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Analyzing a Ground Source Heat Pump Investment in Finland

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AALTO UNIVERSITY SCHOOL OF ECONOMICS ABSTRACT

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ANALYZING A GROUND SOURCE HEAT PUMP INVESTMENT IN FINLAND

Research objectives

The main objective of the study was to analyze a ground source heat pump (GSHP) investment in Finland. In addition the goal was to determine which investment appraisal methods are most suitable for analyzing a ground source heat pump investment. In order to reach these objectives the both the heating systems and investment theory were reviewed in detail.

Sources

The theoretical part of the study was compiled out of a wide range of academic and non-academic literature. These included articles, reports and industry brochures related to investment analysis, energy and heating systems. In the empirical part historical energy price data was used. Heating system data was attained from heating system companies, expert organization and other relevant sources.

Research method

After the necessary data collection exercise and selection the suitable investment analysis method, the actual investment simulations calculations were completed and analyzed. The chosen methods are widely used and considered reliable in academic research.

Results

Analysis of the results showed that investing in a ground source heat pump heating system would be the most economical investment in the cases studied and under the selected settings. After 10 years the GSHP had the lowest NPV (most economical) in all cases except for one; in the old 240 m2 building the wood-pellet had a lower NVP mean in the 10 year scenario. However the probability distributions of the GSHP and the wood-pellet system suggest that the GSHP system has less risk as the probability distribution is more triangular. The wood-pellet system and the CHP district heating systems were the next economical choices. Direct electricity and oil heating were found to be uneconomical investment when using similar risk variables.

Keywords

Ground source heat pump, heating system, energy, investment analysis, NPV, Monte Carlo simulation.

Table of Contents

List of figures

1. Introduction

1.1. Background and Motivation

Historically, world primary energy consumption has been based mainly on oil (35%), coal (25%) and natural gas (21%) at relatively cheap costs. Today, the price of natural gas is rising and is putting up the cost of 20% of world electricity, while the cost of coal remains relatively low and is the favored fuel for 40% of the world's power plants. (IEA Heat Pump Centre, 2009). High usage of fossil fuels does serve one purpose now almost unanimously accepted worldwide: to cut greenhouse-gas emissions to levels which will not cause irreparable damage to the world's climate. It is expected that global energy related greenhouse-gas emissions increase by 45 % by 2030 (IEA, World energy outlook 2008).

A priority in energy efficiency is the cost-effective reduction of greenhouse-gas emissions. The European Union has set a common goal to increase efficiency by 20 % by 2020. Climate policy is not the only driver in cutting energy consumption, traditional reasons are also important for example, securing access to energy, energy cost reduction and other environmental considerations (TEM, 2011).

Finland is one of the leading countries internationally in energy saving measures and energy efficiency. Combined heat and power (CHP), voluntary energy efficiency agreements, and systematic implementation of energy reviews are good examples of successful energy efficiency (TEM, 2011).

Energy is very important in today's society. It is used both in households, agriculture, transport, industrial production as well as in services. Energy consumption per se is not anyone's goal. It is used to produce light and heat and to run industrial processes and in production of services. In business and industry, energy conservation means energy efficiency, i.e. the production of a product or service with minimum use of energy. Cost savings, as well as favorable environmental impacts of a product or service and also raised approval among consumers of a product or service are reasons of support for energy efficiency efforts (EK, 2011).

The global rate of fossil fuel consumption might lead to an energy crisis in the coming decades. Global CO_2 emissions come from power generation (40%), industry (17 %), buildings (14 %) and transport (21 %). According to the Kyoto Protocol, the industrialized nations are required to reduce greenhouse gas emissions to below 1990 levels. In spite of this, our reliance on fossil fuels is not expected to change significantly between now and 2050 (IEA Heat Pump Centre, 2009).

This context opens up opportunities for developing alternative renewable and clean energy sources, such as solar, wind, hydrogen, water hydrokinetic, nuclear, ambient air and geothermal. The key strategic policy will concern energy efficiency and security, and the reduction of related greenhouse gas emissions by investments in technology development, manufacturing and commercialization of emerging clean technologies. (IEA Heat Pump Centre, 2009)

2009 in Finland 24, 7 % of the overall energy production was used to the heating of buildings (Statistics Finland, 2009), therefore studying also the economical side of energy efficient heating systems is current.

In order to understand the energy related investments and promote the acceptance of energy efficiency investments, more comprehensive analysis needs to be done to justify energy efficiency investments to private- and corporate customers.

Most house builders consider the choice of a heating system particularly, in economic terms. More and more also take into account the effects on the environment. Comparison of costs is quite challenging and outside consultation is often needed. The total costs of a heating system consist of several elements, from the construction phase, from the annual energy costs and fixed charges as well as basic maintenance and repair costs. The total cost of the heating system is challenging to calculate, because the calculation period is usually several years. Accurate prediction of future energy price development is impossible and even the best calculations are estimates. More likely, however, in all forms of energy, the prices continue to rise in the near future (Pientalon lämmitysjärjestelmät, Motiva 2009).

1.2. Research problem, question and objective of the study

This master's thesis concentrates on comparing different heating systems from an economical perspective. The study is conducted as a case study by studying heating system investments in different buildings. Emphasis is given to the chosen investment appraisal method. The research problem of this study is:

Is an investment in ground source heat pump economical in Finland?

The research problem can be solved by using three research questions. These questions are formulated so that they expand the research problem into three distinct questions that can be answered within the scope of this research.

What is the most suitable investment appraisal method for evaluating a ground source heat pump investment in Finland?

What kinds of differences are in the performance of the investments in different buildings in Finland?

Are other heating systems more economical in the case buildings?

These three research question guide the research and its direction. By answering the three research questions, an answer for the research problem can be generated, and the objective of this research can be reached.

The main objective of the study is to analyze an investment in ground source heat pump in Finland. Another research objective is to determine which investment appraisal methods are most suitable for analyzing ground source heat pump investments. In order to analyze the investment carefully, an understanding of the energy market and the heating systems needs to be developed.

2. Methodology

This study is a quantitative multiple case study, the purpose of this paper is to find out whether a ground source heat pump is economically a sensible investment. The aim is to explore the heating system investments and compare them together in terms of finances. This section presents the methodology used for this study. In addition, the reliability and validity of the data are discussed.

According to Yin (2009, p, 18) "a case study is an empirical enquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". He continues the definition by explaining that a case study enquiry copes with technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis.

2.1. Designing the case study

Yin (2009) divides case studies into two categories: those that focus on only one case (single-case study) and those that focus on multiple cases inside the same subject (multiple-case study). In addition, Yin divides these categories into two types: those, which examine the different levels within a case study (embedded), and those which examine only one level (holistic).

Eisenhardt (1989) focuses on the construction of the theory of the case study. She presents an eight-stage roadmap for building a theory. Eisenhardt's roadmap is as follows:

Step 1: Getting Started

Definition of research question, possibly a priori constructs

Step2: Selecting Cases

Neither theory nor hypotheses, Specified population, Theoretical, not random, sampling

Step 3: Crafting Instruments and Protocols

Multiple data collection methods, Qualitative and quantitative data combined, multiple investigators

Step 4: Entering the Field

Overlap data collection and analysis, including field notes, Flexible and opportunistic data collection methods

Step 5: Analyzing Data

Within-case analysis, Cross-case pattern search using divergent techniques

Step 6: Shaping Hypotheses

Iterative tabulation of evidence for each construct, Replication, not sampling, logic across cases, Search evidence for "why" behind relationships

Step 7: Enfolding Literature

Comparison with conflicting literature, Comparison with similar literature

Step 8: Reaching Closure

Theoretical saturation when possible

The dialogue between the case that is being studied and the related theory is essential in a case study research. Testing the research framework is also important. (Bryman 2008, 52-59)

An essential feature of theory building is comparison of the emergent concepts, theory, or hypotheses with the extant literature. This involves asking what is this similar to, what does it contradict, and why. A key to this process is to consider a broad range of literature (Eisenhardt, 1989, p.544). However scholars disagree about when the relevant literature should be reviewed and how it should be incorporated into a study Ellinger et al, 2005).

According to Ellinger et al (2005) the research design may dictate whether a literature review should be used to ground the hypotheses of the study, as in many quantitative designs or whether the literature should not be carried out until after data are collected, as in a phenomenological study, in which the literature is used to add depth of understanding to the themes elicited by those interviewed about the phenomenon.

The literature is used differently in case study research depending on the study's questions and research design. Multiple or collective-type case study examines a number of similar types of Cases in order to achieve further understanding of a phenomenon (Stake, 2005).

Yin (2009, p 27) describes five important components of a case study design. The first component is *study questions,* the form of the question in terms of who, what, where, how and why helps to explain what research method should be used. The second component is *study propositions*. Each proposition guides the study to something that should be examined within the study. Only if one is forced to state some propositions will one move in the right direction. The third component is *unit of analysis.* According to Yin the selection of the appropriate unit of analysis will start to occur when one accurately specifies one's primary research question. Yin continues that if one's questions do not lead to a favoring of one unit of analysis over another, one's questions are probably too vague or too numerous. This complicates the case study process.

The fourth and fifth components are *linking data to propositions* and *criteria for interpreting the findings.* According to Yin (2009) the actual analysis will require that one combines or calculates one's case study data as a direct reflection of one's initial study propositions. Criteria for interpreting the findings can vary, good examples are statistical analyses that offer some explicit criteria. Another strategy might be to identify and address rival explanations for one's findings (Yin, 2009).

In this study the research design is built in line with Yin's five research design components with some elaboration.

2.2. Implementing the research design

1. Study questions

According to Yin (2009) study questions of a case study can be asked among different levels. For example, questions asked of the individual case or questions asked of the pattern of findings across multiple cases.

When designing a case study and its study questions one should keep in mind that every question requires a list of possible sources of evidence. A diverse use of sources adds credibility to a study. (Yin 2009).

In this study the main focus of enquiry is given to the evaluation of a ground source heat pump investment, hence the study questions are related to the economical side of this heating system. The questions can be answered through investment calculations and simulations. The quantitative data for the calculations derives from multiple sources. Primary sources of data for this study are expert publications that are related to the field of heating systems. Data is also acquired from government and industry publications. Secondary sources include a wide range of academic publications, which will add depth and ease the understanding of this study.

2. Study propositions

As Yin (2009) states a researcher needs study propositions to point attention in the right direction. Study propositions help to limit the scope of a study, which is important in order to keep the study meaningful. Study propositions also help to suggest possible links between phenomena.

In this study the study propositions have guided the research into testing the proposition that a ground source heat pump is an economical investment in Finland. Academic theoretical propositions for a similar research could not be found, but data from the industry and public organizations was available, which were used to study the research question previously stated. The theoretical framework in this study is linked to the investment theory applied when evaluating the financial impact of the cases studies.

According to Yin (2009) the more a case study contains specific questions and propositions, the more it will stay within feasible limits. For these reasons this study is built to answer specific questions which keep it in feasible limits. The author's aim is to find answers to these questions by keeping the study simple enough to be valid and feasible in the boundaries of a master's thesis.

3. Unit of analysis

One's tentative definition of the unit of analysis (case) is closely related to the way one has defined the initial research questions (Yin, 2009). As the study questions are specifically focused on the economical side of heating systems investments in Finland, the units of analysis focus on a selection of six representative case buildings and four typical heating systems, which are later covered in more detail.

4. Linking data to propositions

Analysis will require that one combines or calculates one's case study data as a direct reflection of one's initial study propositions (Yin, 2009). One will need to gather only such empirical knowledge that is related to the problem; this will enable to restrict the material that is being analyzed. In this type of quantitative case study it was not too difficult to limit the amount of material because of the investment calculations.

However one could have speculated and gathered excessive amounts of data, for example, when forecasting the future energy prices.

Logic linking of the data to the propositions is an important part of a case study. In this study the rival patterns are the other heating systems which are being evaluated in terms of investments against the ground source heat pump investment.

5. Criteria for interpreting the findings

This aspect of the case study methodology is the most difficult (Yin, 2009). Yin (2009) encouraged researchers to make every effort to produce an analysis of the highest quality. In order to accomplish this, he presented four principles that should attract the researcher's attention:

1. Show that the analysis relied on all the relevant evidence
2. Include all major rival interpretations in the analysis
3. Address the most significant aspect of the case study
4. Use the researcher's prior, expert knowledge to further the analysis

Stake (2005) recommended categorical aggregation as another means of analysis and he also suggested developing protocols for this phase of the case study to enhance the quality of the research. Yin (2009) continues to add that an important part of the analysis is the investigators own style of rigorous empirical thinking, along with the sufficient presentation of evidence and consideration of alternative interpretations.

In this study the criteria for interpreting the findings is based mostly on financial aspects, however some qualitative aspects are also discussed. The criteria are discussed in detail in the investment section of this study, where the theory of investment analysis is presented.

2.3. Validity and reliability of the study

The validity of the study is an important criterion when evaluating the quality of a study (Koskinen et al, 2005). Validity refers to whether the study actually answers the research questions (Tuomi & Sarajärvi 2002).

Yin (2009) describes four tests to evaluate the quality of a case study research, these test are commonly used to evaluate the quality of empirical research. The four tests are: construct validity, internal validity, external validity and reliability.

Tactics to construct validity are that the researcher uses multiple sources of evidence. In this study a wide range of sources have been used to construct validity. Secondly the researcher has to establish a chain of evidence and thirdly have the key informants review the case study report. A clear chain of evidence has been created while collecting the data for this study (Yin 2009).

Tactics to test internal validity are pattern matching, explanation building, addressing rival explanations and using logic models. In this study rival explanations are used to enhance internal validity by searching if some of the theoretically relevant explaining conditions might be articulated in empirical findings. Pattern matching by comparing empirically based patterns with predicted ones increases internal validity (Yin, 2009).

External validity refers to the generalizability of the findings beyond the immediate case study (Yin, 2009). The cases were chosen so that they would represent very typical building types used in Finland. The heating systems were also chosen to represent most common heating systems in Finland. These factors increase external validity of this study.

Reliability of the research refers to possibility of repeating the case study with the same results. All calculations and theory used can be found in this study; hence the reliability can be tested and audited.

3. Heating systems

There are several methods that can be used to heat a building. This chapter will provide a basic introduction of the primary heating applications most common in Finland and provide insight about the applications used later in the investment calculations as well as a review of their use in practice. A more in depth introduction is made of ground source heat pump because of its central role in this study.

3.1. Introduction

Annually a total of 10 000 to 15 000 new single-family houses are built in Finland and in another 50 000 small houses the heating system is renovated. In recent years, in roughly 70 - 80% of renovation cases the former heating system is kept, and in rest the heating system is changed to a new system (Metla, 2010).

Quite often a cheaper heating system investment means higher operating costs, and consequently a larger investment into a heating system means smaller operating costs. When choosing a heating system one should also consider the future and future energy prices. A wise solution would be for example, a heating system, where the energy source can easily be replaced. Sensible would be to build houses that consume very little heating energy, hence are energy efficient. This way one could protect himself against possible fluctuations in energy prices. (Pientalojen lämmitysjärjeslmät, Motiva, 2009). Future energy prices cannot be accurately predicted, but it is likely prices will rise. (IEA, World Energy Outlook, 2010).

Heating consumes about half of the residential building energy consumption. Lighting of homes has grown to be the largest electricity consumer in domestic residential houses excluding heating. As mentioned heating consumes a big part of home energy usage, hence heating constitutes the largest single cost item in residential buildings (Motiva, Näin säästät energiaa, 2011).

Heating energy consumption in buildings is divided almost equally between the air leakage of building envelope, ventilation and hot water heating (Motiva, Koti ja asuminen, 2011).

Air permeability determination is the testing of the uncontrolled leakage of air through the envelope cavities created by structural damage, poor workmanship, weather, design or deterioration of materials. The air permeability of building shell influences the energy consumption level as well as the perceived indoor air comfort, pressure balance and ventilation system control, spreading of impurities, and humidity of structures. Good airtightness is an indicator of good construction quality. The air permeability of buildings is affected by structural solutions, such as insulation and tightness of the structure (vtt, air permeability, 2010).

The volume of air and the ventilation system determine the amount of heating energy consumption in ventilation. Heat recovery system can reduce the use of ventilation heat consumption by more than half compared with conventional ventilation systems. DHW energy consumption is affected by the amount of water used, piping insulation and hot water heaters connected into the domestic hot water network (Motiva, Koti ja asuminen, 2011).

Heating buildings is a vital function in northern Europe because of the harsh winters. About 20% of energy used in Finland is for heating buildings and about a third part of that is used for heating small residential houses (VTT, Future development trends in electricity demand, Koreneff, et al. 2009).

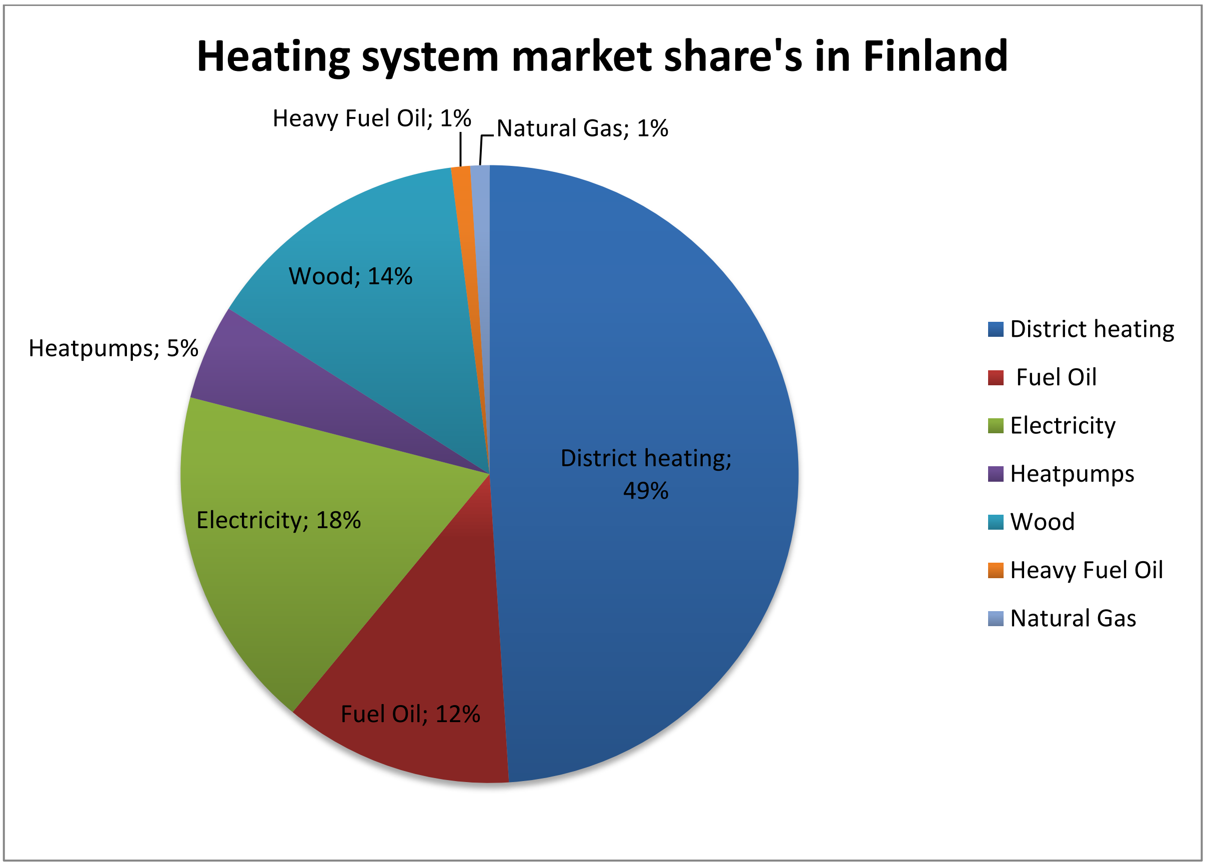


Figure 1. Heating system market share's in Finland (Statistics Finland, 2009)

3.2. Ground source heat pump

As mentioned earlier the author will focus on a closed loop ground source heat pumps in this study. This system type is the most used option in Finland (Aittomäki, lämpöpumppulämmitys. 2001). One way that a decrease in energy costs, as well as a decrease in reliance on non-renewable energy sources, can be achieved is through the use of geothermal heat pump (GHP) systems, through which heat is extracted from the earth or a qualifying water source and utilized in structures like greenhouses and homes. GHP systems have been used in greenhouses, homes and commercial businesses for over 30 years (Miller, 2009).

There is a vast amount of thermal energy in the natural environment. Heat comes from the sun and is stored in the earth, bedrock or water. This is called geothermal heat and is processed with the ground source heat pump to produce heating water and domestic hot water. According to Bloomquist (2000) "development trends can be divided into several distinct designs, including pumped wells with central or distributed heat pumps and loop systems, horizontal or vertical, relying primarily on a distributed heat pump system layout. Fortunately for the industry, all of the above seem to offer unique solutions to meet building design or retrofit requirements. Unfortunately, the industry has not yet matured to the point where all engineering design teams feel comfortable with all available technical alternatives, and thus design is often as much a factor of prior experience as it is a conscious decision to select the most appropriate technology for a given application".

Another difference is in geography; this research focuses on Finland in particular. Although extreme temperature fluctuations make the country an interesting focus, most current research does not specifically include Finland. Thermal solar-assisted heat pump studies have also been performed in Turkey. One example is a research study by Ozgener and Hepbasli (2005) at Ege University in Turkey. The research had two objectives: to introduce a decision-making method for the integrated solar assisted geothermal heat pump system installed in Ege University, and to review geothermal heat pump use in Turkey's greenhouses.

In countries with cold climates such as northern Europe, heat pumps are often used for heating only. In warmer climates, heat pumps serving hydronic systems with fan coils provide heat in winter and cooling in the summer. These types of systems are becoming available which provide both floor panel heating and fan coil heating or cooling. These systems were not so popular around the world prior to 1995, but have increased steadily since that time (UNEP, 2006).

The installed base of ground-source heat pumps was estimated to be about 110,000 units in 1998. The proportion of these units that are used for hydronic heating (typically floor heating) is not specified in the reference but is believed to be high (UNEP, 2006) Despite the fact that geothermal heat pumps have been in use for years now (the first were in the USA), market penetration of this technology is still in its infancy around the world, with fossil fuels dominating the space heating market and air-to-air heat pumps that of space cooling. In Germany, Switzerland, Austria, Sweden, Denmark, Norway, France and the USA, large numbers of geothermal heat pumps are already operational, and installation guidelines, quality control and contractor certification are now major issues of debate (Sannera et al. 2003).

According to Sannera et al. (2003) most European countries cannot boast abundant hydrothermal resources that could be tapped for direct use (with the exception of, e.g., Iceland, Hungary, and France). They continue "the utilization of low-enthalpy aquifers to supply district heating to a large number of customers is limited so far to regions with specific geological settings. In this situation utilizing the ubiquitous shallow geothermal resources in de-centralized GSHP systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. The outcome is a rapid market penetration of such systems; the number of commercial companies operating in this field is on the increase and their products have reached the ''yellow pages'' stage".

The climatic conditions in central and northern Europe, where most of this market development took place, are such that by far the greatest demand is for space heating; air conditioning is rarely requested. Therefore, unlike ''geothermal heat pumps'' in the USA, the heat pumps in Europe usually operate mainly in the heating mode (Sannera et al., 2003).

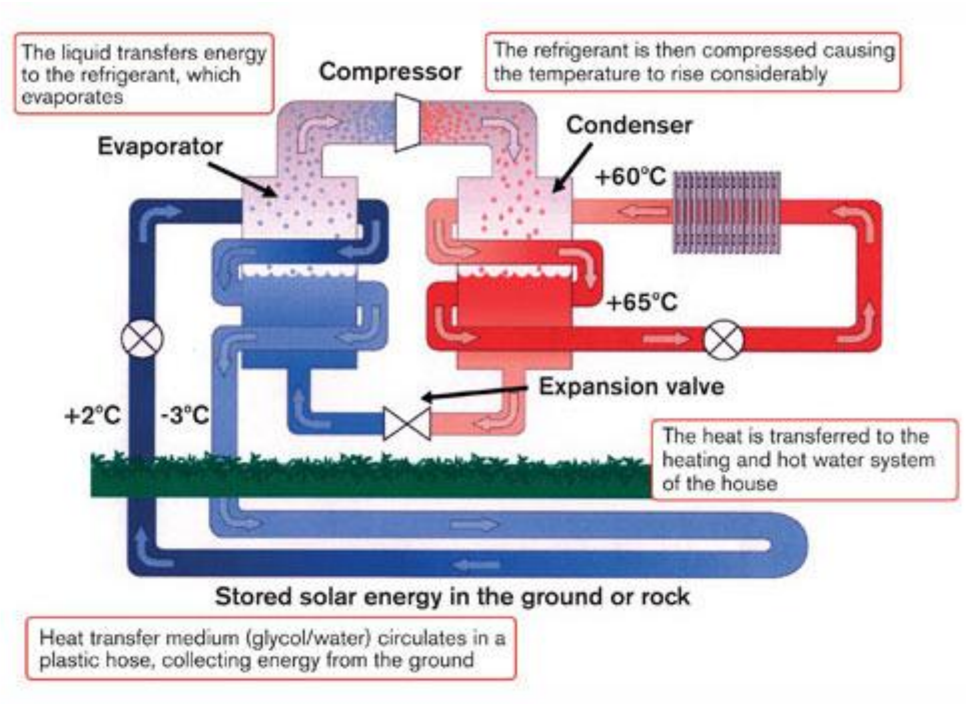


Figure 2. Ground source heat pump basic operating principle. Note: temperatures are too high (heatexchanger-design, 2011).

In the lower subsoil of the so-called near-surface geothermal layer lies a heat source that can be utilized all year long, which has an almost constant temperature. It can be used for almost every building type, large or small, public or private. Depending on the region it is also referred to as, vertical absorption, ground spit or ground lance. It requires little space and the ground probe can be drilled on quite small plots (Nibe, 2010).

Heat is extracted in geothermal heat pumps from the soil either in a horizontal pipeline in the depth of one meter or of a vertical hole drilled in a rock. In both systems, the normal method of heat transfer from the heat pump is the cycling of an alcohol-water mixture (or a similar anti-freeze solution) in a plastic tube. In the soil the solution warms approximately two or three degrees. The same principle can also be used to extract the heat from the bottom of the lake, for example, where the tube is anchored with weights. Nowadays, in new houses, the normal method of heat distribution is under floor heating. The traditional radiator heating is possible, but a heat pump is less favorable for radiator heating because it requires a higher water temperature (Aittomäki, 1999).

Heat energy stored in the near surface layers comes predominantly from the sun.
Heat energy in the deeper bedrock comes mainly from the decay of radioactive materials. When talking about geothermal heat in Finland it usually means depths of less than 200 meters. Average annual temperature in the soil is two degrees higher than the annual average outside air temperature and varies with geographic location. The soil temperatures also vary locally. In developed areas it may be several degrees higher than for example in a natural forest (Ympäristöopas, 2009).

Ground and bedrock near surface temperatures in Finland varies with the annual average air temperature, but usually stabilizes in depths of 14-15 meters to five-six degrees. Deeper in the bedrock geothermal energy raises the average temperature from 0.5 to 1 degree per 100 m. Thus, in the southern parts of Finland the bedrock temperature in 200 meters of depth is around 6-8 ˚ C. Finnish rock types have variation in their thermal conductivity. Issues that mostly affect the bedrock’s thermal characteristics are the composition of the soil and bedrock, consistency and groundwater movements. Groundwater and scattered bedrock enhance heat transfer in the Earth's crust. Scattered bedrock may complicate heat dwell drilling structures and their stability (Ympäristöopas, 2009).

Heat pump differs in many respects from conventional oil heating and direct electrical heating. As the oil burner, a heat pump is a central heating system, in other words, heat is transferred to the rooms by water or air. A heat pump is electrically operated, but it needs only a small proportion of that of a direct electric heating. Heat pump operation is often compared to a refrigerator. Fridge cooling mechanism takes the heat inside the cabinet, from a temperature of 4 ... 5 ° C and removes the heat (pumps the heat out), at a temperature of 30 - 40 ˚C. The heat pump mechanism is functionally similar, but more efficient, from approximately 4 kW upwards. Refrigerator wattage is only tens of watts, hence less than a hundredth part of that of a heat pump (Aittomäki, Lämpöpumppulämmitys, 2001).

The ground source heat pump can be sized up to full capacity or a partial capacity. On partial capacity, the maximum capacity of the heat pump is sized up to correspond around 60-100% of a building's heating requirements. In practice, the pump will provide 85-100% of the annual energy requirements. On the full capacity sizing, the ground source heat pump is sized up according to the maximum capacity requirements of the building (Oilon, 2010). The operation is based on the circulation of the so-called refrigerant. The refrigerant is evaporating and condensing in the system. Vaporization requires heat, which the refrigerant takes in the evaporator from the refrigerant at low temperatures. This will produce a vapor which is then compressed to a higher pressure, when it also heats up. The high pressure hot steam is cooled in a condenser, where it liquefies. The heat released, heats water or air flowing through the condenser. The liquid is returned to the evaporator expansion valve lowering its pressure. Compression requires a compressor, which is an electric motor. In addition, geothermal heat pump consumes electricity in the pump that is circulating the refrigerant solution and also small amounts in the adjustment devices (Aittomäki, Lämpöpumppulämmitys, 2001).

The term coefficient of performance (COP) is used to describe the ratio of useful heat movement to work input. Most vapor compression heat pumps utilize electrically powered motors for their work input. Thus, with a coefficient of performance of three one gets for every 1 kW of electrical power 3 kW of heating power. The difference in temperature is taken for example from the soil. Coefficient of performance of a heat pump depends on the properties of the heat source but also of the properties of the heating application. At best the heating source has a high temperature and the heating application uses the lowest temperature (Aittomäki, Lämpöpumppulämmitys, 2001).

One should keep in mind that as conditions vary during the year, so do the operating conditions of a heat pump. The most important time is when the maximum capacity is required, which is the winter season. Operating values should be averaged over conditions. The average COP is three or more (Aittomäki, Lämpöpumppulämmitys, 2001).

Service water heating is an important part of the heating system. Both the amount of water and the temperature of water are vital functions. Occasionally temperature levels have to rise to at least 55 ° C in order to avoid the risks of Legionella bacteria. Water over 55 ° C is too hot to be distributed to outtake points. Therefore one needs a mixing valve, which automatically adjusts the outgoing water temperature suitable for distribution by mixing hot water with cold. Typically the final service water heating is done with a superheating system or with a final electrical heating in the water boiler. In all the systems heat has to be restored because heat pump power capacity is not sufficient to handle a large momentary rise in service water usage. In a superheating system hot steam, which is coming from the compressor, is used to heat the water to temperatures up to 80-85 ° C without increasing the condensing temperature (Aittomäki, Lämpöpumppulämmitys, 2001).

According to Aittomäki (2001) the right design and placement of the parts is essential in order for the water heater to work efficiently in all situations. In many cases the superheating method mentioned earlier is not used but the interval final service water heating is done with a heat pump or with electric heaters. Depending on the needed size of the heat pump unit, a specialized GSHP company determines the depth and amount of bore holes in which the u-shaped plastic tubing is installed and pressed (Nibe, 2010). GSHPs have a higher seasonal heating efficiency than ASHPs, although their installation costs are higher (IEA, Technology Roadmap Energy-efficient Buildings, 2011).

When a ground source heat pump is installed one should confirm that all the pump settings are correct. Thus the pump should not be in test mode after installation is completed. It is a common mistake because in many cases during the installation the pump is set to a test mode, which is a sort of manufacturer's general mode of operation for testing. Afterwards the pump settings have to be adjusted to fit house-specific pipeline lengths (Suomen kiinteistölehti, 2008).

3.3. District heating

District heating is the most common heating system in Finland. It can be wound in almost all population centers and cities. According to Finnish Energy Industries around 2, 6 million Finns live in houses heated by district heat and almost 95% of apartment buildings and most public and commercial buildings are connected to the district heating network. In single-family houses, just over 6% of the heating energy comes from district heat (Energiateollisuus, 2010). District heat is produced in CHP (combined heat and power) plants or heating plants. Clients receive heat from the hot water circulating in the district heating network (Pentti, 2004).

The temperature of district heating water varies between 65 and 115ºC, depending on the weather. The temperature is at its lowest during summer when heat demand is at its lowest and heat is needed only for hot service water. The temperature of water returning from customers to the production plants ranges between 40 and 60ºC. Heat is used in houses for the heating of rooms and service water, as well as for ventilation (Energiateollisuus, 2010).

When a client joins the district heating network, it is necessary to install a district heating distribution system. A new customer will also have to pay a connection fee to the district heat provider. The system is reliable and needs little maintenance. In small houses the center may be a good space saving solution.

District heating water is treated against mechanical impurities and oxygen, in order to protect the pipe and to prevent internal corrosion. Often the water is colored in order to locate possible leaks or damage. The coloring is not dangerous to health or harmful towards environment (kaukolampo.fi, 2011).

The most common fuels that are used to produce district heating are natural gas, coal, peat, oil and, increasingly timber and other renewable energy sources such as biogas. Almost 80% of district heating is produced in combined heat and power (CHP) plants, industrial oddment heat or landfill biogas combustion. In small towns these heat sources are often not available. In these cases, the district heating is produced only heat-producing centers. District heat supply is a very reliable heating system. District heating networks are often coiled, which allows customers access to the heat input from more than one direction (kaukolampo.fi, 2011).

District heating pipes are usually installed to a depth of 0.5 - 1 m from the ground, under streets, sidewalks and pedestrian paths or under park land. The pipes are insulated effectively. The energy lost during the heat distribution on average, is less than 10 per cent (Energiateollisuus, 2010).

3.4. Direct electricity heating

The simplest direct electric heating can be done by using electric heating cables. The heating cable or foil is suitable for example to floor- and wall heating. Under floor heating with heating cables is the most common way of direct electric heating. Also electric radiators are commonly used in electric heating. Most often the radiators that are suitable for this purpose are enclosed electric heaters, the flow heater and combination heaters (Seppänen & Seppänen, 2004).

Direct electric heating is cheap to build, easy-care, and maintenance-free, however operating costs are high. Electric storage heating system reserves the cheaper off-peak electricity at night. Heat can also be conveyed in a concrete slab mounted electrical installation (omakotitalo.net, 2010).

A ceiling mounted electric heating, the heating element, a heating foil, is installed above the first level of the ceiling. The heating foil heats the ceiling material, which then transfers the heat radiation into the room (WebDia, 2010). Electric heating is the general name for methods that are based on the change of electrical energy into heat. In direct electric heating electricity is transformed into heat in that specific space. Electricity consumption correlates heat consumption. Direct electric heating does not require expensive investments and there are no serviceable parts subject to wear, which is why it is a very common form of heating in smaller residential buildings. Electricity infrastructure is ready and is available almost everywhere. Energy conservation efforts are rather easy to carry out in electric heating houses, because the modern heaters and thermostats make sure that the premises do not spend extra energy. Electric heating system will also react quickly to changes in room temperature (Motiva, näin säästät energiaa, 2011).

3.5. Oil heating

There are around 200 000 oil heated houses in Finland. It is possible to upgrade the oil heating system by installing alongside a renewable energy system such as a solar panel system (Oil.fi, 2011).

By renovating an old oil heating system one can expect approximately 10-30% savings in oil consumption. Furthermore there are other measures to create more savings, as mentioned above; by using solar panels together with oil heating. Many boilers and other oil heating system equipment have been renovated in recent years, hence the vast majority of oil-heated houses are nowadays equipped with modern parts, which are in good condition (Oil.fi, 2011).

Oil heating system consists of the oil boiler, oil burner, control devices and the oil tank. The system produces heating water for space heating as well as heat for service water, hence a separate service water storage tank is not needed. Heat is distributed with a hydronic system. Modern oil boilers have a very good GOP, about 90-95%, and the combustion is very clean (Motiva, Pientalojen lämmitysjärjestelmät, 2009).

The share of oil heating in new residential buildings is low, due to rising oil prices and interest rate fluctuations. Oil heating can be combined with solar heating, when approximately 25-35% of the heat demand can be covered by solar thermal system. In addition, there is a dual-chamber boilers, in which wood can be used alongside oil (Motiva, Pientalojen lämmitysjärjestelmät, 2009).

An electric backup system is usually installed in case malfunctions. Periodic maintenance by a professional should be done once a year in order to ensure clean burning and efficient fuel use. Oil tank is cleaned every 5-10 years depending on the tank (Motiva, Pientalojen lämmitysjärjestelmät, 2009).

3.6. Wood-pellet heating

Pellet heating is a relatively new form of heating in Finnish single-family homes. The first pellet boilers were installed in houses in the 1990s, but they began to gain popularity in the 2000s. At the end of 2009 there was an estimated 22 000 homes in Finland that were heated with wood-pellets and nowadays an estimated 25 000 (Pellet Energy Association, 2010)

This corresponds to about two per cent of the residential housing portfolio in Finland. After the initial enthusiasm for the new system the popularity of pellet-detached houses as a form of heating has been marginal: the last few years, only about 5% of single-family builders have chosen a wood-pellet heating system. Also in residential renovations only 5% replaces the former system with a pellet-based system (Metla, 2010).

Wood based fuels are domestic bio-energy, which computationally do not increase greenhouse gases and sulfur emissions. In order to minimize the harmful particle emissions it is important to adjust the burner, keep the combustion chamber clean and the boiler clean. In addition, the fuel used must be sufficiently dry. The wood-Pellet is a cylindrical shape hard-pressed pure and very dry wood pulp, which is made of carpentry and sawmill by-product of dry shavings, sawdust and sanding dust. The pellet is dry wood, and thus burns cleanly. As the bark is not used in the manufacture of pellets, the burning process produces less ash than the traditional wood heating and ash removal is needed less often. Pellet heating system comprises of a pellet burner, which is connected to the boiler and of automatic system controls. Heat distribution is usually done with a hydronic system. A Wood-Pellet heating system can be fitted to an old house, with a hydronic heat distribution system (Motiva, pellettilämmitys, 2009).

The system design and installation might be wise to acquire as a turnkey project, which in its various parts work well together. In the design one has to decide how automated will the system be, how the pellets are stored and in what quantities they will be delivered in the future. It also is possible to connect water heater with an electric back-up system, also some boilers are equipped with electric resistors. A vertical water heater can be connected to solar panels (Motiva, pellettilämmitys, 2009).

Pellets can be stored in a separately positioned pellet silo, in the boiler room, into a smaller storage or into an underground storage for pellets. Pellets can be purchased in small bags (16 or 20 kg), big bags (500 or 1 000 kg) or in bulk delivered by a pellet truck. Purchasing bags of pellets will always require manual labor, when the pellets are transferred into the silo. The pellet truck has to get about 15 meters away from the filling hole. The burner is fed most commonly by a screw feeder or by air pressure. The automated system supplies the burner the needed amount of pellets. The burner can be a fixed part of the system. These combination boilers have a good GOP, normally over 80 %, and such systems have often an auto-cleaning technology, the system needs some maintenance, only 2-3 times a year. Pellet heating is automatically controlled by control devices. A separate pellet burner and boiler require little maintenance once or twice a month. Temperature rises in the exhaust gas indicates the need for cleaning the boiler. Manufactures provide good instructions concerning maintenance (Pellet Energy Association, 2010)

One cubic meter of pellets is the equals 300-330 liters of heating oil. A cubic meter of pellets weighs 600-750 kg; hence a ton of pellets needs 1.5 m2 of warehouse space per ton. An average single-family house requires about 8 m2 of pellet storage, with a capacity of 4 000 kg of pellets. A single-family house’s annual wood-pellet demand is approximately 20 cubic meters. The pellets are usually stored in a cold storage space (Motiva, Pellettilämmitys, 2009).

3.7. Future of heating and investment subsidies in Finland

According to IEA (2011) low/zero-carbon and energy-efficient heating and cooling technologies for buildings have the potential to reduce CO2 emissions by up to 2 gigatonnes and save 710 million tons of oil equivalent of energy by 2050. Most of these technologies, which include solar thermal, combined heat and power, heat pumps and thermal energy storage, are commercially available today.

IEA states that an additional USD 3.5 billion a year needs to be made available for research, development and demonstration by 2030. R&D efforts should focus on reducing costs and improving the efficiency and integration of components. R&D into hybrid systems could lead to highly efficient, low-carbon technologies. Beyond 2030, R&D needs to focus on developing technologies that go beyond the best that are currently available. Governments need to create the economic conditions that will enable heating and cooling technologies to meet environmental criteria at least cost (IEA, Heating and Cooling Equipment, 2011).

IEA continues to state that key actions in the next 10 years are that working groups should be convened that include stakeholders from all areas of government to develop policy and ensure that energy-efficient and low-carbon technology priorities are aligned with environmental policies and do not face barriers because of struggle with other policy goals, for example fire, equipment safety and local planning. Governments should develop national roadmaps, tailored to local circumstances, to help to drive market expansion. Policies should set measurable and meaningful targets, such as CO2 emissions reductions, or ensure that program effectiveness is verified regularly (IEA, Heating and Cooling Equipment, 2011).

According to IEA (2011) “governments should improve standard education of key professionals, such as architects, designers, engineers, builders, building owners and operators/users in the potential of existing and soon to be commercialized heating and cooling equipment. Policies such as minimum energy performance standards, labeling, utility programs and financial incentives are needed over the next 10 years to address market barriers; such as high initial costs and low priority of energy efficiency in decision-making and market failures”.

The IEA report continues to add that governments need to highlight the role of technologies in reducing financial risks, such as energy and carbon price volatility. Over the next 10 years governments should expand and/or implement mandatory quality assurance and certification schemes for equipment and installers. These should be coordinated across the heating and cooling technology industry, so that decision makers are faced with a simplified decision process. Industry and governments need to work together and share information on an international level to help lower costs, accelerate technology deployment, and provide quality and performance assurance for installed systems.

Key areas for cooperation include research, market deployment, performance and test procedures, setting of energy and CO2 emissions reduction targets/standards, harmonization/comparability of heating and cooling system tests, and policy development (IEA, Heating and Cooling Equipment, 2011). Finland is committed in conjunction with other EU countries to strict emission cuts by 2020. In practice this means that, among other things, the government is committed into supporting the transfer from fossil fuels to renewable sources of heating. From 2011 onwards investment incentives are used to support the transformation into low emission heating systems in private households. Also the already existing tax incentives, which can be obtained, for example to cover the cost of installing the hardware, will remain in use. The subsidies are obtained from the local municipality, the criteria and schedules can vary. The local municipal technical services have valid information about current issues. Therefore one should contact them in order to get area specific information. Housing Finance and Development Centre of Finland (ARA) is also a good channel for up to date information concerning investment subsidies (Motiva, Ohjeita lämmitysjärjestelmän hankintaan, 2011)

4. Introduction to Finnish energy, heating and electricity market

This part provides a short introduction of the Finnish energy and electricity market. There are approximately 120 electricity-generating companies and about 400 power plants in Finland. Although there is such as large number of electricity generating companies the production is mainly done by two companies; Fortum and Pohjolan-Voima. Major power producers are also the electricity retailers and large energy-intensive industries. Large-scale industry companies are also the main owners of the Pohjolan Voima Corporation. After the liberalization of the Nordic electricity market a couple other significant players have come in to the Finnish electricity market, these are Vattenfall from Sweden and E. ON from Germany (Energiateollisuus, sähkömarkkinat, 2011). Other producers' shares are small. The largest electricity producer's share of electricity production is more than a third, a lower share for the largest electricity producer than in any other EU country (Energiateollisuus, sähkö, 2011).

Electricity is produced in power plants. From power plants, electricity is transferred to the national grid and local distribution networks, from which it goes to people's homes or other usage points. Customers can purchase electric energy from any retailer of electricity, which in turn purchases the electricity from the wholesale electricity market (NordPool). Many manufacturing firms purchase electricity directly from the wholesale market. The wholesale price is formed in the NordPool (Energiateollisuus, sähkömarkkinat, 2011)

The Nordic power exchange Nord Pool, which complements to the supply options of the large electricity users and retailers of electricity. One has to be a member of the NordPool in order to trade there. Power producers, power companies and industrial companies in Finland, Sweden, Norway and Denmark as well as some other countries are the members of NordPool. The NordPool electricity price is also used in electric sales contracts as a price reference. In addition, one can trade with electricity derivatives in the NordPool. Finland is its own price area in the Nordic power exchange (Energiamarkkinavirasto, 2011).

When analyzing the effects of heating in terms of the Finnish energy system, it is good to note the total effects of district-heating. At present, combined heat and power (CHP) produced in Finland, accounts about one-third of the total electrical energy. The overall production efficiency of the CHP production is almost 90% whereas the condensation water efficiency is only 40 %. If the use of district heating is reduced, the amount of electricity produced in CHP plants will also be reduced, which in turn reduces the overall production efficiency (Honkapuro et al., 2009).

5. Investment appraisal methods

This chapter introduces the theory on investment appraisal, which is the theoretical framework of this study. Theory on energy related investments is also discussed. For the most part this study concentrates on academic theory on investments appraisal methods, these methods can also be used in personal finance. This study's point of interest is more closely related to personal finance or small business finance because of the heating systems discussed in this study. An investment is worth undertaking if it creates value for its owners, in order to analyze whether it will create value one needs to use investment appraisal methods. The investment appraisal methods chosen for this study are according to literature the most commonly used ones (Pike & Neale, 2006). In order for all the variables to be taken in to consideration a Monte Carlo simulation is needed, this is done to have the study as realistic as possible.

5.1. Payback period

According to Liljeblom et al. (2004) the Payback period method is the most used investment appraisal method among Finnish companies. Payback period is a simple benchmark return that measures the number of years required for the investor to recoup the cash equity invested (Harvard Business School, 1995).

In other words it calculates the return per year from the start of the project until the accumulated returns are equal to the cost of the investment, at which time the investment is said to have been paid back (Lefley, 1995).

Pike & Neale (2006) note that the payback period has significant shortcomings as a measure of investment worth:

> The time-value of money is ignored (except in the case of discounted payback).

Cash flows arising after the payback period are ignored.

Pike & Neale (2006) continue to state that payback period criterion that firms stipulate for assessing projects has little theoretical basis.

The payback method assumes that a project with shorter payback period is better than an investment with a longer payback period. This can be appealing as a basic method for comparing risk between investments, however the risk might have very little to do with timing of the cash flows (McCrary, 2010).

Payback period fails to take into account any possible risk differences, as the payback would be calculated the same way for both very risky and very safe investments. The biggest weakness of payback period rule is how to decide the right cutoff period. There is no objective basis for choosing a certain cutoff period, in most cases one ends up using a cutoff period that is randomly chosen.

Lefley (1995) states that, in many cases the determination of the required payback period is based on subjective assessments, taking into account past experience and the perceived level of project risk. The typical payback period expected by management appears to be in the region of two to four years.

According to Wambach (2000) "It is not clear why an investment project with a shorter payback period should, in general, be preferred. In particular, it is very easy to construct examples where in one project the payoffs accrue at a later point in time, while for the other, the payoffs are large in the beginning but small later on. In this case, the payback criterion might allow for the latter project, but reject the first, which might not be optimal. The payback criterion systematically undervalues projects with a later payoff stream." He continues "One argument in favor of the payback rule is that if firms are constrained in their capital, it might be better to go for the investment project, which pays out earlier. However, one has to impose some form of asymmetric information to support this argument, otherwise, credit rationing will not hold. Another quite commonly heard argument is that if either the payoff or the lifetime of the project is uncertain, it is better to choose the project with the lower payback period. Although the latter is a very intuitive argument, it is not clear how a static concept, based on expected values, can be used as a means to decide between different uncertain projects. In particular, a possible finite lifetime should already be incorporated in the value of the expected payoff stream or at least in the project-specific discount rate, and it should not be the payback period, which differentiates between projects with different expected lifetimes."

Payback period method is usually used as a secondary method together with more complicated investment appraisal methods like the NPV (Lefley, 1995). Payback period method might be useful in a high risk investment environment where return of capital may be more important than a significant projected future payoff (Harvard Business School, 1995).
As mentioned the payback period method is widely used, and in many cases it can be a useful tool. However it has too many weaknesses to be used in this type of an in-depth investment analysis as done in this study.

5.2. Net present value (NPV)

In the Net Present Value method, the initial investment and the expected future cash flows are discounted back to their present value and summed. If the present value of the sum is positive, the investment is profitable. The method has the disadvantage that in a comparison between different projects, it does not take into account the differences in the size of projects and projects in real productivity (Kurki, 1997). Public companies are significantly more likely to use NPV and the internal rate of return (IRR) than are private corporations (Graham & Harvey, 2001).

Where the corporate goal is to maximize the wealth of its shareholders, the simple decision rule is:

When the NPV is positive, accept the investment.

When the NPV is negative, reject the investment (Pike & Neale, 2006).

There are two very important components that can be adjusted to take into account the uncertainties and risks in an investment: adjusting the expected cash flows, and adjusting the discount rate. Textbooks recommend adjusting the expected cash flows (Shapiro, 1999).

However, because NPV analysis is easy to understand and to apply, it is convincing and practical. NPV also has weaknesses, especially in its treatment of information and uncertainty. These weaknesses result because cash flows are usually assumed for simplicity, leaving the discount rate to incorporate both the time value of money and to account for uncertainty about the projected cash flows (Johnson, 1994).

Johnson (1994) states that the following extensions to the traditional NPV approach are possible:

> Uncertainty about the amount of future cash flows can be represented explicitly.
>
> With cash flow uncertainty represented explicitly, the discount rate can be used to isolate the time value of money.
>
> The state of information of the decision maker can be represented explicitly, and the value of changing this state of information by gathering information or hiring experts can be calculated in monetary terms.
>
> Project stages, including intermediate decision points, can be represented (research phase, pilot program, full scale implementation).

Johnson (1994) continues that each of these extensions requires conceptual extensions to the standard theory as well as more advanced computation methods.

5.3. Other common methods

It is important to mention that there are a number of other basic investment appraisal methods that are used in investment analysis. These include methods like the internal rate of return (IRR), accounting rate of return (ARR) and profitability index (PI).

The IRR of an investment is the discount rate at which the net present value of costs of the investment equals the net present value of the benefits of the investment (Drury, 2008).

The ARR calculates the return generated from net income of the proposed capital investment. However the ARR does not take into account the concept of time value of money, which is one of its major weaknesses (Shapiro, 2005).

The profitability index is calculated by dividing the present value of cash proceeds by the initial cost of the investment. If the investment is greater than 1, the investment should be accepted (Drury, 2008).

5.4. Why NPV

In many cases, the choice of DCF method has no effect on the investment advice, and it is simply a matter of personal preference. In certain circumstances, however, the choice does matter. Pike & Neale (2006) state three such circumstances:

1 Mutually exclusive projects.

2 Variable discount rates.

3 Unconventional cash flows.

The decision to accept or reject a project cannot always be separated from other investment projects. Project scale should be taken into consideration. Pike & Neale

(2006) recommend the NPV method when assessing mutually exclusive projects of different size or duration.

NPV uses all the differences between every possible IRR for a project and its cost of capital; therefore NPV is a richer concept than the orthodox IRR alone (Osborne, 2010).

However Jackson (2008) states that payback period is commonly used in energy related investments because of the difficulties in incorporating uncertainty into NPV analysis, this problem is further discussed later in this study.

According to Johnson (1994) also “the CAPM (capital asset pricing model) and APT (arbitrage pricing theory) depend on assumptions which are tailored to securities market investments and are inappropriate for investment in real assets, only the conceptual value of their insights, and not their precise pricing formulae, appear relevant to energy technology decisions”. Johnson (1994) states that various extensions to traditional NPV methods were shown to be flexible and conceptually simple, yet capable of presenting a relatively complete representation of an investment's return characteristics, as well as of the decision maker's information gathering alternatives. The price of these benefits is that a computational solution is generally required.

6. Risk and uncertainty management in heating related investments

Jackson (2008) explains risk and uncertainty as follows, “beginning with Frank Knight, one of the first economists to address risk and uncertainty in 1921, uncertainty is often used to characterize an outcome where there is no information available, distinguishing it from the term risk, which is associated with a process where some information on outcomes exists. This terminology is inconsistent with common applications of these terms. Risk is defined as the probability or likelihood of a negative outcome; for example, there is a risk associated with a specific energy-efficiency investment. Uncertainty means that the outcome is uncertain but not necessarily unquantifiable. That is, the statement that the commute time from office to home is uncertain does not mean that the time is unknowable, only that there are a variety of potential outcomes.”

Jackson (2008) states that energy efficiency investments are real, irreversible assets that are different from liquid assets because the investment cannot be sold if it is performing poorly. Jackson continues that risk analysis, in this case, must be modified to consider the “real option” value of postponing the investment decision for some time period, if there is likely to be more information in the future that narrows the uncertainty associated with the investment return. However in this study the author makes the assumption that the investment is mandatory and postponing the investment is not an option.

Energy costs are considered part of operating costs and are not usually considered investment opportunities that can generate income. Most operating costs can be reduced only with reduced services or negotiating lower-cost contracts. However, energy costs are different. Profitable investments increase revenue by reducing energy costs more than the amortized cost of the investment (Jackson, 2008).

Energy efficiency and investment in energy efficiency has been extensively concluded to be a risk management tool itself. (Russell, 2005)Reducing energy costs reduces exposure to energy price volatility (Jackson, 2008).

The enormous potential for energy savings is well established, but progress in so called energy efficiency investment has been slow. This is due to the lack of understanding between established financial decision making and risk assessment frameworks relating to energy saving investments (Mills et al., 2006).

To date, however, no energy-efficiency risk management framework has been advanced to provide the intuitive appeal of the simple payback decision variable along with a substantive investment risk evaluation. Such a framework could presumably provide the basis for building owners and their financial managers, energy engineers , energy service companies and financial institutions to view energy- efficiency projects and investments from a more common and accurate viewpoint (Jackson, 2008).

There are various ways to describe and analyze risk. Mills et al (2006) state that industries should build a risk framework to address:

“Project intrinsic volatilities: those energy consumption elements directly affected by changes within the facility, which are measurable, verifiable, and controllable. This includes the energy volume risk (quantitative changes in energy use), asset performance risk, and energy baseline uncertainty risk.”

“Project extrinsic volatilities: those energy consumption risks that are outside the facility, and hedgeable. These include energy price risk, labor cost risk, interest rate risk, and currency risk (for cross-border projects).”

Often energy-related investments are made without a clear financial understanding of their values, risks, and volatilities. Many investor is shown to implement the most certain and easily understood measure. This is due to risk avoidance; however it is not always the best choice (Mills et al., 2006).

Companies classify investments into different categories and different investments have different profit yield requirements as well as different discount rates. A simple categorization is to divide investments into investments that expand, improve or replace the companies operations. Furthermore these can be divided into two classes in which an investment is an optional or a mandatory one. This same categorization can also be applied into personal finance investments (Kurki, 1997).

Uncertainty in energy markets is formed by many different factors, such as future demand growth, fuel prices, environmental regulations and technological improvements (Şener, 2009). According to the Harvard business school report (1995) the longer the time horizon, the more difficult it is to calculate future benefits. Probabilities increase for major changes, which may be either for the better or for the worse. In a financial analysis it becomes necessary to make judgments about such changes. These can be categorized as follows:

1. Operating changes
2. Physical changes
3. Financial changes´
4. Market changes

Operating changes can be brought about in two ways. First, in the analysis of the setup, projections can be made by assuming changes in operating income over time while financial payments stay constant. These projections should be factored into the final calculation of value. Second, change can come from operating policy decisions, such as those calling for more efficient operation or for a policy of limited maintenance or those that seek a different market through upgrading the clientele. All of these changes should be reflected in the projected final setup that the buyer and seller use to determine value. (Harvard Business School, 1995).

Mills et al. (2006) explain that accurate and robust analysis demands a high level of understanding of the physical aspects of energy-efficiency, which enables the translation of physical performance data into the language of investment.

6.1. Incorporating risk into NPV

According to Shapiro (2005) there are two common methods how one can incorporate uncertainty and risk into a NPV investment analysis. The more common way is to incorporate the time value of money in relation to the risk-free rate of return and the risk in the investments cash flows into the discount rate of the NPV analysis. The other method, which the author will be using in this study, is to adjust the cash flows of the investment to represent the risks of the investment and use a risk free discount rate in the analysis.

Shapiro (2005) explains that adjusting the cash flows makes it possible to study the scale and timing of risks and their effects for the projected cash flows of the investment. By doing this one can control and change the effects of each individual risk. Adjusting the cash flows reflects the unsystematic risks of the investment. This means that these risks and their effects should not be included in the discount rate of the investment. However, if the project has risks that are systematic (market risk), the discount rate should be adjusted to incorporate its effects on the investment. (Shapiro, 2005)

When adjusting the cash flows instead of the discount rate the use of high discount rates cannot spoil the later cash flows more than the early ones. The adjustment of cash flows allows all data to be taken into account when assessing the risks and its impacts on the investment in the future. (Shapiro, 2005).

Johnson (1994) has supported the cash flow adjustment technique in energy efficiency investment analysis because of the failure of decision-makers incorporate data about the investment's risk into the discount rate. The unsystematic risk of energy prices seems suitable to be incorporated in the cash flows instead of the discount rate. Johnson (1994) recommends that the extent of uncertainty should be included as distributions of potential cash flow values instead of using point estimates for cash flows. This approach would describe the risks of uncertain variables more systematically and demonstrate the range of the outcomes better. This kind of analysis can be done by using sensitivity and simulation analysis, Monte Carlo simulation is discussed in the next part of this study.

6.2. Monte Carlo simulation analysis

Monte Carlo simulation allows one to simulate possible outcomes and assess the impact of risk, allowing for better decision making under uncertainty. Monte Carlo simulation is a computerized mathematical technique that allows one to account for risk in quantitative analysis and decision making. The method is used in widely disparate fields such as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment (Palisade, 2011).

Monte Carlo simulation provides the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. The method was first used by scientists working on the atom bomb (Palisade, 2011).

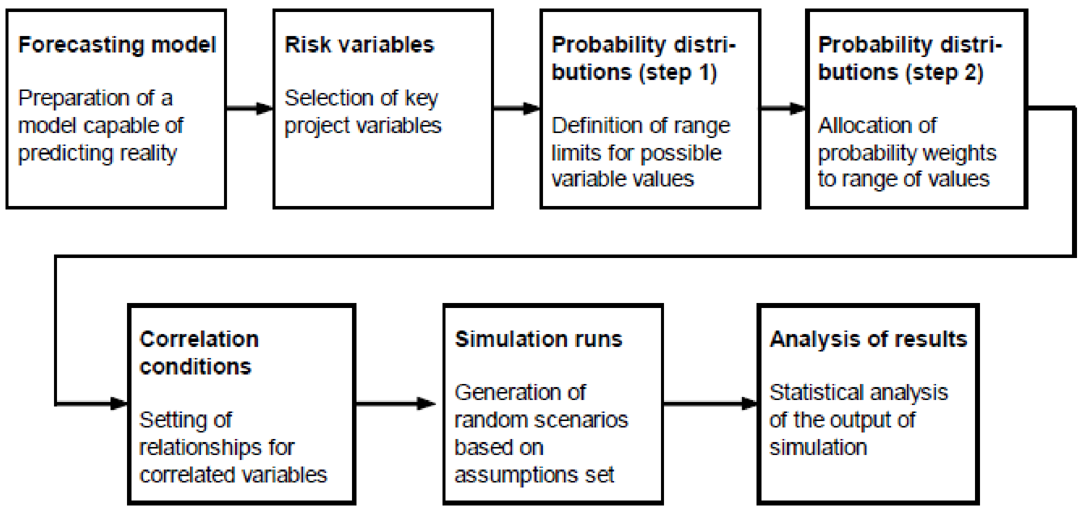


Figure 3. Monte Carlo analysis process by Savvides (1994).

Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values (a probability distribution) for the chosen risk variables. It then calculates results over and over, each time using a different set of random values from the probability functions (Palisade, 2011).

Hacura et al. (2001) explain the analysis process as follows:

1. Developing a conceptual model of the problem under study.

   This involves the creation of a forecasting model, which defines the mathematical relationships between numerical variables that relate to forecasting the future.

2. Building the simulation model.

   This includes selection of key project variables and determining their probability distributions.

3. Verification and validation of the model.

   Verification refers to the process of ensuring that the model is free from logical errors. Data validity includes ensuring that all input data and probability distributions are truly representative of the system being modeled.

4. Performing the experiments

   Generation of random scenarios based on assumption set.

5. Analysis of the results.

Next the simulation process is introduced in more detail.

6.2.1. Forecasting model

The first stage of a risk analysis process is the need for a strong model capable of predicting correctly if fed with the correct data. This simply means that one should create a forecasting model, in which the mathematical relationships of the numerical variables are defined and their relationships are understood. Savvides (1994) explains that “a good model is one that includes all the relevant variables (and excludes all non-relevant ones) and postulates the correct relationships between them”.

6.2.2. Risk variables

The second stage consists of the selection of the risk variables. According to Savvides (1994) “a risk variable is defined as one which is critical to the viability of the project in the sense that a small deviation from its projected value is both probable and potentially damaging to the project worth. A project variable with high uncertainty should not be included in the probabilistic analysis unless its impact on the project result, within the expected margins of uncertainty, is significant.”

There are two main reasons for including only the most important and sensitive variables in to the model. Savvides (1994) explains that “the greater the number of probability distributions employed in a random simulation, the higher the likelihood of generating inconsistent scenarios because of the difficulty in setting and monitoring relationships for correlated variables”. Secondly, the cost, in this case the expert time and effort needed to define accurate probability distributions and correlation conditions for many variables with a small possible impact on the result is likely to outweigh any benefit to be derived (Savvides, 1994). In other words it is wiser to concentrate on the most sensitive and uncertain variables, rather than extend the analysis to all possible variables with limited significance.

An assessment of uncertainties has to examine and weigh a multiplicity of factors. When using Monte-Carlo analysis techniques, the uncertainties of multiple variables are being integrated into a unified economic assessment method. Under this approach, the probabilistic characteristics of each risk component are isolated to identify uncertainties and appropriate risk management activities and priorities (Mills et al., 2006).

6.2.3. Probability distribution

In defining the uncertainty surrounding a given project variable one should widen the uncertainty margins to account for the lack of sufficient data or the inherent errors contained in the base data used in making the estimate. While it is almost impossible to forecast accurately the actual value that a variable may assume sometime in the future, it should be possible to include the true value within the limits of a sufficiently wide probability distribution (Savvides, 1994)

The analyst should use the available information and expert opinions in order to define the range of values in which the future event will take place. The planning of a probability distribution for the selected project variable involves setting up a range of values and allocating probability weights to it (Savvides, 1994).

The level of variation possible for each identified risk variable is specified through the setting of limits, in other words setting the minimum and maximum values.

When data are available, the definition of range limits for project variables is a simple process of processing the data to arrive at a probability distribution. Savvides (1994) explains that it is usually needed to rely on judgment of the analyst and subjective factors for determining the most likely values of a project appraisal variable.

In the final analysis the definition of range limits rests on the good judgment of the analyst. The analyst should be able to understand and justify the choices made. It should be obvious, however, that the decision on the definition of a range of values is not independent of the decision regarding the allocation of probability (Savvides, 1994).

6.2.4. Correlated variables

After the above mentioned steps one could start the simulation process, however the analyst should take interest in the possibility of significant correlations between two or more variables.

Savvides (1994) explains that “two or more variables are said to be correlated if they tend to vary together in a systematic manner. It is not uncommon to have such relationships in a set of risk variables. The precise nature of such relationships is often unknown and cannot be specified with a great deal of accuracy as it is simply a conjecture of what may happen in the future. The existence of correlated variables among the designated risk variables can, however, distort the results of risk analysis. The reason for this is that the selection of input values from the assigned probability distributions for each variable is purely random. It is therefore possible that the resultant inputs generated for some scenarios violate a systematic relationship that may exist between two or more variables. Before proceeding to the simulation runs stage, it is therefore imperative to consider whether such relationships exist among the defined risk variables and, where necessary, to provide such constraints to the model that the possibility of generating scenarios that violate these correlations is diminished”.

The main objective of the correlation analysis is to control the values of the dependent variable so that uniformity is maintained with their counter values of the independent variable.

6.2.5. Simulation runs

The simulation runs stage is the part of the risk analysis method in which the computer and the simulation program do all the work. During a simulation the values of the risk variables are selected randomly within the specified ranges and in line with the set probability distributions and correlation conditions. The results of the model (that is the net present value of the project) are then computed and stored after each simulation run. Savvides (1994) explains that "except by coincidence, each run generates a different result because the input values for the risk variables are selected randomly from their assigned probability distributions. The result of each run is calculated and stored away for statistical analysis."

6.2.6. Analysis of results

The final stage in the risk analysis process is the analysis and interpretation of the results collected during the simulation runs stage. Every run represents a probability of occurrence equal to:

$p= 1/n$

where: p = probability weight for a single run
n = sample size

Hence, the probability of the project result being below a certain value is merely the number of results having a lower value times the probability weight of one run. By sorting the data in ascending order it becomes possible to plot the cumulative probability distribution of all possible results. Through this, one can observe the degree of probability that may be expected for the result of the project being above or below any given value. (Savvides, 1994).

Similarly as in the basic NPV analysis, when choosing among mutually exclusive projects, the decision rule is to select the one with the best NPV. Being aware of the fact that the key project variables are not certain is also important. The results are collected and analyzed statistically so as to arrive at a probability distribution of the potential outcomes of the project and to estimate various measures of project risk (Hacura et al., 2001)

Because of the significant amounts of resources needed for the analysis, simulation is often recommended only for the most important investment projects (Drury, 2008). Drury, Colin. Management and cost accounting. London: Thomson Learning, 2008, 2008.

7. Statistical principles in forecasting

Statistical forecasting methods are based on existing data. There are two statistical forecasting methods, these are time series and causal methods. Time series method uses only historical values whereas causal methods use data that somehow correlates with the variable being forecasted (Nahmias, 2009).

There are three requirements that have to be fulfilled in order to use statistical forecasting models: Information of the past must be available, it must be possible to convert the information used into numerical data, and it should also be expected that the data pattern continues in the future somehow corresponding to the historical data. (Makridakis et al., 1998).

Time series methods require only the historical data of the variable being projected. The parts of a time series forecasting method include level, trend, seasonality, cycles and randomness. A level indicates the scale of time series. A trend can be linear or nonlinear and it describes the pattern of growth or decline. A seasonal pattern is repeated at fixed intervals. A cycle variation is similar to seasonality, however the length is longer than just a season. A random series has no recognizable pattern of data (Nahmias, 2009).

8. Heating system investment case study analysis

In this part of the study the author will present and explain the simulation model and the different variables used in the study. First the model and how it was built and structured is explained. Secondly the risk variables and issues related to them are discussed. Thirdly the actual Monte Carlo simulations and case analysis is done. The investments which are evaluated are the most common heating systems reviewed in a 10 year NPV scenario. The literature introduced previously in this study is used as the foundation for the analysis process.

8.1. Building the Forecasting model

In order to provide credibility and reliability for the investment analysis the author felt that it was necessary to include different sizes of houses. This was done in order to evaluate the investment in a wider range. In this case study there are three different sizes of houses. The sizes of the houses used in the case study are 140 m2, 240 m2 and 340 m2. Each size has two different annual consumption scenarios, one for an “older” house and one for a “new” house with lower annual energy consumption. The variation in the annual heating energy consumption between an old and a new house comes mainly from better insulation in the structure and windows of the “new” house. In total the model has six different houses in which the investment is analyzed.

When building the model a key issue was to decide which heating systems to include in the study. After some careful thought the author decided to include all the most common systems which are oil-heating, direct electricity, CHP district heating, District heating produced without CHP, Wood-pellet heating and a fully scaled ground source heat pump. At this point it should be mentioned that some combination heating system were left out of the study, for example air source heat pumps were left out of the study because they are not suitable to be used as a primary heating system in Finland. A common misconception is that the air source heat pump is a primary heating system however it is used together with other systems to gain savings in energy consumption.

The actual Monte Carlo simulation model is built around a Net Present Value investment appraisal method, which act as the basic forecasting tool in this study. As mentioned in the literature reviewed earlier the NPV method is recommended by the academic community.

8.2. Risk variables

Instead of reflecting the investment risk in the discount rate, the cash flows can be adjusted to account for the risk and uncertainty in the investment, in such a case one can use the risk-free rate as a discount rate (Shapiro, 2005).

As Savvides (1994) explains it is usually necessary to rely on judgment and subjective factors for determining the most likely values of a project appraisal variable. In such a situation the method suggested is to survey the opinion of experts or literature of the subject.

Next the risk variables used in the study are introduced in detail. This part of the case study is very important since the variables affect the study results heavily. After choosing the basic forecasting model (NPV) and the six different houses the next step was to determine the risk variables. After some careful analysis the author chose three risk variables, these being the heating system price, annual energy consumption and energy price. Next the cash flow variables are discussed in more detail. All potential effects of government subsidies are not considered in the models.

Why Monte Carlo risk analysis uses multi-value instead of deterministic probability distributions for the risk variables to feed the appraisal model with the data is what distinguishes the simulation from the deterministic approach to project evaluation (Savvides, 1994).

8.2.1. Heating system price variables

The heating system price is a key variable when it comes to analyzing the investment in the 10 year scenario. The prices for the heating systems were collected from Rakentaja.fi, which is a Finnish internet based building service webpage. They provided their registered users information on almost every aspect of building. They have their own partners that market and sell their products at Rakentaja.fi. However they also have a heating system cost comparison calculator. It is possible to change many of the specifications in the calculator that affect the investment. For example the size of the house which affects the size of the heating system needed, hence the price of the system changes. One can access the calculator after registering to the service, the system is free and does not cost anything.

The heating system prices taken from the service included the systems for the three different house sizes as well as estimated service and repair cost for the 10 year period being evaluated. The main reason why this service was selected, was to gain a benchmark price for every system. Moreover it was also important that the prices came from the same source. This added credibility to the study. It would have been very difficult to gather reliable data from many different sources as the house specification could have changed. One other source could have been Motiva, however they declined to help.

The system prices are of course estimations. However the author felt that in order to add reliability to the study the prices should be used as one of the risk variables. Therefore every system price has a 10 % increase and decrease (figure 4.) from the benchmark price acquired from Rakentaja.fi. This decreases the possibility of the wrong price skewing the analysis results. The system price variable is also added with a triangulated probability. So during the simulation most of the values come from closer to the benchmark value rather them being totally random. This means that the variable mean price has a higher probability and the maximum and minimum values are used but not abundantly.

	Direct electricity	Oil	GSHP	District heating	Wood-Pellet
INVESTMENT 140m2, 0%	4 955,00 €	11 058,00 €	15 158,00 €	11 401,00 €	15 758,00 €
INVESTMENT 140m2, -10 %	4 459,50 €	9 952,20 €	13 642,20 €	10 260,90 €	14 182,20 €
INVESTMENT 140m2, + 10%	5 450,50 €	12 163,80 €	16 673,80 €	12 541,10 €	17 333,80 €
	Direct electricity	Oil	GSHP	District heating	Wood-Pellet
INVESTMENT 240m2, 0%	7 573,00 €	13 814,00 €	25 729,00 €	14 317,00 €	18 514,00 €
INVESTMENT 240m2, -10 %	6 815,70 €	12 432,60 €	23 156,10 €	12 885,30 €	16 662,60 €
INVESTMENT 240m2, + 10%	8 330,30 €	15 195,40 €	28 301,90 €	15 748,70 €	20 365,40 €
	Direct electricity	Oil	GSHP	District heating	Wood-Pellet
INVESTMENT 340m2, 0%	10 671,00 €	18 390,00 €	32 861,00 €	18 044,00 €	24 470,00 €
INVESTMENT 340m2, -10 %	9 603,90 €	16 551,00 €	29 574,90 €	16 239,60 €	22 023,00 €
INVESTMENT 340m2, + 10%	11 738,10 €	20 229,00 €	36 147,10 €	19 848,40 €	26 917,00 €

Figure 4. Range limits for the heating system investment prices used in the study.

8.2.2. Energy consumption variable

Energy consumption was chosen to be the second risk variable in the study. As mentioned earlier the model was built to include three different house sizes (140m2, 240m2 and 340m2) and each size has an estimated energy consumption for new and old house (figure 5.) . Every house has specific annual energy consumption but most consumptions fit inside a certain range of consumption per m3. The author used a heating related book (Rakennusten lämmitys, 2001) to understand and build the range of consumption per m3. Energy consumption range limits are set as a uniform distribution, hence every consumption scenario between the maximum and minimum value is as likely as any other consumption.

				Room height 2,5 m		
OLD	minimum	**55**	kWh/build. -m3	equals	**137,5**	kWh/build. -m2
OLD	maximum	**70**	kWh/build. -m3	equals	**175**	kWh/build. -m2
NEW	minimum	**30**	kWh/build. -m3	equals	**75**	kWh/build. -m2
NEW	maximum	**50**	kWh/build. -m3	equals	**125**	kWh/build. -m2

Figure 5. Annual heating energy consumptions (Seppänen, 2001).

8.2.3. Energy price variable

The variable with most risk that was chosen to be used in the study is the energy price variable. It is impossible to see the future which means there are a great deal of uncertainty and risk involved with this variable. Furthermore the electricity markets in Scandinavia will undergo structural changes in the near future. There is expected demand growth and increasing fuel and CO2 prices, new investments in power generation capacity are expected as well as decommissioning of old power plants. There is a variety of highly sophisticated models developed to forecast energy demand and price trends. The models are usually very specific and could not be used in this type of a study. However, most of the studies forecast a trend where energy consumption increases as well as energy prices.

After some careful consideration a new, simple statistical forecasting model was developed for the purposes of this study. The model uses historical data for every energy source and counts the average annual growth percentage of the price of each energy source. This average annual growth percentage is then added every year to the next year's price to forecast the future prices, in total the prices were forecasted until the year 2021. The price information was collected mainly from Statistics Finland and from the Energy Market Authority. The price data can be found in the appendixes.

In order to count for the uncertainty obvious in such a forecasting the variable is given a 10 % increase and decrease from the forecasted benchmark price, this done to create the range settings for this risk variable. This risk variable has a uniform probability distribution. Which means that all the values within the set range limits has the same probability. The author chose to use a uniform probability distribution because the energy price forecasting model already takes into account the expected growth of energy prices mentioned in related literature and publications.

After all the risk variables were selected and the range limits set and whole model built, one is ready to start the simulation runs. However one should have a serious look at the correlation conditions and check if there are variables that correlate in a systematic way.

If this issue is not properly dealt with it can skew the analysis results. However in the author’s model there are no significant correlations that would affect the analysis.

It should also be mentioned that the coefficient of performance used in the study for GSHP are three in the “old” house and four in the “new” house. Prices used for Wood-pellet, both District heating methods and for direct electricity were already in the cents/kWh form so there was no need to include the efficiency rates in the model. However oil price was in the form of cents/liter. Heat of combustion in oil is per liter approximately 10 kWh of heat. After the author had the oil price in the cents/kWh form, the coefficient of performance for the oil burner could be selected. In this study the oil burner has a 90% coefficient of performance.

9. Simulation runs and analysis of results

The simulation runs stage is the part of the risk analysis process in which the computer takes over. In this study the model run 5000 iterations per house, in total there were six different houses. Old house and new house energy consumptions for each of the three different house sizes were simulated during the analysis. The concluding phase in the risk analysis process is the analysis and interpretation of the results collected during the simulation runs stage. The risk free discount rate used was 2, 43 %, which was the 10 year Finnish government bond rate at the time (bloomberg.com, 2011).

Next the author will introduce the results and analyze them. Starting with the 140 m2 old house Monte Carlo NPV analysis. And after this proceeding to the other cases. However it should be mentioned that contrarily to the basic decision rule for a project appraisal where the simple rule to accept or reject the project depending on whether its NPV is positive or negative, in this study the cash flows are actually cash out flows, hence the investment with the lowest NPV is actually the best investment (most economical to operate in the 10 year scenario) in this study.

9.1. Results old 140 m2

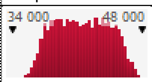
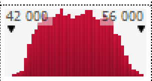
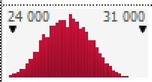
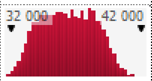
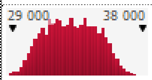
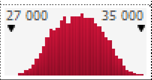
Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C40		35 718,97 €	41 592,34 €	47 404,88 €	37 548,42 €	45 747,09 €	0
NetPresentValueOIL	E40		42 807,35 €	49 159,70 €	55 792,09 €	44 811,27 €	53 589,07 €	0
NetPresentValueGSHP	G40		24 155,67 €	27 049,96 €	30 093,74 €	25 313,50 €	28 801,38 €	0
NetPresentValue DistrictHeatingnonCHP	I40		32 127,29 €	36 504,24 €	41 217,00 €	33 573,96 €	39 447,52 €	0
NetPresentValue DistrictHeatingCHP	K40		29 160,52 €	33 186,02 €	37 376,67 €	30 611,79 €	35 758,14 €	0
NetPresentValuePELLET	M40		27 739,25 €	31 171,85 €	34 888,57 €	29 092,24 €	33 244,73 €	0

Figure 6. Results of the 140 m2 old house Monte Carlo analysis.

At 5000 iterations, the best expected NPV mean can be achieved with the GSHP. The Second best with the Wood-Pellet system, after which the CHP District heating system. District heating without CHP, and especially oil and direct electricity are far behind. From the graphs in Figure 6. one is able to see that GSHP and Wood-Pellet have a more triangular probability distribution, which means that they are not so sensitive to the risk variable changes. Their maximum values are also close to mean of the investment NVP.

This can be explained with a regression analysis which is one of the outputs given by the simulation program after the simulation model is well built. The regression analysis helps one to understand how the value of the dependent variable changes when any one of the independent variables is varied. In all the heating systems the variable with the highest influence is the initial system investment after which the energy price variables, especially the energy price variables in the end of the 10 year period. With the exception of direct electricity, in which case the all the most influential variables are the energy prices. This is due to the lower initial investment compared to the other heating systems.

GSHP systems is not particularly sensitive to energy price fluctuations because the GSHP system has a high coefficient of performance, hence it is better protected from fluctuations in electricity price. In the case of Wood-Pellets the price of pellets in the forecasts is rather low, which explains the lower risk. However both systems have a higher initial investment compared to the other systems. Since the probability distribution For the GSHP and Wood-Pellet are in a triangular form, it can be stated that future cash flows are better known compared to the other systems.

The probability of investment outcomes can be also illustrated by using cumulative probability distribution these can be found in the appendixes for all the cases.

9.2. Results old 240 m2

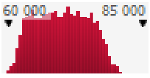
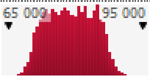
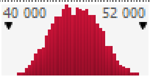
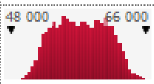
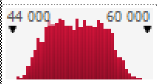
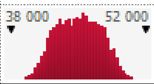
Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C40		60 679,05 €	70 400,34 €	80 666,76 €	63 475,84 €	77 588,13 €	0
NetPresentValueOIL	E40		68 147,34 €	79 252,88 €	90 907,20 €	71 863,81 €	86 601,35 €	0
NetPresentValueGSHP	G40		41 302,32 €	46 121,52 €	51 387,03 €	43 158,97 €	49 119,81 €	0
NetPresentValue DistrictHeatingnonCHP	I40		50 011,81 €	57 474,86 €	65 496,38 €	52 567,41 €	62 452,93 €	0
NetPresentValue DistrictHeatingCHP	K40		45 116,11 €	51 787,04 €	59 025,18 €	47 424,86 €	56 170,14 €	0
NetPresentValuePELLET	M40		39 989,97 €	45 140,59 €	50 419,77 €	41 835,95 €	48 486,53 €	0

Figure 7. Results of the 240 m2 old house Monte Carlo analysis.

At 5000 iterations, the best expected NPV mean can be achieved with the Wood-Pellet system. The Second best NPV mean is with the GSHP system, after which the CHP District heating system. District heating without CHP, direct electricity and oil NPV's are significantly larger.

Again it can be noticed that in Figure 7. GSHP and Wood-Pellet have a more triangular probability distribution. In the 240 m2 old house wood-pellet system has a lower mean NPV than the GSHP. However the GSHP probability distribution is more risk averse than the Wood-Pellet probability distribution.

As the consumption grows the systems that are more sensitive to energy price fluctuations are performing weaker. The larger house changes the risk variable impacts, for example in the oil system the initial investment variable loses significance and is no more the most significant variable but the energy price variables are the most important ones. The same can be seen in the direct electricity system.

The economical difference between these investments has grown considerably and the impact of the risk variables starts to show as the energy consumption increases.

9.3. Results old 340 m2

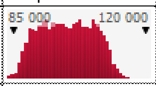
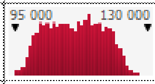
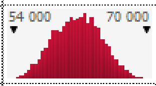
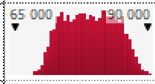
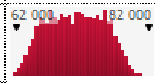
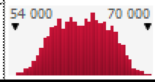
Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C40	 85 000 120 000	85 083,27 €	99 678,38 €	115 029,50 €	89 691,05 €	109 707,50 €	0
NetPresentValueOIL	E40	 95 000 130 000	96 356,48 €	111 123,70 €	127 057,60 €	100 689,80 €	121 690,10 €	0
NetPresentValueGSHP	G40	 54 000 70 000	55 026,89 €	61 835,62 €	69 112,51 €	57 660,19 €	65 990,08 €	0
NetPresentValue DistrictHeatingnonCHP	I40	 65 000 90 000	69 356,08 €	79 236,79 €	89 911,87 €	72 347,10 €	86 207,98 €	0
NetPresentValue DistrictHeatingCHP	K40	 62 000 82 000	62 475,02 €	71 180,25 €	80 552,23 €	65 090,99 €	77 317,59 €	0
NetPresentValuePELLET	M40	 54 000 70 000	54 920,63 €	62 231,23 €	69 957,86 €	57 585,63 €	66 865,95 €	0

Figure 8. Results of the 340 m2 old house Monte Carlo analysis.

The 340 m2 case building simulations are very close to 240 m2 case results, except that the cash out flows are larger. But the actual investments perform very similarly. The GSHP system has a slightly better NPV mean than the Wood-Pellet system. Again the probability distribution of the GSHP investment is more risk averse than the Wood-Pellet probability distribution. As the other investments have more flat probability distribution, hence they are more risk sensitive.

The most significant risk variables are very much the same as in the 240 m2 case. Direct electricity and oil heating investment is mostly sensitive to the energy price variables. The other investments still have the initial system investment as a key risk variable in their investment performance. The minimum and maximum differences have become considerable and the risk differences between the mutually exclusive investments have increased as we can see from the graphs.

9.4. Results new 140 m2

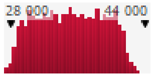
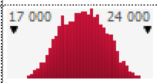
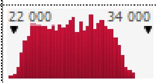
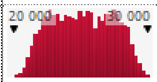
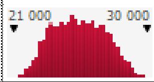
Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C40		21 598,60 €	28 360,07 €	35 579,07 €	23 049,42 €	33 681,57 €	0
NetPresentValueOIL	E40		28 062,53 €	35 348,55 €	43 061,63 €	29 723,75 €	40 931,23 €	0
NetPresentValueGSHP	G40		17 937,08 €	20 678,88 €	23 493,95 €	18 978,47 €	22 358,73 €	0
NetPresentValue DistrictHeatingnonCHP	I40		22 167,56 €	27 370,68 €	32 594,42 €	23 605,52 €	31 151,27 €	0
NetPresentValue DistrictHeatingCHP	K40		20 527,23 €	25 244,66 €	29 857,88 €	21 958,30 €	28 510,29 €	0
NetPresentValuePELLEt	M40		21 631,59 €	25 487,97 €	29 602,42 €	22 997,88 €	28 077,61 €	0

Figure 9. Results of the 140 m2 new house Monte Carlo analysis.

The "new" case houses bring an interesting aspect to the analysis. As we saw from the old case buildings, the energy prices were the most influential variables. However in the new houses the annual energy consumption is lower than in the old case houses, which could have affected the investment analysis results.

At 5000 iterations, the best expected NPV mean can be achieved with the GSHP system. After this the CHP district heating has the second lowest mean NPV followed closely by the wood-pellet system. District heating without CHP, and especially direct electricity and oil have a higher mean NPV. Furthermore we can still see that the GSHP system has more triangular probability distribution, which means that it is not so sensitive to the risk variable changes, in this case the energy price. Even though the consumption is lower in the "new" case buildings it seems that the GSHP system's energy consumption is low enough to overcome the high initial investment.

The CHP district heating had a little lower NPV mean than the wood-pellet system however when looking at the probability distributions we can see that the CHP district heating system has a rather flat probability distribution compared to the more triangular probability distribution of the wood-pellet system. From this we can intrepid that the wood-pellet system has higher probability of actually reaching the NPV mean simulated.

When looking at the regression analysis based sensitivity of the variables, the variables are similar to the 140 m2 "old" case. The most influential variable is the initial system investment in all except oil heating system and direct electricity, in these the energy price variables are the most significant. In all of the other heating systems the most significant variables according to the regression are the energy prices. Especially the energy price variables in the end of the 10 year period are the ones with high influence. The initial system investment variable has a very significant influence on the GSHP and wood-pellet investments.

9.5. Results new 240 m2

Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C45	35 000 60 000	36 249,05 €	47 717,34 €	59 851,00 €	38 566,97 €	56 893,57 €	0
NetPresentValueOIL	E45	40 000 70 000	43 371,54 €	55 575,00 €	68 372,11 €	45 990,22 €	65 173,80 €	0
NetPresentValueGSHP	G45	30 000 41 000	30 390,30 €	35 199,93 €	40 189,75 €	32 221,64 €	38 139,13 €	0
NetPresentValue DistrictHeatingnonCHP	I45	32 000 52 000	33 246,70 €	41 814,82 €	50 903,22 €	35 535,34 €	48 230,31 €	0
NetPresentValue DistrictHeatingCHP	K45	30 000 48 000	30 700,66 €	38 175,85 €	46 174,37 €	32 673,06 €	43 772,24 €	0
NetPresentValuePellet	M45	28 000 42 000	29 364,88 €	35 397,38 €	41 683,02 €	31 318,67 €	39 552,61 €	0

Figure 10. Results of the 240 m2 new house Monte Carlo analysis.

At 5000 iterations, the best expected NPV mean can be achieved with the GSHP system. The Second best NPV mean is with the Wood-Pellet system, after which the CHP District heating system. District heating without CHP, direct electricity and oil NPV's are significantly larger.

As the consumption grows the systems that are more sensitive to energy price fluctuations are performing weaker. The larger house changes the risk variable impacts, for example in the oil system the initial investment variable loses significance, but the energy price variables are the most important ones. The same can be seen in the direct electricity system.

The results are similar to the 140 m2 “new” case results, the difference being that the NPV are higher and the probability distributions are more scattered and flat, this is due to the higher energy consumption, hence the energy price variable has a greater effect on the simulation results.

9.6.Results new 340 m2

Name	Cell	Graph	Min	Mean	Max	5%	95%	Errors
NetPresentValue Direct electricity	C40	50 000 – 90 000	51 725,91 €	67 542,53 €	85 591,05 €	54 578,79 €	80 493,93 €	0
NetPresentValueOIL	E40	60 000 – 100 000	60 392,67 €	77 582,50 €	95 523,18 €	64 063,19 €	90 991,65 €	0
NetPresentValueGSHP	G40	40 000 – 54 000	40 083,10 €	46 362,24 €	53 179,75 €	42 455,95 €	50 364,18 €	0
NetPresentValue DistrictHeatingnonCHP	I40	45 000 – 70 000	45 398,51 €	57 053,03 €	68 868,30 €	48 113,82 €	65 958,89 €	0
NetPresentValue DistrictHeatingCHP	K40	40 000 – 65 000	41 364,18 €	51 896,17 €	63 075,43 €	44 087,69 €	59 798,61 €	0
NetPresentValuePELLET	M40	40 000 – 58 000	40 047,16 €	48 426,30 €	56 918,33 €	42 638,28 €	54 307,54 €	0

Figure 11. Results of the 340 m2 new house Monte Carlo analysis.

The last of the case buildings only works to strengthen the understanding built so far of the investment performance of the different cases. The GSHP, Wood-pellet and CHP district heating are performing better than direct electricity and oil heating systems. GSHP has the lowest NPV mean in the 10 year scenario, followed closely by the Wood-Pellet system.

The probability distributions show that all except the GSHP system have almost a uniform probability distribution. The most sensitive variables remain the same. The initial investment has a high significance in all except direct electricity and oil and the energy prices being the significant variables after that.

After all the cases have been analyzed, it is clear that with the chosen risk variables and simulation runs the GSHP system has the best investment performance and it seem to be the most economical choice. The Wood-Pellet system investment performed almost as well but as shown in the probability distributions, it contains more risk.

The CHP district heating performed rather well. This system might also be more appealing to the investor as the initial system investment is smaller than in the GSHP and Wood-Pellet systems. In places where CHP district heating is not available the district heating without CHP is still a feasible choice. According to this study direct electricity and oil heating systems were shown to be the most expensive investments. Especially oil heating is not a very economical choice when using these risk variables and range limits. For more case specific graphs and data please see the appendixes.

However as Savvides (1994) stated, a general rule is to choose the project with the probability distribution of return that best suits one's own personal preference towards risk. At least the simulation analysis gave some insight to the heating system investment analysis and identified the most important risk variables. The initial investment was shown to be important but as shown the energy price variables have a key impact on the investment and as we cannot precisely forecast the future of the prices the other systems might perform better in a different forecasting model.

10. Discussion and Conclusion

The global energy system faces serious challenges. Concerns about energy security are growing among countries. Also the need to respond to climate change is becoming more important. For these reasons, many governments have increased efforts to promote deployment of renewable energy and low-carbon sources that can strengthen energy security.

Renewable energy and low-carbon system growth is focused on a few of the available technologies. In western countries, managing support costs and system integration of large shares of renewable energy in a time of economic weakness and uncertainty has created political debate about energy production all over the world.

There is a pressing need to accelerate the development of advanced energy technologies in order to address the global challenges of providing clean energy, mitigating climate change and sustainable development.

One of the issues is heating and cooling. In order to be more energy efficient, new heating system needs to be developed and the utilization rate of already existing system that are more efficient should increase. The government can use subsidies and raise awareness, however as with every “new” system there are uncertainties. The economic uncertainty related to these more energy efficient heating systems is a key obstacle for these systems not becoming more widespread. The author saw this as a current topic, one that should be studied from the perspective of the person making the investment. Therefore this study is about analyzing the GSHP investment in Finland, which required the study of other heating systems as well.

Old houses, built in the 1960-1990's, that use a central heating system represent a significant potential for replacing oil and electricity heating systems with more environmentally friendly and economical heating systems in the coming years. There are still over 200 000 oil heated single-family houses in Finland. Many of them in need of a heating system renewal. Houses heated with direct electricity also form a large potential for renewal. Energy issues are becoming more and more important, which will affect the future of heating systems. It is positive to notice that also more attention is given to the subject and that “new” systems are also becoming more popular among homeowners.

The theoretical part of this study first introduced the theory of conducting case studies. The methodology used in this study was for the most parts based on Yin’s (2005) and Eisenhardt’s (1989) theories on how case study research should be done. After this the heating systems essential to this study were introduced. The ground source heat pump was given more attention as its economic performance was of key interest in this study. The other heating systems were introduced superficially because the technical side was not a key focus in this study. A short description of the Finnish energy and electricity market was also provided, these parts would help the reader in understanding the choices made during the research and the purpose of the study.

The most important theoretical part of the study was to identify and introduce the financial analysis methods used in the case study. The investment appraisal methods and risk analysis part first identified the basic financial analysis methods used. The wide use of the simple payback period method was identified as were the use of other simple methods. However as acknowledged, scholars have found these methods often to be insufficient for proper analysis.

The need for more advanced financial analysis methods was explained in the literature. As mentioned, risk and uncertainty should be incorporated in the financial calculations. According to the academic literature the most common methods like the payback period method and simple NPV should not be used but risk adjusted methods which take into account the time value of money. To answer the weaknesses in the basic financial analysis methods the Monte Carlo simulation analysis was chosen as the appraisal method of this study.

After the decision was made to use the Monte Carlo method, the process and steps of making a Monte Carlo simulation analysis were introduced. This included building the forecasting model, selection of key risk variables, defining the range limits and allocating the probability weights to the variables, checking the correlations conditions, running the simulations and finally analyzing the results.

After the theories were introduced the author could start the empirical part of the study. Building the forecasting model was challenging as the author had to find out what are the key technical issues in heating and how to incorporate these issues in the economic model. From the start it was clear that at least two different case houses would be used in the study, however in the end there were six different case buildings.

The case buildings were single-family houses, the size of the houses were 140 m2, 240 m2 and 340 m2. For every size there was one house with an annual energy consumption of an "old" house and one house with an annual energy consumption of a "new" house. In each of the case buildings the model simulated the investment for each of the heating system in a 10 year scenario by using the different values inside the set range limits for the selected key variables.

Analysis of the results showed that investing in a ground source heat pump heating system would be the most economical investment in these cases and under these selected settings. After 10 years the GSHP had the lowest NPV in all except one case, in the 240 m2 old building the wood-pellet had a lower NVP mean in the 10 year scenario. However the probability distributions of the GSHP and the wood-pellet system suggest that the GSHP system has less risk as the probability distribution is more triangular. The wood-pellet system and the CHP district heating systems would be the next economical choices. Direct electricity and oil heating were found to be uneconomical investment when using these risk variables and cases. The key risk variables according to the regression analysis were in almost all of the cases the initial investment had a large influence after which the energy price variables were the ones affecting the investment results most.

The use of a more sophisticated risk analysis method provided a deeper and better understanding of the GSHP investment. The other more simple methods would not have made it possible to analyze the investment in such depth. By using the Monte Carlo method the investment analysis was more comprehensive than it would have been when using the payback period or basic NPV.

However as we know the analysis results are based on many predictions, although all the predictions are logically justified there is room for error. Acknowledging that, one should understand that the possibility of error should not prevent us from making these types of case studies. The author feels that each of the research question presented in the beginning of this study were answered comprehensively.

Esen et al (2006) state that "a major obstacle keeping GSHPs from becoming the heating and cooling unit of choice is customer uncertainty with the technology and its economic benefits. The homeowner, perceiving the GSHP system as a new technology and uncertain of the actual benefits, may be wary of installing a GSHP system. Adding greatly to the customer's perceived risk is the high initial cost, which makes a GSHP system a risk that customers are generally not willing to accept. For the GSHP system to gain popularity, people and utilities need to understand the benefits of a GSHP system financially and environmentally. "

One of the main reasons for this study was to clear this uncertainty associated with the economic benefits. The author wanted to asses an investment in the system and see whether it actually is economical compared to the other systems.

The market for heat pump technologies grows in every emission trading scenario rapidly. However the high initial investment in heat pump systems that require a borehole weakens their competitiveness in the eyes of potential customers. This increases the market for secondary heating systems like the air source heat pump (Metla, 2010). The need to increase energy efficiency has been important topic for some time now, research has shown that energy efficiency or taxes on energy consumption might be the most effective policy options in improving national energy efficiency (Hasset & Gilbert, 1993).

Research has shown that the heating system investment and operating costs have a significant impact on the choices made by consumers. Environmental aspects, seems to be less important than the choice of cost factors (Metla, 2010).

Metla's (2010) research shows that most of the people considering a heating system renovation are also considering changing to a new system. Experience and knowledge of the system reduces the risks associated with the selection of a new heating system. The situation is very different in new construction heating system selection compared to the renovation situation. Low-energy houses which significantly reduce the need for heating are changing the requirements for heating systems. In this case, direct electricity might be a competitive choice with new kinds of complementary technologies.

Possibilities for further research are widespread. This study concentrated almost solely on financial aspects, there are other aspects involved in the investment decision, like how care free the system is, and for example the wood-pellet system requires more attention than district heating or a GSHP system. Other issues could be; does the system require space and what are the government subsidies etc. The author feels that further research especially concentrated on the energy prices would be interesting and add value to the field. A simulation model which would use a very sophisticated energy price forecasting model would increase the understanding in the field of heating system investments. Another interesting research topic would be to study the economic performance of heating systems in a new low-energy house. If reliable research is done and the economical understanding of these system’s increases, it helps private consumers and public entities to make better investment decisions and perhaps increase the usage of energy efficient heating system, which in turn would be environmentally better.

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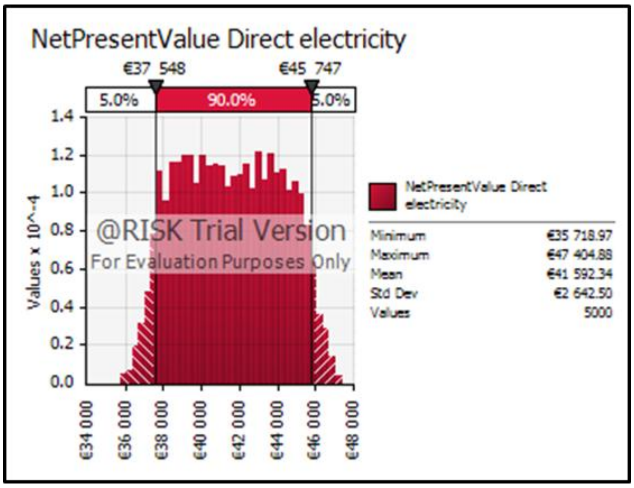
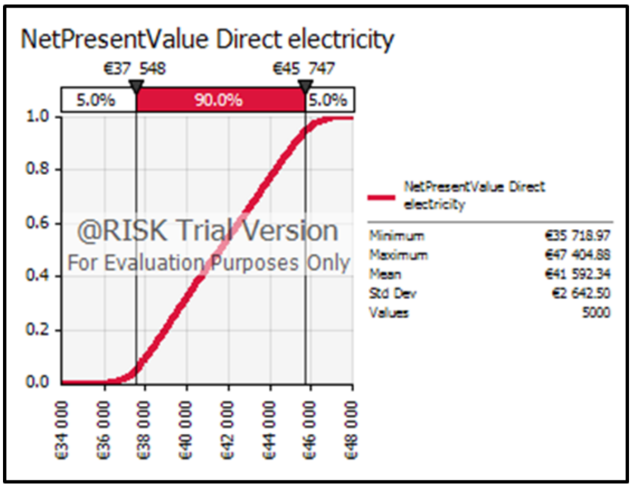
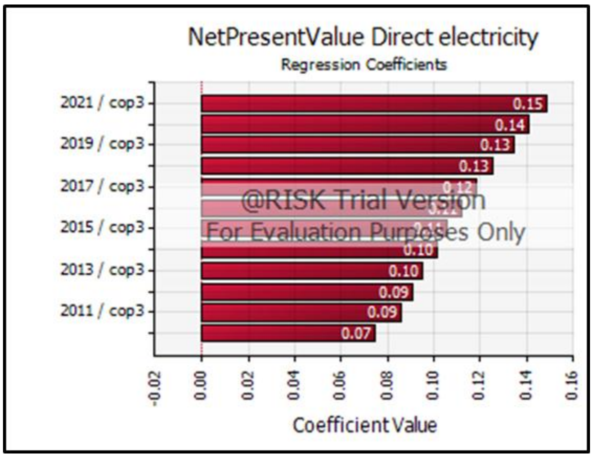
Appendices

Appendix 1. Detailed simulation analysis results of the Old 140 m2 house.

Direct electricity



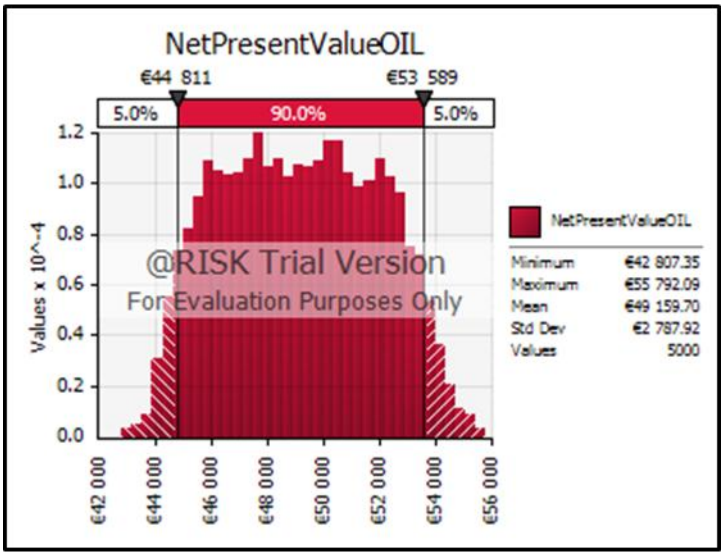




Regression and Rank Information for NetPresentV			
Rank	Name	Regr	Corr
1	2021 / cop3	0,149	0,804
2	2020 / cop3	0,141	0,804
3	2019 / cop3	0,135	0,804
4	2018 / cop3	0,126	0,794
5	2017 / cop3	0,118	0,790
6	2016 / cop3	0,112	0,788
7	2015 / cop3	0,106	0,782
8	2014 / cop3	0,101	0,791
9	2013 / cop3	0,095	0,781
10	2012 / cop3	0,091	0,781
11	2011 / cop3	0,086	0,780
12	Direct electricity	0,075	0,062

Summary Statistics for NetPresentValue Direct el			
Statistics		**Percentile**	
Minimum	35 718,97 €	**5 %**	37 548,42 €
Maximum	47 404,88 €	**10 %**	38 019,91 €
Mean	41 592,34 €	**15 %**	38 517,28 €
Std Dev	2 642,50 €	**20 %**	38 940,59 €
Variance	6982809,79	**25 %**	39 355,54 €
Skewness	0,024707498	**30 %**	39 797,18 €
Kurtosis	1,931156821	**35 %**	40 228,54 €
Median	41 564,27 €	**40 %**	40 662,51 €
Mode	40 429,71 €	**45 %**	41 089,15 €
Left X	37 548,42 €	**50 %**	41 564,27 €
Left P	5 %	**55 %**	42 022,58 €
Right X	45 747,09 €	**60 %**	42 491,96 €
Right P	95 %	**65 %**	42 935,80 €
Diff X	8 198,67 €	**70 %**	43 366,47 €
Diff P	90 %	**75 %**	43 796,07 €
#Errors	0	**80 %**	44 253,79 €
Filter Min	Off	**85 %**	44 705,38 €
Filter Max	Off	**90 %**	45 178,96 €
#Filtered	0	**95 %**	45 747,09 €

Oil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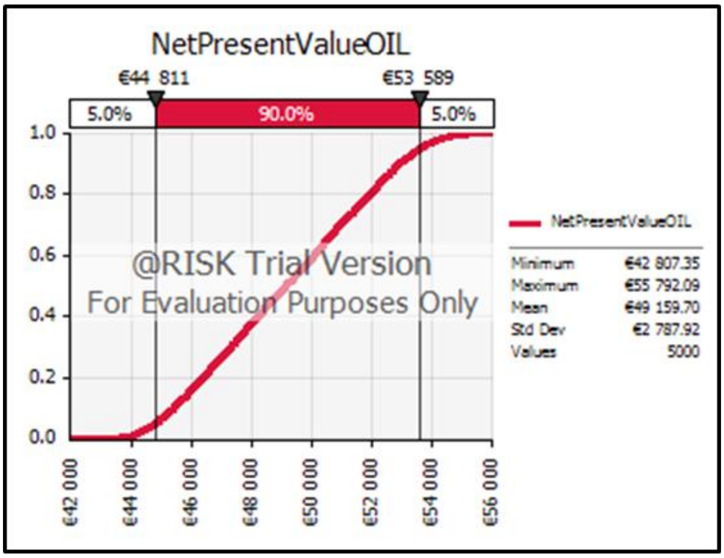
€44 811
€53 589
5.0%
90.0%
5.0%
Values x 10^-4
@RISK Trial Version
For Evaluation Purposes Only
NetPresentValueOIL
Minimum €42 807.35
Maximum €55 792.09
Mean €49 159.70
Std Dev €2 787.92
Values 5000
€42 000
€44 000
€46 000
€48 000
€50 000
€52 000
€54 000
€56 000


NetPresentValueOIL
€44 811
€53 589
5.0%
90.0%
5.0%
@RISK Trial Version
For Evaluation Purposes Only
NetPresentValueOIL
Minimum €42 807.35
Maximum €55 792.09
Mean €49 159.70
Std Dev €2 787.92
Values 5000
€42 000
€44 000
€46 000
€48 000
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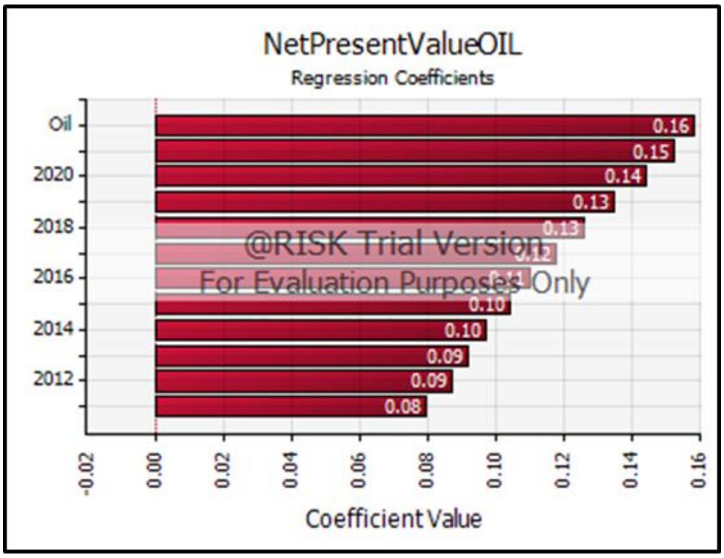
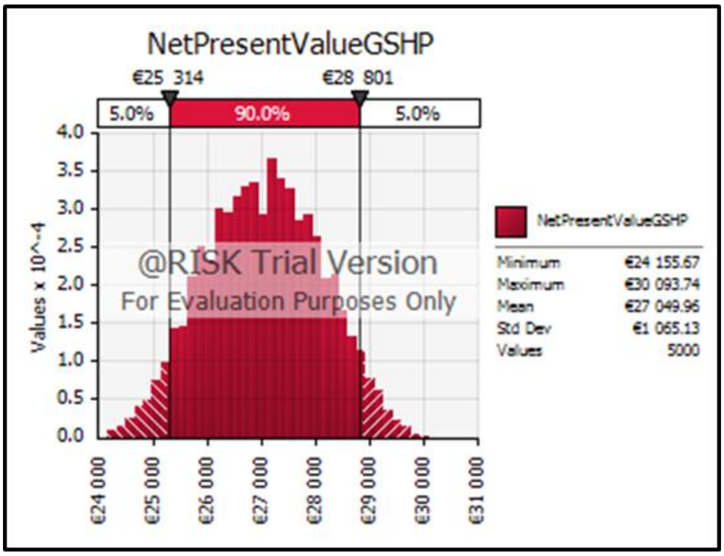
€52 000
€54 000
€56 000

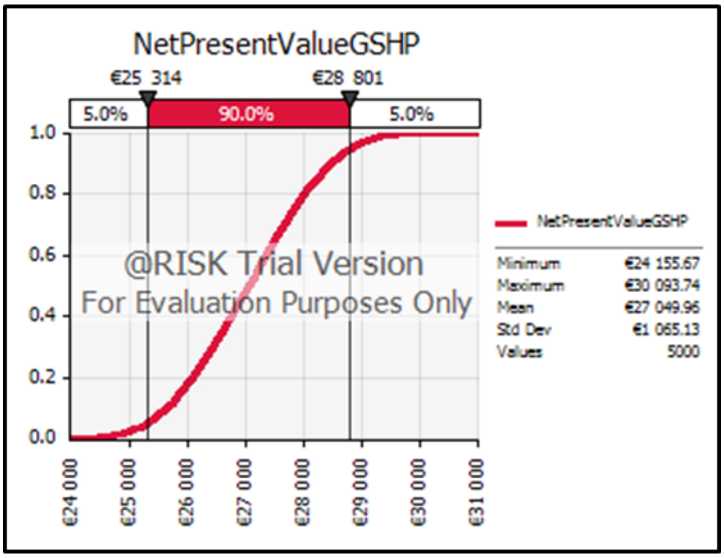


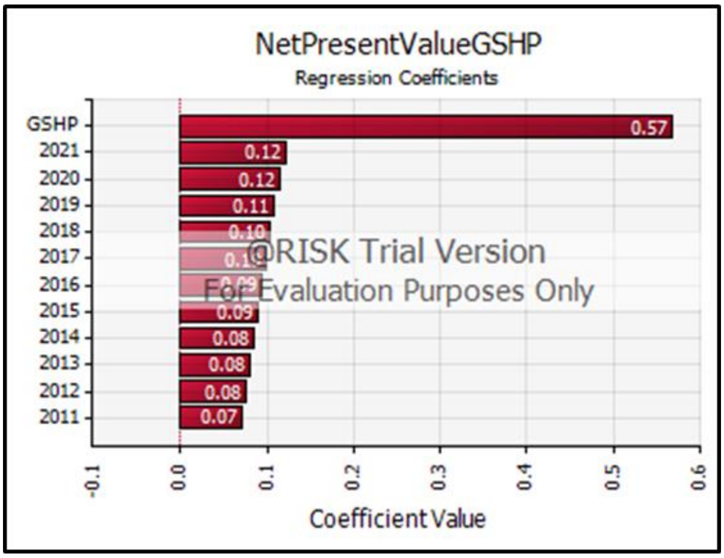
Regression and Rank Information for NetPresentV			
Rank	**Name**	**Regr**	**Corr**
1	Oil	0,158	0,152
2	2021	0,153	0,796
3	2020	0,144	0,800
4	2019	0,134	0,789
5	2018	0,126	0,789
6	2017	0,118	0,782
7	2016	0,110	0,778
8	2015	0,104	0,778
9	2014	0,097	0,773
10	2013	0,092	0,777
11	2012	0,087	0,778
12	2011	0,080	0,770

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	42 807,35 €	**5 %**	44 811,27 €
Maximum	55 792,09 €	**10 %**	45 418,87 €
Mean	49 159,70 €	**15 %**	45 905,60 €
Std Dev	2 787,92 €	**20 %**	46 371,27 €
Variance	7772476,914	**25 %**	46 850,81 €
Skewness	0,037078233	**30 %**	47 312,13 €
Kurtosis	2,001474782	**35 %**	47 761,96 €
Median	49 136,76 €	**40 %**	48 210,29 €
Mode	51 415,38 €	**45 %**	48 676,33 €
Left X	44 811,27 €	**50 %**	49 136,76 €
Left P	5 %	**55 %**	49 603,58 €
Right X	53 589,07 €	**60 %**	50 084,28 €
Right P	95 %	**65 %**	50 483,50 €
Diff X	8 777,80 €	**70 %**	50 950,62 €
Diff P	90 %	**75 %**	51 448,34 €
#Errors	0	**80 %**	51 937,90 €
Filter Min	Off	**85 %**	52 399,81 €
Filter Max	Off	**90 %**	52 916,24 €
#Filtered	0	**95 %**	53 589,07 €

GSHP



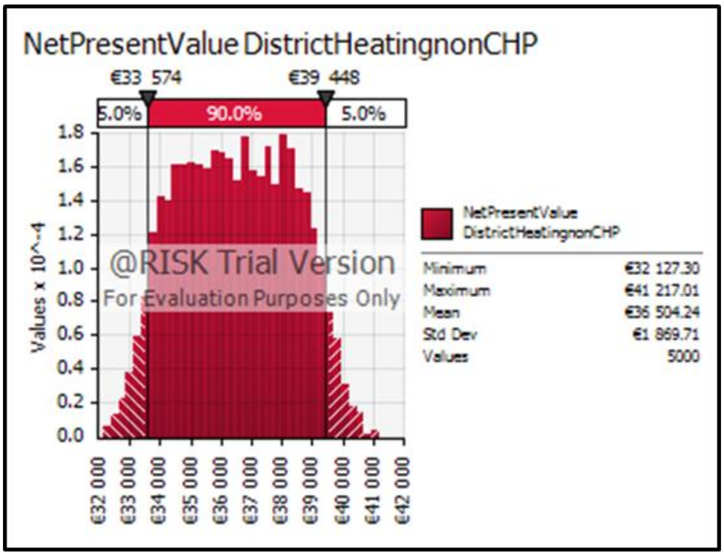


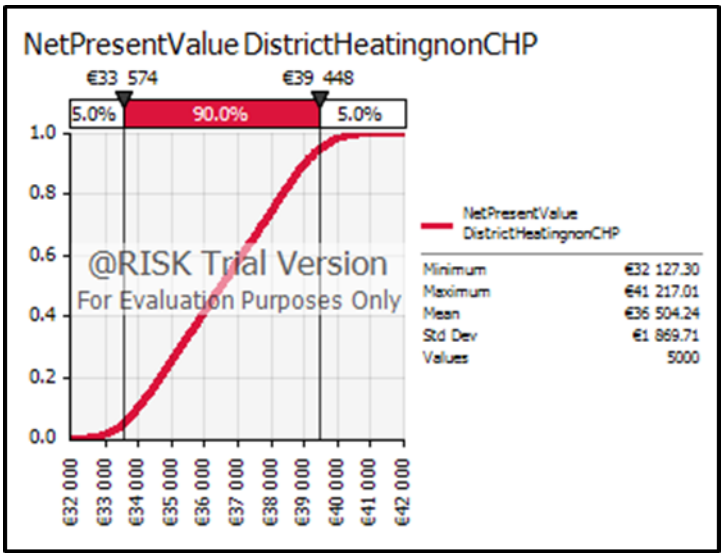


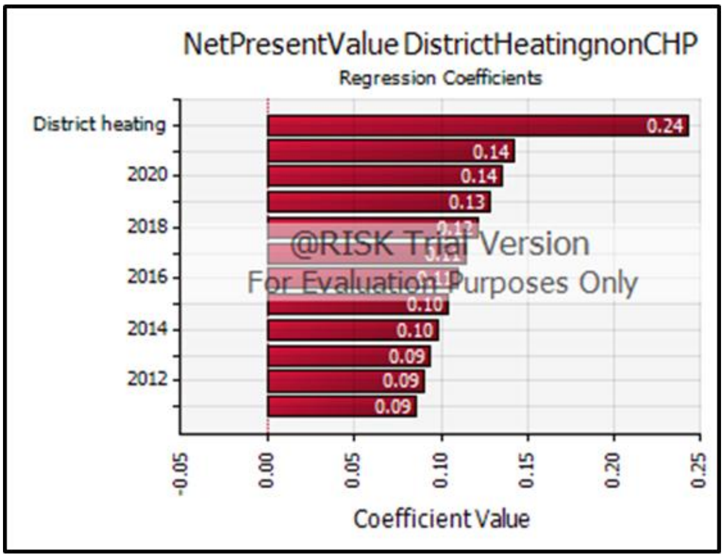
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	GSHP	0,567	0,538
2	2021	0,122	0,661
3	2020	0,116	0,666
4	2019	0,109	0,656
5	2018	0,103	0,660
6	2017	0,098	0,656
7	2016	0,094	0,662
8	2015	0,088	0,656
9	2014	0,084	0,659
10	2013	0,080	0,655
11	2012	0,076	0,659
12	2011	0,070	0,650

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	24 155,67 €	**5 %**	25 313,50 €
Maximum	30 093,74 €	**10 %**	25 660,46 €
Mean	27 049,96 €	**15 %**	25 880,51 €
Std Dev	1 065,13 €	**20 %**	26 084,21 €
Variance	1134504,283	**25 %**	26 256,02 €
Skewness	-0,003277626	**30 %**	26 438,87 €
Kurtosis	2,455743915	**35 %**	26 600,75 €
Median	27 058,76 €	**40 %**	26 747,92 €
Mode	27 189,40 €	**45 %**	26 897,86 €
Left X	25 313,50 €	**50 %**	27 058,76 €
Left P	5 %	**55 %**	27 199,85 €
Right X	28 801,39 €	**60 %**	27 349,77 €
Right P	95 %	**65 %**	27 497,45 €
Diff X	3 487,88 €	**70 %**	27 657,56 €
Diff P	90 %	**75 %**	27 837,39 €
#Errors	0	**80 %**	28 003,50 €
Filter Min	Off	**85 %**	28 231,64 €
Filter Max	Off	**90 %**	28 456,59 €
#Filtered	0	**95 %**	28 801,39 €

District heating without CHP





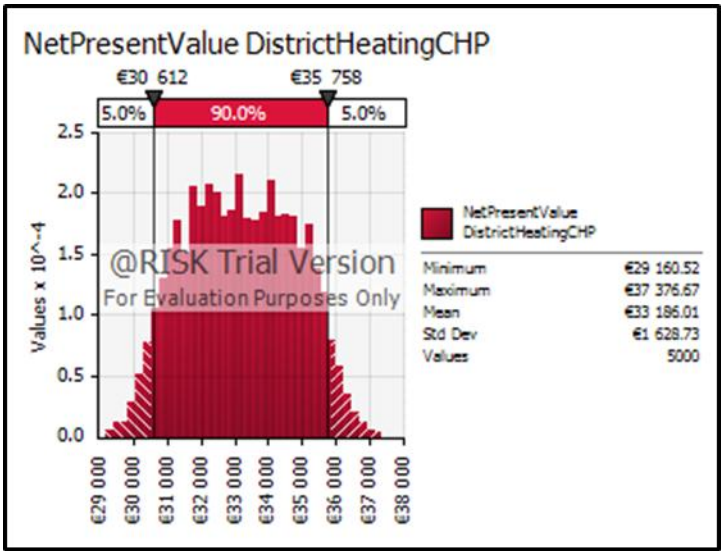


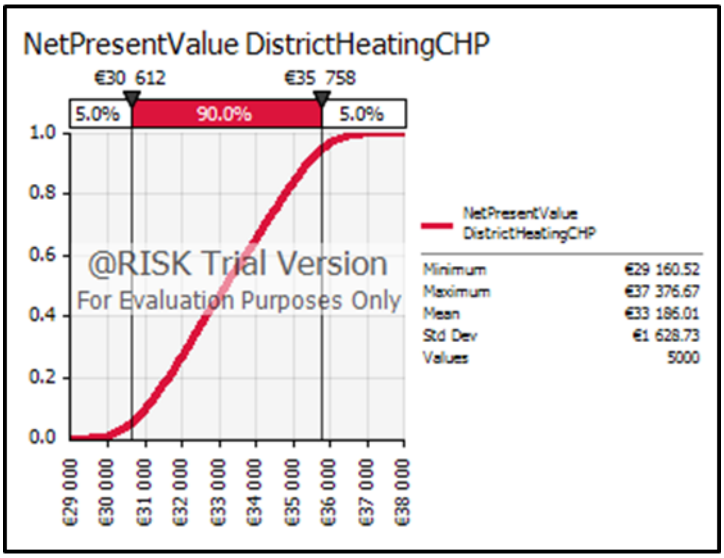
Regression and Rank Information for NetPresent

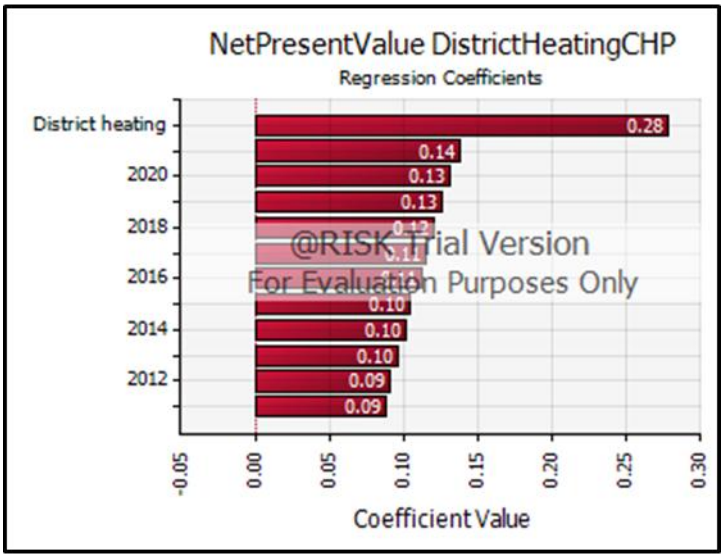
Rank	Name	Regr	Corr
1	District heating	0,243	0,227
2	2021	0,142	0,788
3	2020	0,135	0,786
4	2019	0,128	0,780
5	2018	0,121	0,776
6	2017	0,115	0,767
7	2016	0,110	0,768
8	2015	0,104	0,763
9	2014	0,098	0,757
10	2013	0,093	0,754
11	2012	0,090	0,766
12	2011	0,086	0,766

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	32 127,30 €	**5 %**	33 573,96 €
Maximum	41 217,01 €	**10 %**	33 986,20 €
Mean	36 504,24 €	**15 %**	34 338,35 €
Std Dev	1 869,71 €	**20 %**	34 665,98 €
Variance	3495810,495	**25 %**	34 968,14 €
Skewness	0,012090797	**30 %**	35 275,32 €
Kurtosis	2,053536025	**35 %**	35 584,37 €
Median	36 498,68 €	**40 %**	35 894,86 €
Mode	38 064,90 €	**45 %**	36 197,12 €
Left X	33 573,96 €	**50 %**	36 498,68 €
Left P	5 %	**55 %**	36 797,44 €
Right X	39 447,52 €	**60 %**	37 108,00 €
Right P	95 %	**65 %**	37 429,98 €
Diff X	5 873,56 €	**70 %**	37 733,10 €
Diff P	90 %	**75 %**	38 041,43 €
#Errors	0	**80 %**	38 333,37 €
Filter Min	Off	**85 %**	38 651,68 €
Filter Max	Off	**90 %**	39 001,74 €
#Filtered	0	**95 %**	39 447,52 €

CHP District heating



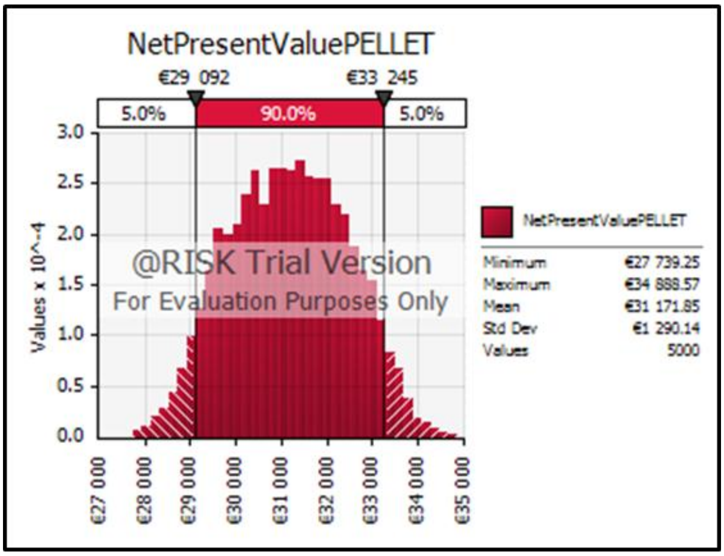


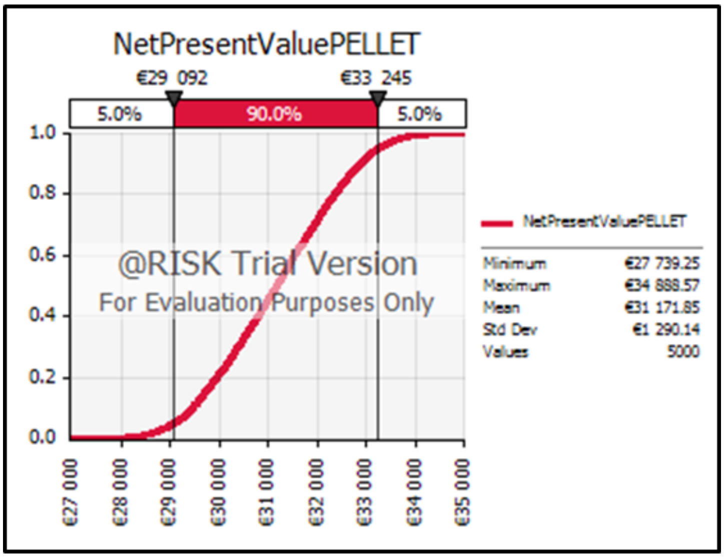


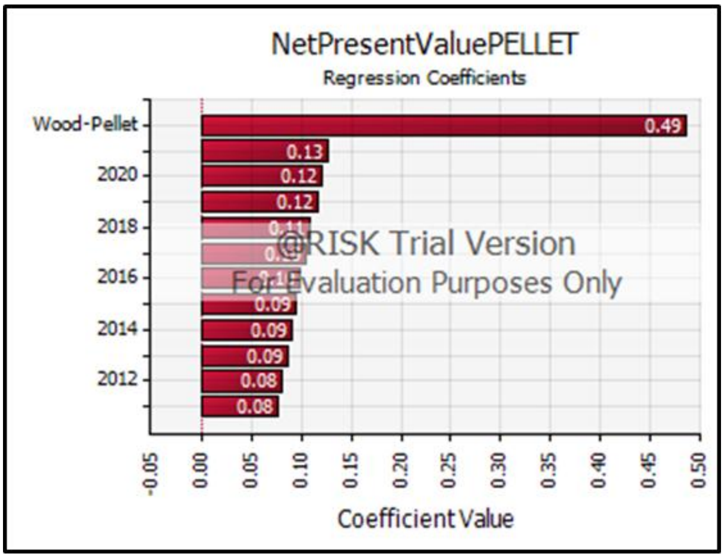
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	District heating	0,279	0,233
2	2021	0,138	0,769
3	2020	0,131	0,769
4	2019	0,125	0,760
5	2018	0,121	0,771
6	2017	0,114	0,763
7	2016	0,112	0,765
8	2015	0,104	0,755
9	2014	0,102	0,771
10	2013	0,096	0,756
11	2012	0,091	0,756
12	2011	0,087	0,755

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	29 160,52 €	**5 %**	30 611,79 €
Maximum	37 376,67 €	**10 %**	31 011,41 €
Mean	33 186,01 €	**15 %**	31 316,56 €
Std Dev	1 628,73 €	**20 %**	31 624,44 €
Variance	2652748,306	**25 %**	31 883,24 €
Skewness	0,017494992	**30 %**	32 149,73 €
Kurtosis	2,12501447	**35 %**	32 386,10 €
Median	33 169,33 €	**40 %**	32 631,68 €
Mode	32 224,14 €	**45 %**	32 928,34 €
Left X	30 611,79 €	**50 %**	33 169,33 €
Left P	5 %	**55 %**	33 427,57 €
Right X	35 758,14 €	**60 %**	33 699,23 €
Right P	95 %	**65 %**	33 969,19 €
Diff X	5 146,35 €	**70 %**	34 219,16 €
Diff P	90 %	**75 %**	34 491,83 €
#Errors	0	**80 %**	34 764,61 €
Filter Min	Off	**85 %**	35 068,84 €
Filter Max	Off	**90 %**	35 368,35 €
#Filtered	0	**95 %**	35 758,14 €

Wood-Pellet





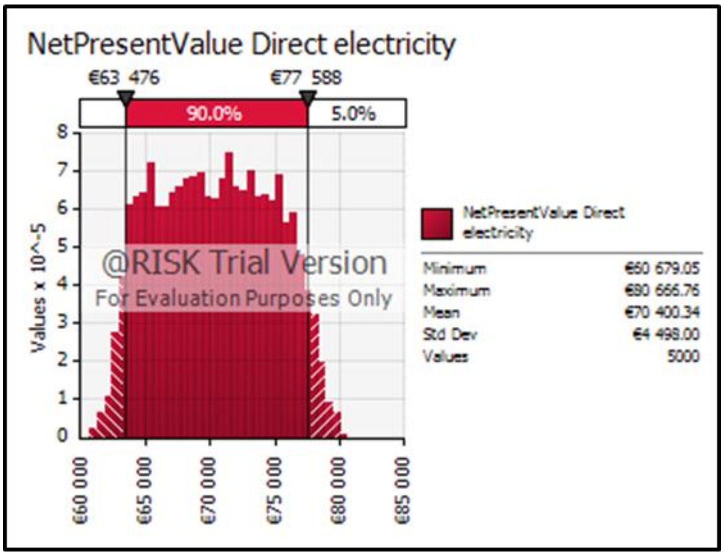


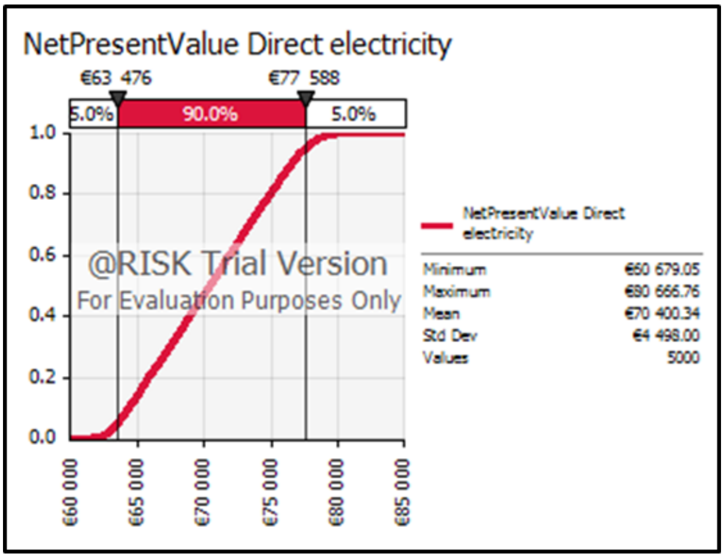
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	Wood-Pellet	0,487	0,464
2	2021	0,126	0,700
3	2020	0,121	0,701
4	2019	0,116	0,705
5	2018	0,109	0,697
6	2017	0,105	0,704
7	2016	0,098	0,693
8	2015	0,094	0,703
9	2014	0,090	0,696
10	2013	0,087	0,701
11	2012	0,080	0,679
12	2011	0,076	0,683

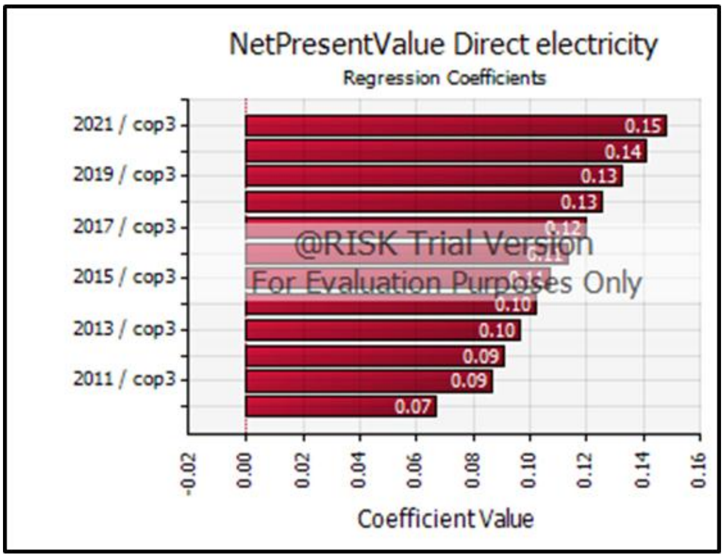
Summary Statistics for NetPresentValuePELLET			
Statistics		**Percentile**	
Minimum	27 739,25 €	**5 %**	29 092,24 €
Maximum	34 888,57 €	**10 %**	29 453,66 €
Mean	31 171,85 €	**15 %**	29 714,13 €
Std Dev	1 290,14 €	**20 %**	29 959,77 €
Variance	1664462,87	**25 %**	30 194,88 €
Skewness	-0,00388938	**30 %**	30 399,06 €
Kurtosis	2,331841836	**35 %**	30 597,13 €
Median	31 187,83 €	**40 %**	30 806,74 €
Mode	31 005,45 €	**45 %**	30 990,68 €
Left X	29 092,24 €	**50 %**	31 187,83 €
Left P	5 %	**55 %**	31 371,19 €
Right X	33 244,73 €	**60 %**	31 545,97 €
Right P	95 %	**65 %**	31 755,70 €
Diff X	4 152,49 €	**70 %**	31 945,53 €
Diff P	90 %	**75 %**	32 139,98 €
#Errors	0	**80 %**	32 360,49 €
Filter Min	Off	**85 %**	32 594,27 €
Filter Max	Off	**90 %**	32 893,66 €
#Filtered	0	**95 %**	33 244,73 €

Appendix 2. Detailed simulation analysis results of the Old 240 m2 house.

Direct electricity





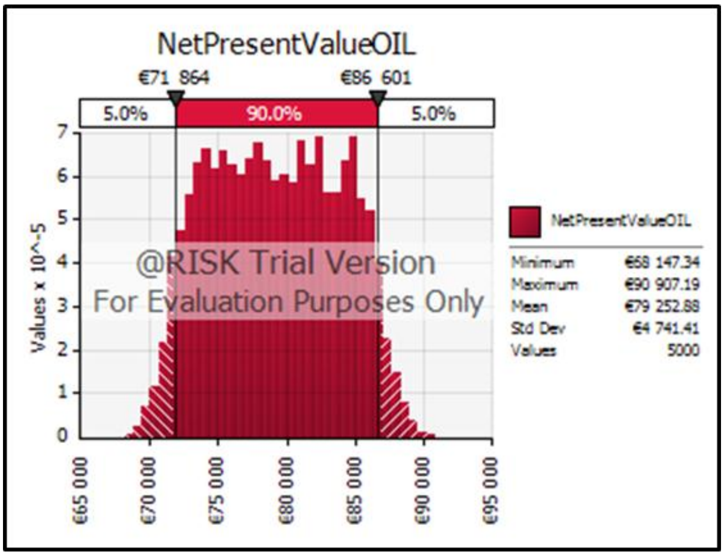


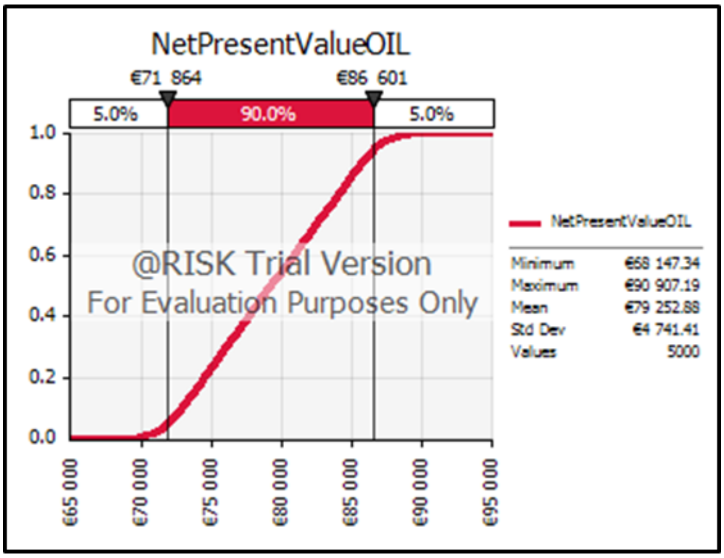
Regression and Rank Information for NetPresent

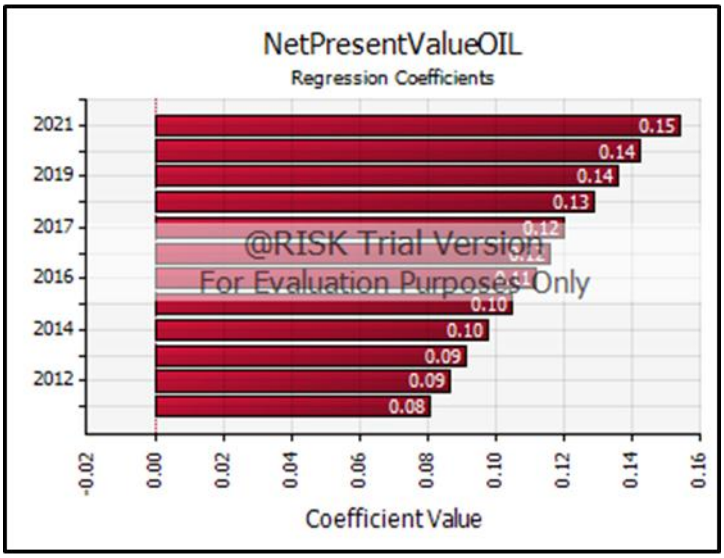
Rank	Name	Regr	Corr
1	2021 / cop3	0,148	0,801
2	2020 / cop3	0,141	0,802
3	2019 / cop3	0,133	0,790
4	2018 / cop3	0,125	0,788
5	2017 / cop3	0,120	0,794
6	2016 / cop3	0,114	0,791
7	2015 / cop3	0,107	0,784
8	2014 / cop3	0,102	0,786
9	2013 / cop3	0,096	0,784
10	2012 / cop3	0,091	0,779
11	2011 / cop3	0,087	0,780
12	Direct electricity	0,067	0,042

Summary Statistics for NetPresentValue Direct el			
Statistics		Percentile	
Minimum	60 679,05 €	5 %	63 475,84 €
Maximum	80 666,76 €	10 %	64 298,10 €
Mean	70 400,34 €	15 %	65 070,67 €
Std Dev	4 498,00 €	20 %	65 772,90 €
Variance	20231959,34	25 %	66 619,38 €
Skewness	0,034652346	30 %	67 410,48 €
Kurtosis	1,942911462	35 %	68 166,05 €
Median	70 374,56 €	40 %	68 876,43 €
Mode	63 539,49 €	45 %	69 619,42 €
Left X	63 475,84 €	50 %	70 374,56 €
Left P	5 %	55 %	71 151,32 €
Right X	77 588,13 €	60 %	71 839,82 €
Right P	95 %	65 %	72 629,21 €
Diff X	14 112,29 €	70 %	73 334,98 €
Diff P	90 %	75 %	74 121,57 €
#Errors	0	80 %	74 918,51 €
Filter Min	Off	85 %	75 657,79 €
Filter Max	Off	90 %	76 526,49 €
#Filtered	0	95 %	77 588,13 €

Oil



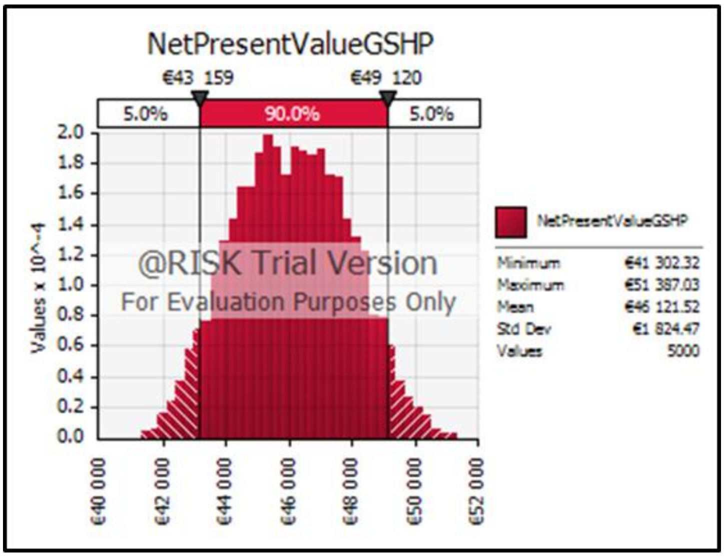


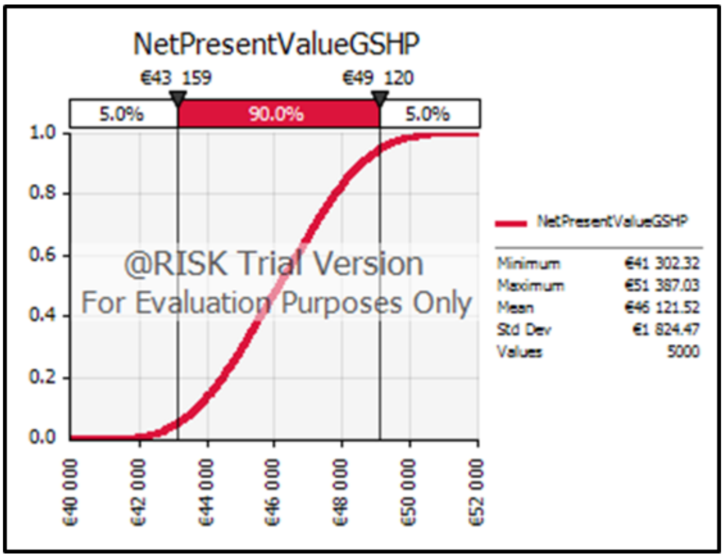


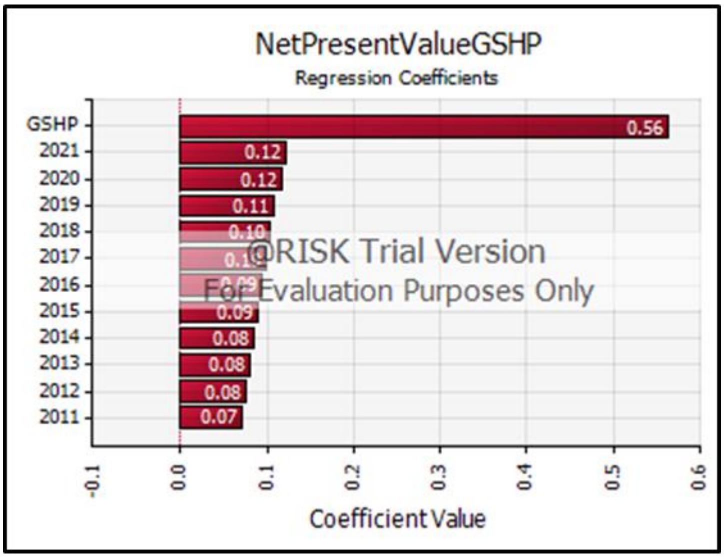
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	2021	0,154	0,803
2	2020	0,142	0,795
3	2019	0,136	0,801
4	2018	0,129	0,799
5	2017	0,120	0,790
6	Oil	0,116	0,109
7	2016	0,112	0,780
8	2015	0,105	0,784
9	2014	0,097	0,776
10	2013	0,091	0,774
11	2012	0,086	0,777
12	2011	0,081	0,774

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	68 147,34 €	**5 %**	71 863,81 €
Maximum	90 907,19 €	**10 %**	72 857,11 €
Mean	79 252,88 €	**15 %**	73 721,11 €
Std Dev	4 741,41 €	**20 %**	74 465,99 €
Variance	22480981,95	**25 %**	75 274,56 €
Skewness	0,013876044	**30 %**	76 043,96 €
Kurtosis	1,9473599	**35 %**	76 874,42 €
Median	79 168,04 €	**40 %**	77 646,16 €
Mode	78 475,02 €	**45 %**	78 416,93 €
Left X	71 863,81 €	**50 %**	79 168,04 €
Left P	5 %	**55 %**	80 037,44 €
Right X	86 601,35 €	**60 %**	80 854,66 €
Right P	95 %	**65 %**	81 627,95 €
Diff X	14 737,53 €	**70 %**	82 391,74 €
Diff P	90 %	**75 %**	83 225,79 €
#Errors	0	**80 %**	84 070,08 €
Filter Min	Off	**85 %**	84 825,11 €
Filter Max	Off	**90 %**	85 654,18 €
#Filtered	0	**95 %**	86 601,35 €

GSHP



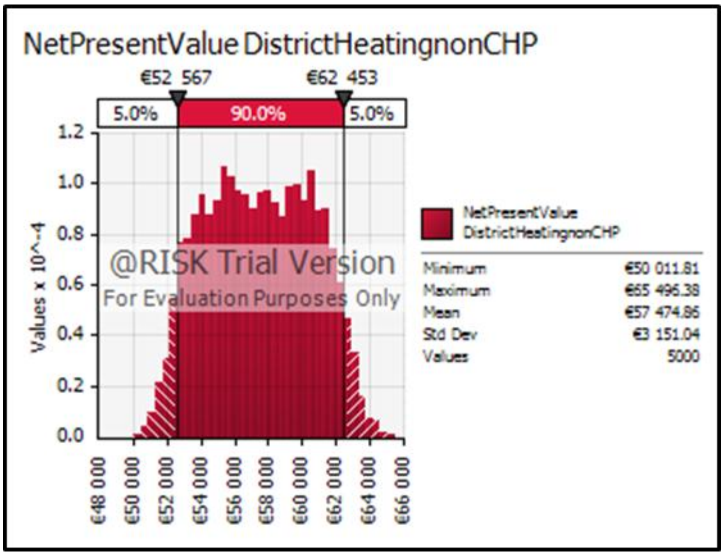


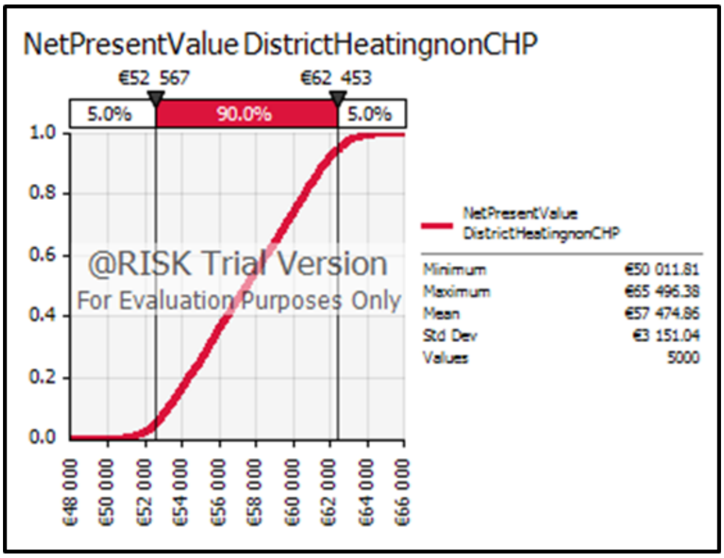


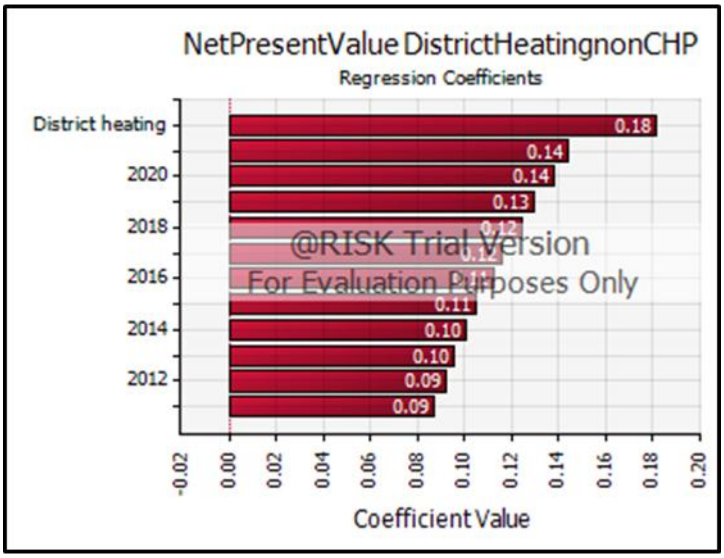
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	GSHP	0,562	0,539
2	2021	0,123	0,663
3	2020	0,116	0,671
4	2019	0,108	0,657
5	2018	0,104	0,663
6	2017	0,098	0,652
7	2016	0,093	0,653
8	2015	0,088	0,664
9	2014	0,085	0,661
10	2013	0,079	0,664
11	2012	0,076	0,662
12	2011	0,071	0,665

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	41 302,32 €	**5 %**	43 158,97 €
Maximum	51 387,03 €	**10 %**	43 710,71 €
Mean	46 121,52 €	**15 %**	44 121,74 €
Std Dev	1 824,47 €	**20 %**	44 462,66 €
Variance	3328682,438	**25 %**	44 761,97 €
Skewness	0,029314838	**30 %**	45 057,22 €
Kurtosis	2,417214907	**35 %**	45 313,62 €
Median	46 114,17 €	**40 %**	45 580,18 €
Mode	45 756,67 €	**45 %**	45 833,01 €
Left X	43 158,97 €	**50 %**	46 114,17 €
Left P	5 %	**55 %**	46 386,41 €
Right X	49 119,81 €	**60 %**	46 651,20 €
Right P	95 %	**65 %**	46 919,11 €
Diff X	5 960,83 €	**70 %**	47 181,04 €
Diff P	90 %	**75 %**	47 469,33 €
#Errors	0	**80 %**	47 767,10 €
Filter Min	Off	**85 %**	48 103,35 €
Filter Max	Off	**90 %**	48 500,25 €
#Filtered	0	**95 %**	49 119,81 €

District heating without CHP



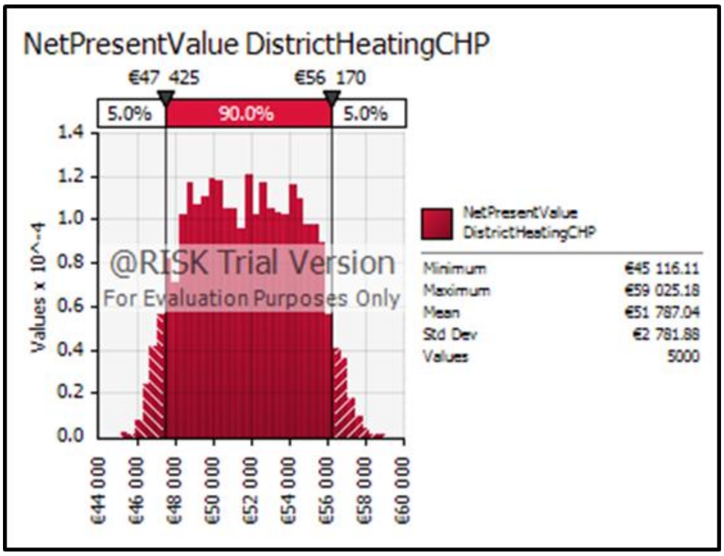


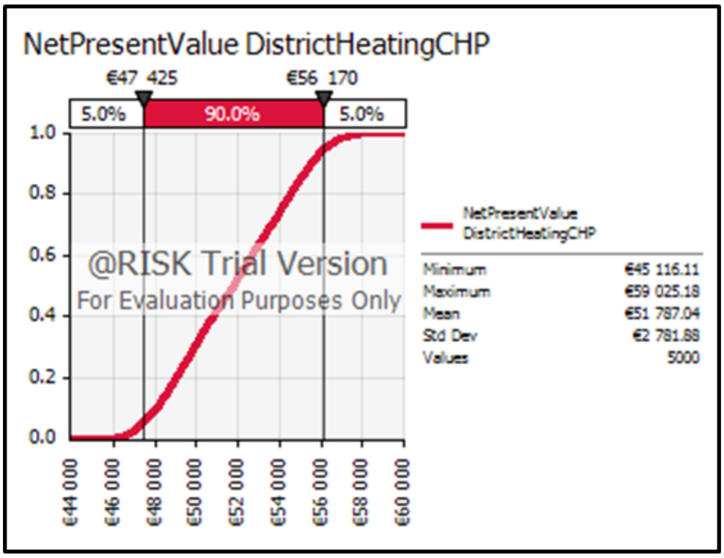


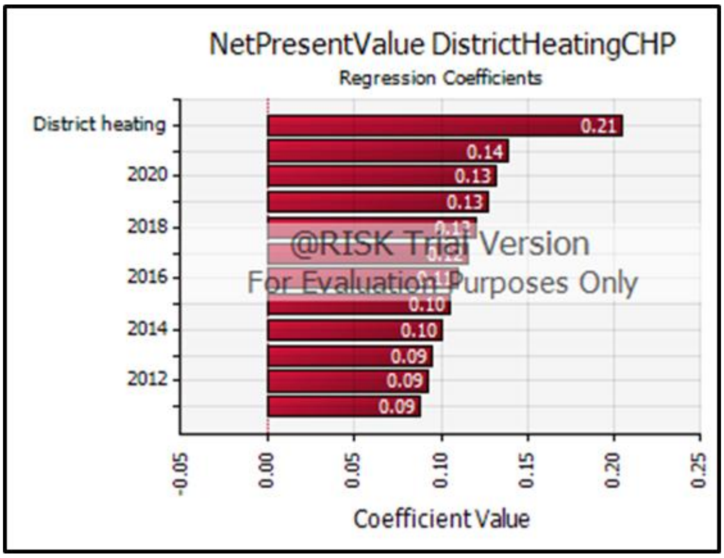
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,181	0,169
2	2021	0,144	0,792
3	2020	0,138	0,792
4	2019	0,129	0,785
5	2018	0,125	0,781
6	2017	0,116	0,773
7	2016	0,112	0,781
8	2015	0,105	0,767
9	2014	0,101	0,774
10	2013	0,095	0,768
11	2012	0,092	0,773
12	2011	0,087	0,772

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	50 011,81 €	**5 %**	52 567,41 €
Maximum	65 496,38 €	**10 %**	53 226,36 €
Mean	57 474,86 €	**15 %**	53 819,19 €
Std Dev	3 151,04 €	**20 %**	54 332,79 €
Variance	9929033,149	**25 %**	54 926,37 €
Skewness	0,014518015	**30 %**	55 385,02 €
Kurtosis	2,011441121	**35 %**	55 882,61 €
Median	57 461,29 €	**40 %**	56 389,88 €
Mode	57 499,92 €	**45 %**	56 913,99 €
Left X	52 567,41 €	**50 %**	57 461,29 €
Left P	5 %	**55 %**	57 956,30 €
Right X	62 452,93 €	**60 %**	58 516,61 €
Right P	95 %	**65 %**	59 066,19 €
Diff X	9 885,52 €	**70 %**	59 575,62 €
Diff P	90 %	**75 %**	60 078,82 €
#Errors	0	**80 %**	60 590,16 €
Filter Min	Off	**85 %**	61 114,26 €
Filter Max	Off	**90 %**	61 681,80 €
#Filtered	0	**95 %**	62 452,93 €

CHP District heating



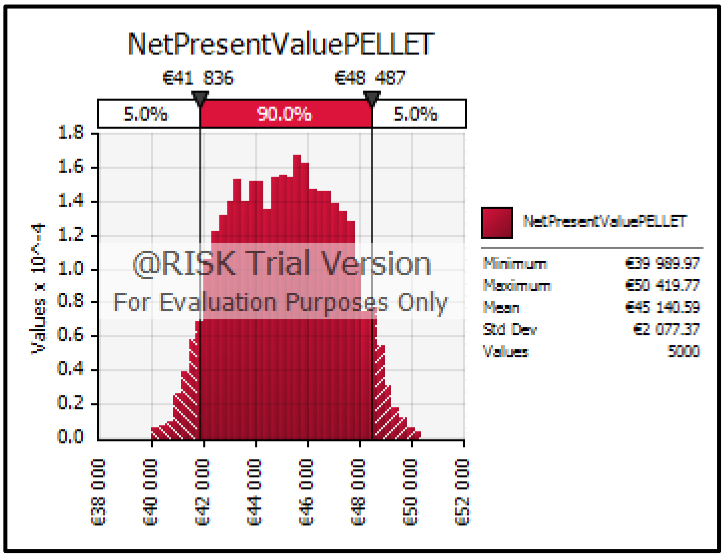


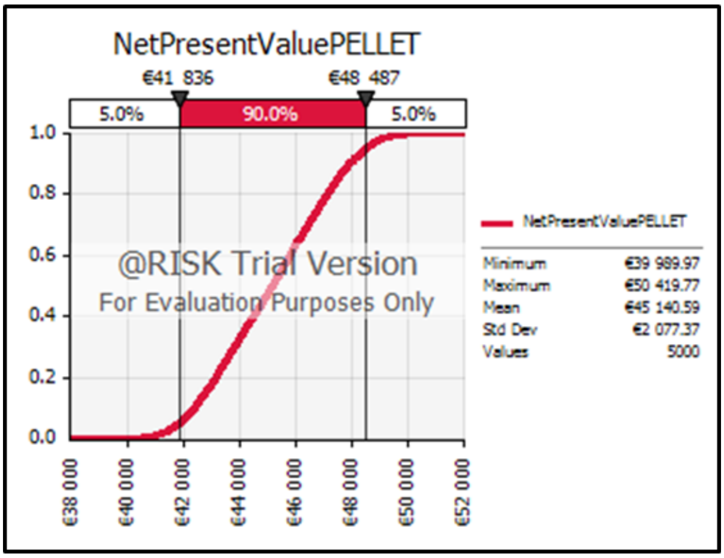


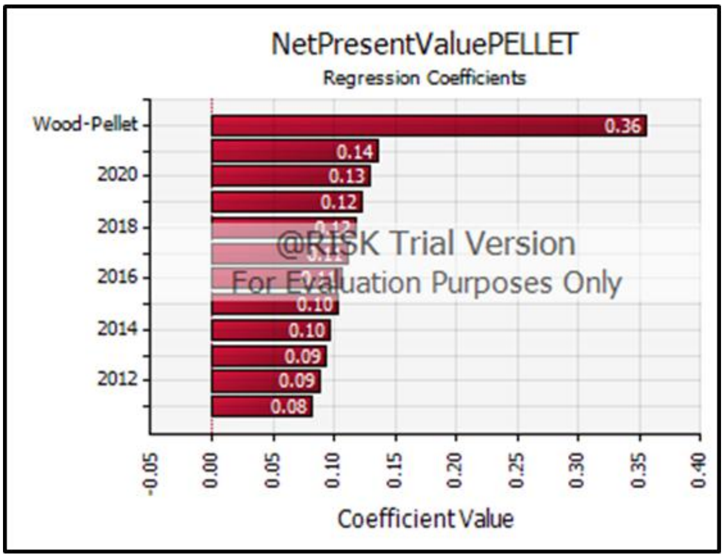
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,205	0,222
2	2021	0,139	0,788
3	2020	0,132	0,780
4	2019	0,127	0,783
5	2018	0,121	0,778
6	2017	0,116	0,779
7	2016	0,110	0,771
8	2015	0,105	0,772
9	2014	0,101	0,769
10	2013	0,095	0,768
11	2012	0,093	0,781
12	2011	0,088	0,769

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	45 116,11 €	**5 %**	47 424,86 €
Maximum	59 025,18 €	**10 %**	48 077,84 €
Mean	51 787,04 €	**15 %**	48 599,90 €
Std Dev	2 781,88 €	**20 %**	49 032,81 €
Variance	7738848,147	**25 %**	49 497,85 €
Skewness	0,033110166	**30 %**	49 926,18 €
Kurtosis	2,018027961	**35 %**	50 358,88 €
Median	51 797,74 €	**40 %**	50 809,05 €
Mode	52 738,86 €	**45 %**	51 282,83 €
Left X	47 424,86 €	**50 %**	51 797,74 €
Left P	5 %	**55 %**	52 220,71 €
Right X	56 170,14 €	**60 %**	52 710,61 €
Right P	95 %	**65 %**	53 127,75 €
Diff X	8 745,28 €	**70 %**	53 621,10 €
Diff P	90 %	**75 %**	54 080,30 €
#Errors	0	**80 %**	54 529,60 €
Filter Min	Off	**85 %**	55 001,85 €
Filter Max	Off	**90 %**	55 519,69 €
#Filtered	0	**95 %**	56 170,14 €

Wood-Pellet





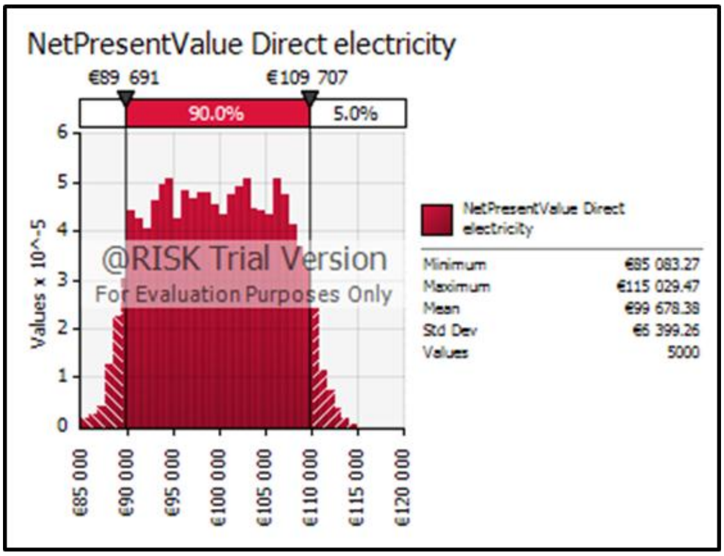


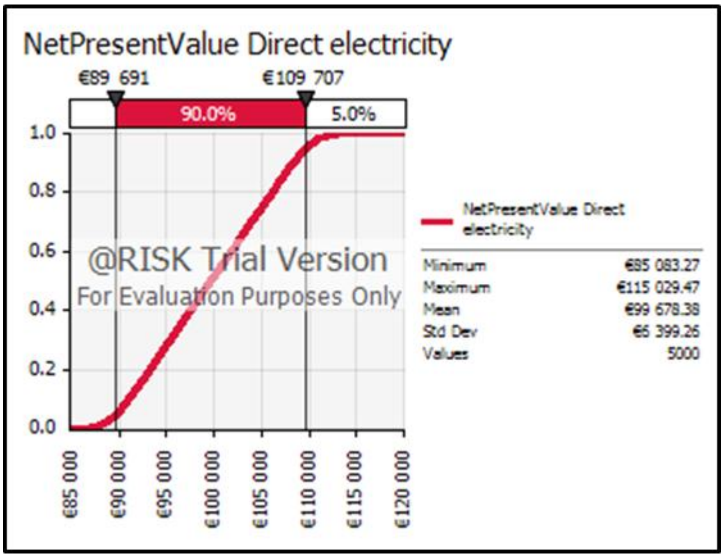
Regression and Rank Information for NetPresentValu			
Rank	**Name**	**Regr**	**Corr**
1	Wood-Pellet	0,355	0,326
2	2021	0,136	0,755
3	2020	0,129	0,750
4	2019	0,123	0,754
5	2018	0,117	0,744
6	2017	0,110	0,747
7	2016	0,106	0,741
8	2015	0,102	0,756
9	2014	0,095	0,736
10	2013	0,092	0,747
11	2012	0,087	0,740
12	2011	0,082	0,728

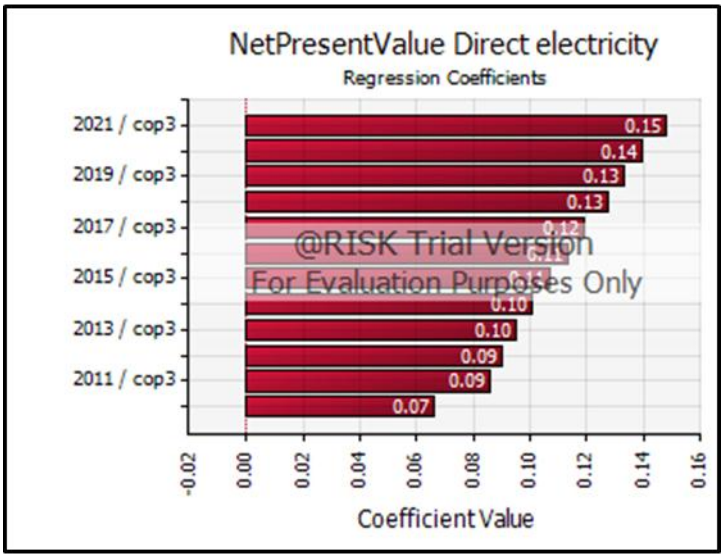
Summary Statistics for NetPresentValuePELLET			
Statistics		**Percentile**	
Minimum	39 989,97 €	**5 %**	41 835,95 €
Maximum	50 419,77 €	**10 %**	42 377,73 €
Mean	45 140,59 €	**15 %**	42 785,32 €
Std Dev	2 077,37 €	**20 %**	43 144,08 €
Variance	4315450,788	**25 %**	43 460,69 €
Skewness	0,01508488	**30 %**	43 802,11 €
Kurtosis	2,167659826	**35 %**	44 136,47 €
Median	45 157,27 €	**40 %**	44 483,70 €
Mode	43 369,75 €	**45 %**	44 822,26 €
Left X	41 835,95 €	**50 %**	45 157,27 €
Left P	5 %	**55 %**	45 482,47 €
Right X	48 486,53 €	**60 %**	45 781,75 €
Right P	95 %	**65 %**	46 101,21 €
Diff X	6 650,59 €	**70 %**	46 434,68 €
Diff P	90 %	**75 %**	46 767,96 €
#Errors	0	**80 %**	47 133,18 €
Filter Min	Off	**85 %**	47 486,67 €
Filter Max	Off	**90 %**	47 918,85 €
#Filtered	0	**95 %**	48 486,53 €

Appendix 3. Detailed simulation analysis results of the Old 340 m2 house.

Direct electricity



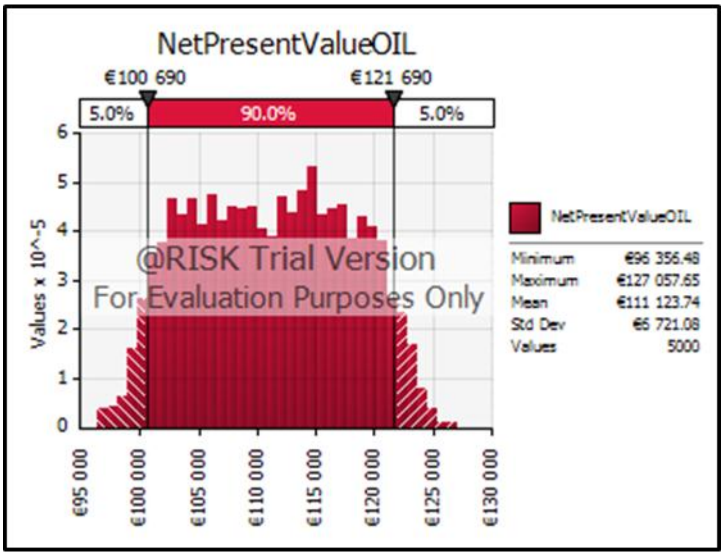

NetPresentValue Direct electricity
€89 691
€109 707
90.0%
5.0%
1.0
0.8
0.6
0.4
0.2
0.0
€85 000
€90 000
€95 000
€100 000
€105 000
€110 000
€115 000
€120 000
@RISK Trial Version
For Evaluation Purposes Only
NetPresentValue Direct electricity
Minimum €85 083.27
Maximum €115 029.47
Mean €99 678.38
Std Dev €6 399.26
Values 5000


NetPresentValue Direct electricity
Regression Coefficients
2021 / cop3
2019 / cop3
2017 / cop3
2015 / cop3
2013 / cop3
2011 / cop3
0.15
0.14
0.13
0.13
0.12
0.10
0.10
0.09
0.09
0.07
@RISK Trial Version
For Evaluation Purposes Only
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Coefficient Value

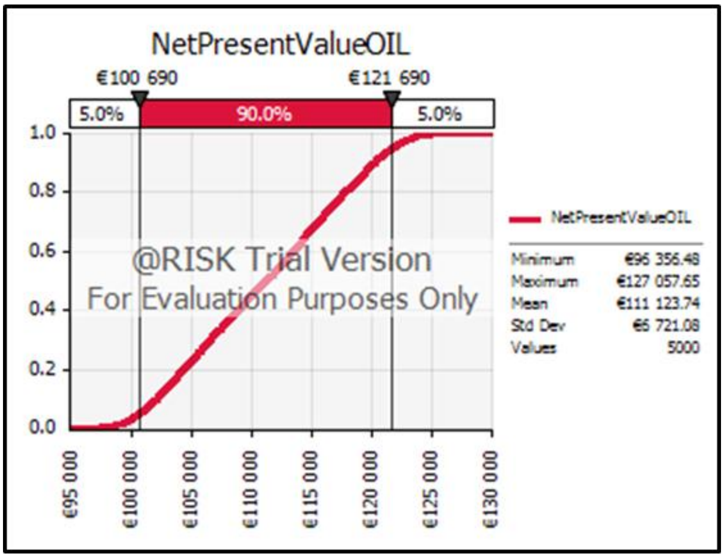
Regression and Rank Information for NetPresentV			
Rank	**Name**	**Regr**	**Corr**
1	2021 / cop3	0,148	0,804
2	2020 / cop3	0,140	0,798
3	2019 / cop3	0,133	0,801
4	2018 / cop3	0,127	0,802
5	2017 / cop3	0,119	0,796
6	2016 / cop3	0,113	0,791
7	2015 / cop3	0,107	0,784
8	2014 / cop3	0,101	0,780
9	2013 / cop3	0,095	0,775
10	2012 / cop3	0,090	0,776
11	2011 / cop3	0,086	0,778
12	Direct electricity	0,066	0,063

Summary Statistics for NetPresentValue Direct el			
Statistics		**Percentile**	
Minimum	85 083,27 €	**5 %**	89 691,05 €
Maximum	115 029,47 €	**10 %**	90 959,64 €
Mean	99 678,38 €	**15 %**	92 146,16 €
Std Dev	6 399,26 €	**20 %**	93 272,51 €
Variance	40950576,81	**25 %**	94 301,47 €
Skewness	0,013800508	**30 %**	95 355,90 €
Kurtosis	1,95686253	**35 %**	96 444,99 €
Median	99 622,37 €	**40 %**	97 498,45 €
Mode	96 362,74 €	**45 %**	98 576,45 €
Left X	89 691,05 €	**50 %**	99 622,37 €
Left P	5 %	**55 %**	100 749,74 €
Right X	109 707,49 €	**60 %**	101 865,32 €
Right P	95 %	**65 %**	102 895,99 €
Diff X	20 016,44 €	**70 %**	103 878,99 €
Diff P	90 %	**75 %**	105 042,70 €
#Errors	0	**80 %**	106 113,65 €
Filter Min	Off	**85 %**	107 149,20 €
Filter Max	Off	**90 %**	108 322,85 €
#Filtered	0	**95 %**	109 707,49 €

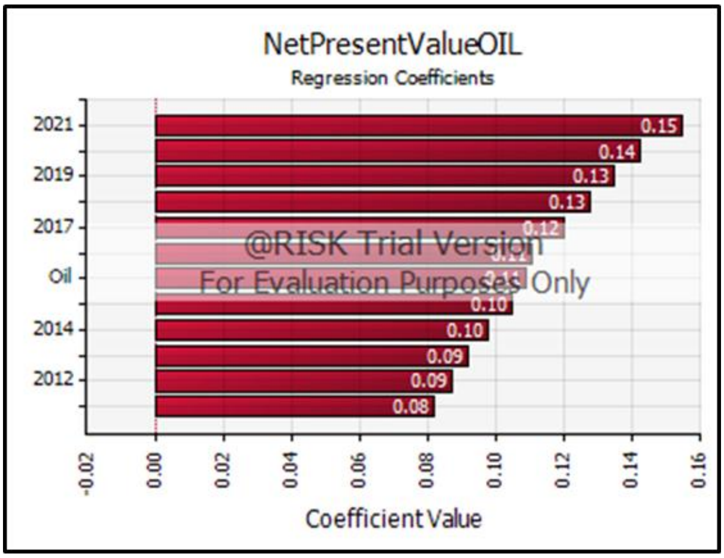
Oil



NetPresentValueOIL
€100 690
€121 690
5.0%
90.0%
5.0%
Values x 10^-5
@RISK Trial Version
For Evaluation Purposes Only
NetPresentValueOIL
Minimum €96 356.48
Maximum €127 057.65
Mean €111 123.74
Std Dev €6 721.08
Values 5000
€95 000
€100 000
€105 000
€110 000
€115 000
€120 000
€125 000
€130 000



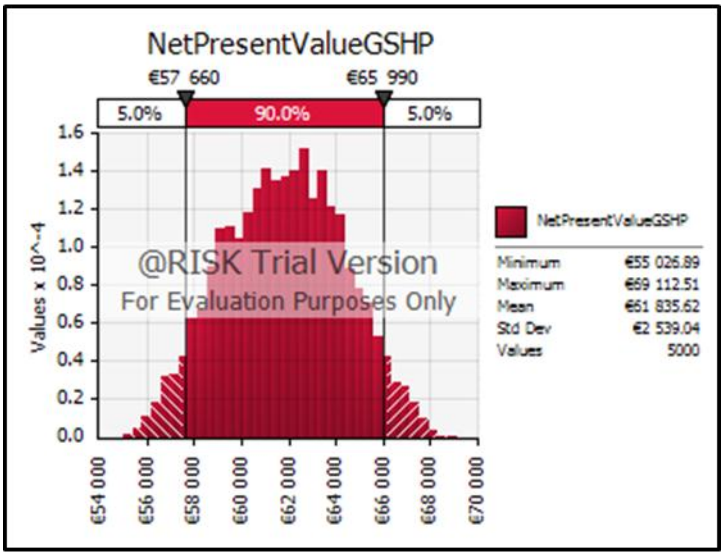
NetPresentValueOIL
€100 690
€121 690
5.0%
90.0%
5.0%
@RISK Trial Version
For Evaluation Purposes Only
NetPresentValueOIL
Minimum €96 356.48
Maximum €127 057.65
Mean €111 123.74
Std Dev €6 721.08
Values 5000
€95 000
€100 000
€105 000
€110 000
€115 000
€120 000
€125 000
€130 000

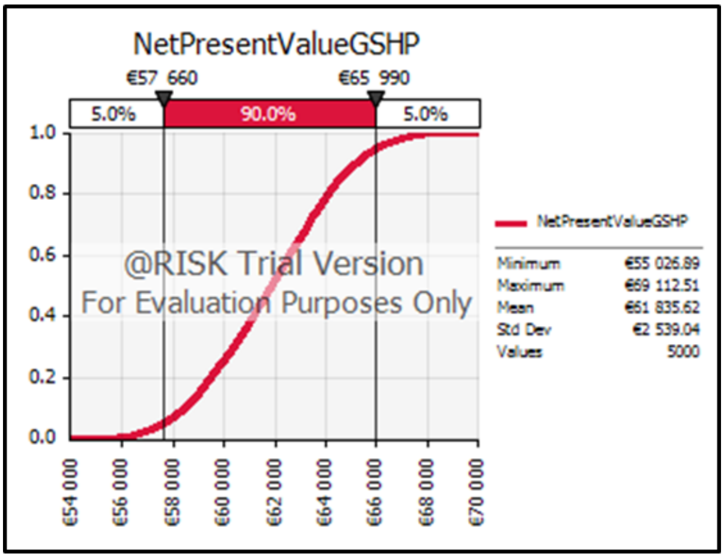


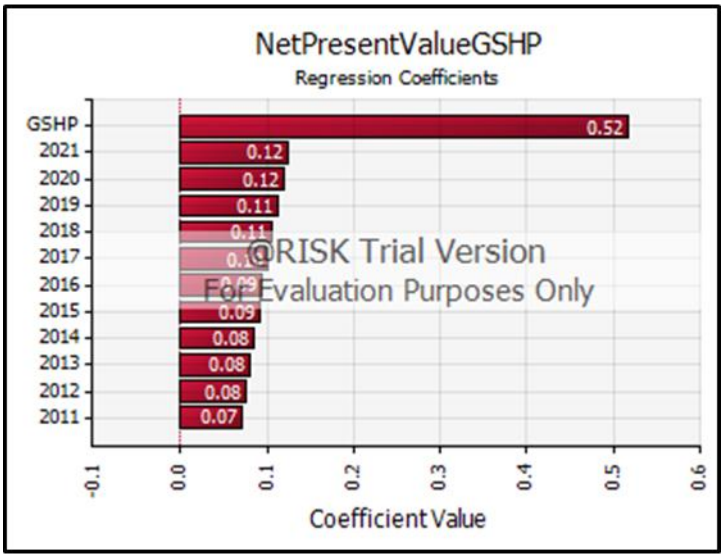
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	2021	0,155	0,804
2	2020	0,142	0,787
3	2019	0,135	0,798
4	2018	0,128	0,796
5	2017	0,120	0,795
6	2016	0,110	0,788
7	Oil	0,109	0,092
8	2015	0,105	0,785
9	2014	0,098	0,781
10	2013	0,092	0,781
11	2012	0,087	0,782
12	2011	0,082	0,784

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	96 356,48 €	**5 %**	100 689,81 €
Maximum	127 057,65 €	**10 %**	102 132,42 €
Mean	111 123,74 €	**15 %**	103 193,63 €
Std Dev	6 721,08 €	**20 %**	104 267,70 €
Variance	45172953,87	**25 %**	105 479,39 €
Skewness	0,011082337	**30 %**	106 549,19 €
Kurtosis	1,958324345	**35 %**	107 718,86 €
Median	111 222,36 €	**40 %**	108 830,95 €
Mode	114 379,04 €	**45 %**	109 955,84 €
Left X	100 689,81 €	**50 %**	111 222,36 €
Left P	5 %	**55 %**	112 365,47 €
Right X	121 690,09 €	**60 %**	113 461,60 €
Right P	95 %	**65 %**	114 451,73 €
Diff X	21 000,27 €	**70 %**	115 496,90 €
Diff P	90 %	**75 %**	116 585,07 €
#Errors	0	**80 %**	117 740,36 €
Filter Min	Off	**85 %**	119 059,03 €
Filter Max	Off	**90 %**	120 229,06 €
#Filtered	0	**95 %**	121 690,09 €

GSHP



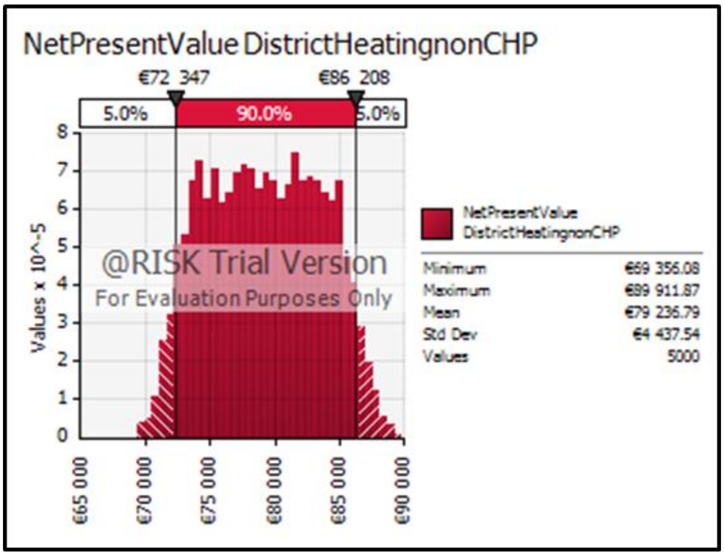


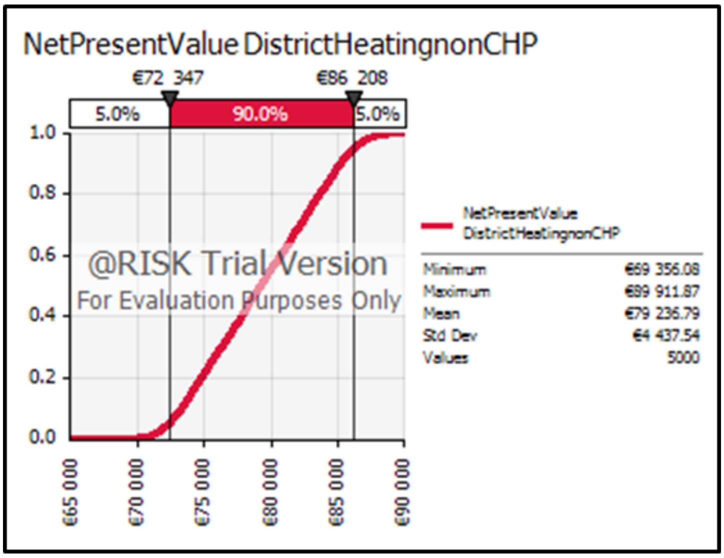


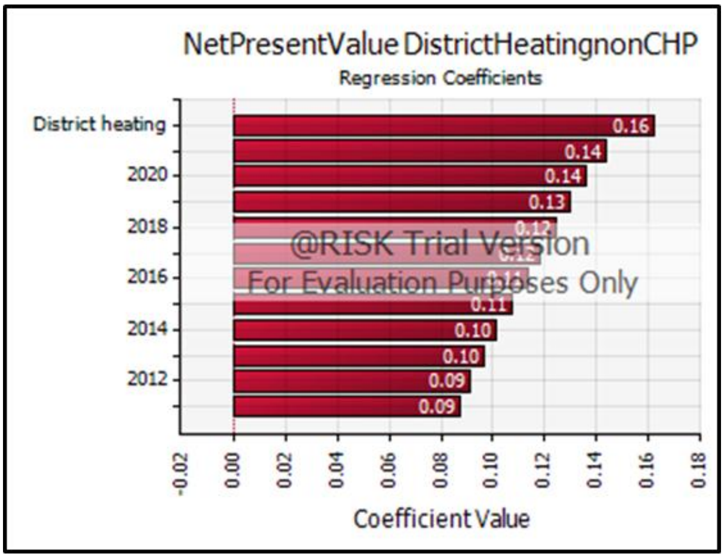
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	GSHP	0,516	0,512
2	2021	0,124	0,696
3	2020	0,119	0,690
4	2019	0,112	0,688
5	2018	0,107	0,691
6	2017	0,101	0,696
7	2016	0,095	0,685
8	2015	0,091	0,680
9	2014	0,084	0,667
10	2013	0,080	0,671
11	2012	0,077	0,690
12	2011	0,072	0,678

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	55 026,89 €	**5 %**	57 660,19 €
Maximum	69 112,51 €	**10 %**	58 464,21 €
Mean	61 835,62 €	**15 %**	59 024,97 €
Std Dev	2 539,04 €	**20 %**	59 490,08 €
Variance	6446715,26	**25 %**	59 939,30 €
Skewness	-0,014913888	**30 %**	60 387,24 €
Kurtosis	2,429810438	**35 %**	60 781,46 €
Median	61 874,14 €	**40 %**	61 159,73 €
Mode	63 270,42 €	**45 %**	61 518,53 €
Left X	57 660,19 €	**50 %**	61 874,14 €
Left P	5 %	**55 %**	62 226,97 €
Right X	65 990,07 €	**60 %**	62 572,96 €
Right P	95 %	**65 %**	62 924,20 €
Diff X	8 329,89 €	**70 %**	63 299,25 €
Diff P	90 %	**75 %**	63 689,48 €
#Errors	0	**80 %**	64 085,54 €
Filter Min	Off	**85 %**	64 560,01 €
Filter Max	Off	**90 %**	65 161,02 €
#Filtered	0	**95 %**	65 990,07 €

District heating without CHP



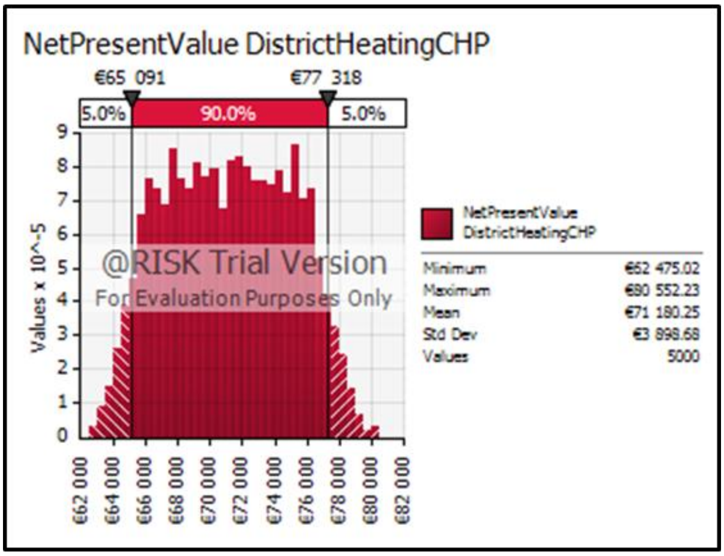


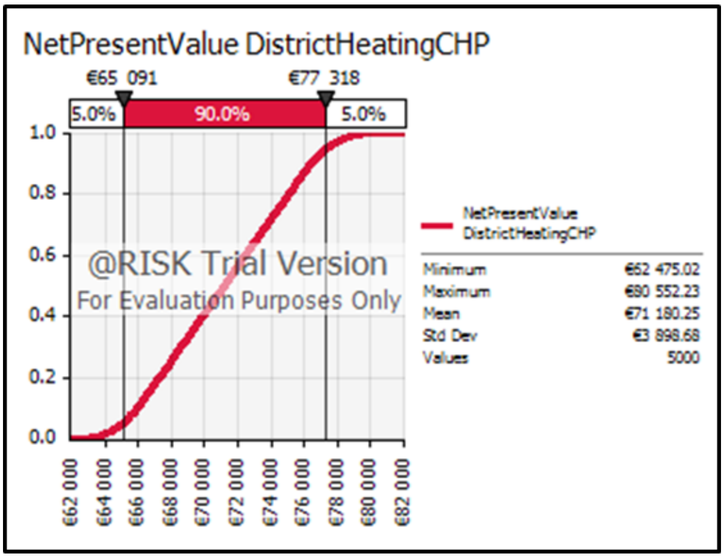


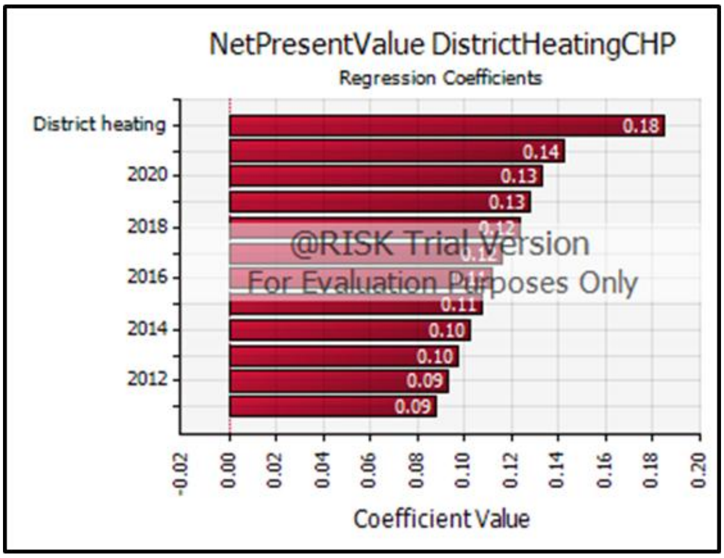
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,162	0,146
2	2021	0,144	0,788
3	2020	0,136	0,786
4	2019	0,130	0,787
5	2018	0,124	0,788
6	2017	0,118	0,783
7	2016	0,114	0,784
8	2015	0,107	0,781
9	2014	0,102	0,781
10	2013	0,097	0,777
11	2012	0,091	0,770
12	2011	0,087	0,771

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	69 356,08 €	**5 %**	72 347,10 €
Maximum	89 911,87 €	**10 %**	73 291,26 €
Mean	79 236,79 €	**15 %**	74 019,03 €
Std Dev	4 437,54 €	**20 %**	74 753,95 €
Variance	19691788,56	**25 %**	75 518,33 €
Skewness	0,015436776	**30 %**	76 296,45 €
Kurtosis	1,983645572	**35 %**	77 048,03 €
Median	79 206,06 €	**40 %**	77 763,03 €
Mode	81 666,32 €	**45 %**	78 458,56 €
Left X	72 347,10 €	**50 %**	79 206,06 €
Left P	5 %	**55 %**	79 928,32 €
Right X	86 207,98 €	**60 %**	80 719,01 €
Right P	95 %	**65 %**	81 465,81 €
Diff X	13 860,88 €	**70 %**	82 187,19 €
Diff P	90 %	**75 %**	82 894,15 €
#Errors	0	**80 %**	83 632,30 €
Filter Min	Off	**85 %**	84 456,79 €
Filter Max	Off	**90 %**	85 178,03 €
#Filtered	0	**95 %**	86 207,98 €

CHP District heating



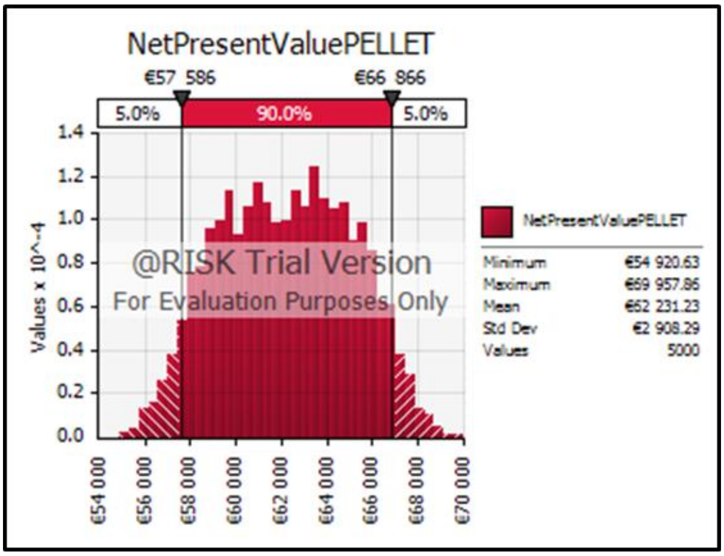


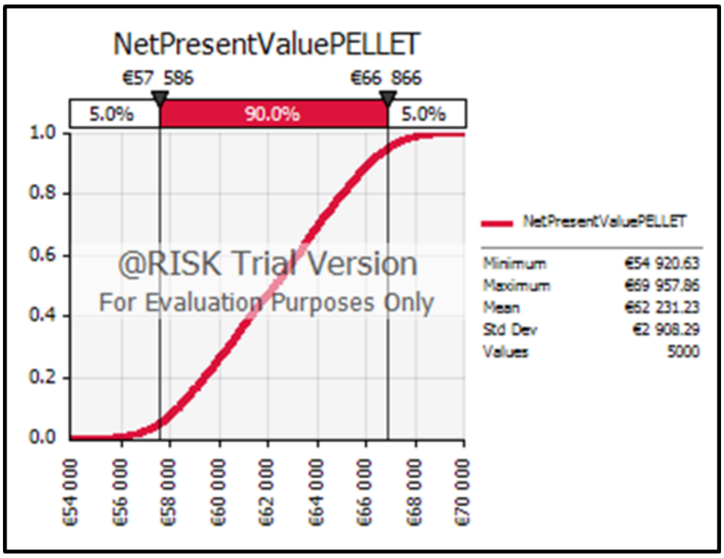


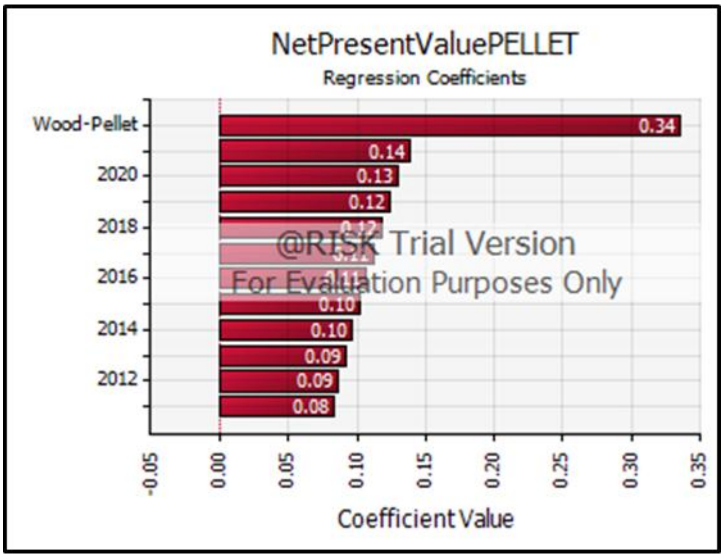
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	District heating	0,184	0,166
2	2021	0,143	0,796
3	2020	0,133	0,789
4	2019	0,127	0,786
5	2018	0,123	0,780
6	2017	0,116	0,780
7	2016	0,111	0,775
8	2015	0,107	0,783
9	2014	0,102	0,777
10	2013	0,097	0,769
11	2012	0,093	0,777
12	2011	0,088	0,763

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	62 475,02 €	**5 %**	65 090,99 €
Maximum	80 552,23 €	**10 %**	65 938,20 €
Mean	71 180,25 €	**15 %**	66 618,82 €
Std Dev	3 898,68 €	**20 %**	67 304,07 €
Variance	15199739,76	**25 %**	67 953,66 €
Skewness	0,012399821	**30 %**	68 568,08 €
Kurtosis	2,008113026	**35 %**	69 253,68 €
Median	71 193,74 €	**40 %**	69 864,77 €
Mode	69 669,34 €	**45 %**	70 515,78 €
Left X	65 090,99 €	**50 %**	71 193,74 €
Left P	5 %	**55 %**	71 804,17 €
Right X	77 317,59 €	**60 %**	72 440,63 €
Right P	95 %	**65 %**	73 115,94 €
Diff X	12 226,60 €	**70 %**	73 752,57 €
Diff P	90 %	**75 %**	74 405,18 €
#Errors	0	**80 %**	75 077,80 €
Filter Min	Off	**85 %**	75 673,39 €
Filter Max	Off	**90 %**	76 360,55 €
#Filtered	0	**95 %**	77 317,59 €

Wood-Pellet





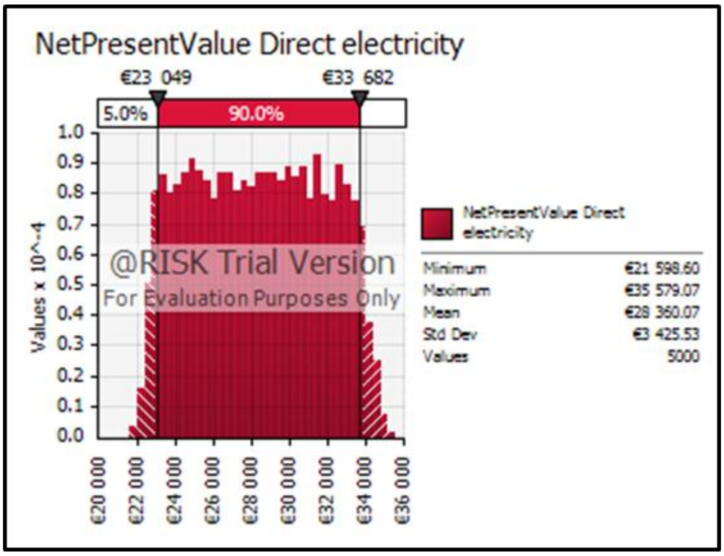


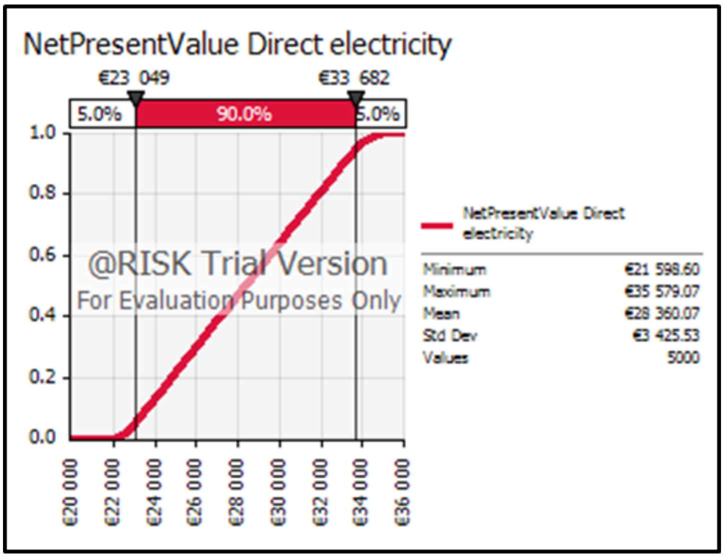
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	Wood-Pellet	0,335	0,321
2	2021	0,138	0,761
3	2020	0,130	0,755
4	2019	0,124	0,753
5	2018	0,118	0,750
6	2017	0,112	0,748
7	2016	0,107	0,754
8	2015	0,102	0,745
9	2014	0,096	0,745
10	2013	0,092	0,743
11	2012	0,086	0,740
12	2011	0,083	0,735

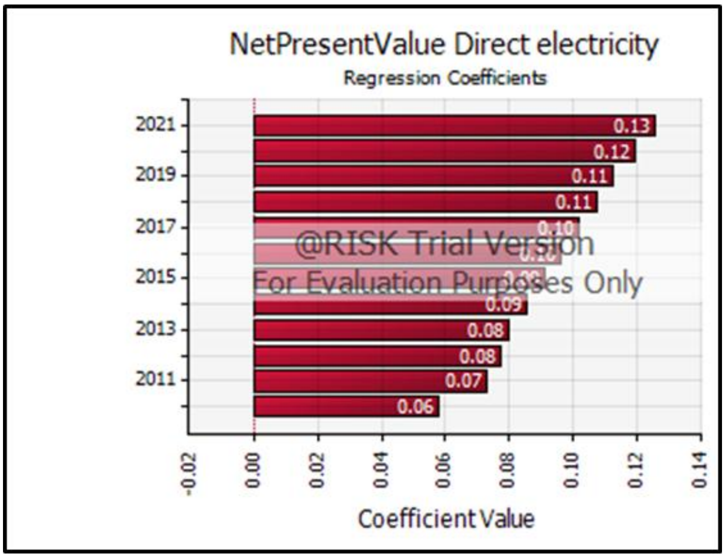
Summary Statistics for NetPresentValuePELLET			
Statistics		**Percentile**	
Minimum	54 920,63 €	**5 %**	57 585,63 €
Maximum	69 957,86 €	**10 %**	58 353,85 €
Mean	62 231,23 €	**15 %**	58 886,97 €
Std Dev	2 908,29 €	**20 %**	59 411,28 €
Variance	8458123,894	**25 %**	59 887,88 €
Skewness	-0,010849565	**30 %**	60 399,12 €
Kurtosis	2,141728078	**35 %**	60 841,80 €
Median	62 273,74 €	**40 %**	61 297,66 €
Mode	63 345,68 €	**45 %**	61 764,53 €
Left X	57 585,63 €	**50 %**	62 273,74 €
Left P	5 %	**55 %**	62 737,47 €
Right X	66 865,95 €	**60 %**	63 198,57 €
Right P	95 %	**65 %**	63 614,30 €
Diff X	9 280,32 €	**70 %**	64 046,34 €
Diff P	90 %	**75 %**	64 543,00 €
#Errors	0	**80 %**	65 011,17 €
Filter Min	Off	**85 %**	65 540,24 €
Filter Max	Off	**90 %**	66 113,27 €
#Filtered	0	**95 %**	66 865,95 €

Appendix 4. Detailed simulation analysis results of the New 140 m2 house.

Direct electricity



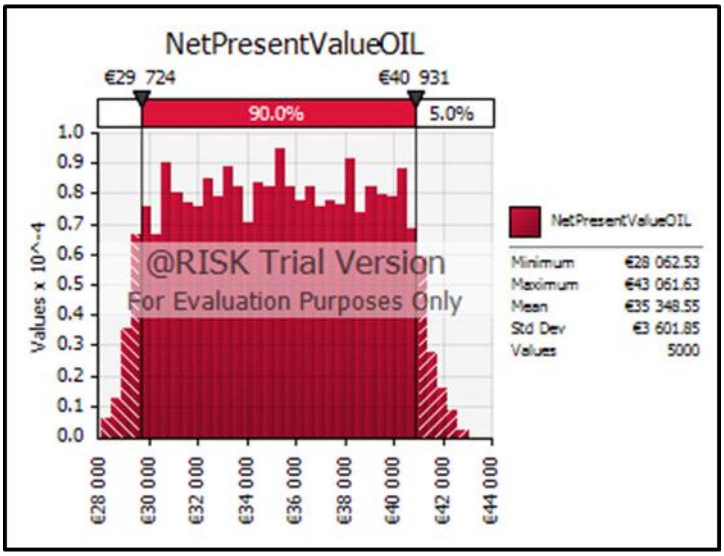


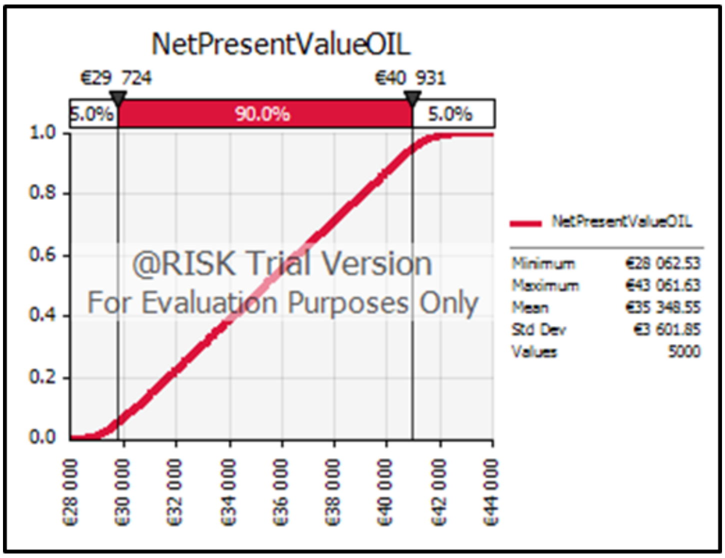


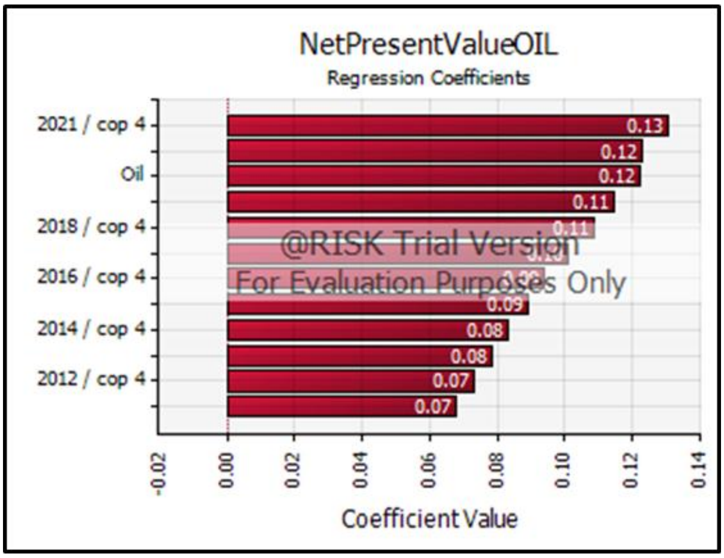
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	2021	0,125	0,940
2	2020	0,120	0,942
3	2019	0,112	0,938
4	2018	0,107	0,939
5	2017	0,102	0,938
6	2016	0,096	0,939
7	2015	0,091	0,937
8	2014	0,085	0,934
9	2013	0,080	0,933
10	2012	0,077	0,935
11	2011	0,073	0,934
12	Direct electricity	0,058	0,053

Summary Statistics for NetPresentValue Direct el			
Statistics		**Percentile**	
Minimum	21 598,60 €	**5 %**	23 049,42 €
Maximum	35 579,07 €	**10 %**	23 628,54 €
Mean	28 360,07 €	**15 %**	24 251,00 €
Std Dev	3 425,53 €	**20 %**	24 818,46 €
Variance	11734223,87	**25 %**	25 410,77 €
Skewness	0,013586962	**30 %**	25 967,04 €
Kurtosis	1,841012497	**35 %**	26 569,06 €
Median	28 373,74 €	**40 %**	27 188,84 €
Mode	30 394,55 €	**45 %**	27 779,34 €
Left X	23 049,42 €	**50 %**	28 373,74 €
Left P	5 %	**55 %**	28 941,75 €
Right X	33 681,57 €	**60 %**	29 546,49 €
Right P	95 %	**65 %**	30 107,46 €
Diff X	10 632,15 €	**70 %**	30 707,70 €
Diff P	90 %	**75 %**	31 290,71 €
#Errors	0	**80 %**	31 861,14 €
Filter Min	Off	**85 %**	32 485,64 €
Filter Max	Off	**90 %**	33 048,49 €
#Filtered	0	**95 %**	33 681,57 €

Oil



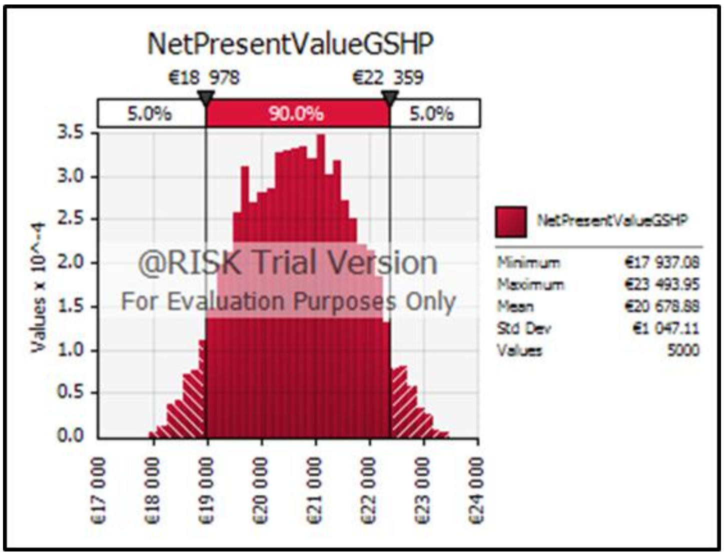


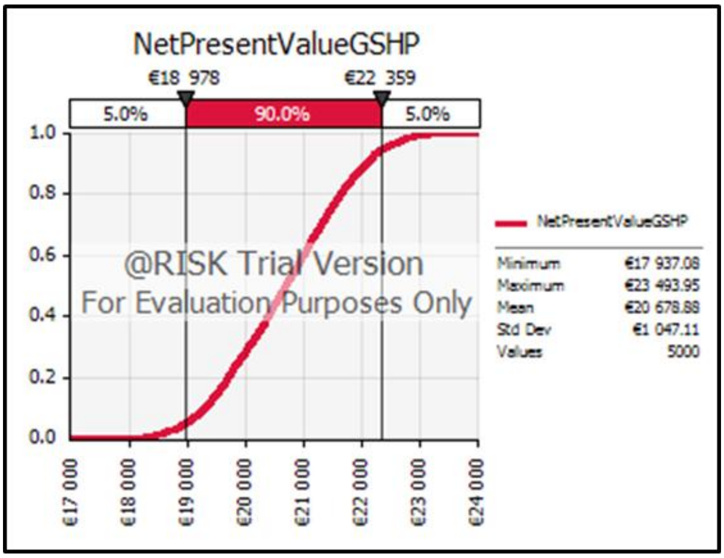


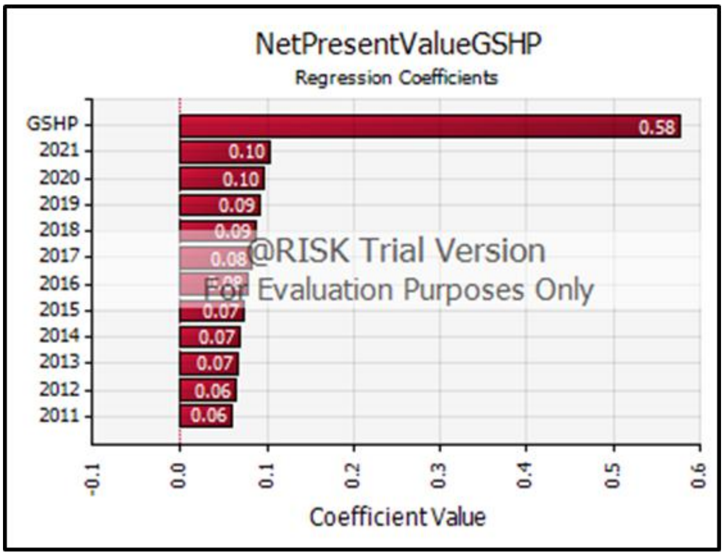
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	2021 / cop 4	0,130	0,937
2	2020 / cop 4	0,123	0,936
3	Oil	0,122	0,119
4	2019 / cop 4	0,115	0,934
5	2018 / cop 4	0,108	0,936
6	2017 / cop 4	0,101	0,933
7	2016 / cop 4	0,094	0,931
8	2015 / cop 4	0,089	0,932
9	2014 / cop 4	0,083	0,931
10	2013 / cop 4	0,078	0,931
11	2012 / cop 4	0,073	0,928
12	2011 / cop 4	0,068	0,927

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	28 062,53 €	**5 %**	29 723,75 €
Maximum	43 061,63 €	**10 %**	30 398,86 €
Mean	35 348,55 €	**15 %**	31 014,55 €
Std Dev	3 601,85 €	**20 %**	31 629,58 €
Variance	12973288,91	**25 %**	32 273,49 €
Skewness	0,004984641	**30 %**	32 882,41 €
Kurtosis	1,871190303	**35 %**	33 489,02 €
Median	35 328,56 €	**40 %**	34 139,10 €
Mode	31 342,54 €	**45 %**	34 763,73 €
Left X	29 723,75 €	**50 %**	35 328,56 €
Left P	5 %	**55 %**	35 922,03 €
Right X	40 931,22 €	**60 %**	36 546,13 €
Right P	95 %	**65 %**	37 171,66 €
Diff X	11 207,48 €	**70 %**	37 817,58 €
Diff P	90 %	**75 %**	38 408,01 €
#Errors	0	**80 %**	39 039,41 €
Filter Min	Off	**85 %**	39 679,86 €
Filter Max	Off	**90 %**	40 283,42 €
#Filtered	0	**95 %**	40 931,22 €

GSHP



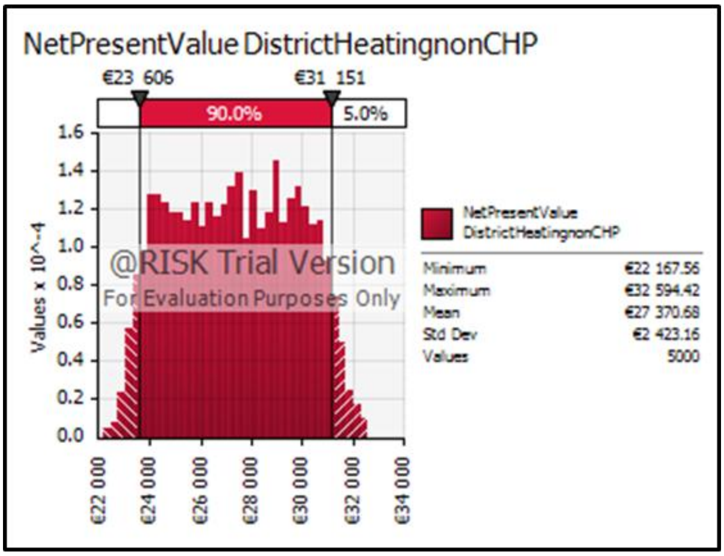


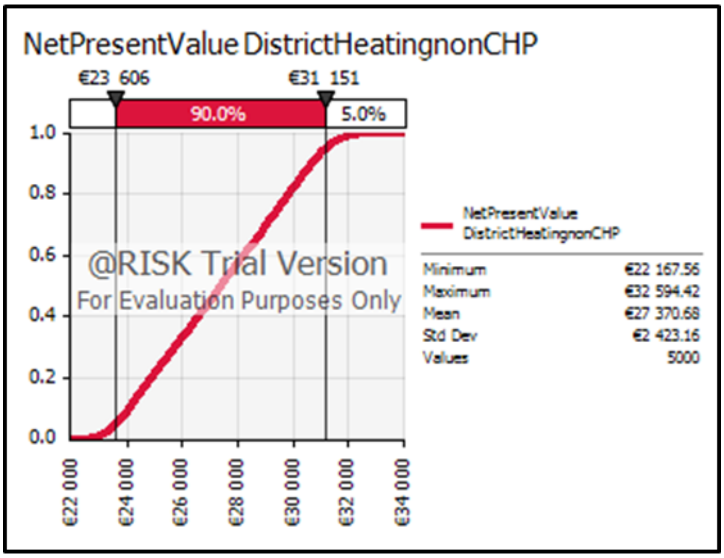


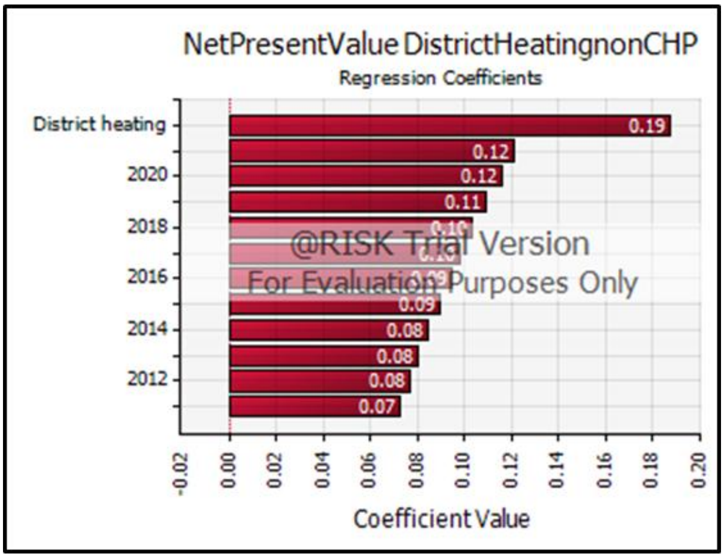
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	GSHP	0,577	0,554
2	2021	0,103	0,771
3	2020	0,097	0,779
4	2019	0,092	0,778
5	2018	0,088	0,770
6	2017	0,083	0,774
7	2016	0,078	0,779
8	2015	0,074	0,769
9	2014	0,069	0,779
10	2013	0,067	0,765
11	2012	0,063	0,776
12	2011	0,060	0,774

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	17 937,08 €	**5 %**	18 978,47 €
Maximum	23 493,95 €	**10 %**	19 295,16 €
Mean	20 678,88 €	**15 %**	19 521,64 €
Std Dev	1 047,11 €	**20 %**	19 699,77 €
Variance	1096439,537	**25 %**	19 868,50 €
Skewness	-0,003745987	**30 %**	20 049,71 €
Kurtosis	2,362300949	**35 %**	20 228,62 €
Median	20 689,38 €	**40 %**	20 388,73 €
Mode	20 647,88 €	**45 %**	20 534,47 €
Left X	18 978,47 €	**50 %**	20 689,38 €
Left P	5 %	**55 %**	20 834,62 €
Right X	22 358,74 €	**60 %**	20 990,77 €
Right P	95 %	**65 %**	21 133,83 €
Diff X	3 380,26 €	**70 %**	21 295,15 €
Diff P	90 %	**75 %**	21 455,44 €
#Errors	0	**80 %**	21 638,20 €
Filter Min	Off	**85 %**	21 831,62 €
Filter Max	Off	**90 %**	22 063,85 €
#Filtered	0	**95 %**	22 358,74 €

District heating without CHP



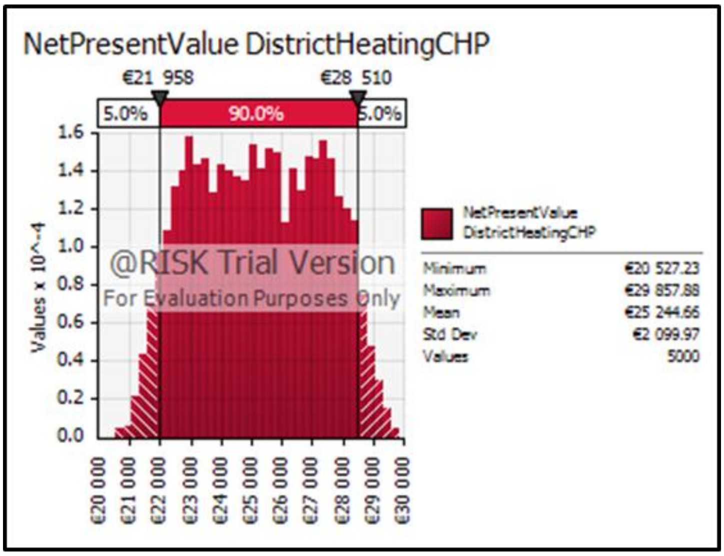


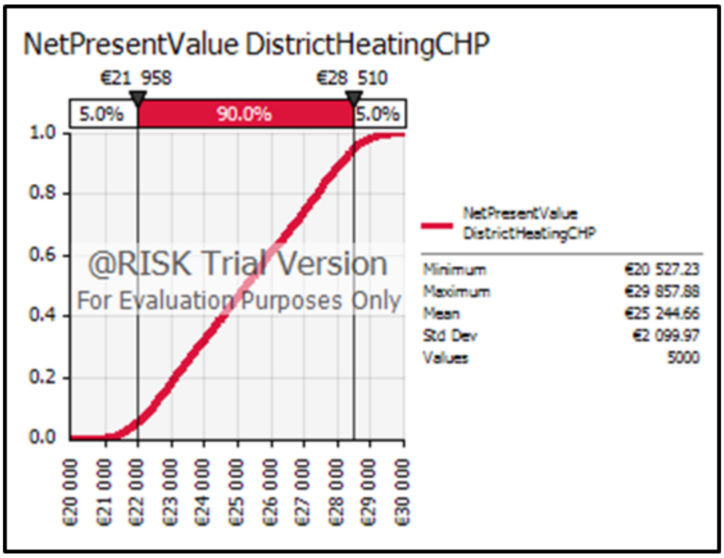


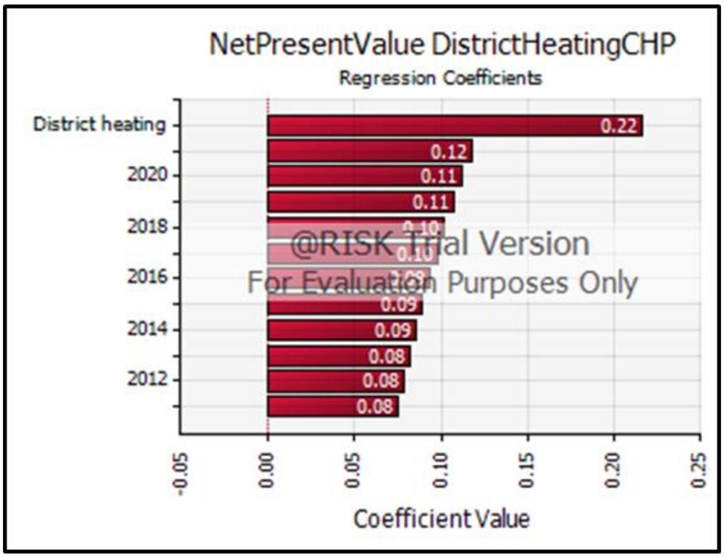
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,188	0,208
2	2021	0,121	0,926
3	2020	0,116	0,929
4	2019	0,109	0,924
5	2018	0,103	0,925
6	2017	0,098	0,925
7	2016	0,094	0,925
8	2015	0,090	0,922
9	2014	0,084	0,921
10	2013	0,080	0,921
11	2012	0,077	0,922
12	2011	0,073	0,922

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	22 167,56 €	**5 %**	23 605,52 €
Maximum	32 594,42 €	**10 %**	24 071,37 €
Mean	27 370,68 €	**15 %**	24 467,01 €
Std Dev	2 423,16 €	**20 %**	24 868,39 €
Variance	5871717,732	**25 %**	25 294,67 €
Skewness	0,008358348	**30 %**	25 725,20 €
Kurtosis	1,905457471	**35 %**	26 175,63 €
Median	27 377,60 €	**40 %**	26 568,02 €
Mode	24 046,03 €	**45 %**	26 989,63 €
Left X	23 605,52 €	**50 %**	27 377,60 €
Left P	5 %	**55 %**	27 750,47 €
Right X	31 151,26 €	**60 %**	28 178,60 €
Right P	95 %	**65 %**	28 634,12 €
Diff X	7 545,74 €	**70 %**	29 015,37 €
Diff P	90 %	**75 %**	29 418,56 €
#Errors	0	**80 %**	29 812,47 €
Filter Min	Off	**85 %**	30 224,41 €
Filter Max	Off	**90 %**	30 636,06 €
#Filtered	0	**95 %**	31 151,26 €

CHP District heating



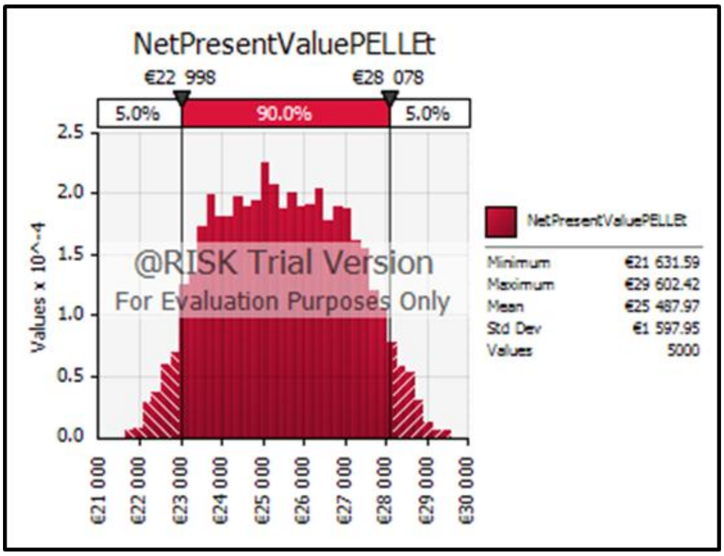


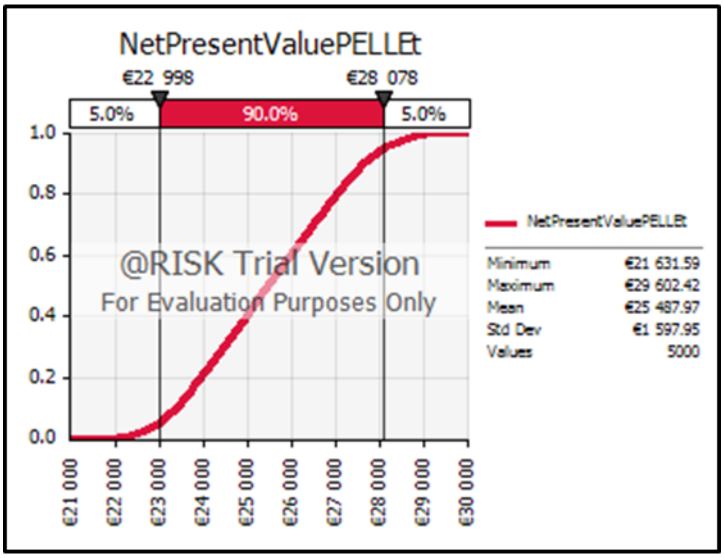


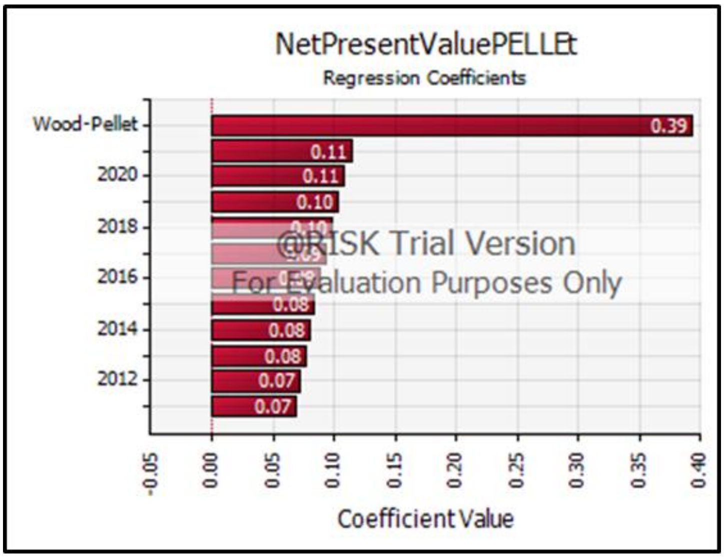
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,216	0,220
2	2021	0,118	0,922
3	2020	0,112	0,920
4	2019	0,107	0,920
5	2018	0,102	0,919
6	2017	0,098	0,915
7	2016	0,093	0,918
8	2015	0,089	0,917
9	2014	0,086	0,919
10	2013	0,082	0,917
11	2012	0,078	0,917
12	2011	0,075	0,916

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	20 527,23 €	**5 %**	21 958,30 €
Maximum	29 857,88 €	**10 %**	22 425,39 €
Mean	25 244,66 €	**15 %**	22 780,85 €
Std Dev	2 099,97 €	**20 %**	23 097,98 €
Variance	4409887,462	**25 %**	23 473,19 €
Skewness	0,000610512	**30 %**	23 809,73 €
Kurtosis	1,924006234	**35 %**	24 178,07 €
Median	25 242,48 €	**40 %**	24 540,43 €
Mode	23 572,49 €	**45 %**	24 906,83 €
Left X	21 958,30 €	**50 %**	25 242,48 €
Left P	5 %	**55 %**	25 597,00 €
Right X	28 510,29 €	**60 %**	25 907,87 €
Right P	95 %	**65 %**	26 333,93 €
Diff X	6 551,99 €	**70 %**	26 679,01 €
Diff P	90 %	**75 %**	27 035,69 €
#Errors	0	**80 %**	27 387,15 €
Filter Min	Off	**85 %**	27 693,76 €
Filter Max	Off	**90 %**	28 076,02 €
#Filtered	0	**95 %**	28 510,29 €

Wood-Pellet





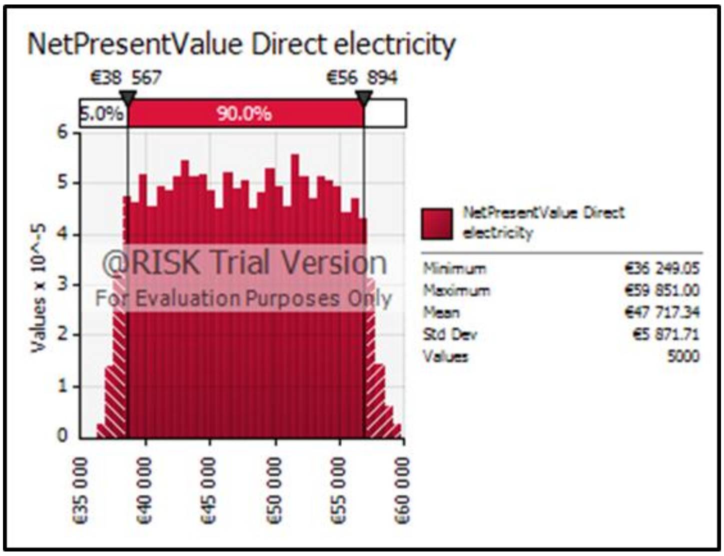


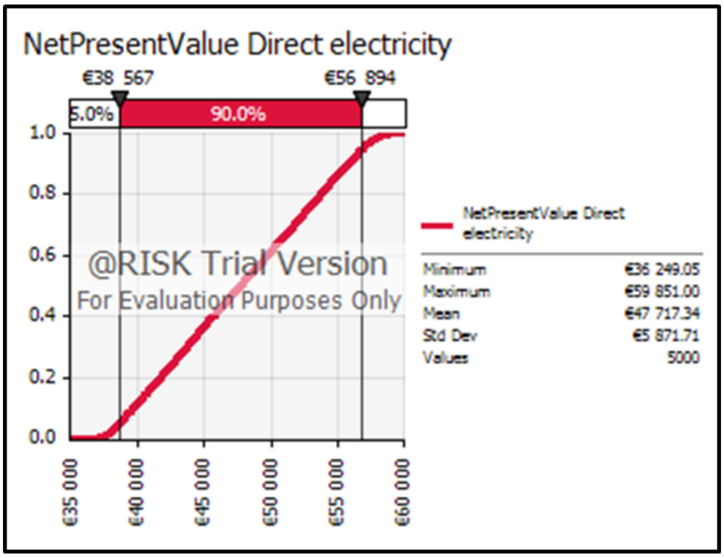
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	Wood-Pellet	0,393	0,372
2	2021	0,115	0,875
3	2020	0,108	0,875
4	2019	0,103	0,865
5	2018	0,098	0,869
6	2017	0,093	0,870
7	2016	0,088	0,868
8	2015	0,084	0,869
9	2014	0,079	0,867
10	2013	0,076	0,864
11	2012	0,072	0,869
12	2011	0,068	0,866

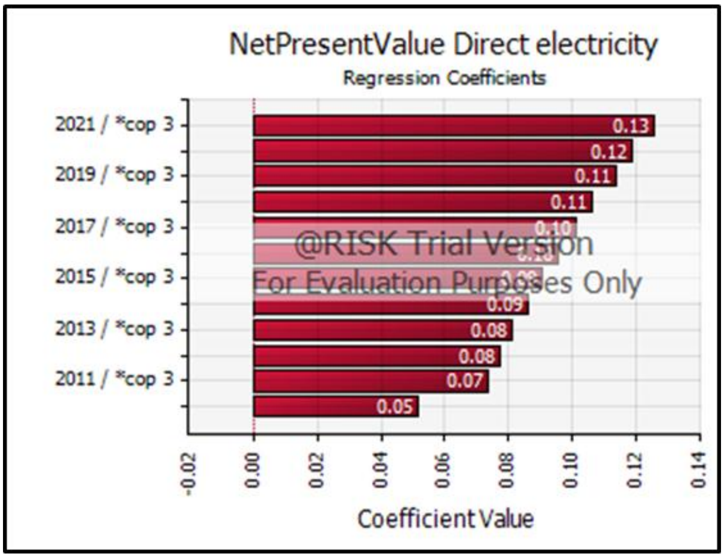
Summary Statistics for NetPresentValuePELLEt			
Statistics		**Percentile**	
Minimum	21 631,59 €	**5 %**	22 997,88 €
Maximum	29 602,42 €	**10 %**	23 370,26 €
Mean	25 487,97 €	**15 %**	23 683,22 €
Std Dev	1 597,95 €	**20 %**	23 931,47 €
Variance	2553458,049	**25 %**	24 210,51 €
Skewness	0,052814878	**30 %**	24 458,61 €
Kurtosis	2,155124214	**35 %**	24 729,40 €
Median	25 452,77 €	**40 %**	24 981,09 €
Mode	23 760,99 €	**45 %**	25 204,47 €
Left X	22 997,88 €	**50 %**	25 452,77 €
Left P	5 %	**55 %**	25 707,57 €
Right X	28 077,61 €	**60 %**	25 974,71 €
Right P	95 %	**65 %**	26 230,35 €
Diff X	5 079,72 €	**70 %**	26 487,16 €
Diff P	90 %	**75 %**	26 748,57 €
#Errors	0	**80 %**	27 017,54 €
Filter Min	Off	**85 %**	27 295,36 €
Filter Max	Off	**90 %**	27 624,80 €
#Filtered	0	**95 %**	28 077,61 €

Appendix 5. Detailed simulation analysis results of the New 240 m2 house.

Direct electricity



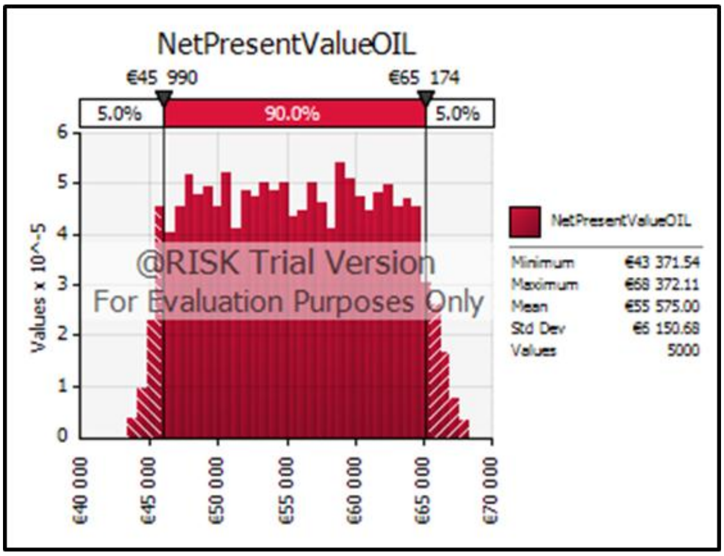


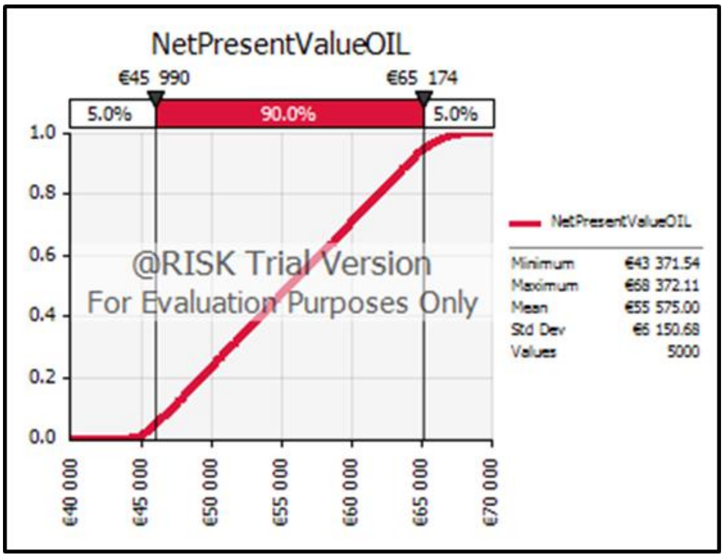


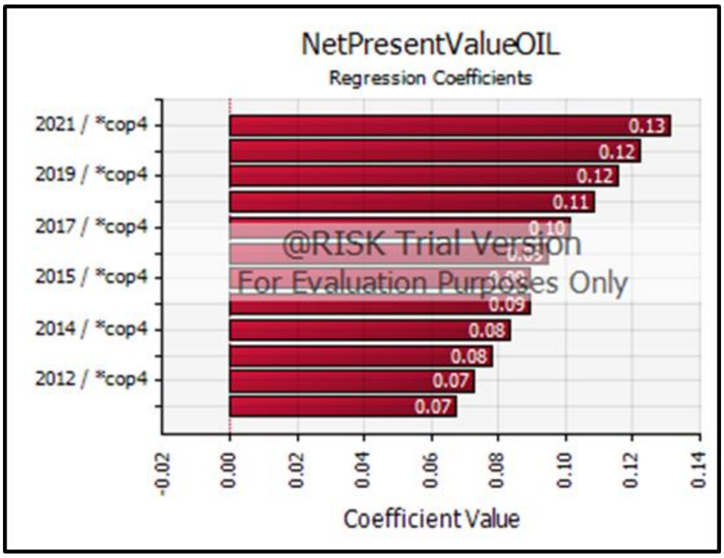
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	2021 / *cop 3	0,125	0,941
2	2020 / *cop 3	0,119	0,941
3	2019 / *cop 3	0,114	0,941
4	2018 / *cop 3	0,106	0,938
5	2017 / *cop 3	0,101	0,937
6	2016 / *cop 3	0,096	0,937
7	2015 / *cop 3	0,090	0,936
8	2014 / *cop 3	0,086	0,937
9	2013 / *cop 3	0,081	0,936
10	2012 / *cop 3	0,077	0,935
11	2011 / *cop 3	0,074	0,935
12	Direct electricity	0,051	0,057

Summary Statistics for NetPresentValue Direct el			
Statistics		**Percentile**	
Minimum	36 249,05 €	**5 %**	38 566,97 €
Maximum	59 851,00 €	**10 %**	39 643,15 €
Mean	47 717,34 €	**15 %**	40 683,09 €
Std Dev	5 871,71 €	**20 %**	41 698,31 €
Variance	34476995,88	**25 %**	42 718,63 €
Skewness	0,013845577	**30 %**	43 675,40 €
Kurtosis	1,843837993	**35 %**	44 625,31 €
Median	47 674,79 €	**40 %**	45 671,28 €
Mode	51 850,03 €	**45 %**	46 673,07 €
Left X	38 566,97 €	**50 %**	47 674,79 €
Left P	5 %	**55 %**	48 732,97 €
Right X	56 893,57 €	**60 %**	49 725,40 €
Right P	95 %	**65 %**	50 733,55 €
Diff X	18 326,60 €	**70 %**	51 776,39 €
Diff P	90 %	**75 %**	52 711,78 €
#Errors	0	**80 %**	53 739,89 €
Filter Min	Off	**85 %**	54 708,21 €
Filter Max	Off	**90 %**	55 795,92 €
#Filtered	0	**95 %**	56 893,57 €

Oil



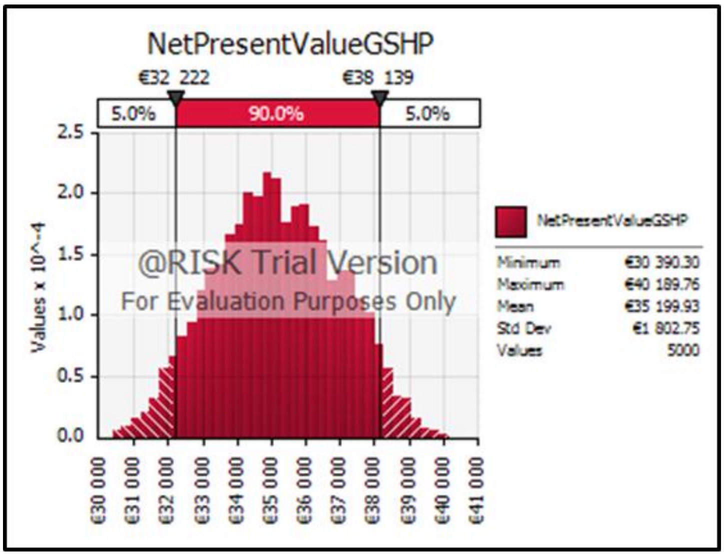


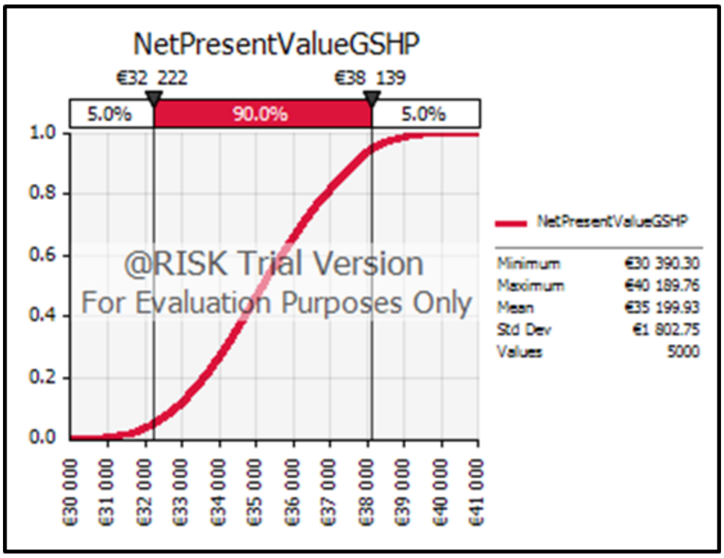


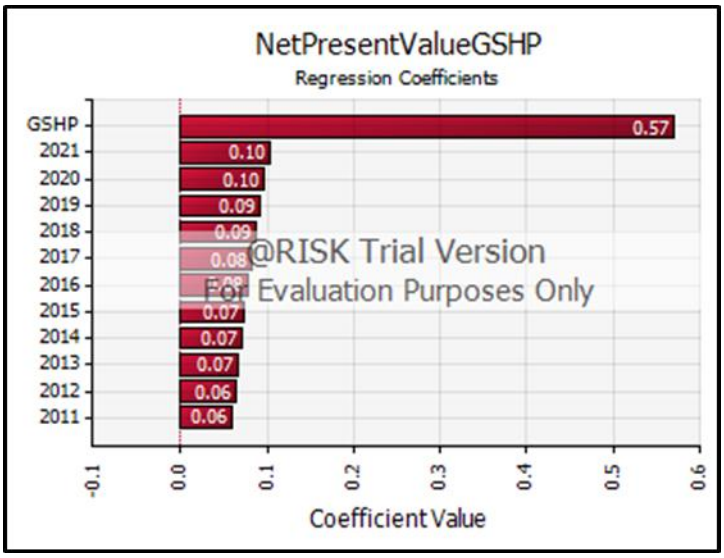
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	2021 / *cop4	0,131	0,940
2	2020 / *cop4	0,122	0,938
3	2019 / *cop4	0,115	0,939
4	2018 / *cop4	0,109	0,937
5	2017 / *cop4	0,101	0,935
6	2016 / *cop4	0,095	0,934
7	2015 / *cop4	0,090	0,935
8	Oil	0,090	0,110
9	2014 / *cop4	0,084	0,934
10	2013 / *cop4	0,078	0,932
11	2012 / *cop4	0,073	0,933
12	2011 / *cop4	0,067	0,930

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	43 371,54 €	**5 %**	45 990,22 €
Maximum	68 372,11 €	**10 %**	47 225,07 €
Mean	55 575,00 €	**15 %**	48 190,07 €
Std Dev	6 150,68 €	**20 %**	49 245,22 €
Variance	37830811,06	**25 %**	50 285,56 €
Skewness	0,02015918	**30 %**	51 321,48 €
Kurtosis	1,860359981	**35 %**	52 415,48 €
Median	55 510,72 €	**40 %**	53 443,85 €
Mode	50 786,00 €	**45 %**	54 473,92 €
Left X	45 990,22 €	**50 %**	55 510,72 €
Left P	5 %	**55 %**	56 647,70 €
Right X	65 173,81 €	**60 %**	57 623,93 €
Right P	95 %	**65 %**	58 785,60 €
Diff X	19 183,59 €	**70 %**	59 786,28 €
Diff P	90 %	**75 %**	60 779,33 €
#Errors	0	**80 %**	61 836,84 €
Filter Min	Off	**85 %**	62 917,69 €
Filter Max	Off	**90 %**	63 983,83 €
#Filtered	0	**95 %**	65 173,81 €

GSHP



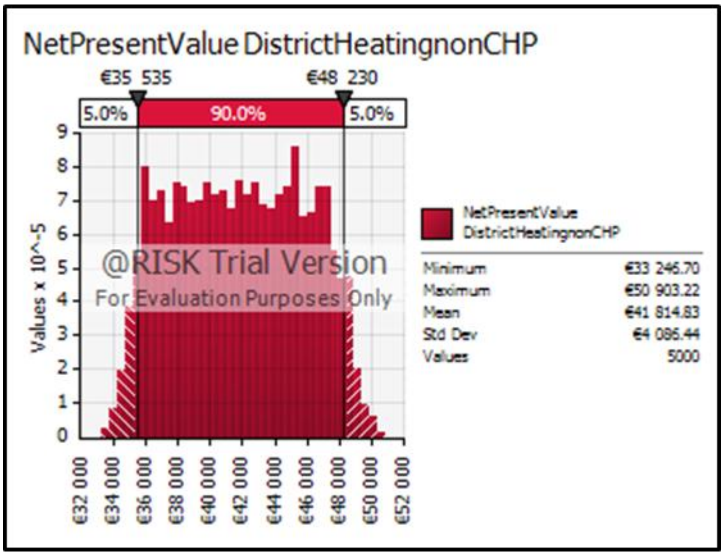


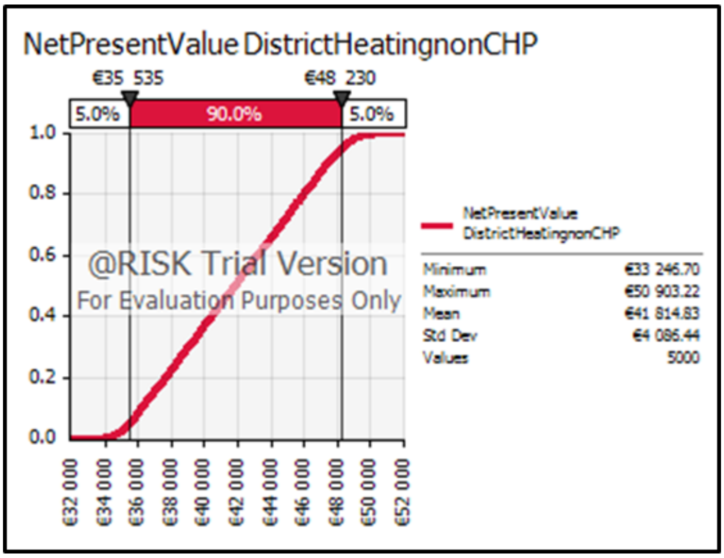


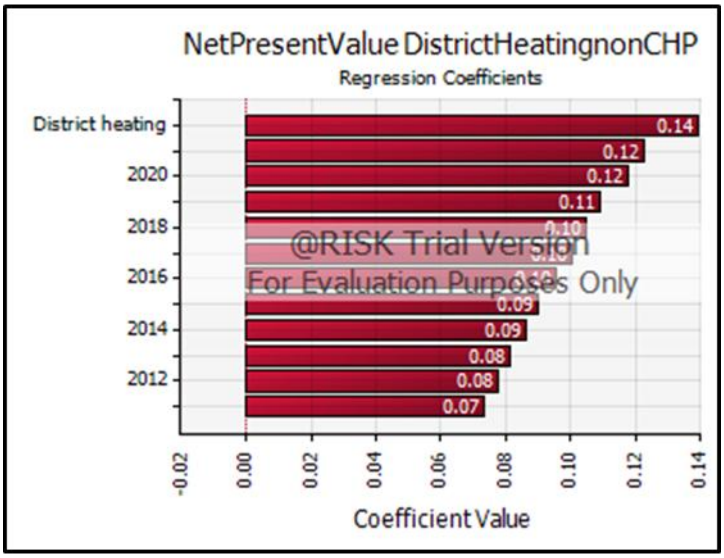
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	GSHP	0,569	0,554
2	2021	0,103	0,783
3	2020	0,097	0,783
4	2019	0,092	0,782
5	2018	0,087	0,778
6	2017	0,082	0,782
7	2016	0,078	0,780
8	2015	0,074	0,778
9	2014	0,070	0,775
10	2013	0,066	0,781
11	2012	0,063	0,783
12	2011	0,059	0,775

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	30 390,30 €	**5 %**	32 221,64 €
Maximum	40 189,76 €	**10 %**	32 816,74 €
Mean	35 199,93 €	**15 %**	33 215,91 €
Std Dev	1 802,75 €	**20 %**	33 585,83 €
Variance	3249909,559	**25 %**	33 891,05 €
Skewness	0,013023276	**30 %**	34 174,86 €
Kurtosis	2,413378564	**35 %**	34 434,90 €
Median	35 168,11 €	**40 %**	34 675,00 €
Mode	35 272,80 €	**45 %**	34 921,13 €
Left X	32 221,64 €	**50 %**	35 168,11 €
Left P	5 %	**55 %**	35 406,11 €
Right X	38 139,13 €	**60 %**	35 684,93 €
Right P	95 %	**65 %**	35 949,33 €
Diff X	5 917,50 €	**70 %**	36 225,94 €
Diff P	90 %	**75 %**	36 521,37 €
#Errors	0	**80 %**	36 875,56 €
Filter Min	Off	**85 %**	37 237,96 €
Filter Max	Off	**90 %**	37 629,18 €
#Filtered	0	**95 %**	38 139,13 €

District heating without CHP



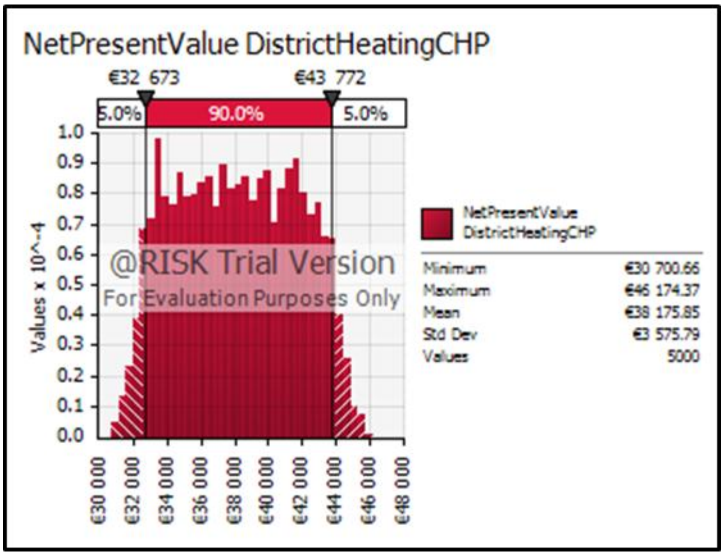


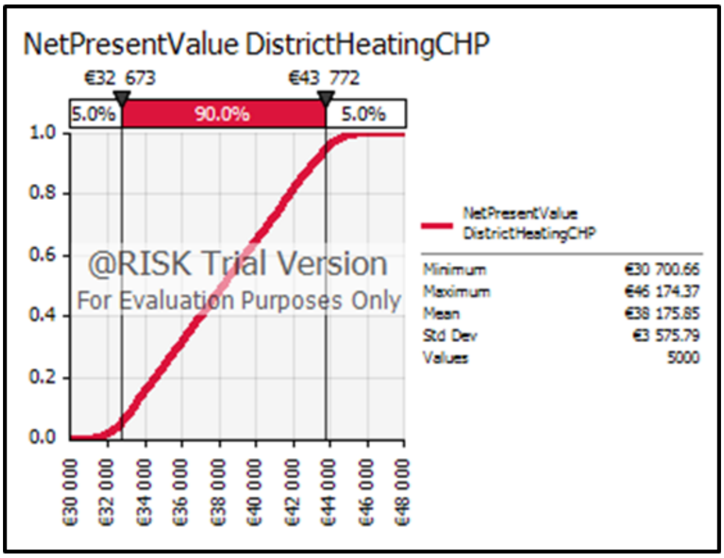


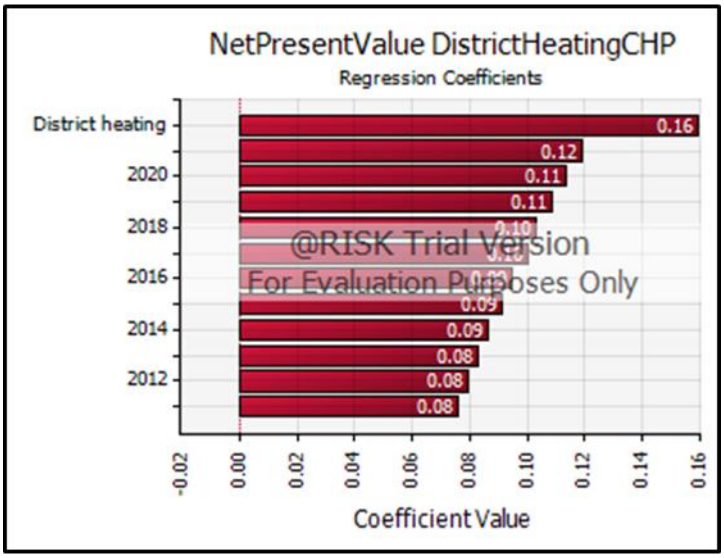
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,140	0,148
2	2021	0,123	0,935
3	2020	0,118	0,934
4	2019	0,109	0,930
5	2018	0,105	0,931
6	2017	0,100	0,931
7	2016	0,095	0,931
8	2015	0,090	0,929
9	2014	0,086	0,928
10	2013	0,081	0,928
11	2012	0,077	0,928
12	2011	0,073	0,927

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	33 246,70 €	**5 %**	35 535,35 €
Maximum	50 903,22 €	**10 %**	36 210,49 €
Mean	41 814,83 €	**15 %**	36 933,78 €
Std Dev	4 086,44 €	**20 %**	37 656,68 €
Variance	16699031,55	**25 %**	38 317,92 €
Skewness	0,016884899	**30 %**	39 022,40 €
Kurtosis	1,893391002	**35 %**	39 728,73 €
Median	41 833,12 €	**40 %**	40 427,38 €
Mode	37 994,33 €	**45 %**	41 115,08 €
Left X	35 535,35 €	**50 %**	41 833,12 €
Left P	5 %	**55 %**	42 509,08 €
Right X	48 230,31 €	**60 %**	43 163,53 €
Right P	95 %	**65 %**	43 900,60 €
Diff X	12 694,96 €	**70 %**	44 601,73 €
Diff P	90 %	**75 %**	45 249,25 €
#Errors	0	**80 %**	45 946,02 €
Filter Min	Off	**85 %**	46 648,54 €
Filter Max	Off	**90 %**	47 315,97 €
#Filtered	0	**95 %**	48 230,31 €

CHP District heating



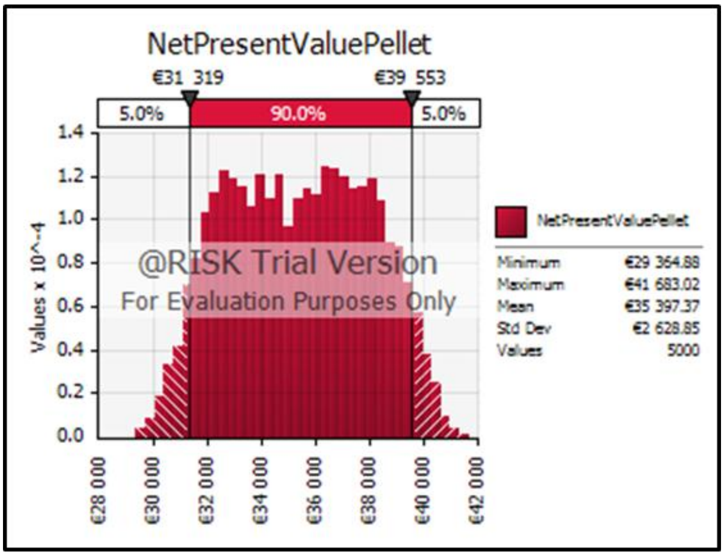


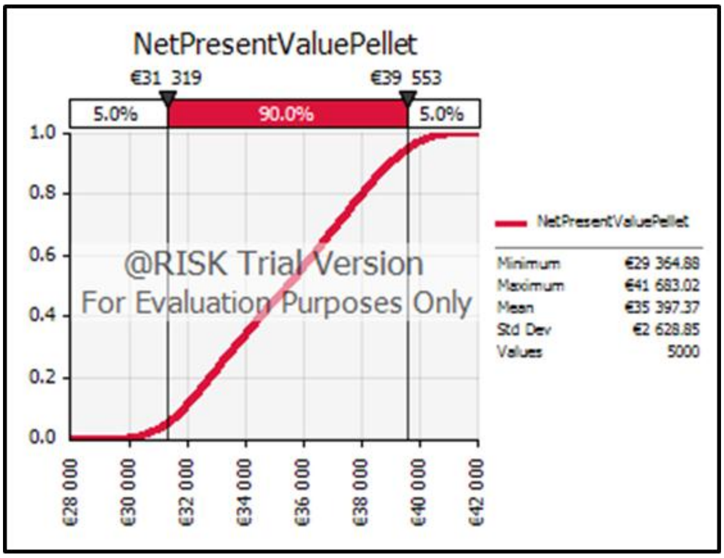


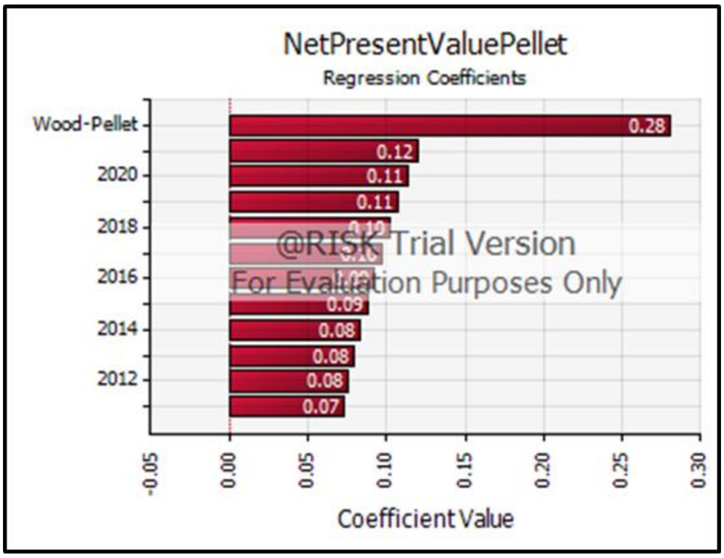
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,160	0,164
2	2021	0,119	0,933
3	2020	0,114	0,929
4	2019	0,109	0,930
5	2018	0,103	0,928
6	2017	0,100	0,929
7	2016	0,095	0,929
8	2015	0,091	0,929
9	2014	0,086	0,926
10	2013	0,083	0,925
11	2012	0,079	0,926
12	2011	0,076	0,924

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	30 700,66 €	**5 %**	32 673,06 €
Maximum	46 174,37 €	**10 %**	33 345,59 €
Mean	38 175,85 €	**15 %**	33 864,45 €
Std Dev	3 575,79 €	**20 %**	34 538,81 €
Variance	12786268,99	**25 %**	35 123,96 €
Skewness	0,015860648	**30 %**	35 745,07 €
Kurtosis	1,89674907	**35 %**	36 352,02 €
Median	38 200,82 €	**40 %**	36 959,88 €
Mode	41 844,25 €	**45 %**	37 556,87 €
Left X	32 673,06 €	**50 %**	38 200,82 €
Left P	5 %	**55 %**	38 771,73 €
Right X	43 772,24 €	**60 %**	39 384,27 €
Right P	95 %	**65 %**	39 961,23 €
Diff X	11 099,18 €	**70 %**	40 620,71 €
Diff P	90 %	**75 %**	41 228,15 €
#Errors	0	**80 %**	41 796,69 €
Filter Min	Off	**85 %**	42 378,32 €
Filter Max	Off	**90 %**	43 054,86 €
#Filtered	0	**95 %**	43 772,24 €

Wood-Pellet





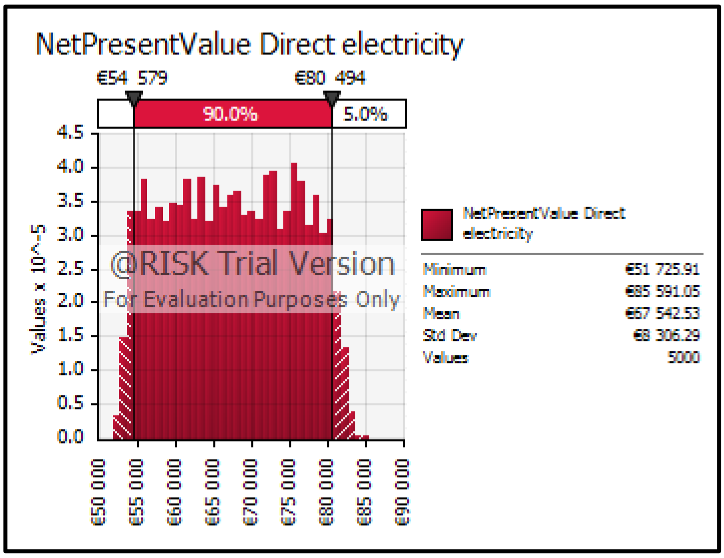


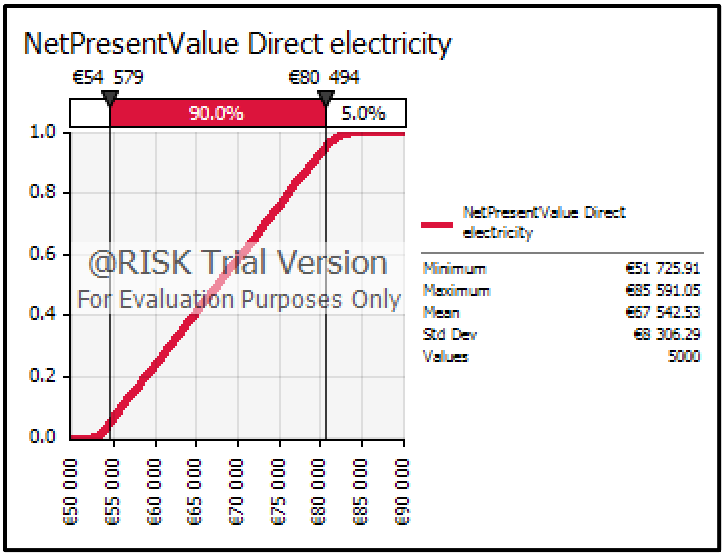
Regression and Rank Information for NetPresent			
Rank	**Name**	**Regr**	**Corr**
1	Wood-Pellet	0,281	0,258
2	2021	0,120	0,911
3	2020	0,113	0,908
4	2019	0,107	0,903
5	2018	0,102	0,903
6	2017	0,097	0,908
7	2016	0,092	0,904
8	2015	0,087	0,902
9	2014	0,083	0,904
10	2013	0,079	0,903
11	2012	0,075	0,901
12	2011	0,073	0,904

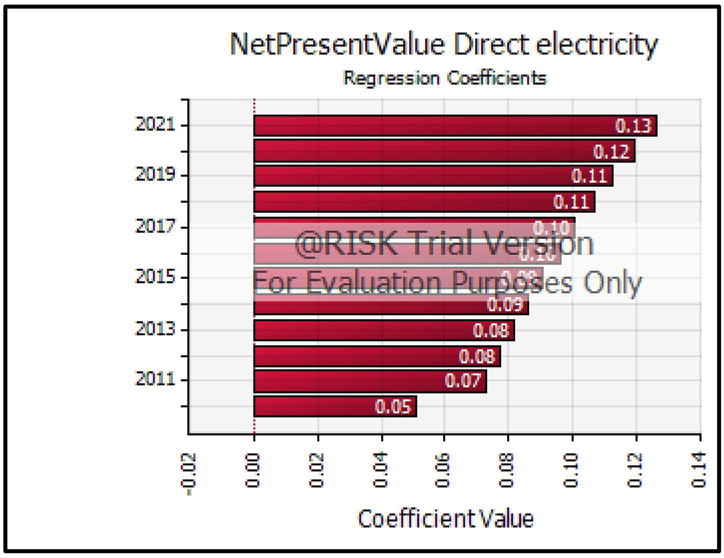
Summary Statistics for NetPresentValuePellet			
Statistics		**Percentile**	
Minimum	29 364,88 €	**5 %**	31 318,67 €
Maximum	41 683,02 €	**10 %**	31 887,19 €
Mean	35 397,37 €	**15 %**	32 366,22 €
Std Dev	2 628,85 €	**20 %**	32 756,98 €
Variance	6910869,688	**25 %**	33 168,86 €
Skewness	0,005064722	**30 %**	33 620,25 €
Kurtosis	1,992036893	**35 %**	34 060,45 €
Median	35 426,16 €	**40 %**	34 524,57 €
Mode	36 257,31 €	**45 %**	34 938,51 €
Left X	31 318,67 €	**50 %**	35 426,16 €
Left P	5 %	**55 %**	35 875,13 €
Right X	39 552,61 €	**60 %**	36 292,86 €
Right P	95 %	**65 %**	36 720,76 €
Diff X	8 233,94 €	**70 %**	37 132,04 €
Diff P	90 %	**75 %**	37 558,29 €
#Errors	0	**80 %**	37 993,37 €
Filter Min	Off	**85 %**	38 412,90 €
Filter Max	Off	**90 %**	38 942,30 €
#Filtered	0	**95 %**	39 552,61 €

Appendix 6. Detailed simulation analysis results of the New 340 m2 house.

Direct electricity



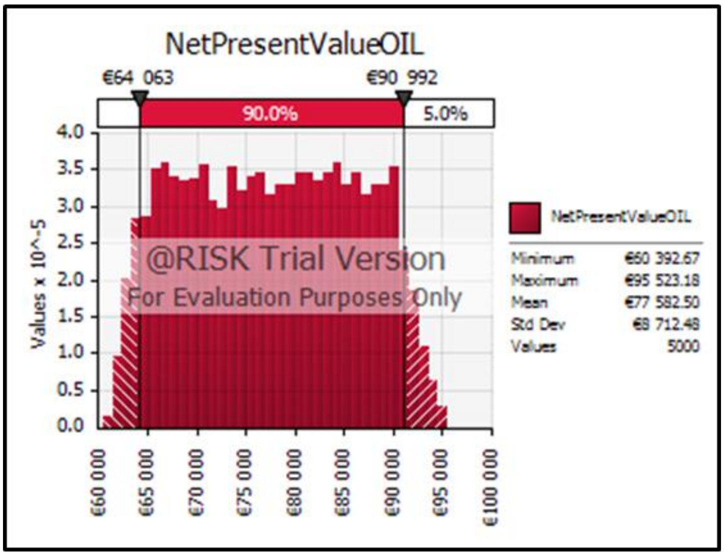


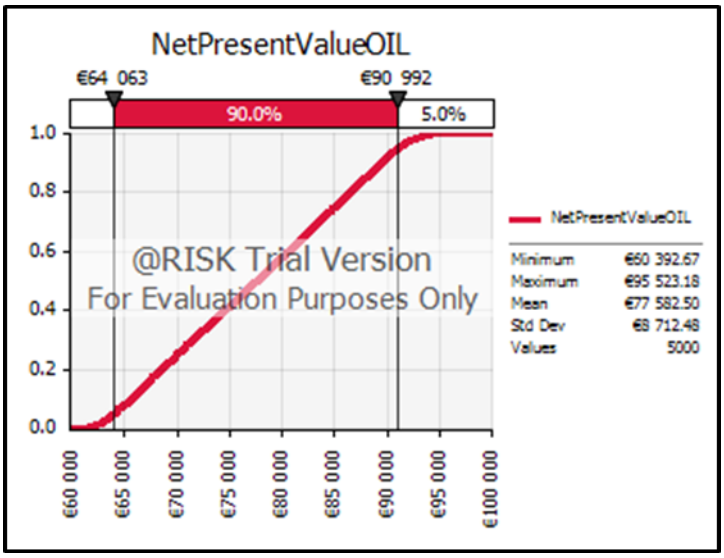


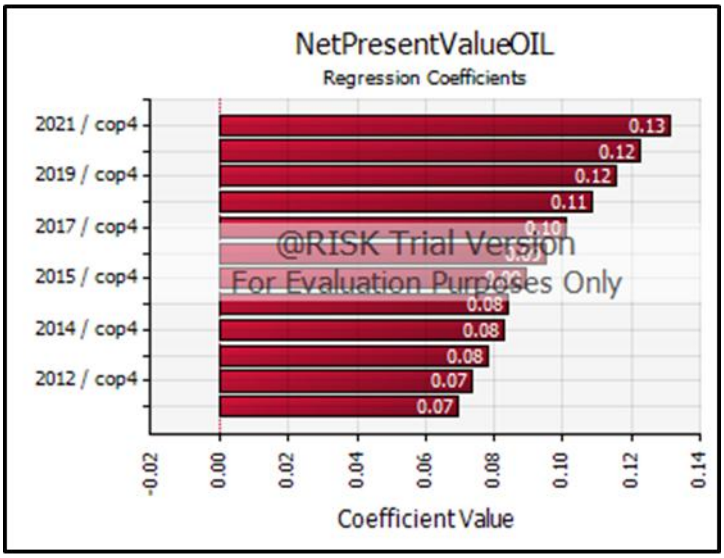
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	2021	0,126	0,942
2	2020	0,119	0,941
3	2019	0,113	0,939
4	2018	0,107	0,939
5	2017	0,101	0,937
6	2016	0,096	0,938
7	2015	0,090	0,936
8	2014	0,086	0,935
9	2013	0,081	0,936
10	2012	0,077	0,934
11	2011	0,073	0,935
12	Direct electricity	0,051	0,053

Summary Statistics for NetPresentValue Direct el			
Statistics		**Percentile**	
Minimum	51 725,91 €	**5 %**	54 578,78 €
Maximum	85 591,05 €	**10 %**	55 892,70 €
Mean	67 542,53 €	**15 %**	57 560,07 €
Std Dev	8 306,29 €	**20 %**	58 952,55 €
Variance	68994372,7	**25 %**	60 408,75 €
Skewness	0,004720748	**30 %**	61 842,83 €
Kurtosis	1,837202395	**35 %**	63 271,35 €
Median	67 566,73 €	**40 %**	64 746,39 €
Mode	55 807,72 €	**45 %**	66 086,85 €
Left X	54 578,78 €	**50 %**	67 566,73 €
Left P	5 %	**55 %**	68 906,75 €
Right X	80 493,93 €	**60 %**	70 439,57 €
Right P	95 %	**65 %**	71 923,78 €
Diff X	25 915,15 €	**70 %**	73 195,89 €
Diff P	90 %	**75 %**	74 716,40 €
#Errors	0	**80 %**	76 049,20 €
Filter Min	Off	**85 %**	77 461,37 €
Filter Max	Off	**90 %**	78 879,27 €
#Filtered	0	**95 %**	80 493,93 €

Oil



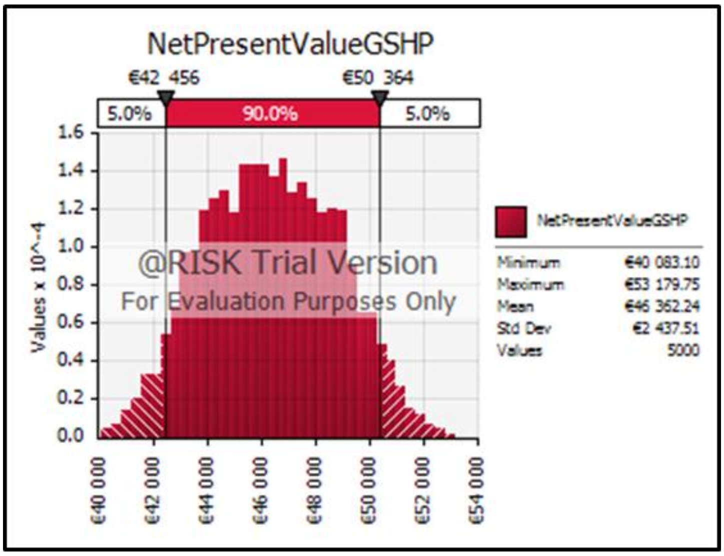


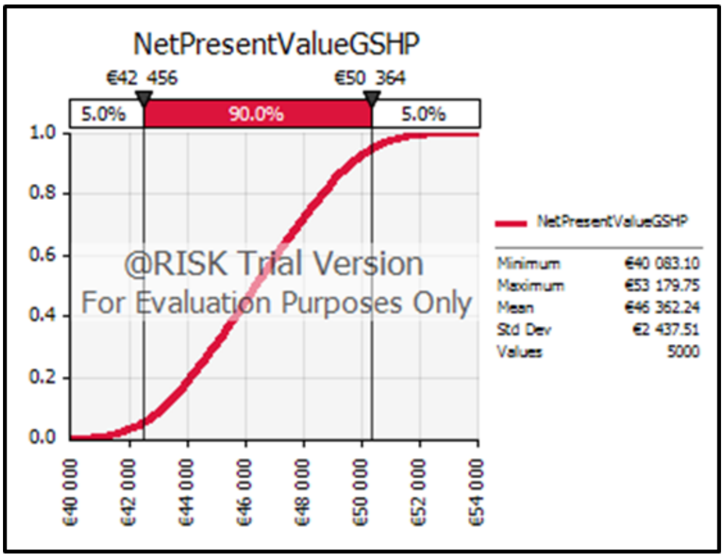


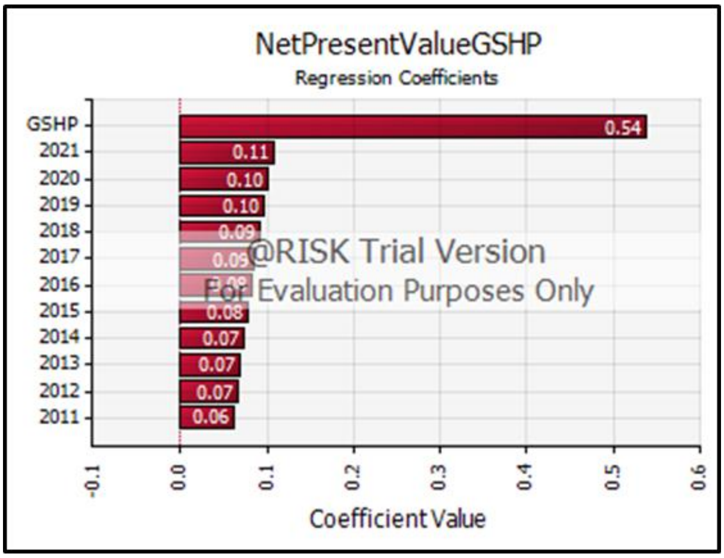
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	2021 / cop4	0,131	0,940
2	2020 / cop4	0,123	0,938
3	2019 / cop4	0,116	0,939
4	2018 / cop4	0,108	0,937
5	2017 / cop4	0,101	0,936
6	2016 / cop4	0,095	0,935
7	2015 / cop4	0,089	0,935
8	Oil	0,084	0,085
9	2014 / cop4	0,083	0,932
10	2013 / cop4	0,078	0,933
11	2012 / cop4	0,073	0,934
12	2011 / cop4	0,069	0,934

Summary Statistics for NetPresentValueOIL			
Statistics		**Percentile**	
Minimum	60 392,67 €	**5 %**	64 063,19 €
Maximum	95 523,18 €	**10 %**	65 700,39 €
Mean	77 582,50 €	**15 %**	67 073,50 €
Std Dev	8 712,48 €	**20 %**	68 578,56 €
Variance	75907372,46	**25 %**	70 033,70 €
Skewness	0,006762738	**30 %**	71 615,37 €
Kurtosis	1,851201097	**35 %**	73 156,86 €
Median	77 630,64 €	**40 %**	74 537,78 €
Mode	71 715,77 €	**45 %**	76 076,13 €
Left X	64 063,19 €	**50 %**	77 630,64 €
Left P	5 %	**55 %**	79 094,66 €
Right X	90 991,65 €	**60 %**	80 637,73 €
Right P	95 %	**65 %**	82 054,11 €
Diff X	26 928,46 €	**70 %**	83 537,79 €
Diff P	90 %	**75 %**	85 020,44 €
#Errors	0	**80 %**	86 431,14 €
Filter Min	Off	**85 %**	88 065,48 €
Filter Max	Off	**90 %**	89 486,65 €
#Filtered	0	**95 %**	90 991,65 €

GSHP



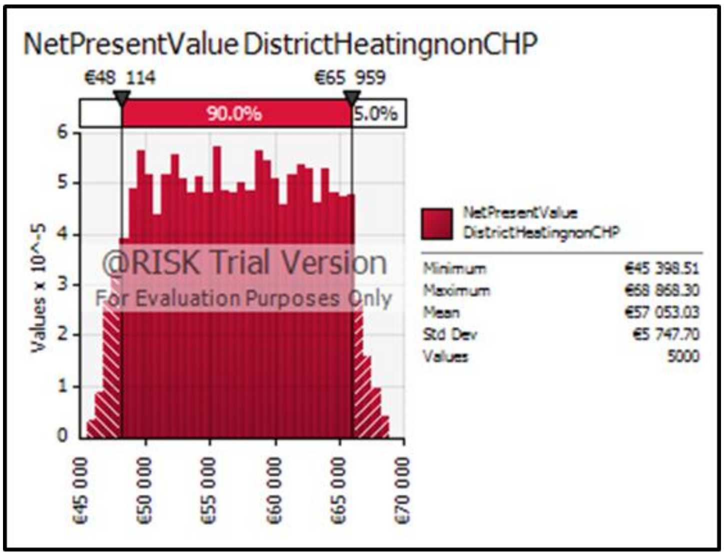


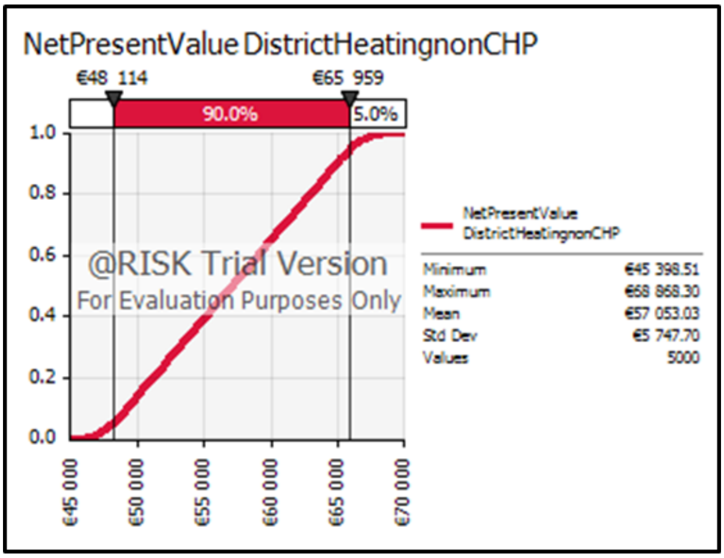


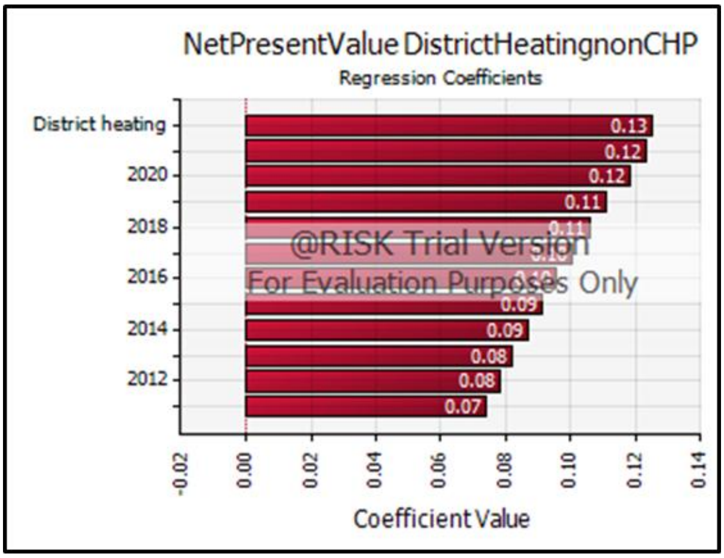
Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	GSHP	0,537	0,500
2	2021	0,108	0,807
3	2020	0,100	0,803
4	2019	0,096	0,801
5	2018	0,091	0,804
6	2017	0,086	0,805
7	2016	0,082	0,796
8	2015	0,077	0,794
9	2014	0,074	0,795
10	2013	0,069	0,794
11	2012	0,065	0,796
12	2011	0,062	0,794

Summary Statistics for NetPresentValueGSHP			
Statistics		**Percentile**	
Minimum	40 083,10 €	**5 %**	42 455,95 €
Maximum	53 179,75 €	**10 %**	43 151,64 €
Mean	46 362,24 €	**15 %**	43 668,74 €
Std Dev	2 437,51 €	**20 %**	44 094,39 €
Variance	5941453,974	**25 %**	44 500,23 €
Skewness	0,026680598	**30 %**	44 899,51 €
Kurtosis	2,347901041	**35 %**	45 280,88 €
Median	46 323,49 €	**40 %**	45 634,19 €
Mode	47 156,69 €	**45 %**	45 988,22 €
Left X	42 455,95 €	**50 %**	46 323,49 €
Left P	5 %	**55 %**	46 702,66 €
Right X	50 364,18 €	**60 %**	47 047,90 €
Right P	95 %	**65 %**	47 422,51 €
Diff X	7 908,24 €	**70 %**	47 814,02 €
Diff P	90 %	**75 %**	48 208,66 €
#Errors	0	**80 %**	48 622,05 €
Filter Min	Off	**85 %**	49 049,63 €
Filter Max	Off	**90 %**	49 573,90 €
#Filtered	0	**95 %**	50 364,18 €

District heating without CHP



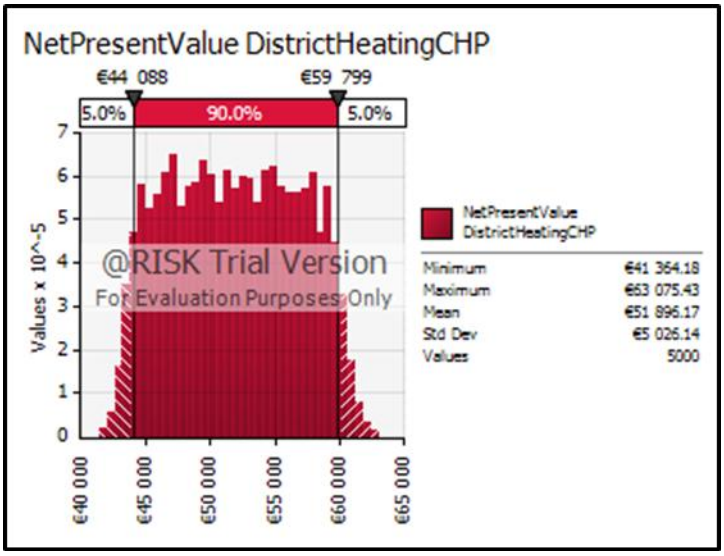


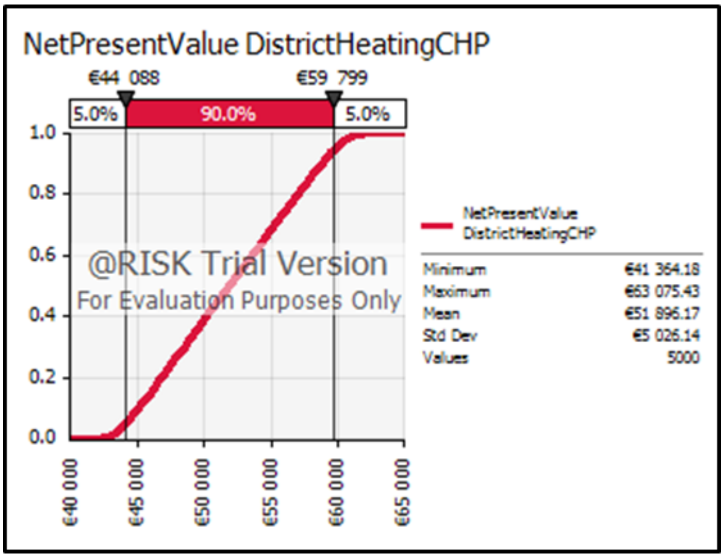


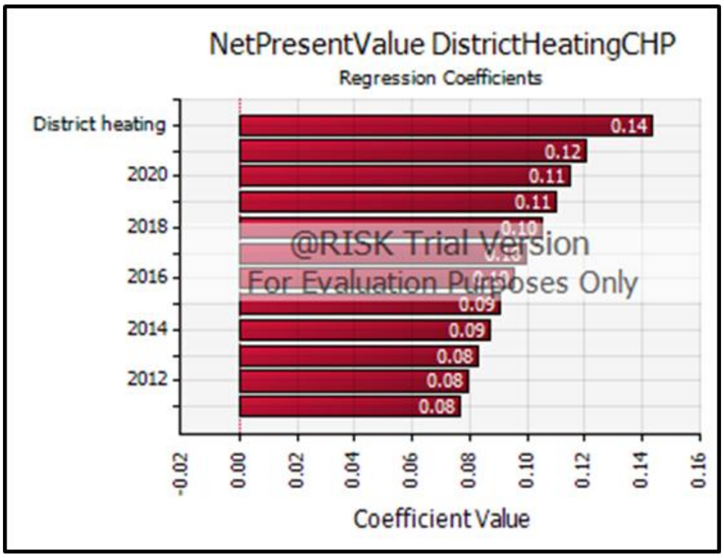
Regression and Rank Information for NetPresent\			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,125	0,088
2	2021	0,124	0,934
3	2020	0,118	0,935
4	2019	0,111	0,932
5	2018	0,106	0,933
6	2017	0,100	0,933
7	2016	0,095	0,930
8	2015	0,091	0,932
9	2014	0,087	0,931
10	2013	0,082	0,929
11	2012	0,078	0,929
12	2011	0,074	0,929

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	45 398,51 €	**5 %**	48 113,82 €
Maximum	68 868,30 €	**10 %**	49 220,66 €
Mean	57 053,03 €	**15 %**	50 100,34 €
Std Dev	5 747,70 €	**20 %**	51 184,43 €
Variance	33036046,14	**25 %**	52 133,83 €
Skewness	0,003437092	**30 %**	53 129,15 €
Kurtosis	1,86841764	**35 %**	54 139,53 €
Median	57 067,27 €	**40 %**	55 134,93 €
Mode	52 063,57 €	**45 %**	56 040,57 €
Left X	48 113,82 €	**50 %**	57 067,27 €
Left P	5 %	**55 %**	58 090,61 €
Right X	65 958,89 €	**60 %**	59 020,38 €
Right P	95 %	**65 %**	59 977,32 €
Diff X	17 845,07 €	**70 %**	60 970,56 €
Diff P	90 %	**75 %**	61 945,13 €
#Errors	0	**80 %**	62 903,56 €
Filter Min	Off	**85 %**	63 894,21 €
Filter Max	Off	**90 %**	64 924,00 €
#Filtered	0	**95 %**	65 958,89 €

CHP District heating



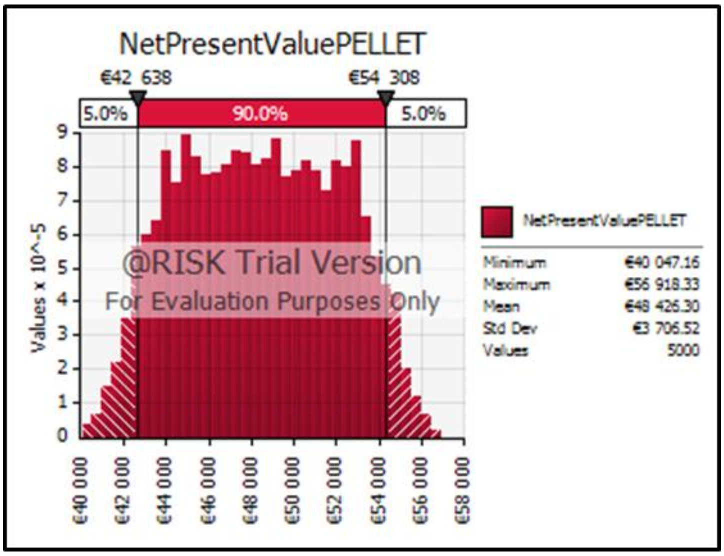


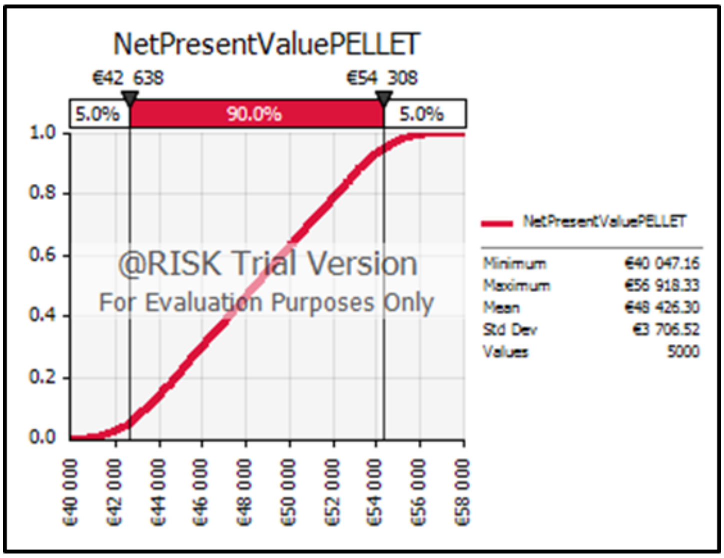


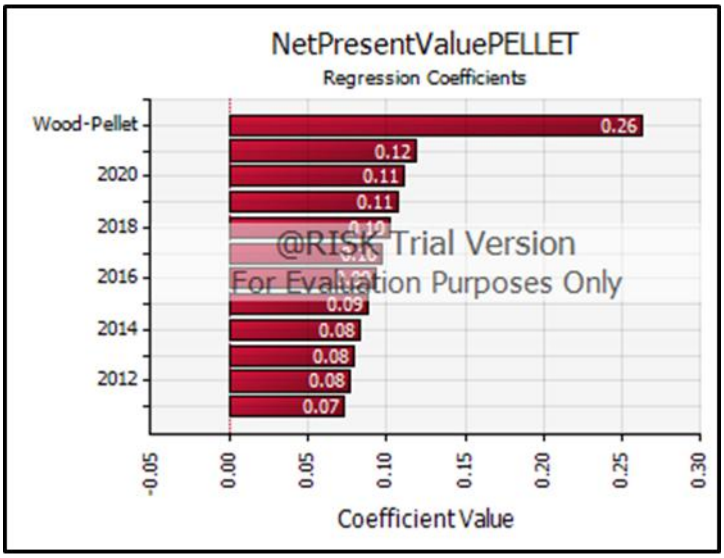
Regression and Rank Information for NetPresentV			
Rank	**Name**	**Regr**	**Corr**
1	District heating	0,143	0,125
2	2021	0,121	0,934
3	2020	0,115	0,933
4	2019	0,110	0,931
5	2018	0,105	0,932
6	2017	0,099	0,931
7	2016	0,095	0,931
8	2015	0,090	0,927
9	2014	0,087	0,929
10	2013	0,083	0,928
11	2012	0,079	0,926
12	2011	0,076	0,928

Summary Statistics for NetPresentValue DistrictH			
Statistics		**Percentile**	
Minimum	41 364,18 €	**5 %**	44 087,69 €
Maximum	63 075,43 €	**10 %**	45 040,53 €
Mean	51 896,17 €	**15 %**	45 990,89 €
Std Dev	5 026,14 €	**20 %**	46 775,84 €
Variance	25262033,08	**25 %**	47 558,66 €
Skewness	0,02290738	**30 %**	48 517,02 €
Kurtosis	1,889869538	**35 %**	49 343,53 €
Median	51 861,52 €	**40 %**	50 143,00 €
Mode	46 348,93 €	**45 %**	51 019,08 €
Left X	44 087,69 €	**50 %**	51 861,52 €
Left P	5 %	**55 %**	52 707,22 €
Right X	59 798,61 €	**60 %**	53 561,16 €
Right P	95 %	**65 %**	54 457,49 €
Diff X	15 710,93 €	**70 %**	55 248,77 €
Diff P	90 %	**75 %**	56 125,41 €
#Errors	0	**80 %**	57 024,44 €
Filter Min	Off	**85 %**	57 869,84 €
Filter Max	Off	**90 %**	58 842,09 €
#Filtered	0	**95 %**	59 798,61 €

Wood-Pellet







Regression and Rank Information for NetPresent\			
Rank	Name	Regr	Corr
1	Wood-Pellet	0,263	0,268
2	2021	0,119	0,911
3	2020	0,111	0,910
4	2019	0,107	0,908
5	2018	0,102	0,908
6	2017	0,097	0,911
7	2016	0,093	0,911
8	2015	0,088	0,909
9	2014	0,083	0,908
10	2013	0,079	0,907
11	2012	0,076	0,909
12	2011	0,072	0,906

Summary Statistics for NetPresentValuePELLET			
Statistics		**Percentile**	
Minimum	40 047,16 €	**5 %**	42 638,28 €
Maximum	56 918,33 €	**10 %**	43 462,91 €
Mean	48 426,30 €	**15 %**	44 132,05 €
Std Dev	3 706,52 €	**20 %**	44 764,34 €
Variance	13738310,46	**25 %**	45 328,12 €
Skewness	0,00845565	**30 %**	45 956,45 €
Kurtosis	1,990023015	**35 %**	46 580,14 €
Median	48 405,18 €	**40 %**	47 191,05 €
Mode	49 820,30 €	**45 %**	47 807,98 €
Left X	42 638,28 €	**50 %**	48 405,18 €
Left P	5 %	**55 %**	49 022,99 €
Right X	54 307,53 €	**60 %**	49 629,26 €
Right P	95 %	**65 %**	50 241,29 €
Diff X	11 669,26 €	**70 %**	50 871,71 €
Diff P	90 %	**75 %**	51 508,42 €
#Errors	0	**80 %**	52 132,12 €
Filter Min	Off	**85 %**	52 780,72 €
Filter Max	Off	**90 %**	53 422,32 €
#Filtered	0	**95 %**	54 307,53 €

Appendix 7. Energy price data.

Direct electricity

	Formula used for forecasting the annual growth(End year/Year 1)^(1/number of years - 1) = x			
	Source: http://www.energiamarkkinavirasto.fi/data.asp?articleid=2703&pgid=67&languageid=246			
		Energiamarkkinavirasto, example house L2 (small single family house. Annual average use 20 000 kWh)		
	June prices		Annual growth rate	1,081576
Direct Electricity		Cent/kWh		
	2001	5,4915753		
	2002	5,9555438		
	2003	6,9528051		
	2004	6,9077266		
	2005	6,7964092		
	2006	7,2941452		
	2007	7,645428		
	2008	8,83		
	2009	9,44		
	2010	9,94		
	2011	12,03		
	2012	**13,01135**		
	2013	**14,07276**		
	2014	**15,22076**		
	2015	**16,4624**		
	2016	**17,80533**		
	2017	**19,25781**		
	2018	**20,82877**		
	2019	**22,52789**		
	2020	**24,36562**		
	2021	**26,35326**		

Oil

	Formula used for forecasting the annual growth(End year/Year 1)^(1/number of years - 1) = x			
	Source: http://pxweb2.stat.fi/Dialog/varval.asp?ma=040_ehi_tau_104_fi&ti=Polttonesteiden+kuluttajahinnat+%28sis%E4lt%E4%E4+alv%3An%29&path=../Database/StatFin/ene/ehi/&lang=3&multilang=fi			
		Tilastokeskus (statistics Finland) prices include VAT		
	June prices		Annual growth rate	1,092566
Oil		Cent/l		
	2001	44,065		
	2002	34,776		
	2003	36,12		
	2004	42,7		
	2005	60,716		
	2006	67,8		
	2007	62,5		
	2008	102,5		
	2009	62,9		
	2010	80		
	2011	106,8		
	2012	**116,6861**		
	2013	**127,4872**		
	2014	**139,2883**		
	2015	**152,1816**		
	2016	**166,2685**		
	2017	**181,6593**		
	2018	**198,4749**		
	2019	**216,8469**		
	2020	**236,9196**		
	2021	**258,8503**		

Wood-Pellet

Formula used for forecasting the annual growth(End year/Year 1)^(1/number of years - 1) = x

Source: Finnish Pellet Energy Association.

Acquired by Email (14.3.2011) from the association’s executive director. 2002- 2008 data is based on Vapo’s statistics, 2008-2011 data is based on statistics Finland data.

June prices | Annual growth rate 1,077366

Wood-Pellet	Cent/kWh
2002	2,7
2003	2,7
2004	2,7
2005	3
2006	3,4
2007	3,7
2008	4,2
2009	5,3
2010	5,18
2011	5,28
2012	5,6884936
2013	**6,128591**
2014	**6,602737**
2015	**7,113565**
2016	**7,663915**
2017	**8,256843**
2018	**8,895644**
2019	**9,583866**
2020	**10,32533**
2021	**11,12417**

District heating

Formula used for forecasting the annual growth(End year/Year 1)^(1/number of years - 1) = x

Source: http://www.energia.fi/tilastot/kaukolammon-hinnat-tyyppitaloissa-eri-paikkakunnilla

Finnish Energy Industries

July prices

District heating	Annual growth rate 1,07789439509476	Annual growth rate 1,07251043602201
	District heating without CHP	CHP District heating
	€/MWh	€/MWh
2004	50,06	46,32
2005	52,83	48
2006	58,88	52,75
2007	60,43	55,43
2008	67,55	60,72
2009	71,32	66,59
2010	79,21	70,06
2011	84,63	75,61
2012	**91,2222**	**81,0925**
2013	**98,3279**	**86,9726**
2014	**105,987**	**93,279**
2015	**114,243**	**100,043**
2016	**123,142**	**107,297**
2017	**132,734**	**115,077**
2018	**143,073**	**123,421**
2019	**154,218**	**132,371**
2020	**166,23**	**141,969**
2021	**179,179**	**152,263**