table 4.5, according to the capacity of the unit.

In order to assess the price for the sale of heat to the community, there are different ways to do so, such as to assume the same price as in another DH network or to take the price equal to the cost of another heating option. Here, it is decided to study the DH network of the town of Ptolemaida (see section 4.2) as a successful example in Greece. There the operation of the network is under the responsibility of the municipality and in 2010, the selling price of the heat to the consumers was 37.74 €/MWh (DETIP 2011). In the case of the industry, it is assumed that the Municipality of Komotini will apply a similar price to the consumers and that a percentage of the price will go for the annual standing charges of the network, so the price for the remuneration of the producer of district heat, i.e. the Paper Mill, is set to approximately 30 €/MWh.

Operation expenditures: The operation expenditures include the fuel costs and the operation and maintenance costs (O&M) of the units. The fuel costs are found through the contact persons, except of the price of mazut which is found through an online source describing the fuel prices in the Greek energy market. Therefore, the fuel cost of the sunflower pellet is 100 €/ton, of the woodchips 70 €/ton, of the cotton straw 30 €/ton and of the mazut 644.7 €/ton (154.09)[11]. (Gravouniotis 2015, Papageorgiou 2015, Econews.gr 2013)

The total O&M costs of the biomass boiler are chosen equal to 2.7 €/MWh, 5.4 €/MWh and 4 €/MWh for the sunflower pellet, the woodchips and the cotton straw respectively, while the total O&M costs of the mazut boiler are set to 6 €/MWh based on the Danish Catalogue for Energy Plants. Concerning the O&M costs of the CHP unit, they are assumed to be equal to 8.5 €/MWh. (DEA and Energinet.dk 2012, EPA 2007)

Investments: The investment costs are assessed only for the new units that are introduced, i.e. the CHP unit, and not for the biomass and the mazut boiler which were installed by the industry before the planning period. The price includes the engineering, procurement and construction costs, as well as the infrastructure and connection costs and it is taken equal to 2.5 M€/MW_e (EPA 2007).

5.4 Conclusion

This Chapter is a presentation of the case study of this report. It is about a Greek Paper Mill located in North-eastern Greece, which has recently invested in a biomass boiler for the production of the necessary process heat, and it is interested in CHP or in other innovative investments.

Different scenarios are simulated in energyPRO, i.e. the current operation of the industry, the possibility of a CHP unit and the possibility of a CHP unit together with a small-scale DH network connected to the neighbouring community. The used inputs are described analytically in this Chapter.

[11] The same prices can be expressed in €/GJ based on the outputs of the energyPRO on the fuel consumption. The pellet cost is equal to 5.78 €/GJ, the woodchips cost 5.3 €/GJ, the cotton straw cost 1.67 €/GJ and the mazut cost 15.85 €/GJ.

6 Techno-economic analysis

This Chapter is a presentation of the results of the techno-economic analysis made via the energyPRO software. The results are presented and discussed separately under each scenario. For Scenario 2 a sensitivity analysis is made as well, in order to examine how the results are affected by the variation of different factors.

6.1 Scenario 1

As it is said in Section 5.2, Scenario 1 is a simulation of the existing units of the industry which are a biomass and a mazut boiler. The operation of the biomass boiler is simulated with three different fuels, i.e. sunflower pellet (which is currently used by the industry), woodchips with 20% moisture content and cotton straw. For all the fuels, the simulation period is 17 years, it is assumed that the process heat demand of the industry will remain constant over the years and the priority between the boilers will not change (see Section 5.3 for inputs). Table 6.1 presents the technical results for one operational year:

Types of fuels	Process heat production (MWh/y)		Hours of operation (h)		Turns on (times)		Fuel consumption (tons)	
	Biomass Boiler	Mazut Boiler	Biomass Boiler	Mazut Boiler	Biomass Boiler	Mazut Boiler	Biomass Boiler	Mazut Boiler
Sunflower pellet and mazut	50,222.7	2,757.9	8,304	456	14	2	11,612.2	271.2
Woodchips and mazut	50,222.7	2,757.9	8,304	456	14	2	15,219	271.2
Cotton straw and mazut	50,222.7	2,757.9	8,304	456	14	2	11,160.6	271.2

Table 6.1: Technical results of Scenario 1 after simulation in energyPRO

As it was expected, the operation of the boilers, regarding the process heat production, the hours of operation and the turns on, is the same and independent of the used biomass fuel. The only difference noticed is the fuel consumption, which is explained by the calorific value of the fuels. The biggest fuel consumption (15,219 tons) is needed when the biomass boiler burns woodchips having a calorific value of 13.2 MJ/kg, followed by the consumption of sunflower pellet (11,612.2 tons) with a calorific value of 17.3 MJ/kg and finally the consumption of cotton straw (11,160.6 tons) with a calorific value of 18 MJ/kg.

Moving to the economics of Scenario 1, Table 6.2 and Table 6.3 present the results of the financial analysis. This analysis consists of a year-by-year calculation of the operational expenditures of the industry for the next 17 years of operation, assuming that the costs increase between the years with an inflation rate of 0.6%. Moreover, the net present value of those expenditures using a discount rate of 6% is calculated.

Looking at Table 6.2, cotton straw is the fuel that results to the lowest operational expenditures and woodchips to the highest, with a slight difference compared to pellet. The operational expenditures are defined as a sum of the fuels costs and O&M costs. When cotton straw is used, the O&M costs are not the lowest, but the fuel costs are less than the half compared to woodchips' and pellet's fuel costs. This is a result of the combination of two parameters: a) cotton straw is locally produced, so it is bought in very low price and b) cotton straw has a high calorific value leading to the least biomass fuel consumption as it was said before.

Year 2015							
Types of fuels	**Fuel costs (€)**		**Total Fuel costs (€)**	**O&M costs (€)**		**Total O&M costs (€)**	**Total operational expenditures (€)**
	Biomass Boiler	**Mazut Boiler**		**Biomass Boiler**	**Mazut Boiler**		
Sunflower pellet and mazut	1,161,219	174,829	1,336,048	135,601	16,547	152,149	1,488,196
Woodchips and mazut	1,065,330	174,829	1,240,159	271,203	16,547	287,750	1,527,909
Cotton straw and mazut	334,818	174,829	509,647	200,891	16,547	217,438	727,085

Table 6.2: Financial results of Scenario 1 after simulation in energyPRO

The distribution of the operational expenditures over the years is realised better by the use of the discount rate and the calculation of the net present value. It is a way to realise today the value of the money in the future. Table 6.3 shows the net present value (NPV) of the three simulated cases with a nominal discount rate of 6%. It is negative because it only includes the user defined expenses of the industry. However, it is verification that cotton straw is the best choice when the operational expenses of the industry are examined, as it results to the least negative value.

Types of fuels	NPV of all expenditures (€)
Sunflower pellet and mazut	-16,678,744
Woodchips and mazut	-17,123,882
Cotton straw and mazut	-8,147,510

Table 6.3: NPV of the operational expenditures of Scenario 1

6.2 Scenario 2

In Scenario 2, the energy conversion units are a biomass CHP, which is assumed to be the main operation unit, and the already installed biomass boiler, which is assumed to work as a backup for the periods of maintenance of the first. As in Scenario 1, the planned years are equal to 17 years and simulations are made for the three biomass fuels. Table 6.4 illustrates the technical results of the Scenario 2 for one operational year:

Types of fuels	Process heat production (MWh/y)		Electricity production (MWh/y)	Hours of operation (h)		Turns on (times)		Total Fuel consumption (tons)
	CHP	Biomass Boiler	CHP	CHP	Biomass Boiler	CHP	Biomass Boiler	CHP & Biomass Boiler
Sunflower pellet	50,077.6	2,903	12.067	8,280	480	15	3	13,226.3
Woodchips	50,077.6	2,903	12.067	8,280	480	15	3	17,334.5
Cotton straw	50,077.6	2,903	12.067	8,280	480	15	3	12,712

Table 6.4: Technical results of Scenario 2 after simulation in energyPRO

It is seen that the lowest fuel consumption is made when cotton straw is burnt (12,712 tons), followed by pellet (13,226.3 tons) and woodchips (17,334.5 tons). This is explained, as in Scenario 1, based on the calorific value of the fuels.

Continuing with the financial analysis of Scenario 2, this analysis consists of a year-by-year calculation of the cash flow of the industry. In this Scenario, apart from the operational expenditures, which are assumed to increase between the years with an inflation rate of 0.6%, are also included: the CHP investment cost and the revenues from the sale of the cogenerated electricity. Table 6.5 and Table 6.6 illustrate the results of the simulations:

Year 2015							
Types of fuels	CHP investment cost (€)	Total Fuel costs (€)	O&M costs (€)		Total O&M costs (€)	Total operational expenditures (€)	Total revenues from electricity export (€)
			Biomass Boiler	CHP			
Sunflower pellet	4,554,250	1,322,632	7,838	425,659	433,498	1,756,129	2,051,385
Woodchips	4,554,250	1,213,414	15,676	425,659	441,336	1,654,750	2,051,385
Cotton straw	4,554,250	381,359	11,612	425,659	437,271	818,630	2,051,385

Table 6.5: Financial results of Scenario 2 after simulation in energyPRO

Types of fuels	NPV (€)	IRR (%)
Sunflower pellet	-2,144,799	Not found
Woodchips	-1,008,297	2.2
Cotton straw	8,363,159	30.7

Table 6.6: NPV and IRR of Scenario 2 after simulation in energyPRO

Based on the data given by the user, energyPRO calculates the NPV of all the payments and the internal rate of return (IRR) of the project (see Table 6.5). It is concluded that the CHP investment is profitable only in the case that cotton straw is used as a fuel, because only then the NPV is calculated with a positive value. Moreover, the IRR in this case is higher than the discount rate (6%) which also indicates that this investment is profitable. Considering that the revenues and the investment costs are set the same in the simulations of the different fuels, it can be said that NPV is affected by the variation of the operational expenditures. Indeed, the least operational expenditures are found for cotton straw, followed by those of woodchips and finally pellet's (see Table 6.4).

Figure 6.1 illustrates the difference in the total annual operational expenditures between the currently used pellet boiler and the cotton straw CHP. The expenditures increase during the years in both cases because of the inflation, but the cotton straw CHP annual expenses are approximately 45% less than the pellet boiler expenses.

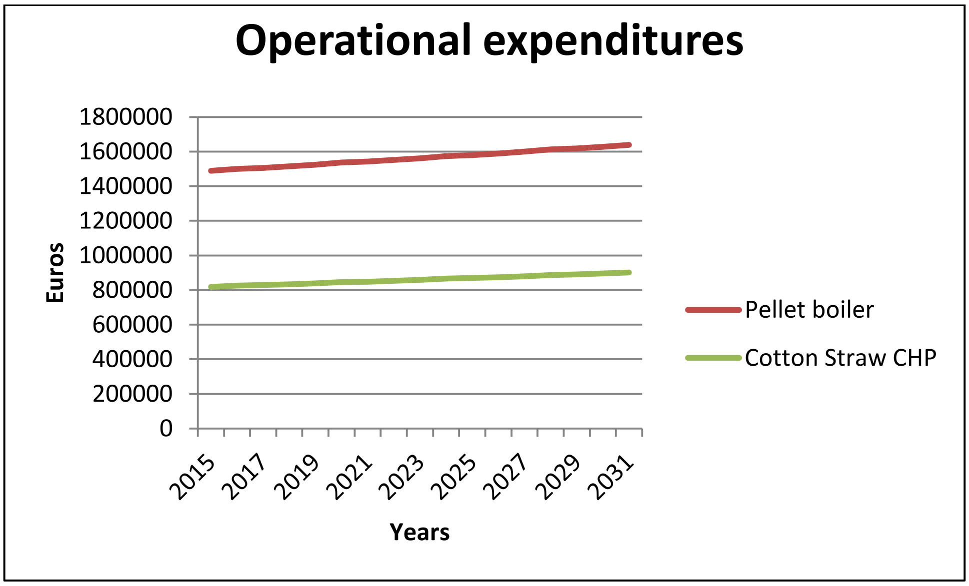

Figure 6.1: Operational expenses of pellet boiler vs. cotton straw CHP

Assuming that the industry has the necessary capital in order to invest in a cotton straw CHP unit and that it will get paid by LAGIE the established FIT for the cogenerated electricity, the decreased expenses in combination with the revenues from the sale of electricity is seen as a long-term benefit for the industry and a good motivation in order to make this investment. The costs/risks and the benefits of the industry from this investment are summarised below:

Benefits

- Reduced operational expenses compared to the current pellet boiler
- Extra revenues through the exported electricity to the grid
- Security of energy supply, especially if the burnt biomass fuel is locally produced
- Environmental benefits through the almost zero GHG emissions
- Increase in the overall efficiency of the system
- Contribution to the RE and EE targets of the country

Costs/Risks

- High investment cost in times of economic scarcity

- Risk of not being remunerated in time for the cogenerated electricity injected into the grid (see Section 4.1)
- Possible extra costs for the connection to the grid
- Possible delay during the license procedure of the unit
- Risk of not enough biomass resources in the neighbouring territory
- Extra costs for the transportation and the storage of the biomass fuel

The detailed results from the simulation in energyPRO of the Scenario 2 – cotton straw can be found in Appendix C.

6.2.1 Sensitivity analysis

For Scenario 2, it is decided to make a sensitivity analysis, in order to examine how the discount rate, the fuel price and the electricity FIT influence the NPV of the project. The analysis is made only for the case of the cotton straw CHP, which results in a profitable investment.

For the discount rate, the prices of 4%, 8%, 10%, 12% and 14% are simulated apart from the chosen 6%. It is noticed that the increase of the discount rate lowers the value of the NPV, but it remains positive under all cases, see Figure 6.2:

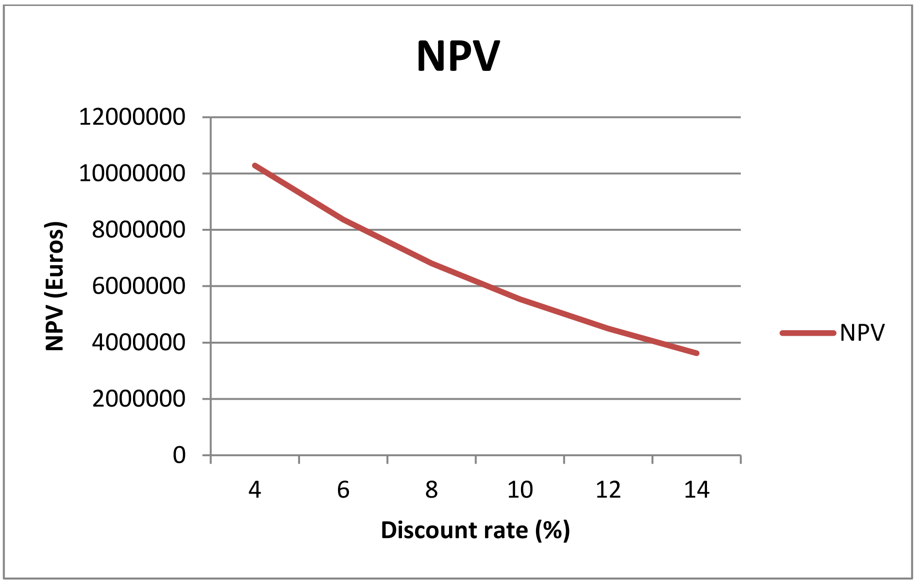

Figure 6.2: NPV sensitivity to discount rate

According to Gravouniotis, the price of the cotton straw varies in the local market in a range of 20-40 €/ton (Gravouniotis 2015). A further increase of the price is chosen to be made in order to see what would happen if the cotton straw was sold at the price of the pellet, i.e. at 100 €/ton. It is noticed that the NPV becomes negative at a price of around 90 €/ton, which is three times higher than the current price and it is rather unlikely to happen, see Figure 6.3:

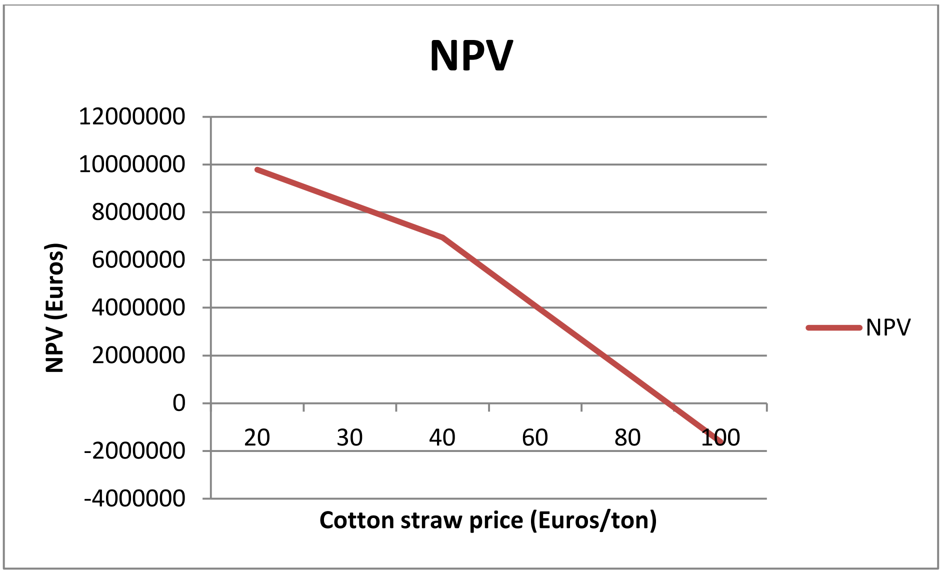

Figure 6.3: NPV sensitivity to cotton straw price

Regarding the FIT of the cogenerated electricity, the price of 170 €/MWh which is used in the Scenarios is applied with the assumption that the investment will not be granted a subsidy. In case it was granted a subsidy, the price would be 155 €/MWh (see Table 4.5). In addition, if the project had applied as a HECHP project and not as an RE project, the prices would be 85 €/MWh without a subsidy and 80 €/MWh with a subsidy (see Table 4.5). All these prices are simulated and the results are shown in Figure 6.4. It is noticed that the FIT affects the NPV a lot more than the other examined factors. The value becomes negative at an electricity FIT of around 100 €/MWh.

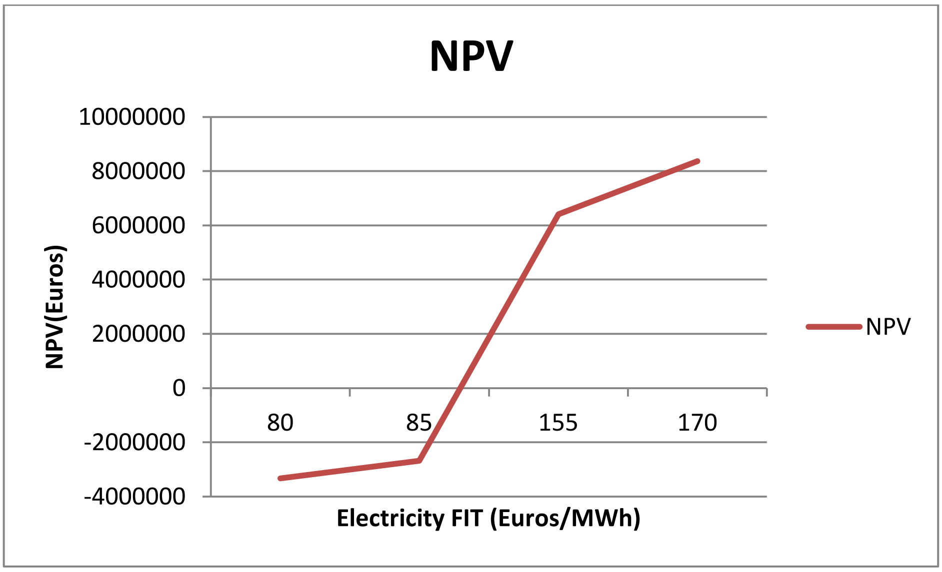

Figure 6.4: NPV sensitivity to electricity FIT

6.3 Scenario 3

In Scenario 3, the community heat demand of Thrilorio is added in the field. The energy conversion units remain the same as in Scenario 2, i.e. it is a CHP unit and a biomass boiler, but in this case it is decided to utilise separately the flue gas condenser of the CHP unit in order to produce district heat for the community. Only cotton straw is decided to be used as fuel in the simulations. Figure 6.5 shows how the different demands are covered by the hourly production of the energy units:

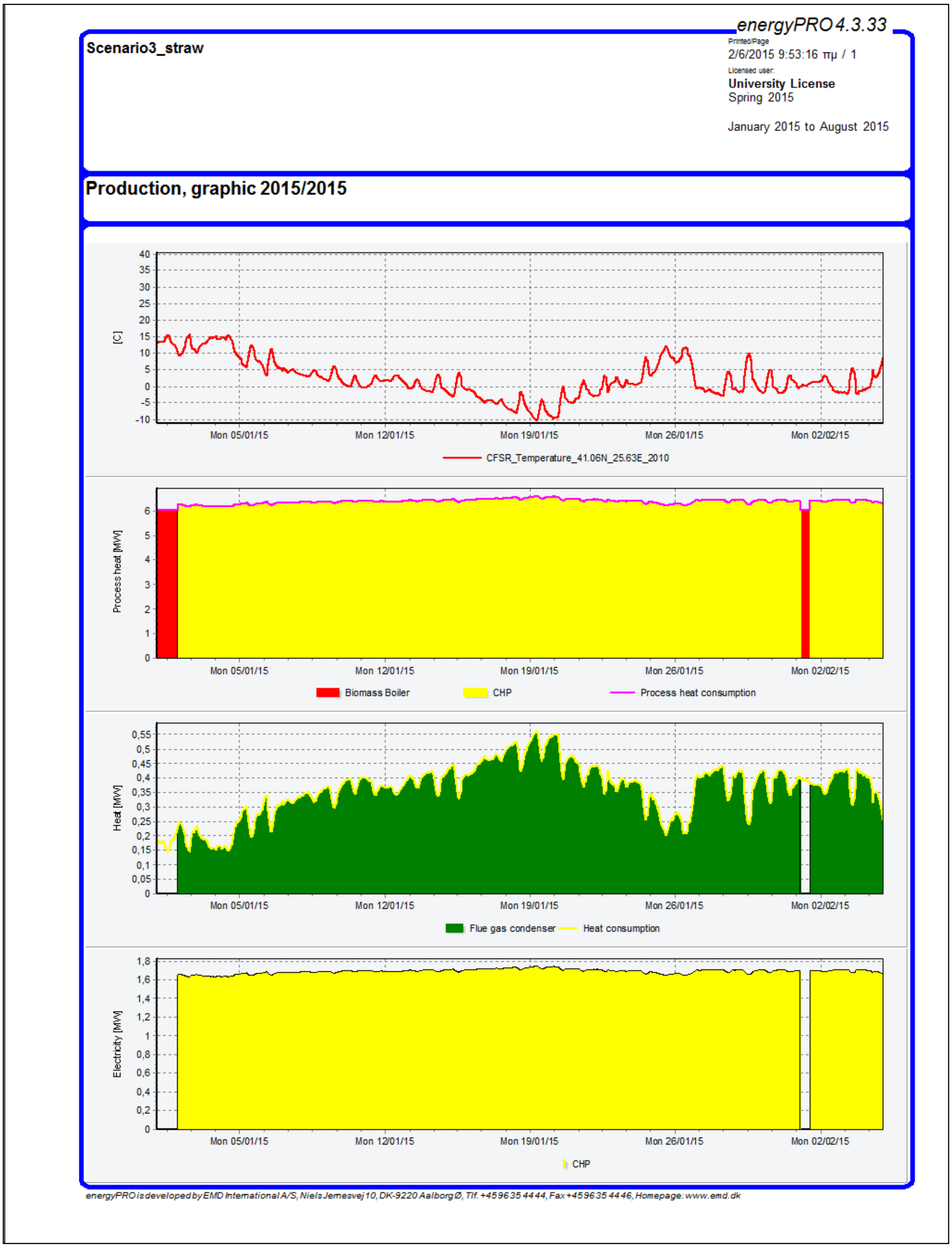

Figure 6.5: Production graphic for January 2015 for Scenario 3

The process heat demand is 100% covered by the CHP unit and the biomass boiler, but the community heat demand is covered partially by a percentage of 96% (see Appendix C for detailed results). This is due the fact that when the CHP unit is stopped for maintenance, the district heat production by the condenser stops as well. A solution to this shortage would be to install an additional flue gas condenser to the biomass boiler, or the use of an alternative heating option by the inhabitants only for the hours of the year that the CHP does not operate.

The financial results of Scenario 3 are illustrated in Table 6.7. In this case the electrical capacity of the unit is a bit higher based on the chosen efficiencies, this is why the CHP investment cost is also higher when comparing Scenario 2 and 3. It can also be noticed that there is extra revenue, apart from the sale of the electricity to the grid operator, referring to sale of the heat to the municipality, in order to provide it afterwards to the community. Concerning the NPV of all payments and the IRR calculated by the software, these are equal to 10,589,675 € and 34.6% respectively. Both values are higher than the cotton straw case in Scenario 2, which means that the investment of Scenario 3 is a better choice for the industry.

Year 2015							
Fuel	**CHP investment cost (€)**	**Total Fuel costs (€)**	**Total O&M costs (€)**	**Total operational expenditures (€)**	**Revenues from electricity export (€)**	**Revenues from sale of heat (€)**	**Total revenues (€)**
Cotton straw	4,973,750	426,975	450,483	877,457	2,309,875	48,078	2,357,953

Table 6.7: Financial results of Scenario 3 after simulation in energyPRO

The costs and benefits of the industry are similar to those discussed in Scenario 2, and some of them, such as the environmental benefits and the security of energy supply apply also for the neighbouring community. It is interesting though to see what will be the economic benefits of the community after this investment. For this purpose, an assumption is made that the Municipality of Komotini will apply the same price to the district heating consumers as the Municipality of Ptolemaida, i.e. a price of around 38 €/MWh (DETIP 2011). An average single-family dwelling in the area has an annual heat demand of approximately 8.6 MWh, as it was discussed in Section 5.3. This means that the total expenses for a consumer connected to the district heating network will be around 330 €/year.

The heating alternative resources used in the area are heating oil and burning wood. Starting with the heating oil, the average regional selling price for the domestic consumers during the previous year was 0.97 €/litre. The annual heat demand of an average residence with the same characteristics as those used in the scenarios is around 2000 litres of heating oil (Municipality_of_Komotini 2015), which is equal to expenses of 1,940 €/year. This means that the district heating option offers savings of more than 80%. The same figures when burning wood is used are approximately 6 tons of burning, wood which is found in an average price of 120 €/ton, resulting to total expenses of 720 €/year. The district heating option appears again as a more cost effective solution for the covering of the heat demand resulting to 55% less expenses. (Ministry_of_Developement 2015, Municipality_of_Komotini 2015)

7 Discussion

After the presentation of the techno-economic results of the case study, this Chapter answers the second part of the RQ concerning the opportunities and the barriers for development of Cogeneration and District Heating in Greece. It starts with the application of the theories described in Chapter 2 and later on, it presents a series of opportunities and barriers related to the implementation of the sectors both on a national and a regional level, discussing at the same time some of the findings of the case study of this report.

7.1 Application of relevant theories

In Chapter 2, three different theoretical concepts relevant to the problem of this report are explained: a) Concrete Institutional Economics, b) Choice Awareness, and c) The Carbon Lock-in concept. After the presentation of the current situation of CHP and DH in Greece and the case study, it is time to discuss the application of the selected theories.

The problem of the Greek energy sector can be related to the Concrete Institutional Economics. Despite the liberalisation of the market, it is a fact that the electricity sector is almost a monopoly owned by PPC. In 2003, PPC owned 75% of the power production units and the entire electricity distribution network, while it was responsible for the 98% of the distributed electricity to the consumers. Concerning the transmission network, this is owned by a PPC subsidiary. (RAE(d) 2015) PPC, being the dominant actor, appears not to take any major decisions that could harm the interests of the company. As it is said in the Introduction, lignite power plants remain the leading way for electricity generation. Alternative technologies do exist and develop, but their penetration is made with delay.

The case study of this report proves that PPC is reluctant to promote the development of CHP and DH under the specific conditions of the area. As it was said in Chapter 5, there is an installed power production unit in the industrial area owned by PPC; although the economic potential of applying a DH network in the area has been found satisfactory, PPC has not accepted to modify the unit, because this would generate extra costs in order to meet the electricity demand. Applying the theory of the Institutional Economy, it seems that in order to change this situation it is essential to emphasize on the Greek energy market and the institutional changes that need to be made.

The existing problem shall be examined by considering the theory of Choice Awareness, as well. Taking the heating sector as an example, the change from individual oil boilers, used by the majority of the Greek consumers, towards a district heating network can be seen as a radical technological change, because it involves a change in more than one of the previously described factors, i.e. in technique and in organisation.

Awareness among the involved actors is an important factor which has not been discussed in this report so far. HACHP has assessed the awareness on cogeneration through qualitative interviews with relevant Greek experts and the conclusion is that there is low awareness, despite the recent energy policies and the established action plans of the country. To be more specific, different groups of actors have been analysed and the main outcomes are:

- Households and SMEs are almost unaware of cogeneration technologies.
- Industries and utilities do know and are often interested in cogeneration, but because of the economic situation they are doubtful to invest.

- Actors related to the market, such as installers, consultants and grid operators usually have the knowhow, but there is a lack of Greek CHP manufacturing and installation companies.
- Policy makers, including the national legislators, are slightly informed about the advantages of cogeneration and it seems that they enact only because they have to comply with the EU Directives. (HACHP 2014)

As for district heating, there is a low level of awareness among the citizens, except of a small percentage of those living in the towns/cities where DH networks are currently applied. There might be a part of the population that has heard of the concept of DH, but it ignores the technological aspects and the benefits of the application. This is the case for the local citizens of the area of the case study of this report, verified through the communication with the Municipality of Komotini. According to Choice Awareness, the awareness of the Greek society that it does have other options for heating, such as district heating, would be advantageous. Moreover, the proposed methodology of the theory could be used in the evaluation of the development of a large-scale DH network.

In addition, the general problem seems to be close to the Carbon Lock-in concept. As it was discussed before, the developed fossil fuel based system appears as very stable and dominant; there are established environmental policies and emergence of alternative technologies, but the development is slow and probably not up to the extent that it could be. According to the Carbon Lock-in theory, escaping from this situation could be supported by the society after the proper educational programmes or it could happen together with a possible climate crisis in the country.

7.2 Opportunities for development of CHP and DH

7.2.1 National potential

In 2008, the Ministry of Development conducted an "*Assessment of the national potential for combined heat and power in Greece*". (Writing_team 2008) Under this study, the technical and economical potential in the residential, industrial and in the tertiary sector was assessed, as well as the potential for biomass applications of CHP.

By 2020, the total economical potential for CHP installations has been estimated equal to 1,455 MW_e, of which 90 MW_e (6.2%) in the tertiary sector, 24 MW_e (1.6%) in the residential sector, 1,271 MW_e (87.3%) in the industrial sector, and 70 MW_e (4.8%) in refineries. Obviously, the highest economical potential has been found in the industrial sector, which is also the reason why the writer of this report chose to investigate a relevant case. The industrial sub-sectors showing the most promising potential are "Food, beverages & tobacco" and "Iron & Steel and non-ferrous metals". (Writing_team 2008)

Concerning the study of the tertiary sector, this has included hotels, hospitals, university campuses and office buildings, and the highest rate of development has been projected for hotels and hospitals. As for CHP applications in residences, these types of investments have been found profitable only in cases of apartment buildings with long hours of operation and with a subsidy of over 50%. (Writing_team 2008)

According to "*Energy Roadmap for 2050*" conducted by YPEKA, the strategy for further penetration of CHP and DH in the Greek energy system shall include the following three axes:

- The development of the DH networks shall be made in combination with the existing power production units or by utilising natural gas.
- There shall be further penetration of CHP and DH in the industrial sector together with the development of natural gas networks.
- Tri-generation shall be developed in the tertiary sector, exploiting the potential of CHP for the heating and cooling demands in hotels, hospitals and big office buildings. (National_Planning_Committee 2012)

Analysing this strategy, it is seen that the Greek Ministry of Environment, Energy and Climate Change prefers to follow a tested approach regarding the development of DH networks, i.e. the development of district heating through the modification of the existing power production units, while it considers natural gas as the "key fuel" for development. However, the case study of this report has proved that there are also opportunities for development through the use of biomass, especially in the industrial sector, coming along with significant benefits as it was discussed in Section 6.2.

The technical potential for biomass CHP applications has been estimated equal to 290.09 MW_e for manufacturing installations with the use of biomass products, and 83.1 MW_e for district heating applications in the residential and tertiary sectors with the use of agricultural and forest residues. This potential is considered quite high and it can result to economical profitable investments providing that there is a subsidy of 40%. The reason why the Ministry probably hesitates to develop CHP plans based on biomass is the fact that there is not yet a national market with stable quality and prices of products. Factors such as the seasonal availability and the low energy intensity of the biomass make more difficult to design large scale units compared to conventional fuels. (Writing_team 2008)

7.2.2 Legal and financial support

The biggest part of the legislative framework presented in Section 4.3 is considered encouraging and it promotes the exploitation of the previously described potential. The most helpful provisions are repeated here and it is discussed their possible effect.

1) ***The electricity produced by HECHP units is given priority by LAGIE into the electric grid***. (Greek_Government 2006)
This is a measure that is also promoted by the recent EU Directive (2012/27/EU), and it can be seen as a way to escape from the conventional power systems and to increase the energy efficiency of the national energy system.

2) ***It is not required to obtain an electricity generation license by RAE for CHP units ≤1 MW_e.*** (Greek_Government(b), Law 3851/2010 2010)
This is seen as an opportunity for the development of small scale applications, as depending on the conditions the licensing process might be a time-consuming process.

3) ***By the end of 2019, all new buildings are required to cover their primary energy demand by utilising only RE, CHP, DH systems and heat pumps. The same measure shall be applied to all new buildings of the public sector by the end of 2014.*** (Greek_Government(b), Law 3851/2010 2010)

It is expected that this measure will result to an increase of CHP installations and that the benefits of the improved energy performance of the new buildings will be seen as a motivation for the refurbishment of the old buildings.

The financial supportive mechanisms for someone willing to invest in CHP or DH are basically three: the FIT scheme, the provisions of Law 3908/2011 and the EU funding. FIT is the subsidised pricing for the cogenerated electricity injected into the grid, which was described analytically in Section 4.4 and for sure it is seen as a motivation for investing. However, the most recently established FIT scheme by Law 4254/2014 has changed a lot regarding the categories of the subsidised units and it will be interesting to study the impact on the investments in the near future.

Law 3908/2011 provides for state subsidies and tax exemptions for HECHP units and it is still on (see Section 4.3). However, considering the current economic situation of the country it is doubtful if it can be applied instantly today. Concerning the EU Funding, the Operational Programme of Greece for the sector of "Competitiveness, Entrepreneurship and Innovation" includes goals, such as investments in companies in order to decrease their environmental footprint, and the improvement of the energy efficiency of buildings, which could be seen as beneficial for the growth of the sector of CHP and DH as well. (European_Commission(c) 2015)

7.3 Barriers for development of CHP and DH

Moving now to the barriers for the development of CHP and DH, these can be categorised as technical, financial, legal and administrative barriers and they are discussed below together with some possible solutions in order to be overcome.

7.3.1 Technical barriers

The climate of Greece

The climate of Greece is the so called Mediterranean climate. The characteristics of this type of climate are the mild and rainy winters and the warm and dry summers. (EMY(b) 2015)Despite the big variation of the Greek climate affecting the regional energy needs which were discussed in the Introduction of this report (see sub-Section 1.3.2), it is fact that the heat loads of the country are small and they have a short duration. Most of the times this makes the CHP applications economically unfeasible if they are designed only to cover the heating needs. (Writing_team 2008) A possible solution to this problem would be the design of tri-generation systems, so that not only heating needs are covered but cooling needs as well. However, according to HACHP the investment costs of these systems are quite high and there is not the necessary know how among the installers and the consultants for their implementation. (HACHP 2014)

Connection to the grid

The connection to the grid seems to be a problem mostly for the very large and the very small cogenerators. Starting with the most recent provision of Law 4254/2014 (see Section 4.3), HECHP units > 35 MW_e do not qualify for priority of connection to the grid, which is a serious disincentive for high-capacity investments.

Moreover, the Greek electricity grid is limited and most of the times it needs upgrading for the penetration of the cogenerated electricity. It seems that there are no clear procedures for the connection and the distribution of the costs for the upgrading between the large cogenerators and the Greek Power Transmission Operator (Independent Power Transmission Operator - ADMIE). Micro cogenerators (≤50 kW_e) face the same problem concerning the connection procedure to the low-voltage network. The terms of the connection depend each time on the conditions of the case. (Writing_team 2008, HACHP 2014) This matter could be eased if ADMIE established a concrete procedure for the connection.

7.3.2 Financial barriers

Economic recession

An important barrier for the development of the sectors of CHP and DH is the economic crisis of the country. Often, there is no private capital for investment, and even if there is the economic recession is a factor that prevents the investors from taking the investment risk. Banks and other financing institutions seem also unable to guarantee loans for high-capital investments. This is a barrier that it is expected to be overcome in the future though.

Electricity pricing

Another barrier for CHP currently in Greece is the electricity bills. Apart from the fees for the production, transmission and distribution of electricity (expressed in €/MWh), a series of other fees and taxes have been gradually added in the electricity bill and the continuous increase of them for the past two years has resulted to a setback in CHP and other RE installations. (HACHP 2014, Gravouniotis 2015)

Some of these extra fees are: "*the utility levy*", which is paid in order the power supply of the isolated islands to be at the same price as in the mainland and for the application of low prices to vulnerable consumers, "*the special levy for reducing GHG emissions*", through which PPC actually remunerates the RE independent producers of the grid, "*the special tax for electricity consumption*", which was applied by the State since 2010 and "*the special levy 5‰*", which is also attributed to the State. (PPC(b) 2013)

All these fees are the result of wrong planning and policies by the State and PPC during the previous years and it seems now that the consumers are called to pay for all the deficits. These extra fees are applied to all type of consumers; either they are domestic consumers or big industrial ones and they have to be paid even by the auto-producers of electricity which are connected to the grid (Greek_Government(b) 2011).

Natural gas pricing

Cogenerators from all sectors that have installed natural gas CHP units, face the problem of the fluctuations of the price of natural gas. Natural gas is an imported fuel in the country and it follows the trends of the price of the crude oil (Writing_team 2008). This situation in combination with the fact that LAGIE often delays the compensation of the cogenerated electricity creates financing problems to the investors and it leads to their decision to shut down the CHP units (see Section 4.1).

7.3.2 Legal and administrative barriers

Complexity and instability of legislation

Although there is an established legislative framework for the promotion of CHP and DH, the problem is found on the stability of this framework. As it can be concluded from Section 4.3., national laws are amended and repealed frequently by the establishment of new ones and this causes instability and insecurity for the investors. An example of this instability is the threshold of the 35 MW_e concerning the maximum capacity of CHP that qualifies for priority of connection to the grid. The threshold was firstly introduced in 1999, it was repealed in 2011 and now it is on again since 2014 (see Section 4.3).

In addition, legislation is often too complex and there is bureaucracy that leads to delays for the application of the systems. A lot of different authorities are involved in the license procedure, such as RAE, YPEKA and local authorities, and according to HACHP, the minimum time period for the granting of all the permits is two years. (HACHP 2014) However, as it was said before, a positive measure for the small CHP applications ($\leq$1 MW_e) is the non-requirement of a license by RAE.

Lack of awareness

As it was discussed in Section 7.1, there is limited awareness regarding CHP and DH among most of the involved actors. This is seen as a significant issue especially for the development of DH networks. Local citizens should be involved more actively and informed about the benefits of these systems, probably through educational and informational campaigns. ESCOs and NGOs could also play an important role for the raise of awareness and the promotion of these applications.

8 Conclusion

Nowadays there is more than ever the need to adopt energy saving measures in order to reduce the GHG emissions and to mitigate the global climate change. Cogeneration and District Heating appear as two technological concepts that offer a lot of technical, environmental and socioeconomic benefits and it seems that energy planners worldwide have began to recognise this important role. In Europe, there is big variation concerning the development of the sectors; there are countries where the share of DH is up to 70% in the heat market and the share of CHP up to 40% in the gross electricity generation, whereas others where these shares are close to zero. Greece is a fossil fuel intensive country concerning both the electricity and the heating sector and demonstrates low levels of development of CHP and DH networks. The Research Question that this thesis tried to answer is:

"*What is the current situation of District Heating and Cogeneration in Greece and what are the opportunities and barriers for development?*"

Concerning the first part of the RQ a literature study was made and the main findings are the following: The installed CHP capacity in 2012 was equal to 570 MW_e, representing a share of 3.9% in the total electricity generation. The developed DH networks are only five in the whole country with a total capacity of 468 MW_{th} and they are based on lignite fuelled CHP units operated by PPC, except of one that is natural gas fuelled CHP and is owned by a private company. Moreover, there is an established legislative framework with provisions for cogeneration and district heating network since 1994, but it is noticed that this framework frequently changes. As for the pricing of the cogenerated electricity, there is an established Feed-in Tariff (FIT) scheme that is paid to the cogenerators for the amount of the electricity that they inject into the grid.

For the second part of the RQ a case study of a Greek industry was made, in order to examine the real opportunities and the barriers in the market. The potential for installing a biomass – fuelled CHP in a Paper-Mill industry was examined. It was found out that investing in CHP is a profitable investment providing that specific conditions exist in the market, such as a high FIT for the cogenerated electricity and a low price of the needed fuel. Of course, there are also associated risks and extra costs that should be taken into consideration, such as the cost for the grid connection and the instability in the biomass resources. The possibility of developing a DH network for a neighbouring community through the utilisation of the excess heat of the industry was also examined. It was concluded that the economic benefits for the community are major and therefore it is recommended these applications to be developed in areas with similar characteristics, e.g. in other industrial areas.

The findings of the case study about the opportunities and the barriers were complimented by a literature study. Certainly, there are opportunities for development of CHP and DH in Greece; the total estimated economical potential for CHP is equal to 1,455 $MW_{e.}$ with the largest share found in the industrial sector (87.3%). In addition, there is financial and legal support, but it seems that the existing barriers are more than the drivers. These are technical, financial, legal and administrative ones and as the most important drawback is considered by the writer the lack of awareness about these applications between most of the relevant actors.

Finally, the following aspects are recognised as the necessary conditions that should exist in an environment for the promotion of the development of CHP and DH and therefore they are recommended to energy planners and relevant authorities:

- High level of awareness between all the involved actors
- Steady and straightforward legislation
- Limited or no bureaucracy
- Security concerning the pricing of the electricity and the fuels, so that long –term investments can be made
- Transparency in the rules for connection to the grid

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Appendix A

Figure A.1 demonstrates the four Climatic Zones (A, B, C, D) of Greece. This distribution has been made after an estimation of the HDDs of the locations based on the external air temperature. Moving from Zone A to D means moving from the warmest to the coldest regions (Greek_Government(a) 2010)

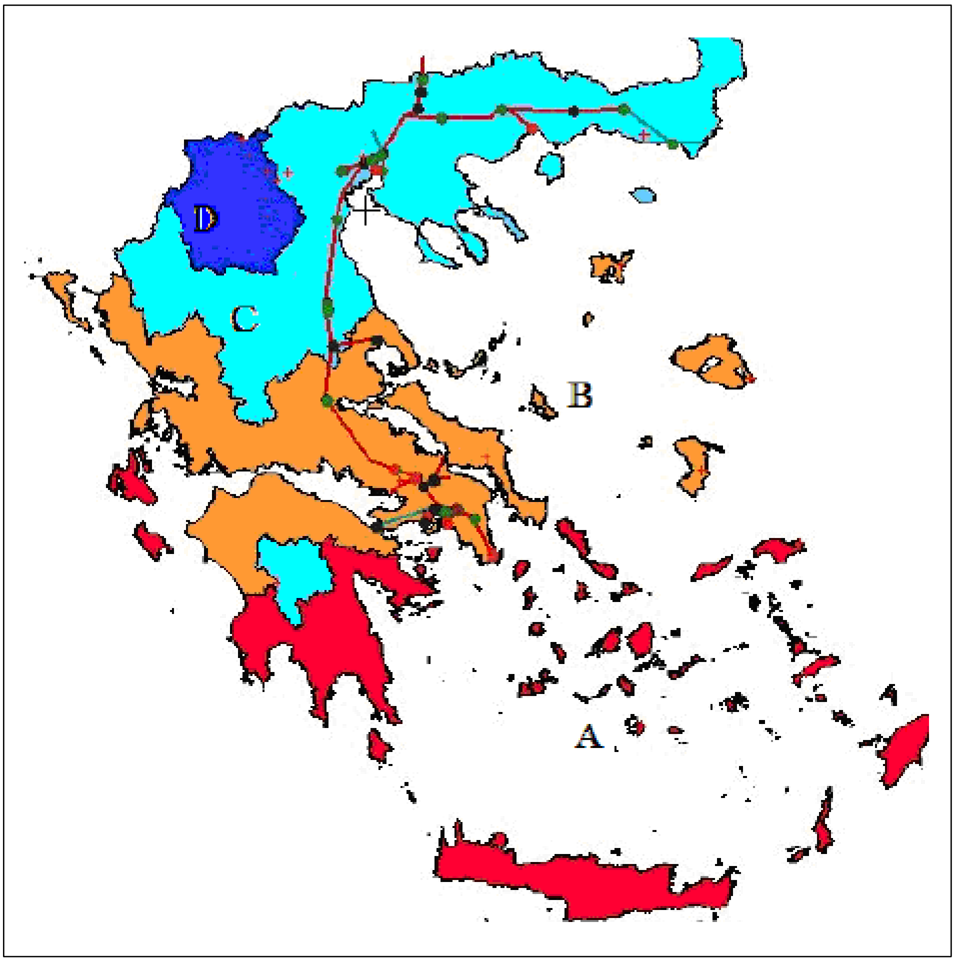

Figure A.1: Climatic Zones of Greece, Source: (Writing_team 2008)

Figure A.2 and A.3 illustrate the geographical distribution of the HDDs and the duration of the heating period among the different Greek regions after a study made by Matzarakis and Balafoutis. HDDs are calculated based on the following formulas (Ματζαράκης and Μπαλαφούτης 2002):

If $Tb > T\max$ then $HDD = Tb - Tmean$

If $Tb < T\max$ and if: a) $Tmean < Tb$ then $HDD = (Tb - T\min)/2 - (T\max - Tb)/4$

b) $Tmean > Tb$ then $HDD = (Tb - T\min)/2$

c) $Tmean = Tb$ then $HDD = 0$ °Day

,where Tb is the basic temperature chosen equal to 14 °C, Tmax the maximum temperature of the day, Tmin the minimum temperature of the day and Tmean the average temperature of the day equal to: $Tmean = (T\max + T\min)/2$

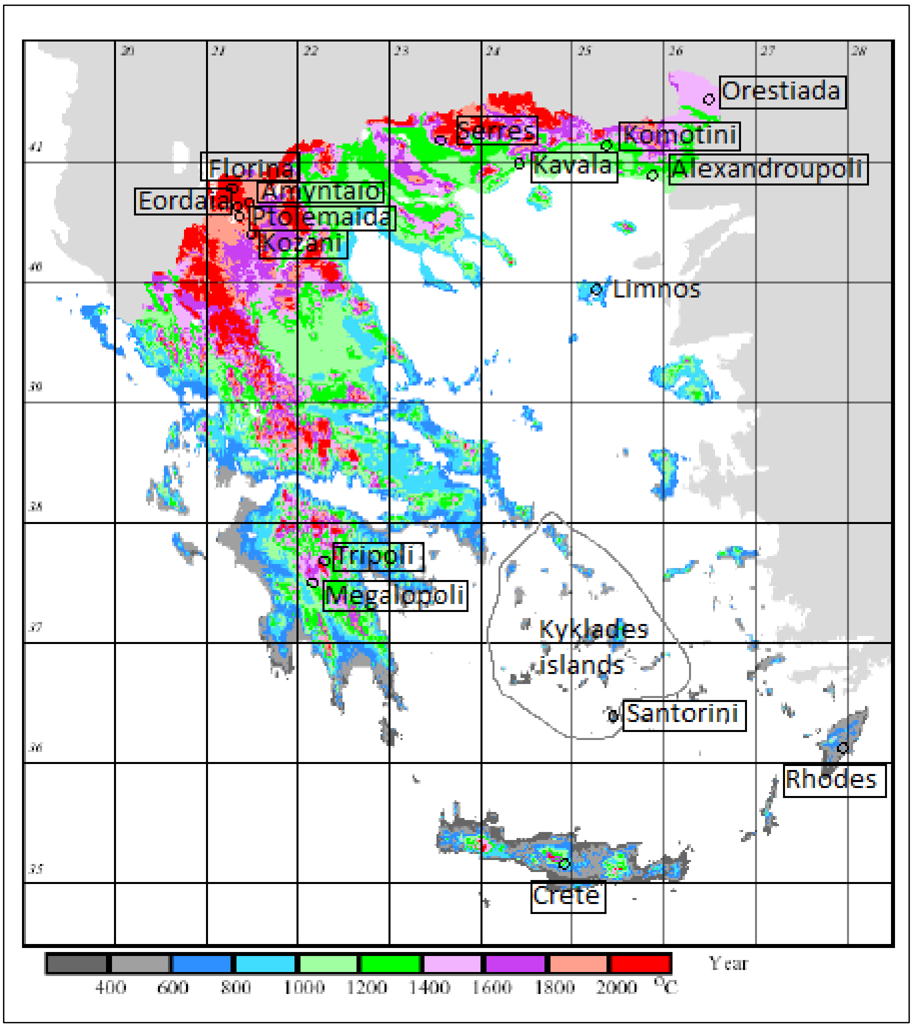

Figure A.2: Geographical distribution of the HDDs in Greece over the coldest period, Source: (Ματζαράκης and Μπαλαφούτης 2002)

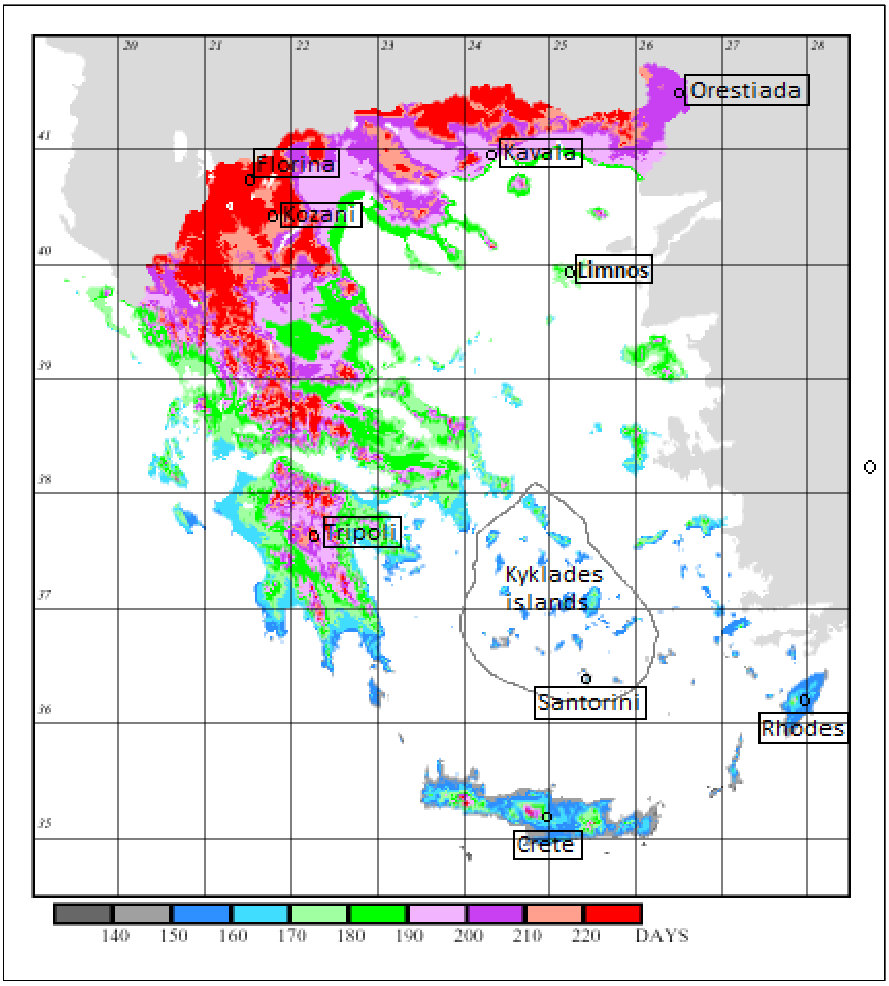

Figure A.3: Duration of the heating period (days per year) among the Greek regions, Source: (Ματζαράκης and Μπαλαφούτης 2002)

Appendix B

The following data are available through the website of the Hellenic Operator of Electricity Market, LAGIE (LAGIE 2015):

CHP UNITS		
Name of industry	**Area of installation**	**Installed capacity (MW_e)**
ALUMINIO A.E.	Agios Nikolaos, County of Viotia	334
EXALKO A.E. – ALUMINIUM INDUSTRY	5th km of the Highway Larissa-Athens , County of Larissa	2.72
INDUSTRY OF PHOSPHATE FERTILIZERS	N. Karvali, County of Kavala	21.22
KOTHALI A.E. – TILE INDUSTRY	Chrysoupoli, County of Kavala	1.13
HELLENIC SUGAR INDUSTRY A.E.	Platy, County of Imathia	13
GENESIS – OBSTETRIC GYNECOLOGY SURGERY CLINIC OF THESSALONIKI A.E.	Pylaia, County of Thessaloniki	0.73
GREENHOUSES OF DRAMA A.E.	Votrys, County of Drama	4.8
NATIONAL KAPODISTRIAN UNIVERSITY OF ATHENS	Boiler house in the University area of Ilisia, County of Athens	2.72
ELFIKO AEE – TEXTILE INDUSTRY	Sximatario, County of Viotia	1.2
AGRITEX ENERGEIAKI A.E. – GREENHOUSES OF ALEXANDRIA	Slaughterhouses of the Municipality of Alexandria, County of Imathia	4.97
THERMI OF SERRES A.E. – DISTRICT HEATING INDUSTRY	Agroktima of Serres (no 3796), County of Serres	16
HELLENIC PETROLEUM A.E.	Industrial area of Thessaloniki, County of Thessaloniki	5.5
BRIGHT SPECIAL LIGHTING A.E.	Monopati in Menidi, County of Athens	0.13
EYDAP – ATHENS SEWAGE AND WATER CO	Centre of Sewage Treatment on the island of Psyttalia, County of Attiki	12.9
DESFA A.E. – HELLENIC GAS TRANSMISSION SYSTEM OPERATOR	Terminal station YFA, County of Athens	13
PAP HOTELS KORP A.E. – ASTORIA HOTEL	Salaminos 8 & Tsimiski, County of Chalkidiki	0.07
DELTA FOODS A.E.	Agios Stefanos, County of Athens	2
DOUKAS PRIVATE SCHOOL A.E.	Marousi, County of Athens	0.34
LAMDA DOMI A.E. - REAL ESTATE EXPLOITATION AND SERVICES	Mall of Golden Hall, County of Athens	2
WONDERPLANT – AGRICULTURE INDUSTRY	Tsakalotopos Petrousas, County of Drama	8
Total		446.43

Table B.1: Registered CHP units by LAGIE, Source: (LAGIE 2015)

Appendix C

Results of Scenario 2 – cotton straw analysed in Chapter 6, Section 6.2:

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Scenario2_straw

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Energy conversion, annual

Calculated period: 01/2015 - 12/2015

Process heat demands:

Process heat demand	52.980,6 MWh
Max heat demand	6,0 MW

Process heat productions:

Biomass Boiler	2.903,0 MWh/year	5,5 %
CHP	50.077,6 MWh/year	94,5 %
Total	52.980,6 MWh/year 100,0 %	

Electricity produced by energy units:

Biomass FIT:

	Biomass FIT [MWh/year]	All periods [MWh/year]	Of annual production
CHP	12.067,0	12.067,0	100,0%

Peak electric production:

CHP	1.457,4 kW-elec.

Hours of operation:

Biomass FIT:

	Biomass FIT [h/Year]	Total [h/Year]	Of annual hours
CHP	8.280,0	8.280,0	94,5%
Out of total in period	8.760,0	8.760,0	

Production unit(s) Not connected to electricity market:

	Total [h/Year]	Of annual hours
Biomass Boiler	480,0	5,5%
Out of total in period	8.760,0	

Turn ons:

Biomass Boiler	3
CHP	15

Fuels:

By fuel

	Fuel consumption
Cotton straw	12.712,0 ton

By energy unit

Biomass Boiler	3.225,6 MWh	=645,1	ton
CHP	60.334,2 MWh	=12.066,8	ton
Total	63.559,8 MWh		

Scenario2_straw

Energy conversion, summary

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Process heat demand [MWh]																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity produced by energy units [MWh]																	
	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067
Exported electricity [MWh]																	
	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067
Peak [MW]	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457
Energy unit: Biomass Boiler																	
Fuel consum. [ton]	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645
Fuel consum. [MWh]	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226
Process heat prod. [MWh]	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903
Turn ons	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Operating hours	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480
Energy unit: CHP																	
Fuel consum. [ton]	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067
Fuel consum. [MWh]	60.334	60.509	60.334	60.334	60.334	60.509	60.334	60.334	60.334	60.509	60.334	60.334	60.334	60.509	60.334	60.334	60.334
Process heat prod. [MWh]	50.078	50.223	50.078	50.078	50.078	50.223	50.078	50.078	50.078	50.223	50.078	50.078	50.078	50.223	50.078	50.078	50.078
Elec. prod. [MWh]	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067	12.102	12.067	12.067	12.067
Turn ons	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Operating hours	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280
Fuel consumption: Cotton straw																	
Fuel consum. [ton]	12.712	12.747	12.712	12.712	12.712	12.747	12.712	12.712	12.712	12.747	12.712	12.712	12.712	12.747	12.712	12.712	12.712
Fuel consum. [MWh]	63.560	63.735	63.560	63.560	63.560	63.735	63.560	63.560	63.560	63.735	63.560	63.560	63.560	63.735	63.560	63.560	63.560
Peak [MW]	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287	7,287

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Scenario2_straw

Cash Flow, summary

(All amounts in Euro)

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Revenues									
Electricityexport	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385
Total Revenues	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385
Operating Expenditures									
Fuel costs									
Cotton straw cost	381.359	384.702	385.949	388.264	390.594	394.019	395.295	397.667	400.053
Fuel costs Total	381.359	384.702	385.949	388.264	390.594	394.019	395.295	397.667	400.053
O&M costs									
O&M biomassboiler	11.612	11.682	11.752	11.822	11.893	11.965	12.037	12.109	12.181
O&M CHP	425.659	429.454	430.783	433.367	435.967	439.855	441.215	443.862	446.525
O&M costs Total	437.271	441.136	442.534	445.190	447.861	451.819	453.251	455.971	458.707
Total Operating Expenditures	818.630	825.839	828.483	833.454	838.455	845.838	848.546	853.638	858.760
Net Cash from Operation	1.232.755	1.231.492	1.222.902	1.217.931	1.212.930	1.211.493	1.202.839	1.197.747	1.192.625
Investments									
CHP investment cost	4.554.250	0	0	0	0	0	0	0	0
Total Investments	4.554.250	0	0	0	0	0	0	0	0
Total Interest on Cash Account	0	0	0	0	0	0	0	0	0
Cash Surplus	-3.321.495	1.231.492	1.222.902	1.217.931	1.212.930	1.211.493	1.202.839	1.197.747	1.192.625
Cash Account	-3.321.495	-2.090.003	-867.101	350.830	1.563.760	2.775.253	3.978.092	5.175.839	6.368.464

	2024	2025	2026	2027	2028	2029	2030	2031
Revenues								
Electricityexport	2.057.331	2.051.385	2.051.385	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385
Total Revenues	2.057.331	2.051.385	2.051.385	2.051.385	2.057.331	2.051.385	2.051.385	2.051.385
Operating Expenditures								
Fuel costs								
Cotton straw cost	403.561	404.868	407.297	409.741	413.334	414.673	417.161	419.664
Fuel costs Total	403.561	404.868	407.297	409.741	413.334	414.673	417.161	419.664
O&M costs								
O&M biomassboiler	12.254	12.328	12.402	12.476	12.551	12.627	12.702	12.779
O&M CHP	450.506	451.900	454.611	457.339	461.416	462.843	465.620	468.414
O&M costs Total	462.761	464.228	467.013	469.815	473.967	475.470	478.323	481.192
Total Operating Expenditures	866.322	869.096	874.310	879.556	887.301	890.142	895.483	900.856
Net Cash from Operation	1.191.010	1.182.289	1.177.075	1.171.829	1.170.030	1.161.243	1.155.902	1.150.529
Investments								
CHP investment cost	0	0	0	0	0	0	0	0
Total Investments	0	0	0	0	0	0	0	0
Total Interest on Cash Account	0	0	0	0	0	0	0	0
Cash Surplus	1.191.010	1.182.289	1.177.075	1.171.829	1.170.030	1.161.243	1.155.902	1.150.529
Cash Account	7.559.474	8.741.763	9.918.838	11.090.667	12.260.697	13.421.939	14.577.841	15.728.370

Scenario2_straw

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Financial Key Figures

Investment Key Figures

Internal Rate of Return (IRR), include all Payments:	:	30,7%
Internal Rate of Return (IRR), include operational payments and investements:	:	30,7%
Net Present Value of		
Net cash from operation and investments	:	8.363.159 Euro
Financial payments	:	0 Euro
All Payments	:	8.363.159 Euro
(at a nominal rate of: 6,0% p.a.)		

Results of Scenario 3 – cotton straw analysed in Chapter 6, Section 6.3:

Scenario3_straw

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Energy conversion, annual

Calculated period: 01/2015 - 12/2015

Heat demands:

Community Heat demand	1.602,6 MWh
Max heat demand	0,6 MW

Heat productions:

Biomass Boiler	0,0 MWh/year	0,0 %
CHP	0,0 MWh/year	0,0 %
Flue gas condenser	1.538,7 MWh/year	100,0 %
Total	1.538,7 MWh/year	100,0 %

Process heat demands:

Process heat demand	52.980,6 MWh
Max heat demand	6,0 MW

Process heat productions:

Biomass Boiler	2.903,0 MWh/year
CHP	51.631,8 MWh/year
Flue gas condenser	-1.554,3 MWh/year
Total	52.980,6 MWh/year 100,0 %

Electricity produced by energy units:
Biomass FIT:

	Biomass FIT [MWh/year]	All periods [MWh/year]	Of annual production
CHP	13.587,5	13.587,5	100,0%

Peak electric production:

CHP	1.741,2 kW-elec.

Hours of operation:
Biomass FIT:

	Biomass FIT [h/Year]	Total [h/Year]	Of annual hours
CHP	8.280,0	8.280,0	94,5%
Out of total in period	8.760,0	8.760,0	

Production unit(s) Not connected to electricity market:

	Total [h/Year]	Of annual hours
Biomass Boiler	480,0	5,5%
Flue gas condenser	8.280,0	94,5%
Out of total in period	8.760,0	

Turn ons:

Biomass Boiler	3
CHP	15
Flue gas condenser	15

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Energy conversion, summary

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Heat demand [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Process heat demand [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity produced by energy units [MWh]	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588
Exported electricity [MWh]	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588
Peak [MW]	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741	1,741
Energy unit: Biomass Boiler																	
Fuel consum. [ton]	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645	645
Fuel consum. [MWh]	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226	3.226
Process heat prod. [MWh]	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903	2.903
Turn ons	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Operating hours	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480
Energy unit: CHP																	
Fuel consum. [ton]	13.587	13.628	13.587	13.587	13.587	13.628	13.587	13.587	13.587	13.628	13.587	13.587	13.587	13.628	13.587	13.587	13.587
Fuel consum. [MWh]	67.937	68.141	67.937	67.937	67.937	68.141	67.937	67.937	67.937	68.141	67.937	67.937	67.937	68.141	67.937	67.937	67.937
Process heat prod. [MWh]	51.632	51.787	51.632	51.632	51.632	51.787	51.632	51.632	51.632	51.787	51.632	51.632	51.632	51.787	51.632	51.632	51.632
Elec. prod. [MWh]	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588	13.628	13.588	13.588	13.588
Turn ons	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Operating hours	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280
Energy unit: Flue gas condenser																	
Heat prod. [MWh]	1.539	1.549	1.539	1.539	1.539	1.549	1.539	1.539	1.539	1.549	1.539	1.539	1.539	1.549	1.539	1.539	1.539
Turn ons	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Operating hours	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280	8.304	8.280	8.280	8.280
Fuel consumption: Cotton straw																	
Fuel consum. [ton]	14.232	14.273	14.232	14.232	14.232	14.273	14.232	14.232	14.232	14.273	14.232	14.232	14.232	14.273	14.232	14.232	14.232
Fuel consum. [MWh]	71.162	71.367	71.162	71.162	71.162	71.367	71.162	71.162	71.162	71.367	71.162	71.162	71.162	71.367	71.162	71.162	71.162
Peak [MW]	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706	8,706

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January 2015 to August 2015

Cash Flow, summary

(All amounts in Euro)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Revenues																	
Electricityexport	2.309.875	2.316.824	2.309.875	2.309.875	2.309.875	2.316.824	2.309.875	2.309.875	2.309.875	2.316.824	2.309.875	2.309.875	2.309.875	2.316.824	2.309.875	2.309.875	2.309.875
Saleofheat	48.078	48.380	48.078	48.078	48.078	48.380	48.078	48.078	48.078	48.380	48.078	48.078	48.078	48.380	48.078	48.078	48.078
Total Revenues	**2.357.953**	**2.365.205**	**2.357.953**	**2.357.953**	**2.357.953**	**2.365.205**	**2.357.953**	**2.357.953**	**2.357.953**	**2.365.205**	**2.357.953**	**2.357.953**	**2.357.953**	**2.365.205**	**2.357.953**	**2.357.953**	**2.357.953**
Operating Expenditures																	
Fuel costs																	
Cotton straw cost	426.975	430.770	432.114	434.706	437.315	441.202	442.578	445.233	447.905	451.886	453.296	456.016	458.752	462.830	464.273	467.059	469.861
Fuel costs Total	**426.975**	**430.770**	**432.114**	**434.706**	**437.315**	**441.202**	**442.578**	**445.233**	**447.905**	**451.886**	**453.296**	**456.016**	**458.752**	**462.830**	**464.273**	**467.059**	**469.861**
O&M costs																	
O&M biomassboiler	11.612	11.682	11.752	11.822	11.893	11.965	12.037	12.109	12.181	12.254	12.328	12.402	12.476	12.551	12.627	12.702	12.779
O&M CHP	438.870	442.832	444.153	446.818	449.499	453.556	454.909	457.638	460.384	464.540	465.925	468.721	471.533	475.789	477.208	480.072	482.952
O&M costs Total	**450.483**	**454.514**	**455.905**	**458.640**	**461.392**	**465.521**	**466.945**	**469.747**	**472.565**	**476.794**	**478.253**	**481.123**	**484.009**	**488.341**	**489.835**	**492.774**	**495.731**
Total Operating Expenditures	**877.457**	**885.284**	**888.018**	**893.346**	**898.706**	**906.723**	**909.523**	**914.980**	**920.470**	**928.681**	**931.549**	**937.138**	**942.761**	**951.170**	**954.108**	**959.833**	**965.592**
Net Cash from Operation	**1.480.496**	**1.479.921**	**1.469.935**	**1.464.607**	**1.459.247**	**1.458.482**	**1.448.430**	**1.442.973**	**1.437.483**	**1.436.524**	**1.426.404**	**1.420.815**	**1.415.192**	**1.414.034**	**1.403.845**	**1.398.120**	**1.392.361**
Investments																	
CHP investment cost	4.973.750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Investments	**4.973.750**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Interest on Cash Account	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cash Surplus	**-3.493.254**	**1.479.921**	**1.469.935**	**1.464.607**	**1.459.247**	**1.458.482**	**1.448.430**	**1.442.973**	**1.437.483**	**1.436.524**	**1.426.404**	**1.420.815**	**1.415.192**	**1.414.034**	**1.403.845**	**1.398.120**	**1.392.361**
Cash Account	**-3.493.254**	**-2.013.333**	**-543.398**	**921.209**	**2.380.455**	**3.838.938**	**5.287.368**	**6.730.340**	**8.167.823**	**9.604.347**	**11.030.752**	**12.451.566**	**13.866.758**	**15.280.793**	**16.684.638**	**18.082.758**	**19.475.119**

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Spring 2015

January 2015 to August 2015

Financial Key Figures

Investment Key Figures

Internal Rate of Return (IRR), include all Payments:	:	34,6%
Internal Rate of Return (IRR), include operational payments and investements:	:	34,6%
Net Present Value of		
Net cash from operation and investments	:	10.589.675 Euro
Financial payments	:	0 Euro
All Payments	:	10.589.675 Euro
(at a nominal rate of: 6,0% p.a.)		