Analysis of risk mitigation benefits for investments into energy efficient and renewable process heat technologies

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Abstract

The European industrial process heat sector stands for around 28% of the total European energy consumption and is still mainly run by conventional and carbon emitting fuel sources. The main reason for the lack of energy efficient and renewable systems within this sector is because investors often perceive investments into process heat as too risky.

An analysis showed that energy contracting schemes and risk mitigation measures have been successfully used in other sectors to decrease the risk perception. While applying them to the process heat sector, specifically to solar thermal process heat systems, a risk assessment model with a risk-adjusted discount rate was developed. The discount rate allowed implementing the risk assessment into an investment analysis, which was conducted for different locations throughout Europe. Each location was assessed based on several risk factors each without and with risk mitigation. Out of different investment parameters solely the NPV (net present value) proved useful when showing how risk mitigation can positively influence the investment assessment of solar thermal process heat systems.

Risk mitigation measures yielded the highest impact in locations with initially high cash flows, e.g. Seville attained an extensive benefit through risk mitigation. The technology cost, as a critical input parameters, proved the benefit of risk mitigation for Seville. As it would need a decrease of technology cost from 400 €/m^2 to 284 €/m^2 at normal risk. Though, with risk mitigation it would only have to be decreased to 332 €/m^2, so that Seville reaches financial viability.

Keywords

Process heat; risk mitigation; energy contracting; net present value; internal rate of return; energy efficiency; renewable energy

Resumo

No sector dos processos industriais, o calor representa cerca de 28% do consumo total de energia na Europa e é principalmente obtido a partir de fontes de combustíveis convencionais. A principal razão para a falta de sistemas mais eficientes e renováveis neste sector é porque investimentos no processamento do calor são tidos como muito arriscados.

Existem análises que mostram que esquemas de contratação da energia e medidas de mitigação de risco têm sido amplamente utilizados noutros sectores para diminuir a percepção de risco. Quando aplicadas ao sector de processamento de calor, especificamente aos sistemas solar térmicos, um modelo de avaliação de risco foi desenvolvido baseado numa taxa de desconto ajustada ao risco, permitindo implementar a avaliação de risco numa análise de investimento. Diferentes locais foram avaliados com base em vários factores de risco cada sem e com mitigação de risco. Dos diferentes parâmetros de investimento, o VAL (valor actual líquido) mostrou-se útil quando se mostra como a mitigação de risco pode influenciar positivamente a avaliação de investimentos de sistemas solares térmicos.

As medidas de redução do risco geraram o maior impacto em locais com fluxos de caixa inicialmente elevados. O exemplo Sevilha alcançou um grande benefício através da mitigação de riscos. Neste caso, o custo da tecnologia, um parâmetro de entrada crítico, com a mitigação de risco diminuiu de 400 €/m^2 para 332 €/m^2, em vez dos 284 €/m^2 para um risco normal, permitindo que Sevilha atinja a viabilidade financeira.

Palavras-chave

Calor de processo; mitigação dos riscos; contratação de energia; valor presente líquido; taxa interna; eficiência energética; energias renováveis

Table of Contents

Table of Figures

List of Tables

Abbreviations

ABS	Asset-backed securities
B2B	Business-to-business
BAU	Business-as-usual
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
CAPEX	Capital expenditure
CDS	Credit default swaps
CHP	Combined heat and power
CPC	Compound parabolic concentrated
DECC	Department of Energy & Climate Change
E3P	European Energy Efficiency Platform
EC	European Commission
ECB	European Central Bank
EEP	“Energie Einspar Protect“
EEX	European Energy Exchange
EJ	Exajoule
EPC	Energy performance contracting
EPC	Engineering, procurement and construction
ESCO	Energy service company
ESO	Energy savings opportunity
ESTIF	European Solar Thermal Industry Federation
ETC	Evacuated tube collectors
FPC	Flat-plate collectors
GHG	Greenhouse gas emissions
GSR	Guarantee of solar results
IDCM	Independent debt capital markets
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
JRC	Joint Research Center
KfW	“Kreditanstalt für Wiederaufbau”
KPI	Key performance indicators
ktoe	Kilo ton of oil equivalent
LCOE	Levelized cost of energy
LCOH	Levelized cost of heat
LIBOR	The London inter-bank offered rate
LNG	Liquefied natural gas
Mtoe	Million ton of oil equivalent
NFM	Non-ferrous metals
NMM	Non-metallic minerals

NPV	Net present value
O&M	Operations and maintenance
OECD	Organization for Economic Co-operation and Development
OPEX	Operational expenditure
PJ	Petajoule
PPA	Power-purchase-agreement
PV	Photovoltaic
R&D	Research and development
RADR	Risk-adjusted discount rate
REN21	Renewable Energy Policy Network for the 21st Century
REPIN	Renewable Energy Platform for Institutional Investors
RFDR	Risk-free discount rate
SEEF	SUSI Energy Efficiency Fund
SME	Small and medium-sized enterprises
SPV	Special purpose vehicle
SUSI	Sustainable Investments
SUSI RE II	SUSI Renewable Energy Fund II
Toe	Ton of oil equivalent
TRFC	The Renewable Finance Company
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added tax
WACC	Weighted average cost of capital

Nomenclature

Symbol	*Description*	*Unit*
P_c	Conventional fuel price	€/kWh
DR	Debt ratio	%
E	Energy produced	kWh
E_r	Energy produced from renewable source	kWh
E_s	Energy savings	kWh
ER	Equity ratio	%
CF_{fin}	Financial cash flow	€/m^2
FC	Financial cost of credit and interest repayments	€/m^2
Inc	Financial incentive	€/m^2
CF_{fis}	Fiscal cash flow	€/m^2
I_{rf}	Impact of risk factor	%
Inf	Inflation	%
i	Interest rate of debt or equity	%
CF_{inv}	Investment cash flow	€/m^2
T	Investment lifetime	a
I	Investment or CAPEX	€/m^2
Dep	Linear annual depreciation	€/m^2
OM	Operation and maintenance cost as percentage of CAPEX	%
CF_{op}	Operational cash flow	€/m^2
P	Premium for end-user	%
P_{rf}	Probability of risk factor	%
RV	Residual value	€/m^2
r_{RPD}	Risk premium for debt	%
r_{RPE}	Risk premium for equity	%
C_D	Risk-adjusted cost of debt	%
C_E	Risk-adjusted cost of equity	%
r_{RF}	Risk-free discount rate	%
Tax	Tax rate as percentage of taxable income	%
CF	Total cash flow	€/m^2
TRS	Total risk score	-
$WACC$	Weighted average cost of capital	%
t	Year	a

1. Introduction

1.1. Problem Definition

The anthropogenic climate change is mainly due to the human usage of carbon containing fossil fuels in the transportation, electricity, heating and processing industry sectors. It has been enhanced and fostered since the beginning of the industrial revolution. Especially in the last decade increasing awareness was raised and policy makers in Europe and around the world introduced legislative changes to decarbonize the above mentioned sectors, which were and still mostly are based on fossil fuels. The most recent and decisive moment in political terms has been the United Nations Climate Change Conference COP21 in Paris in December, 2015 [C2ES, 2015]. Political leaders from around the world came together in Paris negotiating and finally agreeing on main steps towards decreasing the usage of carbon containing fossil fuels.

The amounts of emitted CO_2 are supposed to be decreased, mainly through energy efficiency measures and renewable energy sources. Though, a large focus has been laid on the generation of electricity as a mean of decreasing carbon emissions. As an example, the EU has primarily focused on PV (photovoltaic) and wind power plants from the beginning of first renewable energy policies [PHILIBERT, 2006]. As well, power generation and the residential sector have been treated with a higher priority than industrial sectors [TAIBI ET AL., 2010]. Despite the fact that electricity generation only accounted for 19% of the final global energy consumption in 2009 [IEA, 2012a].

The potential of decreasing the use of conventional energy sources in the processing industry by means of energy efficiency or through renewable energy technologies has "[…] not attracted sufficient attention" [IRENA, 2015b] by political and economic stakeholders. Hence, renewable energy still plays a relative small role in industry [TAIBI ET AL., 2010]. The solar thermal industry stands exemplary for this situation and the president of the ESTIF (European Solar Thermal Industry Federation), Robin M. Welling, clearly states that the solar thermal market is "[…] not on track to realize the industry potential" [ESTIF, 2015]. The mentioned potential refers explicitly to the use of process heat in the industry and not to the total energy demand of the processing industry, as this would include the electricity demand. Process heat is used in industrial processes where energy is the transformation driver in different process units [BANERJEE ET AL., 2012].

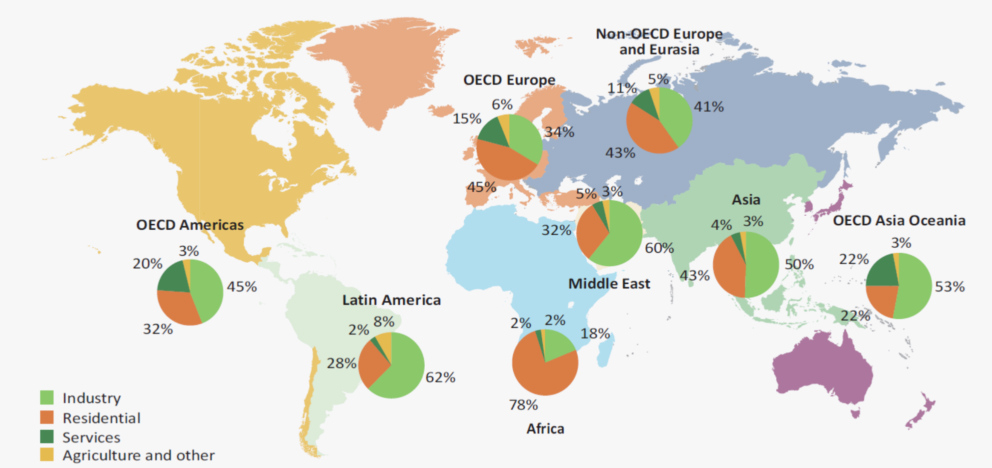


Figure 1: Global heat consumption by region in various sectors in 2009 [IEA, 2012a]

Alone in 2005 the industrial sector accounted for about 30% (115 EJ) of the global final energy use [BANERJEE ET AL., 2012]. Up to 2009 the global industrial sector increased its final energy use to 128 EJ [IRENA, 2015b]. These figures include the energy used in form of electricity. Industrial process heat demand, without electricity, represents about 25% of the global final energy use [PHILIBERT, 2006]. In addition to the above figures researchers have revealed through an exergy analysis that the global industry energy efficiency is only 30% and clearly needs further improvement [BANERJEE ET AL., 2012].

For Europe, researchers from the German Aerospace Center conducted a recent study to estimate the process heat demand for the EU28 member states. Their calculations yielded a total demand of 7356 PJ. More than one-third of European heat demand stems from the industry, including heating for buildings and warm water. *Figure 1* displays that 34% of the total heat consumption in OECD countries in Europe stems from the industrial sectors [IEA, 2012a]. The majority though is process heat, which hence accounts for about 25 – 28% of European total energy demand [NAEGLER ET AL., 2015]. In all other parts of the world, besides Africa, the share of heat consumed by the industry is even higher. Up to almost double the European share, with 62% in Latin America (*Figure 1*).

It becomes clear that there is a large sector that needs to be further addressed by policy makers and yet lacks a sufficient level of awareness by industry leaders and investors, especially with regard to implementing new and less carbon emitting heat generating technologies. Additionally, companies in Europe have to cope with a serious cost disadvantage for energy commodities, especially in comparison to the USA. One of the main energy sources for process heat is natural gas, which, in Europe, has traded at a wholesale price twice that of the US price in 2014 [MOE, 2014]. This means European companies need to be twice as energy efficient to be able to compete with US competitors on an energy cost basis.

To be able to tackle these problems and decrease the energy cost for European processing companies and the amounts of CO_2 that are emitted by this sector, energy efficiency measures and renewable process heat generation will be closer analyzed in the scope of this thesis work.

1.1.1. Energy Efficiency and Renewable Energy Potential for Industrial Process Heat

Just as for energy efficiency measures and renewable energy technologies in the electricity generating sector, there is a large potential for the use of these technologies in process heat applications. Applying these technologies will help in decreasing the final energy cost and the amount of emitted CO_2 in the long run.

Possible energy efficiency measures are to recycle materials or to reuse energy through waste heat recovery. This partially includes the production of energy through co-generation and poly-generation plants, such as CHP (Combined Heat and Power) plants. This kind of generation plants reuse waste heat that is normally lost to the environment, e.g. for the use in either district heating systems or so it can be converted into mechanical power. Further components that are considered to ensure energy efficiency are heat exchangers, economizers and heat pumps. Additionally, energy efficiency improvements often come along with further benefits, next to reduced energy use, such as decreased emissions, waste and lower O&M costs [BANERJEE ET AL., 2012].

The main technologies based upon renewable sources are biomass and solar thermal, the latter is especially viable for low and mid temperature process heat applications. Biomass is the main alternative towards fossil fuel sources and as well applicable to energy-intensive sectors with high temperature process heat demands. Low temperature heat can as well be supplied by geothermal systems and heat pumps [IRENA, 2016a].

The IEA (International Energy Agency) estimates in its alternative policy scenario that, in 2030, more than half of the energy savings in industry sectors can be achieved through energy efficiency measures in the iron and steel, chemicals and non-metallic products sectors. If this scenario goes hand in hand with an increased growth of renewables in the processing industry, an increase of industrial growth can come along without additional CO_2 emissions [BANERJEE ET AL., 2012; IEA, 2006]. Currently, renewable energy technologies account for about 9% of the total energy use in the industry, mainly because of bagasse and rice husk in the sugar industry, just as biogas and black liquor in pulp and paper [BANERJEE ET AL., 2012].

In the REmap 2030 by the IRENA (International Renewable Energy Agency), which explores the potential and cost of doubling the renewable energy share in the global energy mix and the rate of energy efficiency measures by 2030, the industrial energy need that is assumed to be covered by renewables mainly is based on biomass and biogas (*Figure 2*). The heat generation sector is shown to have the largest potential for renewables up to 2030.

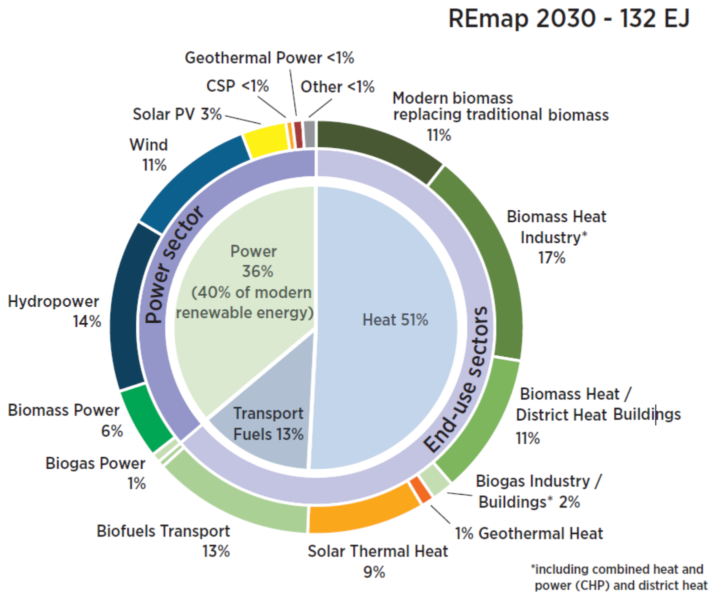


Figure 2: Renewable resources in 2030 after REmap [IRENA, 2015a]

An analysis by TAIBI ET AL. estimates that the renewable share in industry is likely to rise to around 50 EJ/year of the final energy used by the industry in 2050 [TAIBI ET AL., 2010]. Though, current development towards a higher share of renewable sources in process heat production is still hindered through different aspects. One main aspect is the economic viability of investments into new and more efficient process heat technologies, which will be a main focus of this work.

1.1.2. Economic Drawbacks

The financial benefits of energy efficiency measures and renewable heat technologies are cost savings. For the former reduced energy use results into a reduced cost for energy. The latter entails an increased usage of renewable sources that are offered at a lower cost than the conventional source, as well resulting into a reduced cost for energy. Both yield relatively small annual cost savings in comparison to the large upfront investment cost. The main consequences that evolve from relative small annual cost savings are high pay-back periods and consequently low IRRs, two financial parameters which are used readily by investors [STARNBERGER ET AL., 2015].

When an end-user considers investing into an upgrade of his technologies he will often have a constrained budget available and different investment options at hand. An update of a process heat system might be compared to an update of the production line. The former will mostly take longer to pay back through its energy savings than the latter through an increased production capacity. Hence, if an end-user has an available budget he will often favor other investment options than an upgrade of its process heat applications.

For third-party investors a main problem is that the cost savings attained from more energy efficient process heat technologies are considered to be difficult to secure [BANERJEE ET AL., 2012]. The consequence is that precisely what these investments offer is not attractive enough for investors. Hence, securing the main benefits of an update of process heat generating technologies, the energy cost savings, is a critical issue to increase the investment volume into process heat.

Especially the use of the pay-back period as a financial criterion is critical, as it does not account for the total benefits of an investment into energy efficient or renewable heat technologies. An example in *Table 1* and *Figure 3* clarifies how using the pay-back period criterion can lead to disregarding favorable options.

The pay-back period criterion will always favor an investment with a low pay-back period over an investment with a larger pay-back period, no matter what the lifetime of the investments and the eventual benefits that can be attained after the pay-back period [PHILIBERT, 2006]. As an example, two €10,000 investments are compared to each other. The first option has an investment lifetime of four years and is shown in comparison to an investment of eight years lifetime in *Table 1* and *Figure 3*. Investment 1 over four years has a simple pay-back period of 2.5 years, which is shorter than the 4.33 years of simple pay-back period of the investment over eight years. Hence, the first investment option would be favored if the pay-back period would be applied as evaluation criterion, which would neglect the additional cash flows of both options that occur after the pay-back period. Over the total lifetime, the second option actually yields a higher IRR and NPV (at the same discount rate of 4%), which concludes that this is the favorable option. Most investments into energy savings are rather long-lived investments and therefore yield a great amount of their benefit after the pay-back. They are hence deprived by the pay-back period criterion.

Table 1: Comparison of two investment examples

Year	0	1	2	3	4	5	6	7	8
Investment 1	-10,000	4,000	4,000	4,000	4,000	0	0	0	0
Investment 2	-10,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000

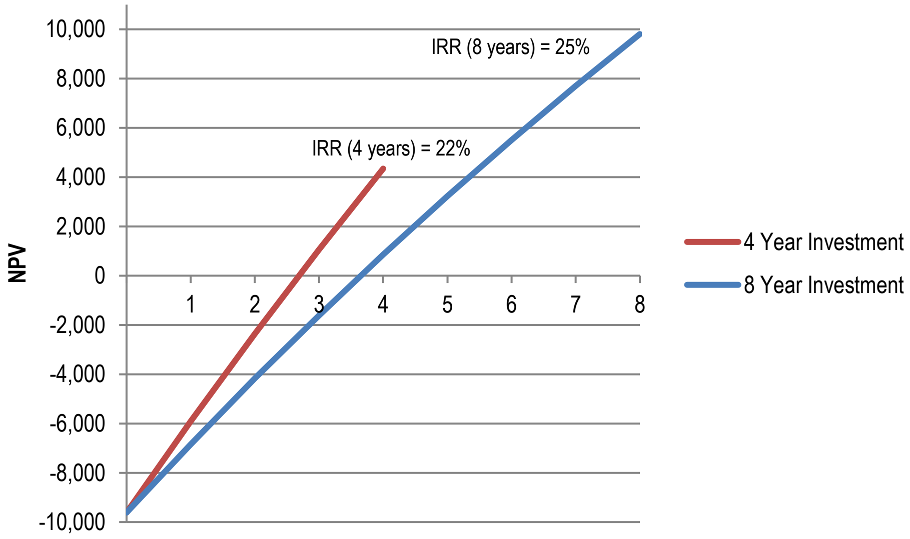


Figure 3: Investment parameters of examples

A further issue is the lack of investment for energy efficient or renewable process heat systems. Despite an increase of global investment into energy efficiency technologies from $710 million in 2005 to $1.1 billion in 2006 [UNEP, 2007], these amounts still represent a rather small share of total investments into the global industrial sector of $1379 billion in 2005 [UNFCCC, 2008]. Just to keep global CO_2 emissions to the 2005 level, the UNFCCC (United Nations Framework Convention on

Climate Change) estimates that $19.1 billion will have to be invested into energy efficiency measures in the industry up to 2030.

A different source yields other values for the total global investment into energy efficiency measures just a couple years later. It defines the total investment as "[…] the monetary value of public expenditure, private funds, public-private ventures and commercial commitments to technologies and assets that lead directly and indirectly to energy savings relative to business-as-usual scenarios" [REN21, 2016]. It calculated that $130 billion were invested into energy efficiency measures in the buildings, transport and industry sectors in 2013 [REN21, 2016]. The amount of investments that are summed up by REN21 (Renewable Energy Policy Network for the 21st Century) is larger than the one accounted for by the UNEP (United Nations Environment Program) source, which is why the large numerical difference is to be noticed. This is mainly because the REN21 source as well included public expenditure and commercial commitments that indirectly led to energy savings. Next to the fact that energy efficiency investments in industrial sectors are rather rare in comparison to the total investments into the industry, a problem is the lacking focus on energy efficiency measures for process heat systems instead of power generating systems.

Investment into renewable energy sources is as well constantly increasing globally, up to $285.9 billion in 2015 (excluding hydropower projects larger than 50 MW). This represents a rise of 5% towards the previous year and the highest total investment volume ever into renewable energies [REN21, 2016]. Most of these investments though go into two electricity generating technologies, which are wind and solar power. In terms of investment volume they lead the other renewable energy sources by far. This verifies that the current focus is strongly on reducing CO_2 emissions through the electricity sector, but not through the heat or transportation sector.

Solar power globally stands for more than 56% of the total investment into renewable source with $161 billion invested in 2015 (*Figure 4*). Investment into wind power just falls short of that, with $109 billion in 2015. Furthermore, these are the only two sectors in which the investment volume increased in comparison to the previous year. Other sectors, such as biomass, waste-to-energy, small-scale hydropower, geothermal and biofuels all had to cope with a decreased investment volume in 2015. Biomass and waste-to-energy represent the largest of the remaining sectors (without wind and solar power) in terms of total global investment with $6 billion [REN21, 2016].

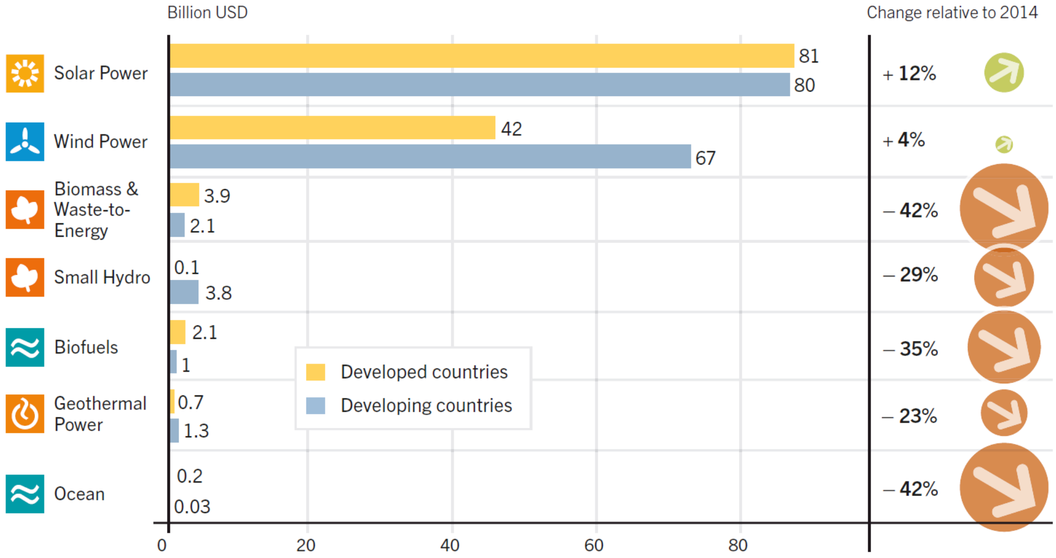


Figure 4: Global investment into renewable energy in 2015 [REN21, 2016]

In Europe the situation looks somewhat worse, of the total $48.8 billion that were invested in 2015 into renewable energies around 58% were allocated to wind power and the total investment volume decreased by 21% from 2014. The large part of the remaining 42% share was invested into electricity generating technologies as well [FRANKFURT SCHOOL, 2016]. For investments into renewable energy systems the same issue as for energy efficiency measures is prevalent, there is a too little focus on process heat systems and the large amount of funds are utilized for updating power generating systems. Process heat generating technologies are hence largely neglected and clearly need additional investment that is allocated to the upgrade of process heat technologies in the industry.

A report on the investor landscape in the renewable energy sector in Europe states that investors take different approaches toward tackling the current energy market changes. Large utilities have recently sold large shares of their renewable energy portfolios, in reaction to an increasing downward pressure on energy prices due to an increase of renewables in the energy mix. The large European utilities divested $7.2 billion of their renewable assets only in 2013 [GCF ET AL., 2013]. Additionally, especially infrastructure funds seek stable and safe investments in well-regulated markets, this means a technology needs to be proven and already in place and successfully financed elsewhere. This is mostly not the case for process heat technologies and updates of these technologies and hence represents a further financing barrier towards their further deployment.

An additional problem is the lack of public support. The most effective measures to enhance further investment into energy optimizations have been found to be government grants, soft loans and tax incentives. Tough, these supportive instruments have been perceived as to be rarely available, especially for process heat applications, due to public budget limitations and complex and demanding application procedures [STARNBERGER ET AL., 2015].

This perception has been verified by JANEIRO ET AL. for the EU28 states in a study analyzing the public funding of energy efficiency from 2012 to 2014. Even if the total available public funding has increased from about €6 billion in 2012 to about €7.1 billion in 2014, the share of funding for the industry sector is minimal in comparison to public funding for energy efficient buildings. In 2014 funds for buildings were identified to be around €5.4 billion, energy efficiency funds for the industry only amounted to €456 million (*Figure 5*). That is around 9% of what was available for the buildings sector [JANEIRO ET AL., 2016]. The overarching segment refers to public funding of energy efficiency measures that aim at several sectors.

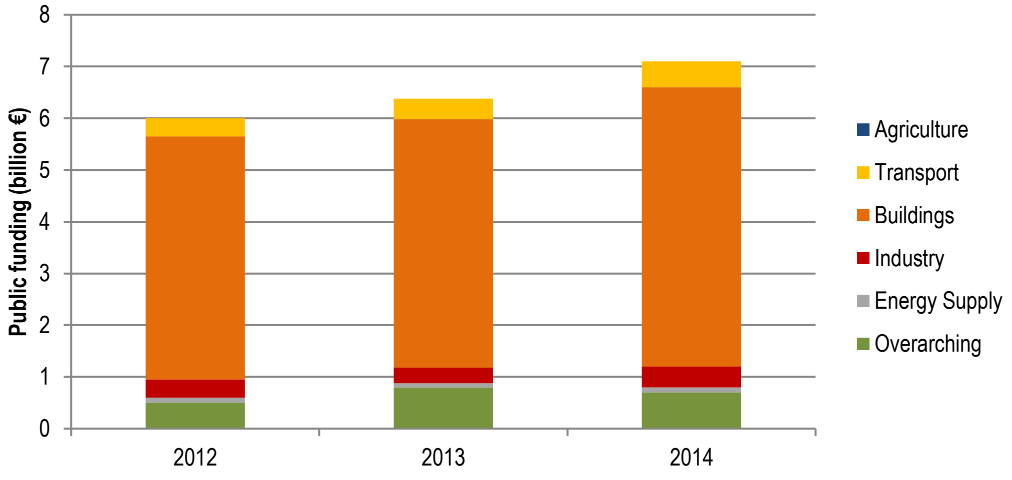


Figure 5: Public funding by sector for energy efficiency in EU28 [JANEIRO ET AL., 2016]

In summary, there is a large need for additional funds that invest into process heat technologies to reach the goals set by public decision makers and consequently to decrease the amount of emitted CO_2. This development is still hindered through lack of awareness and public support, through the usage of inadequate financial criteria such as the pay-back period and through a subsequent relatively high risk perception from investors. Hence, there is a clear need for a financing instrument that takes on the project risks from investments into energy efficient and renewable process heat technologies, something like an ESCO (energy service company) or more like an investment fund, which can bundle a variety of different investment proposals.

1.2. Objectives

This thesis work is conducted in the framework of the TrustEE project, which is part of the Horizon 2020 program of the European Commission (EC) [FRAUNHOFER ISE ET AL., 2016]. The project is being executed by a consortium of different European partner institutions, which are research institutes and companies. In an effort to create an investment fund that will increase the amount of funds allocated to more energy efficient and renewable process heat projects in the industry, this thesis will firstly give an overview of the current status of the process heat industry in Europe. This will be done by analyzing which different process heat consuming sectors exist in Europe and what their future potential is estimated to be. Then the different energy efficiency measures and renewable energy technologies will be laid out and set into relation with the estimated potential and temperature needs.

Secondly, investments analysis parameters and third-party funding options are going to be analyzed. This will include an assessment of the most adequate parameters for this kind of investment of process heat technologies. As well, a summary of different third-party funding options will be conducted, with a focus on the different IRR expectations of investors. Next to this, there will be a main focus on developing a risk assessment approach, which includes a risk-adjusted parameter into the investment analysis. Different risk mitigation measures for process heat applications will be summed up and their impact on the risk perception of the investment assessment will be analyzed. Next to other risk mitigation measures, this can be an agreement between the technical supplier and the end-user, in which the technical supplier ensures a certain energy output. Another option is a purchase agreement, where the end-user agrees to buy a certain amount of energy. Both agreements should decrease the risk that is associated to an investment [FRAUNHOFER ISE ET AL., 2016]. The risk-adjusted parameters and the risk mitigation measures can be applied to investment analyses for energy efficiency and for renewable technologies. The final investment analysis within this thesis will focus on solar thermal systems though.

The main objective of this thesis work will be to analyze the impact and effect that different risk mitigation measures have on the investment assessment. This will be done through defining in which way the risk mitigation measures impact a risk-adjusted parameter of the investment analysis. This will enable to find the measures with the most positive impact on decreasing the risk perception of a process heat investment and this will lead to the adhesion of third-party investors through optimized investment conditions and by bypassing restrictive criteria for SME (small and medium-sized enterprises) financing [FRAUNHOFER ISE ET AL., 2016]. The impact is going to be analyzed under different macroeconomic scenarios, such as energy costs and inflations. Hence, a model will be developed to calculate the economic viability of different process heat systems. These calculations will be based upon technical yield calculations within the project framework.

2. Industrial Process Heat

2.1. Process Heating and Cooling Systems

In industry applications process heating and cooling are essential in a large variety of processes. The different process heat systems can be split into two main categories, heat-driven and electric-driven systems (for reasons of simplicity process heating and cooling will hereafter simply be referred to as process heat). The basic purpose of process heat systems is to generate heat and transfer it to the industry application. There are direct heating methods that generate the heat directly in the material and indirect heating methods, which need to transfer the heat from the process heat system to the material. Which energy source is used mostly depends on the availability and cost of each region. For the direct heating systems another factor is how far the exhaust gas is compatible with the material. Mostly the chosen energy source is gas or electricity, sometimes coal or fuel oil are used as well [LBNL ET AL., 2016].

2.1.1. Heat-Driven

The main type of process heat systems is the heat-driven system. Heat is generated through the combustion of a gaseous, liquid, or solid fuel and either directly or indirectly transferred to the material. These types of systems are common in almost all the industrial sectors [LBNL ET AL., 2016]. *Table 2* gives an overview of typical heat-driven process heat systems.

Steam-driven process heat systems are a sub-category of the heat-driven systems, as they are fired by fuel as well and represent heat. They are based on one single process heat system, a boiler. Because steam-driven systems present such a large share of the total industrial energy consumption, they are considered as an own type. In the pulp and paper sector around 80% of the total energy consumption is based on the production of steam through burning fuel in a boiler. The wide spread usage of steam for process heat applications is due to the significant advantages of steam. It has a very high heat capacity per unit of mass. This means it can hold a lot of heat in relation to its weight. Furthermore, the heat in steam is stored as latent heat, which means that it can be transferred at a constant temperature [LBNL ET AL., 2016].

Table 2: Typical heat-driven process heat systems [LBNL ET AL., 2016]

Process Heat System	Description
Adsorption/absorption chiller	Provides cooling through water by using heat
Atmosphere generators	Prepare and condition protective gas atmospheres
Blast furnaces	Burn solid fuel with a blast of air
Dryers	Remove free water through heating
Flares	Protect environment by burning combustible waste
Kilns	Bake, dry and fire ceramic ware or wood
Lehrs	Anneal glass
Muffle furnaces	Apply heat to the outside of a refractory chamber
Salt bath furnaces	Apply heat to inside or outside of pot through radiant tube
Solid waste incinerators	Dispose solid waste through burning
Thermal oxidizers	Oxidize volatile organic compounds

2.1.2. Electric-Driven

The second main type of process heat system is the electric-driven system. These systems are based on the usage of electric current and electromagnetic waves that heat a material. In the direct heating method an electric current is either passed through or induced into the heated material, or atoms and molecules are excited within the material through electromagnetic radiation. The indirect method uses the same methods to heat an element that consequently heats the material. *Table 3* gives an overview of typical electric-driven process heat systems.

Table 3: Typical electric-driven process heat systems [LBNL ET AL., 2016]

Process Heat System	Description
Arc furnaces	Heat materials by an electric arc
Compression chiller	Removes heat from a liquid through vapor-compression cycle
Electron beam processing	Heat metals by a directed, focused beam of electrons
Induction heating and melting	Heat conductive materials through alternating magnetic fields
Laser processing	Create hardened layer on material through laser beam
Plasma processing	Heat and ionize gas (plasma) through two electrodes
Resistance heating and melting	Passes an electric current through a conductor or resistor
Ultraviolet curing	Transform liquid polymers into a hard film through UV radiation

2.2. Market Potential of Industrial Heating and Cooling Processes

Industrial heat-driven processes are used in many industries and in a large variety of applications. Often an application consists of different heat processes. The common point is that all applications have the need of process heat, which is generated by the process heat systems mentioned above in Chapter 2.1 and then transferred to the application.

Table 4: Overview of main heating and cooling processes [LBNL ET AL., 2016]

Process	Equipment	Industry
Agglomeration – Sintering	Furnaces, Kilns	Metals
Calcining	Furnaces	Metals, Cement, Pulp and Paper
Curing and Forming	Furnaces, Kilns, Ovens, Lehrs, Electron Beam, Induction	Ceramics, Glass, Metals, Chemicals, Plastics
Drying	Dryers, Infrared, Resistance	Stone, Clay, Food, Pulp and Paper
Forming	Furnaces, Ovens	Plastics, Glass
Fluid Heating	Furnaces, Resistance Heaters, Infrared, Immersion Heaters	Food, Chemicals, Machinery
Heating and Melting (High-Temperature)	Furnaces, Kilns, Reactors, Direct Arc, Induction, Plasma	Metals, Glass
Heating and Melting (Low-Temperature)	Ovens, Infrared, Resistance	Plastics, Food, Chemicals
Heat Treating	Furnaces, Ovens, Kilns, Lehrs, Laser, Resistance, Induction	Metals, Glass, Ceramics
Incineration/Thermal Oxidation	Incinerators, Thermal Oxidizers, Resistances, Plasma	Metals, Plastics, Food, Chemicals
Metals Reheating	Furnaces, Ovens, Kilns, Heaters, Induction, Infrared	Metals,
Separating	Distillation, Membranes	Chemicals
Smelting	Furnaces	Metals
Other Heating Processes	Furnaces, Ovens	Food, Glass, Ceramics, Plastics

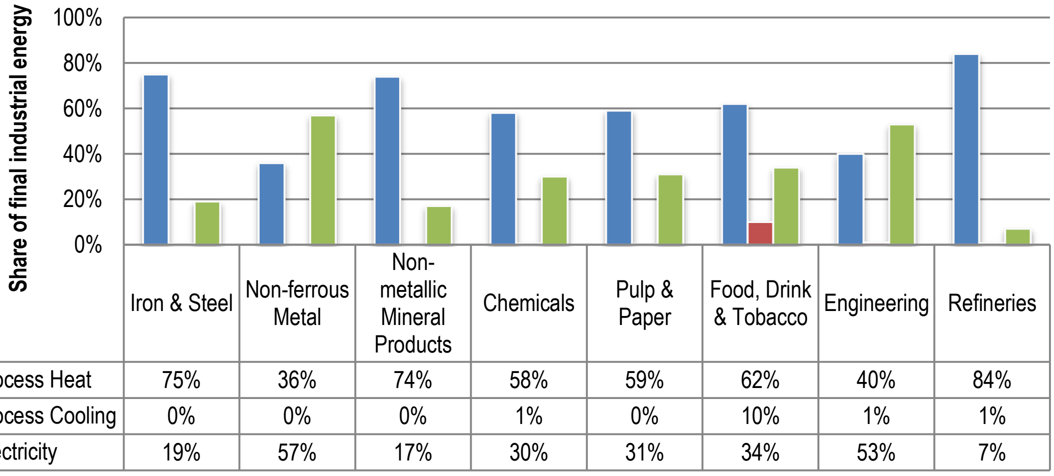
There are around 14 main heating processes, which are displayed in *Table 4*. Each process shows the equipment mostly used for the process and the industry in which the heating process occurs.

The worldwide total industrial energy demand represents about a third of global total energy use. Though, it is supposed to increase by four times up to 2050 [TAIBI ET AL., 2010]. This development highlights the need of increased decarbonization measures around the globe to halt a significant rise of carbon emissions.

The situation in Europe looks quite different though. In the majority of EU countries the share of industrial energy consumption has decreased from 2000 to 2012, on EU average by 3%. Only in Austria, Germany, Latvia, Malta and Slovakia the share of industrial energy use has increased within this timeframe [LAPILLONE ET AL., 2015].

A study by CHAN ET AL. states that the final energy consumption of the eight most energy-intensive industry sectors from the EU28 countries was at 11.41 EJ in 2013, which accounted for around 25% of the total energy consumption. These eight industrial sectors represent 98% of the total final industrial energy consumption. The share of process heat from the total industrial consumption was at 66% in 2013, hence at 7.53 EJ and accounting for the largest part of total industrial energy demand (*Table 5*).

Figure 6 confirms the high share of process heat in industry for different industrial sectors. Refineries have the highest share of process heat with 84%, just followed by the iron and steel sector, in which 75% of its final energy demand stems from process heat. The second largest part of the total industrial energy use is from electric energy with 26%, process cooling only accounts for 1%.



	Iron & Steel	Non-ferrous Metal	Non-metallic Mineral Products	Chemicals	Pulp & Paper	Food, Drink & Tobacco	Engineering	Refineries
🟦 Process Heat	75%	36%	74%	58%	59%	62%	40%	84%
🟥 Process Cooling	0%	0%	0%	1%	0%	10%	1%	1%
🟩 Electricity	19%	57%	17%	30%	31%	34%	53%	7%

Figure 6: Process heat share of final industrial energy in EU28 in 2012 [EC, 2015]

The CHAN ET AL. study assumes in its business-as-usual scenario that up to 2050 only the iron and steel and the chemicals sectors will have increasing energy consumptions. The other six sectors will have slightly decreasing consumptions, which in total will lead to a larger final industrial energy demand of 13.02 EJ in 2050 [CHAN ET AL., 2015]. Two further EU energy efficiency and decarbonization scenarios though display a total energy consumption decrease of 20% to 30% towards the business-as-usual scenario in 2050. Namely these are the EE27 and the GHG40RES30EE30 scenario. The former assumes that greenhouse gas (GHG) emissions are going to be reduced by 40% and the renewable energy share and energy efficiency will reach 27%. The latter as well assumes 40% of GHG emission reduction and 30% of renewable energy and energy efficiency, all in relation to 1990 [EC, 2015].

A further study from BREDIMAS states that the EU28 total industrial heat demand was 11.31 EJ in 2009 (*Table 5*), heat is defined here "[…] as the heat transmitted by a hot heat carrier through heat exchangers or by electrical resistance or by the steam which may be used as heat carrier, process feedstock, mechanical medium or vacuum medium" [BREDIMAS, 2014].

This value is higher than the total process heat demand of 7.53 EJ in 2013 from the Chan et al. study, which is due to the fact that no heat through electrical resistance is included in the latter and because the general industrial energy consumption was higher in 2009. The heat markets in the Bredimas study are divided into two main categories, the plug-in heat market, which consists of all cogeneration plants that supply one or more industrial factories and the extended heat market, which represents all boilers and furnaces that are directly connected to an industry facility [Bredimas, 2014].

A third reference value for the total process heat demand of the EU28 countries is based upon the research of the German Aerospace Center, with 7.36 EJ in 2012 (*Table 5*) it is very close to the Chan et al. study value [Naegler et al., 2015]. The German researchers focused their calculations on two different approaches, which were based on different data sets. The second approach considered low temperature space heat and hot water apart from process heat and hence provided an exact figure for the total process heat demand in Europe.

A fourth and final source states that the total useful heat demand for industry processes is 4.43 EJ (*Table 5)* and hence differs substantially to the above data from the other sources [Pardo et al., 2012]. It is very likely that this reduced value is a result of the difference between useful heat and the generated process heat or the process heat demand. The generated process heat or the process heat demand, which are the same value in the end, include later occurring transportation losses that take place from the process heat generating system to the process heat-driven application. The useful heat on the other hand does not account for the transportation losses and hence represents a smaller final value.

Table 5: Literature research on process heat in EU

Reference	Process Heat in EU
Bredimas [2014]	11.31 EJ in 2009
Chan et al. [2015]	7.53 EJ in 2013
Naegler et al. [2015]	7.36 EJ in 2012
Pardo et al. [2012]	4.43 PJ in 2009

All above sources in *Table 5* state the same in regard to the share of total process heat consumed by the most energy-intensive sectors and the share of high temperature energy. The process heat consumed by most energy-intensive sectors is up to 80% and the share of high temperature energy is up to 62% of the total industrial process heat.

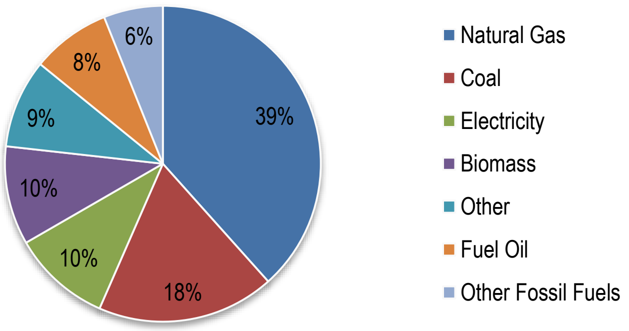


Figure 7: Heating and cooling fuel mix in the industry sector in 2012 [Ec, 2015]

The renewable share for process heating and cooling was still fairly low in 2012, with only biomass accounting for around 10% of the total process heat. Further renewable energy sources had a negligibly small share of below 1% (*Figure 7*). The largest part, around 70%, is still provided by fossil fuel sources [EC, 2015].

Up to 2050, after the EE27 scenario, the main fossil fuel sources gas, oil and coal will decrease drastically and will be mainly replaced by biomass, waste and hydrogen in Europe. Especially oil will be almost totally phased out by 2050 [EC, 2015]. On the global level an analysis from TAIBI ET AL. suggests that around 21% of total industrial energy use and feedstock can be renewable in 2050. This would represent about 50 EJ from around 230 EJ of total industrial energy use [TAIBI ET AL., 2010].

Process heat clearly represents the largest share of final energy consumed by the industry, hence there is a large potential to reduce the GHG emissions through extensive energy efficiency measures and renewable energy sources, especially taking into consideration the low current share of these technologies for process heat. The two energy efficiency scenarios display what is possible if proper energy policies will be implemented and the market framework will be in coherence to a development of less carbon emitting process heating technologies.

2.3. Heating and Cooling Processes in Industrial Sectors

The commonly used subdivision of industrial sectors by the EC and the IEA is as follows [CAPROS ET AL., 2008; IEA, 2007b]:

- Iron and steel
- Non-ferrous metal
- Chemicals
- Non-metallic mineral products
- Pulp and paper
- Food, drink and tobacco
- Textile, leather and clothing
- Ore extraction
- Machinery
- Other

Next to the division into different industrial sectors, heat processes are defined by their quality, hence their temperature levels. Specific information on the temperature requirements of industrial processes is essential to assess the potential of especially renewable energy sources for process heat generation. Depending on the literature source, slightly different temperature levels are defined. Generally though, literature sources divide into high, medium and low temperature levels. According to PARDO ET AL. this thesis work will be based on the following definition:

- High temperature: > 400°C
- Medium temperature: 100°C – 400°C
- Low temperature level: < 100°C

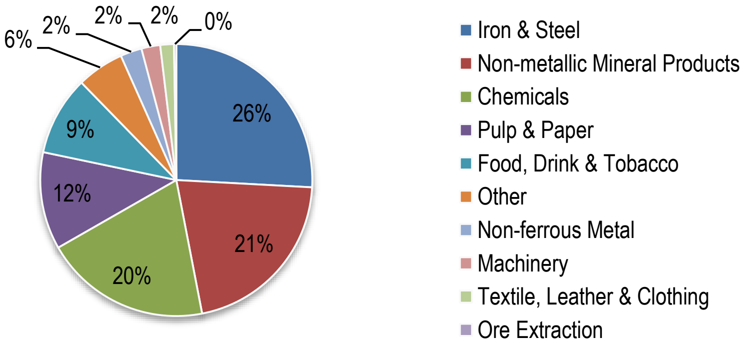
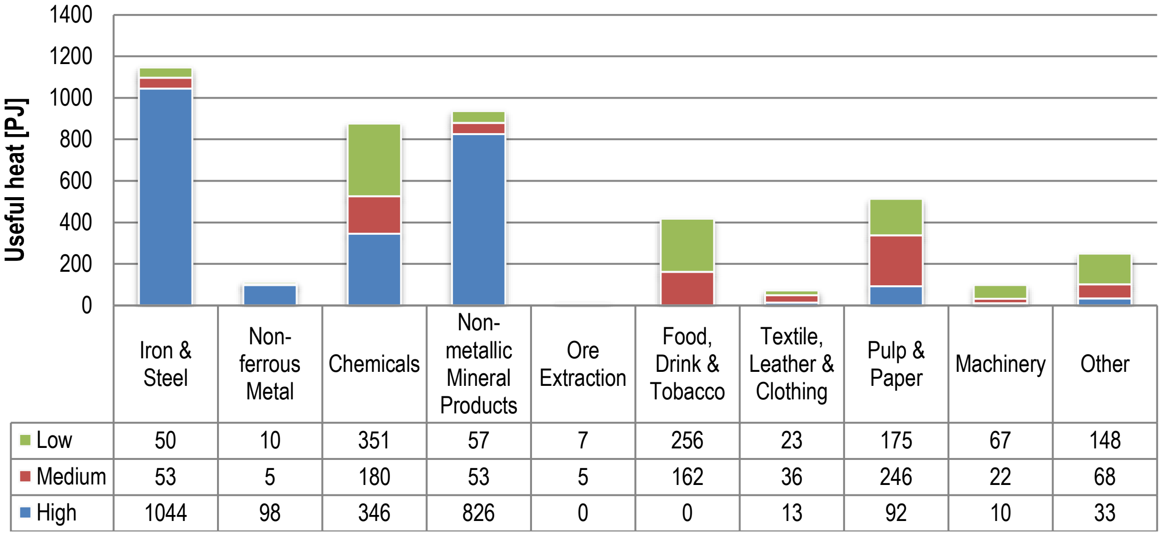


Figure 8: Useful heat share of EU27 energy sectors in 2009 [PARDO ET AL., 2012]

The low range temperature heat is used for washing, rinsing, food preparation, space heating and hot water. Processes like drying and evaporation are mostly done with medium temperature heat. The high temperature range refers to transformation processes like ore reduction, calcination, electric induction and others [Pardo et al., 2012].

The most energy-intensive sectors especially consume energy at high temperature levels above 400°C. They are shown in *Figure 8* and *Figure 9* and are the iron and steel, non-ferrous metals, chemicals, non-metallic mineral products and the pulp and paper sector. They consume about 75% – 81% of the total industrial energy [Taibi et al., 2010; Pardo et al., 2012]. These are the only sectors that have a demand for high temperature energy. Though, the chemicals just as the pulp and paper sector additionally have a large demand for medium and low temperature energy (*Figure 9*) [Pardo et al., 2012].



	Iron & Steel	Non-ferrous Metal	Chemicals	Non-metallic Mineral Products	Ore Extraction	Food, Drink & Tobacco	Textile, Leather & Clothing	Pulp & Paper	Machinery	Other
🟩 Low	50	10	351	57	7	256	23	175	67	148
🟥 Medium	53	5	180	53	5	162	36	246	22	68
🟦 High	1044	98	346	826	0	0	13	92	10	33

Figure 9: Industrial useful heat demand temperature ranges for EU27 in 2009 [Pardo et al., 2012]

Figure 9 shows and approves the above stated for the EU27 states, as Croatia was not part of the EU in 2009. The iron and steel sector has the highest energy demand with 1147 PJ, especially for high temperature energy, the non-metallic mineral products sector follows right after with 936 PJ. The chemicals sector has a very high energy demand of 877 PJ, though more than half of it stems from low and medium temperature energy. The non-ferrous metal, just as the pulp and paper sector are as well considered energy-intensive sectors, due to their high temperature demand, which is considerably less than the demand of the above sectors though.

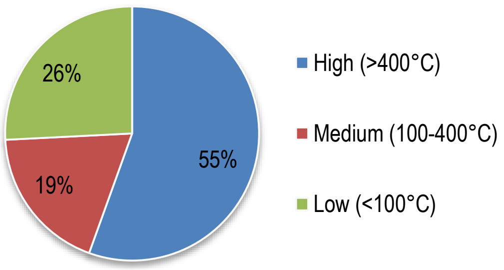


Figure 10: Share of industrial heat temperature ranges for EU27 in 2009 [Pardo et al., 2012]

According to Pardo et al. the share of high temperature heat is clearly the largest in comparison to medium and low temperature with 55%, see *Figure 10* from 2009. This is in accordance with another source from the German Aerospace

Center, which shows that even 62% is high temperature heat demand (*Figure 11*), even though the high temperature range in this case is defined above 500°C [NAEGLER ET AL., 2015].

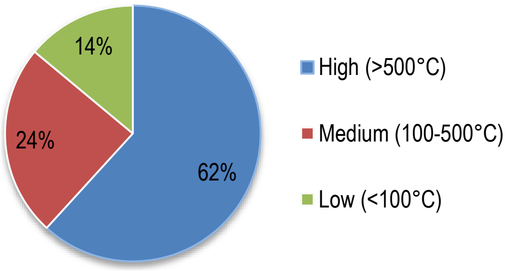


Figure 11: Share of industrial heat temperature ranges for EU28 in 2012 [NAEGLER ET AL., 2015]

The global final industrial energy demand consisted of around 9% renewable production in 2005 [BANERJEE ET AL., 2012]. This comes very close to the mentioned 10% (*Figure 7*) of renewable production for European process heat in industry [EC, 2015]. *Table 6* shows the renewable share of the global final industrial energy demand in 2005. The renewables displayed here mainly consist of combustible renewables and waste and are mainly allocated to the food, drink and tobacco and the pulp and paper sector.

Table 6: Renewable share per sector of global industrial energy demand in 2005 [IEA, 2007a, 2007b]

Industrial Sector	Renewable Share
Iron & Steel	2%
Non-ferrous Metal	0%
Chemicals	1%
Non-metallic Mineral Products	2%
Ore Extraction	0%
Food, Drink and Tobacco	18%
Textile, Leather & Clothing	0%
Pulp & Paper	32%
Machinery	0%
Other	18%

2.3.1. Energy-Intensive Sectors

The energy-intensive sectors were defined to be those that especially have high temperature demands and might include some further demand of medium and even low temperature process heat. The following five sectors follow this definition:

- Iron and steel
- Non-ferrous metals
- Chemicals
- Non-metallic mineral products
- Pulp and paper

A detailed overview over all the sectors can be found below in *Table 7*. They consume about 67 – 81% of the total industrial process heat, depending on the source [LAPILLONE ET AL., 2015; TAIBI ET AL., 2010; PARDO ET AL., 2012]. The energy-intensive sector share of total process heat actually differs from country to country. Luxembourg, Finland and Slovakia had the highest share of around 85% of heat being consumed only by the energy-intensive sectors in 2012. Belgium, Sweden and Norway were at around 80% and each of the further EU countries with a decreasing share [LAPILLONE ET AL., 2015].

Iron and Steel

The largest heat consuming sector with 1147 PJ, 26% of total industrial heat in EU, is the iron and steel sector. 95% of heat for its processes is high temperature heat. There are two main ways of producing crude steel, the blast furnace route (also called integrated steel or primary route) and the electric arc furnace route (also called recycling or secondary route).

The primary route basically has three key processes: raw material preparation, iron making and steel making [CHAN ET AL., 2015].

- Raw material preparation: In the first process coal is reduced to coke and coke oven gas through a pyrolysis process at temperatures of about 1100 – 1300°C, which is then sintered or pelletized to improve the following step.
- Iron making: The iron ore and carbon from coke are reduced to pig iron, which requires about 12 to 15 GJ/t of pig iron.
- Steel making: Part of the carbon from the pig iron is reduced with oxygen to crude steel. The main objective of this step is to control and decrease impurities. The carbon content is reduced from 5% to 0.4%.

The total process requires 17 to 23 GJ/t of crude steel [FLEITER ET AL., 2011; PARDO ET AL., 2012]. Around 16 GJ/t are required for thermal energy only, and consequently represent the largest amount of energy [CHAN ET AL., 2015].

The secondary route does not reduce iron ore to pig iron in an energy-intensive way, because it recycles scarp, which is melted and refined through the use of electricity. It has a much lower energy consumption of only 3 to 5 GJ/t of crude steel [FLEITER ET AL., 2011]. The highest energy consumption for the recycling route stems from thermal energy as well, around 2.5 GJ/t crude steel, which is mainly based on the energy needs for the hot rolling [CHAN ET AL., 2015].

The whole sector has been able to cut its total energy consumption by around 50% from 1972 to 2012, mainly through the increased deployment of the recycling route, which now produces around 40% of the total steel in Europe. As well, the integrated route has lived through extensive efficiency improvements, especially in regard to the blast furnace.

Non-Metallic Mineral Products

In charge of 21% of industrial European heat demand, hence the second largest heat consuming sector, is the non-metallic mineral products sector with a process heat demand of 936 PJ, of which 88% is within the high temperature range. The production of cement, lime, gypsum, glass, bricks and tiles are part of this sector, whereby only the cement industry was in charge of 65% of the total energy consumption of this sector in 2009 [PARDO ET AL., 2012]. Another source states that 58% of the total energy consumption of this sector was based off the cement industry in 2012, 19% from the ceramics industry, 17% from the glass industry and 6% from manufacturing lime [CHAN ET AL., 2015]. The main energy-intensive processes are melting (glass), sintering (cement, ceramics) and thermally decomposing, which require temperatures over 1000°C [CHAN ET AL., 2015].

The main component for the production of cement is clinker, which is gained through the calcination of limestone and likewise represents the most energy-intensive step in the production chain of cement. In 2006 the average energy requirement was 3.6 GJ/t of clinker, which consisted to 80% out of process heat. Through efficiency improvements in the cement industry the total heat consumption has decreased by around 60% from 1960 to 2007.

Within the glass industry the main sub-sectors are container and flat glass, producing 83% of the total European glass production. The average specific energy consumption for the production of container glass was at 7.7 GJ/t of glass, for flat glass the consumption was 10.1 GJ/t of glass in 2005. This consumption was decreased by 60% from 1992 to 2007, due to restructuring within the glass industry. 85% of this specific energy consumption is based upon heat energy demand [CHAN ET AL., 2015].

Regarding bricks and tiles, they are produced through the usage of thermal processing and electricity and require around 2.31 – 8.1 GJ/t [PARDO ET AL., 2012; CHAN ET AL., 2015].

Chemicals

The third most energy consuming sector is the chemicals sector with 877 PJ of heat demand, of which half is for high temperature heat and the remaining half for medium and low temperature heat. Additionally, there is a large demand for energy from feedstock, around 60% of the total energy demand of this sector.

There are many chemical compounds produced in Europe. Though, after PARDO ET AL. only two main processes account for 72% of the fuel consumed for energy, these are the ammonia production and steam cracking. After FLEITER ET AL. polymers, bulk petrochemicals, bulk inorganic chemicals and intermediates account for 85% of the total energy consumption of the sector.

The specific energy demand is around 35 – 40.2 GJ/t for Ammonia, 10 – 12.4 GJ/t for Methanol and 1.2 – 2.3 GJ/t for Chlorine [SAYGIN ET AL., 2009]. Despite a total production increase within Europe of 40% from 1995 to 2008, the total energy consumption was decreased by 14% [PARDO ET AL., 2012].

Pulp and Paper

Even if the pulp and paper sector has slightly less high temperature heat demand than the non-ferrous metal sector it still represents the fourth largest heat consuming industrial sector with 431 PJ of heat demand, due to its large demand for medium and low temperature heat with 246 PJ and 175 PJ respectively. This means that 55% of the total heat demand is for medium temperature heat.

There are two main production steps when making paper from pulp, first the production of pulp and consequently the production of paper out of pulp and some other resources. The latter is the most energy consuming process in relation to the production of pulp. It is mainly concentrated in Germany, Italy and France, which have 43% of the total European paper production market share [CHAN ET AL., 2015]. To make pulp three alternative processes are mainly used: mechanical, chemical and recovered paper.

- Mechanical: The mechanical pulp production is based of wood, which is ground and refined to attain a fibrous pulp. Throughout the process the wood is mixed with water and ground to smaller pieces. This process generally creates large amounts of heat, which softens the lignin that binds the fibers. Hence, the fibers are separated from the lignin and pulp is the product, which consists of whole fibers and fragments of fibers [CHAN ET AL., 2015].
- Chemical: For the production of chemical pulp wood is used as a base product as well. Lignin, which represents 50% of the initial raw material wood, is separated from wood fibers through sulphite or sulphate. A typical sulphate pulp plant has around 84% of its total energy being process heat [CHAN ET AL., 2015]. Then lignin is burnt to create the heat steam that is needed for the separation process.

- Recovered paper: The last process, making pulp out of recovered paper, is an increasingly used process in Europe [Fleiter et al., 2011]. Most of the production plants using this recycling process are integrated plants, which produce pulp and paper. This enables them to use the excess heat of the pulp production more efficiently.

The European pulp market is mainly concentrated in three countries, Germany, Sweden and Finland, in which 66% of the total production capacity is achieved [Chan et al., 2015]. Within the European paper and pulp industry the recovery rate was at 71.7% in 2014, which means that this amount of consumed paper was actually reused. This makes Europe the number one continent in terms of paper recycling [Erpc, 2015]. Regarding paper made out of wood as raw material through either the mechanical or chemical process, 60% of the pulp production took place through the usage of sulphate, 33% through mechanical and semi-chemical pulp and 5% through sulphite pulp.

On average the specific energy consumption per ton of end product is around 4 - 7 GJ/t, the lowest for recycled products and the highest values for special paper and packaging. The pulp and paper sector was able to decrease its specific primary energy consumption by 16% from 1990 to 2006 [Pardo et al., 2012].

Non-Ferrous Metals

The last of the five energy-intensive sectors is the non-ferrous metals sector with a heat consumption of 113 PJ, of which 87% is for high temperature heat. Around 42 non-ferrous metals, ferro-alloys, carbon and graphite are part of this sector. The three main products are aluminum, copper and zinc.

Only aluminum constitutes for 55% of the sectors total energy consumption. It is mainly produced through either the integrated route or the recycling route, the latter constitutes for 58% of the total produced amount of aluminum. The integrated route uses bauxite to produce aluminum oxide and then a melting-electrolysis process to make aluminum. These two processes consume about 76 GJ/t of aluminum. The recycling route only needs 3.8 GJ/t of aluminum to melt aluminum scrap and make new aluminum [Pardo et al., 2012].

To produce copper the raw material needs to consist out of 60% mineral ore, copper scrap and secondary materials. The total energy consumption is around 14 – 20 GJ/t of copper, out of which around 10 GJ/t are heat requirements. Zinc is the third most produced non-ferrous metal in Europe. Primary zinc is mostly produced through the usage of an electrolytic process, instead of a blast furnace. It is produced with an energy consumption of around 14 GJ/t of zinc [Pardo et al., 2012].

Table 7: Energy-intensive industry sectors [Pardo et al., 2012; Saygin et al., 2009; Bredimas, 2014; Chan et al., 2015; Ec, 2015]

Sector	Products	Processes	Energy Driver	Temperatures	Specific Energy Demand
Iron & Steel	Crude Steel	Blast Furnace Route, Recycling Route	75% Heat	800 - 2500°C	17 – 23 GJ/t 3 – 5 GJ/t
Non-metallic Mineral Products	Cement, Lime, Glass, Ceramics, Brick & Tiles	Melting , Sintering, Thermally Decomposing	74% Heat	800 - 1750°C	Glass: 7.7 – 10.1 GJ/t Brick Tiles: 2.31 – 8.1 GJ/t
Chemicals	Polymers, Petrochemicals, Inorganic chemicals	Steam Cracking, Ammonia, Methanol, Chlorine Production	58% Heat	400 - 1000°C	Ammonia: 35 – 40.2 GJ/t Methanol: 10 – 12.4 GJ/t Chlorine: 1.2 – 2.3 GJ/t
Pulp & Paper	Paper	Mechanical, chemical or recovered paper production	59% Heat	Up to 400°C	Paper: 4 – 7 GJ/t
Non-ferrous Metals	Aluminum Copper Zinc	Aluminum: integrated or recycling route	36% Heat	300 - 1500°C	Aluminum: 3.8 – 76 GJ/t Copper: 14 – 20 GJ/t Zinc: 14 GJ/t

Regarding the temperature ranges of the different sectors, the temperatures for each sector are summed up in *Table 7*. A more detailed overview from selected sub-sectors is laid out in *Figure 12*. It only includes the high temperature processes of each sector and shows that the iron and steel sector clearly has the highest and largest temperature range from around 800°C to 2500°C.

The non-metallic mineral products sector reaches from around 800 – 1750°C. The lead and zinc sub-sectors within the non-ferrous metals sector have the comparatively lowest temperature range from the high temperature sectors, with a range of around 300 – 500°C [BREDIMAS, 2014].

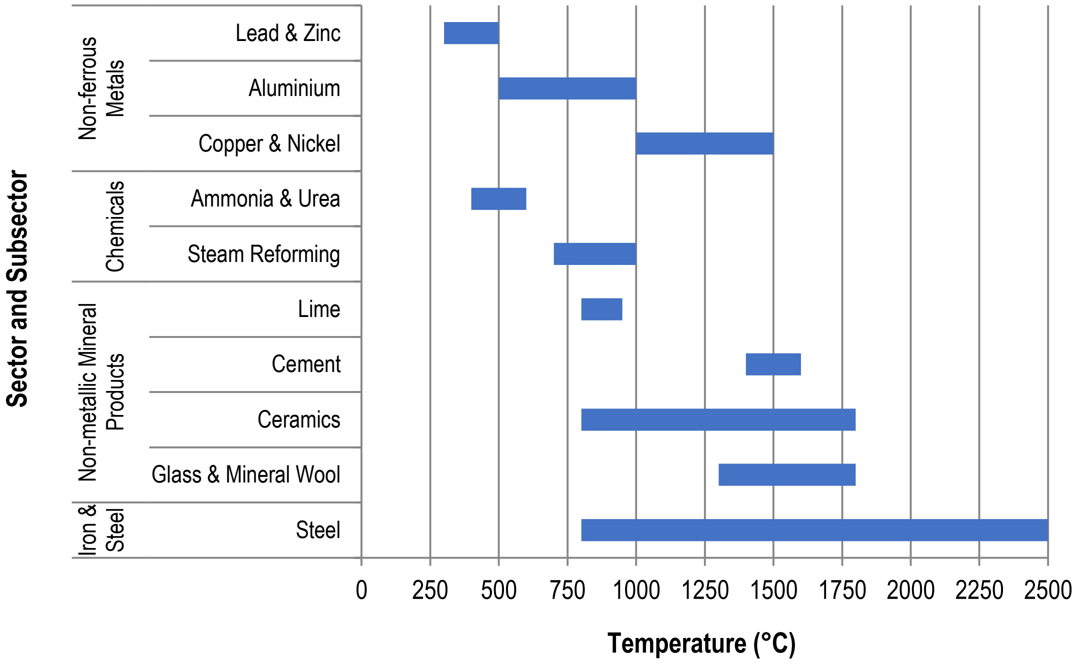


Figure 12: High process temperature ranges by sector [BREDIMAS, 2014]

2.3.2. Non-Energy-Intensive Sectors

The remaining sectors are the ones with nearly zero high temperature heat consumption and therefore referred to as the non-energy-intensive sectors.

- Food, drink and tobacco
- Machinery
- Textile, leather and clothing
- Ore extraction
- Other

They require 59% of their total heat demand to be low temperature heat, 34% medium temperature and 7% high temperature heat [PARDO ET AL., 2012]. A general overview of these sectors can be found below in *Table 8*. Especially the ore extraction and the machinery sectors lack data and hence do not have any entries for their specific energy demand.

Food, Drink and Tobacco

The largest of the non-intensive energy sectors is the food, drink and tobacco sector with a total heat consumption of 418 PJ, out of which 61% is heat from the low temperature range and the remaining heat is medium temperature. Hence, it is only slightly smaller than the energy-intensive pulp and paper sector.

The main energy use within this sector is allocated to process heat, process cooling and electric motors [FLEITER ET AL., 2011]. The largest share of energy consumption is allocated towards the production of food, based upon data from Germany, Spain and Finland from 2011 and 2013 it is around 84 – 89% of the total energy consumption by the food, drink and tobacco sector. The production of drinks accounts for around 11 – 16% and tobacco products are in charge of less than 1% of the sectors' energy consumption.

The total sector had an electricity demand of 34% in 2012, the remaining and larger part of 66% is allocated to fossil fuel sources used as thermal energy source [CHAN ET AL., 2015]. Specific energy requirements for this industry are difficult to measure, due to the broad range of products that exist within this sector [PARDO ET AL., 2012]. Though, within the diary sub-sector fluid milk has a specific energy consumption of 0.7 GJ/t and whey dry needs 11 GJ/t. In the meat sub-sector the production of fish meals has a specific energy demand of 6.9 GJ/t and carcass poultry needs 1.6 GJ/t. To produce wheat starch 11.8 GJ/t are needed [SAYGIN ET AL., 2009].

Machinery

The machinery sector consumes around 99 PJ, of which 67 PJ are in the low temperature range. It can be split up into four groups, which are fabricated metal products; computer, electronic and optical products; electrical equipment and general machinery and equipment. In Germany the respective energy consumption of each of these groups was 40%, 12%, 16% and 32% in 2013. Of the total energy consumption more than half is allocated to electricity [CHAN ET AL., 2015].

Textile, Leather and Clothing

The textile, leather and clothing consumes 72 PJ annually and mainly consists of processes such as spinning, weaving, knitting, dyeing, washing, bleaching and printing. This industry is relatively small in Europe compared to other global regions, as most of it is located in developing countries. Due to the relative small size of this sector there is a lack of energy consumption data. For the weaving process, which yields woven fabric and cloth, an exemplary specific energy consumption of 11 – 65 GJ/t was found. Based on the specific electricity and heat consumption for weaving technologies in Turkey from 2002, calculations yielded that around 45 – 52% of the sub-sectors total energy demand is heat [SAYGIN ET AL., 2009].

Ore Extraction and Other

The ore extraction and the other sectors consume 12 PJ and 249 PJ, respectively. The large amount of their heat requirements are in the low temperature range, directly followed by medium temperatures.

Table 8: Non-energy-intensive industry sectors [ÖHLINGER, 2010; SAYGIN ET AL., 2009; PARDO ET AL., 2012; CHAN ET AL., 2015]

Sector	Products	Processes	Energy Driver	Temperatures	Specific Energy Demand
Food, Drink & Tobacco	Meat, Fish, Vegetables, Fruit, Wine, Beer, Soft Drinks, Cigarettes	Drying, Washing, Boiling, Sterilizing, Heat Treatment	62% Heat	0 - 400°C	Whey Dry: 11 GJ/t Wheat Starch: 11.8 GJ/t Carcass Poultry: 1.6 GJ/t
Textile, Leather & Clothing	Clothes, Bags, Tents, Nets, Umbrellas	Washing, Bleaching, Dyeing	45 – 52% Heat	30 - 160°C	Weaving: 11 – 65 GJ/t
Ore Extraction	Iron, Copper, Mercury	Froth Flotation, Reduction	N.A.	Up to 400°C	N.A.
Machinery	Aerospace, Automotive, Robotics,	Cleaning, Drying	40% Heat	Up to 100°C	N.A.

Next to the above break down into sectors there is a large variety of certain processes that are non-energy-intensive. A first overview of a selected amount of these processes is displayed in *Figure 13*, which as well shows low temperature processes from two energy-intensive sectors: the chemicals and non-ferrous metals sector. The maximum temperature level reached is around 190°C, which reaches into the mid temperature range.

The main processes displayed in *Figure 13* include the generation of warm water and steam at temperatures of 50 – 120°C for washing and cooking; driving out moisture from food, plants, fruits, textiles and wood through drying; production of aromas and alcoholic beverages through distilling; washing and cleaning with around 90°C warm water and increasing the durability of food through pasteurizing and sterilizing at 70 – 140°C [FRISCH ET AL., 2010]. Especially processes from energy-intensive sectors that require low-temperature heat are included as well, such as the chemicals and non-ferrous metals sectors.

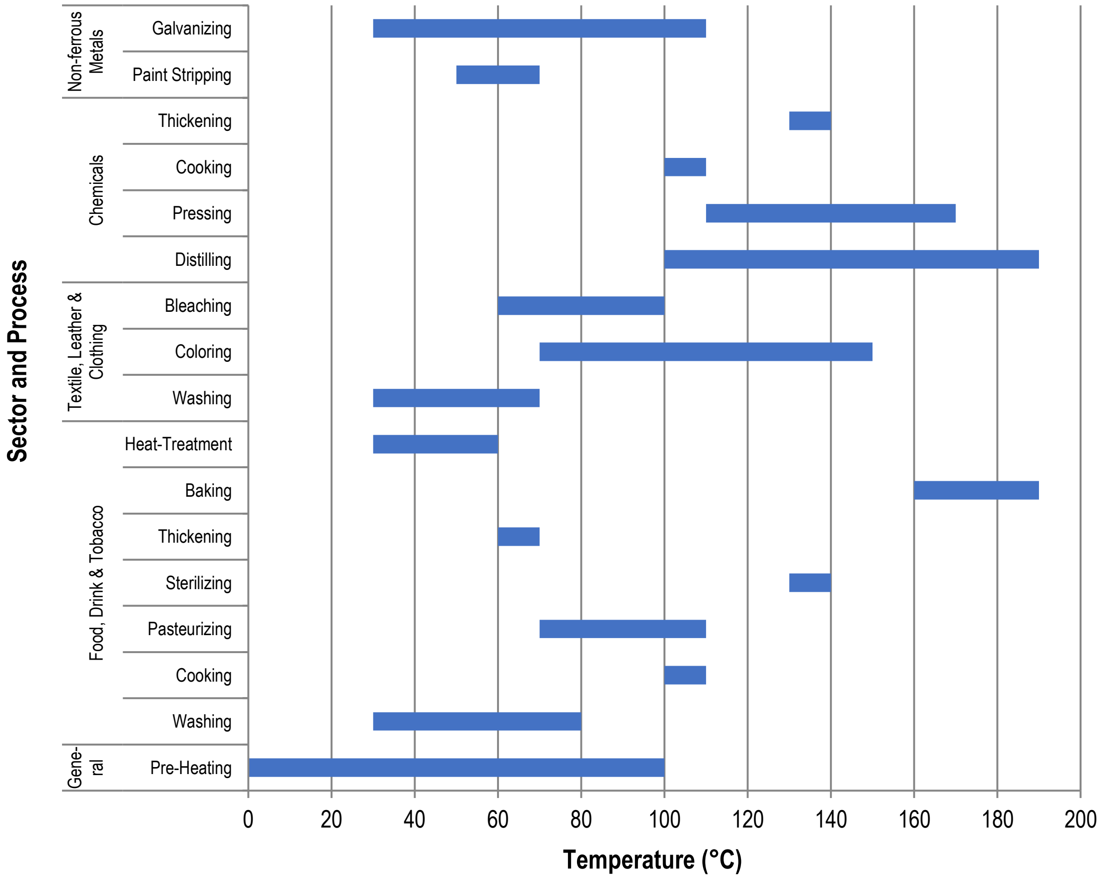


Figure 13: Low process temperature ranges by sector [FRISCH ET AL., 2010]

Further sectors that have energy demands in the low temperature range are the plastics processing sector (gluing and laminating), the buildings materials sector (concrete production and drying of plasterboards) and further commercial enterprises (drying chambers for wood, laundries and car washes) [FRISCH ET AL., 2010].

2.4. Energy Efficiency Measures and Renewable Heat Production

The above chapters have given an overview of process heat systems and the different industrial sectors that use these systems. This chapter will now focus on presenting the different energy efficiency measures and renewable heat production systems that are applicable to improve or replace current process heat systems in the industrial European sectors. Increased deployment of more energy efficient and renewable process heat systems is supposed to be enhanced and the risk mitigation of investments into these systems will be analyzed in this thesis.

2.4.1. Energy Efficiency

This chapter will present energy efficiency measures for process heat systems. Basically, they are separated into two main sections, being heat recovery strategies and retrofitted systems. The former focusing on recovering and using waste heat that otherwise is lost to the environment and represents significant energetic losses and the latter consisting of optimizing and retrofitting process heat systems. Before the specific energy efficiency measures will be introduced, an outlook on the energy savings potentials in each of the above named industrial sectors up to 2050 will be given.

In the recent past the progress of energy savings through energy efficiency measures in the European industrial sectors has slightly decreased, mainly due to the worldwide recession. From 2007 to 2013 the annual energy efficiency progress was down to 0.9%, in comparison to 1.9% from 2000 to 2007. Consequently, the annual energy savings decreased by around 60% after 2007 from an average of 6.3 Mtoe/year to around 2.5 Mtoe/year. One of the main reasons for this development is that many factories and companies had to decrease their production output and hence did not operate at full capacity, which then lead to less energy savings, as the total energy consumption decreased as well. The total sum of energy savings by the European industry is around 150 Mtoe from 1990 to 2013 and around 60 Mtoe from 2000 to 2013 (*Figure 14*) [LAPILLONE ET AL., 2015].

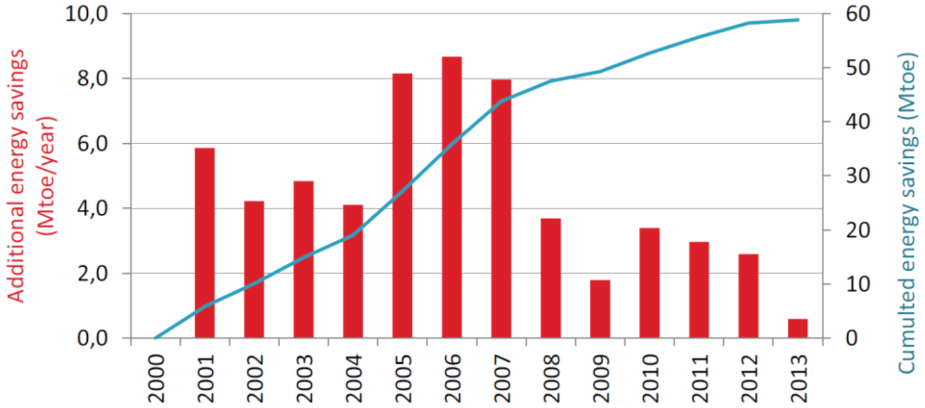


Figure 14: Energy savings in EU industry [SCHLOMANN ET AL., 2015]

The firm ICF International conducted a study analyzing the energy efficiency potential of the European industrial sector. Their analysis is based upon a database of Energy Savings Opportunities (ESOs), which they grouped in regard to their respective industrial sector. An ESO can either represent an energy efficiency measure through a heat recovery strategy or through a retrofitted system. The analysis is based on the energy consumption of a sector that will occur up to 2050 under usual and unchanging conditions, which is represented in the BAU (Business-as-Usual) consumption. It is calculated while accounting for current and upcoming relevant policies for energy efficiency and energy in the industry sectors and by considering the production growth and energy intensity trends of each sector. Further essential data that was used for the calculation of the BAU energy consumptions is displayed in *Table 9* and have been gathered from Eurostat, European member state government reports/databases, sub-sector associations, industry reports and EC reports. The BAU projections were used as the starting point for the analysis and as a baseline for the energy saving scenarios [CHAN ET AL., 2015].

Table 9: ICF International data for scenario development [Chan et al., 2015]

Area	Data per Sector
Economic Indicators	Number of enterprises, number of persons employed, turnover, value added, personnel costs, production value
Market Statistics	Products, historic production, trade flows (imports and exports), market developments and drivers, existing and future competitive strengths and weaknesses
Energy Statistics	Sector consumption trends, energy intensity at the sub-sectoral and/or process level, fuel mix, facility level energy use
Policies	EU and sector/sub-sector policies, description and pertinent measures
Mitigation	Business strategies to address resource/energy efficiency, existing and future mitigation activities

Three different energy saving scenarios were developed in the following for each sector. The largest savings are generally attained through the technical scenario. It includes all ESOs that are technically feasible, regardless of their economic viability. The energy consumption displayed in this scenario is the BAU consumption reduced by all technically feasible ESOs of a sector. The two remaining scenarios are named economic scenario 1 and 2 and are based on all ESOs that reach a certain pay-back period. The economic scenario 1 includes all ESOs with a maximum pay-back period of two years. The economic scenario 2 on the other hand stands for all ESOs with a pay-back period of maximal five years. This means that the economic scenario 1 in general reaches the least energy savings, as there will be ESOs not reaching a pay-back period of two years [Chan et al., 2015].

The sectors analyzed in the ICF International study from 2011 are the iron and steel, the non-metallic mineral products, the chemicals, the pulp and paper, the non-ferrous metals, the machinery and the food and beverage sector.

Iron and Steel

In accordance with *Figure 15*, which represents the BAU consumption and the technical and economic scenarios up to 2050 for the iron and steel sector, Pardo et al. estimates an annual growth of the EU iron and steel sector of 1.18%. Most of the increased production will be covered by the recycling route. Nonetheless, the increase in production will lead to an increased energy consumption of the sector. In 2012 around 45% of the total EU iron and steel sector production was based on the electric recycling route, which requires around one third of the energy from the conventional primary route. Portugal and Slovenia produce 100% of their steel by the recycling route [Schlomann et al., 2015].

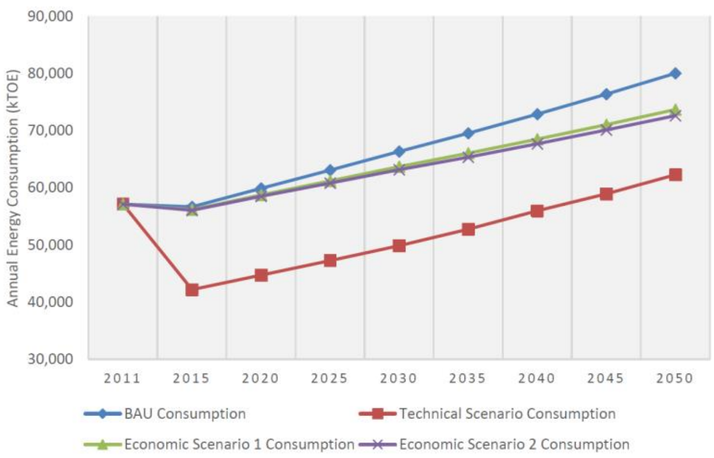


Figure 15: Potential energy saving scenarios for the EU iron and steel sector [Chan et al., 2015]

The technical scenario consists of the energy savings of 94 ESOs within the iron and steel sector (*Table 10*). Of the 94 only 38 ESOs were able to attain a pay-back period with a maximum of two years and were hence included into the economic scenario 1, which results into energy savings of 2.9 Mtoe in 2030 and 6.2 Mtoe in 2050. The economic scenario 2 just represents slightly larger energy savings, due to an additional 19 ESOs that were accounted for, as they stayed below the threshold of five years of pay-back time. These additional energy efficiency measures stand for a very low energy savings impact and only account for 7% of the overall savings [Chan et al., 2015].

Table 10: Energy saving scenario overview for the EU iron and steel sector [Chan et al., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	38	4.3%	8.6%	2.9 Mtoe	6.2 Mtoe
Economic Scenario 2	57	4.6%	9.4%	3.1 Mtoe	6.8 Mtoe
Technical Scenario	94	24%	26%	16.3 Mtoe	18.9 Mtoe

Non-Metallic Mineral Products

Within the non-metallic mineral products sector (*Figure 16*) the expected BAU energy consumption up to 2050 is predicted to decrease slightly, which is mainly due to a slight decrease in production output on the EU level. The study assumed that many ESOs would be available by 2015 and directly implemented, which is displayed in the abrupt increase of energy savings in the technical scenario. The economic scenarios display rather small energy savings up to 2050.

Again, just as in the iron and steel sector, there is almost no difference between the economic scenario 1 and 2, which means that the additional 19 ESOs with a pay-back period larger than two years and smaller than five years represent a rather small part of the overall savings. They account for around 8% of the total economic savings of 1.3 Mtoe in 2030 and 2.6 Mtoe in 2050.

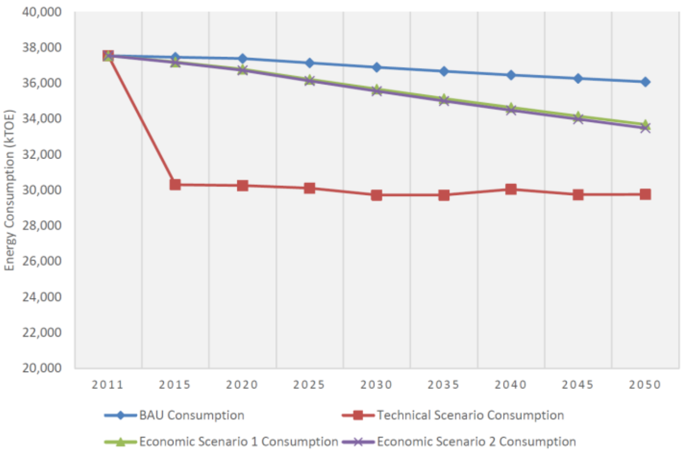


Figure 16: Potential energy saving scenarios for the EU non-metallic mineral products sector [Chan et al., 2015]

The technical scenario is able to reach energy savings of 19% and 18% in 2030 and 2050, respectively. With a total of 83 ESOs, there are 11 less opportunities for energy efficiency measures in this sector in comparison to the iron and steel sector (*Table 11*).

Table 11: Energy saving scenario overview for the EU non-metallic mineral products sector [CHAN ET AL., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	33	3.3%	6.6%	1.2 Mtoe	2.4 Mtoe
Economic Scenario 2	52	3.6%	7.2%	1.3 Mtoe	2.6 Mtoe
Technical Scenario	83	19%	18%	7.2 Mtoe	6.3 Mtoe

Chemicals

The predicted BAU energy consumption of the European chemicals sector is displayed in *Figure 17* and is supposed to increase up to 80 Mtoe in 2050. Yet, the theoretical potential for energy savings in the ammonia, methanol and ethylene production of the final energy use is around 10% to 50% [PARDO ET AL., 2012].

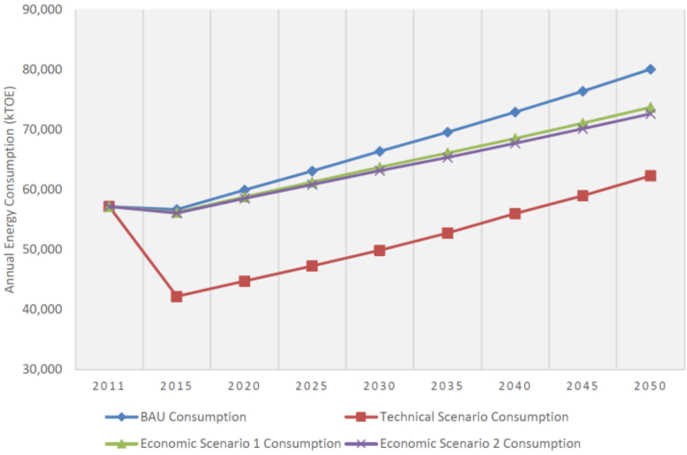


Figure 17: Potential energy saving scenarios for the EU chemicals sector [CHAN ET AL., 2015]

CHAN ET AL. estimates a maximum technical energy savings potential of 25% in 2030 in comparison to the BAU energy consumption of the chemicals sector. These energy savings are supposed to be attained through 99 different ESOs (*Table 12*). Most of the technical feasible ESOs are supposedly available by now, hence the peak in abrupt improvement of the energy savings in 2015.

Some of the 99 represented ESOs in these scenarios of the chemicals sector are e.g. high efficiency boilers, inter-plant process integration, high efficiency non-packaged HVAC equipment, efficiency control with adjustable speed drives, advanced boiler controls and process heat recovery to preheat makeup water [CHAN ET AL., 2015].

Table 12: Energy saving scenario overview for the EU chemicals sector [CHAN ET AL., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	49	4%	7.9%	2.7 Mtoe	6.4 Mtoe
Economic Scenario 2	66	4.9%	9.3%	3.2 Mtoe	7.4 Mtoe
Technical Scenario	99	25%	22%	16.5 Mtoe	18 Mtoe

Pulp and Paper

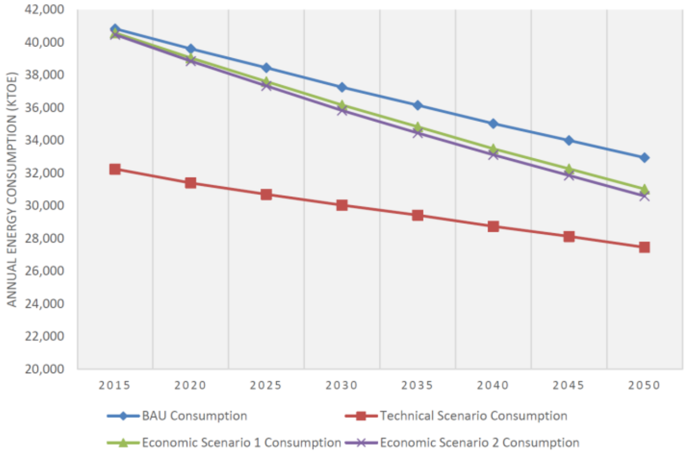


Figure 18: Potential energy saving scenarios for the EU pulp and paper sector [Chan et al., 2015]

The pulp and paper industry will gradually increase its production capacity in Europe up to 2050, while its energy consumption in the BAU scenario will decrease from around 41 Mtoe in 2015 to 35 Mtoe in 2050 (*Figure 18*).

Table 13: Energy saving scenario overview for the EU pulp and paper sector [Chan et al., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	43	3%	6%	1 Mtoe	1.9 Mtoe
Economic Scenario 2	64	4%	7%	1.4 Mtoe	2.3 Mtoe
Technical Scenario	101	19%	17%	7.2 Mtoe	5.5 Mtoe

This in consequence means that the energy intensity of this sector decreases from around 0.39 toe/t of dried paper in 2015 to 0.29 toe/t in 2050 [Chan et al., 2015]. 101 ESOs could technically even further decrease the energy demand of the pulp and paper sector with energy efficiency measures that save 7.2 Mtoe in 2030 and 5.5 Mtoe in 2050.

Non-Ferrous Metals

The non-ferrous metals sector in Europe has one of the highest recycling rates in the world with an average share of metal recycling of 40% in comparison to the global average of 30% [Chan et al., 2015]. Especially the production of secondary aluminum is a main reason for this high recycling rate, which is as well reflected in the sectors energy consumption after the BAU scenario up to 2050 in *Figure 19*.

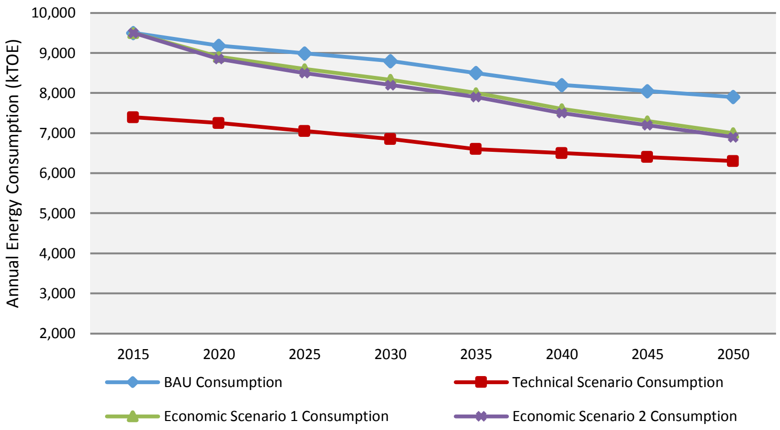


Figure 19: BAU scenario for the EU non-ferrous metals sector [CHAN ET AL., 2015]

Despite a rather steady production output of the sector, the energy consumption is predicted to decrease up to 2050, due to an increased deployment of the more energy efficient production of secondary aluminum, which is made out of scrap metal. The already decreasing BAU energy consumption of the non-ferrous metals sector displayed in *Figure 19* can be further decreased through 97 technically possible ESOs, which would decrease the sectors energy consumption by 22% (1.9 Mtoe) in 2030 and by 21% (1.6 Mtoe) in 2050 (*Table 14*).

Table 14: Energy saving scenario overview for the EU non-ferrous metals sector [CHAN ET AL., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	42	5.5%	12%	0.47 Mtoe	0.9 Mtoe
Economic Scenario 2	61	6%	13%	0.5 Mtoe	1 Mtoe
Technical Scenario	97	22%	21%	1.9 Mtoe	1.6 Mtoe

Out of the technically possible ESOs there are 42 that pertain to the economic scenario 1 and reach a pay-back period of two years and additional 19 ESOs with a pay-back period not longer than five years. They stand for additional energy savings in relation to the BAU scenario of 5.5% to 13%.

Machinery

The European machinery sector has been able to constantly decrease its energy consumption in the past, despite strong increase in turnover and production capacity. In coherence to this past trend the BAU energy consumption up to 2050 is expected to slightly decrease (*Figure 20*), while production output increases [CHAN ET AL., 2015].

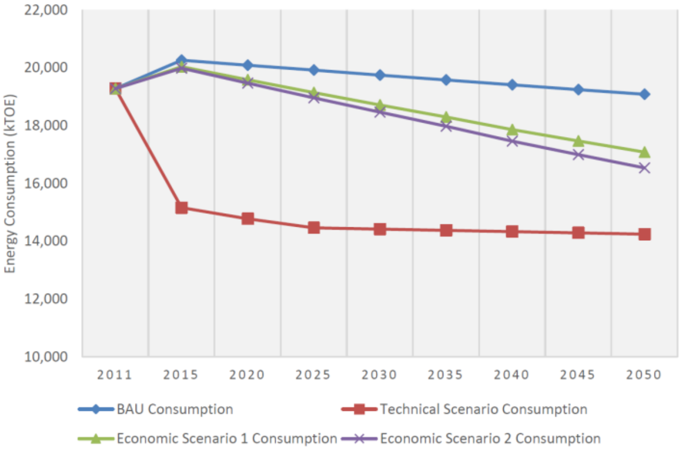


Figure 20: Potential energy saving scenarios for the EU machinery sector [Chan et al., 2015]

Table 15 shows, together with *Figure 20*, how the 91 ESOs of the technical scenario can possibly further reduce the energy consumption of the sector. By 2030 a reduction of 27% (5.3 Mtoe) is achievable and by 2050 a reduction of up to 25% (4.8 Mtoe) can be achieved. While the economic scenarios enable energy savings of 1 to 2.5 Mtoe up 2050.

Table 15: Energy saving scenario overview for the EU machinery sector [Chan et al., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	39	5%	10.5%	1 Mtoe	2 Mtoe
Economic Scenario 2	60	6.5%	13.3%	1.3 Mtoe	2.5 Mtoe
Technical Scenario	91	27%	25%	5.3 Mtoe	4.8 Mtoe

Food and Beverage

The EU food and beverage sector is estimated to continue its path from the last decades, in which it was constantly able to further increase production output and likewise decrease the amount of energy consumed. Hence, predictions estimate that it will likely triple its total sector turnover from 2010 to 2050 and at the same time be able to further reduce its energy consumption, as displayed in *Figure 21* through the BAU scenario [Chan et al., 2015].

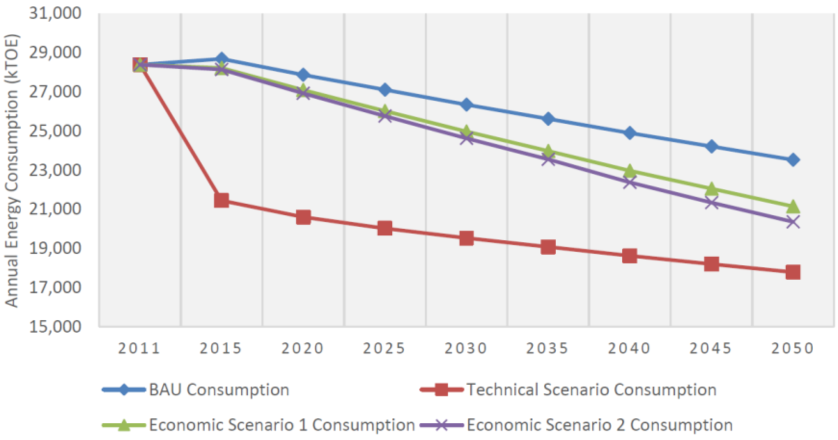


Figure 21: Potential energy saving scenarios for the EU food and beverage sector [Chan et al., 2015]

Further reductions through energy efficiency measures are technically feasible through 93 different ESOs. Economically viable opportunities that pay back after a maximum of five years would entail energy savings of 6.5% (1.7 Mtoe) in 2030 and 14.5% (3.2 Mtoe) in 2050 (*Table 16*).

Table 16: Energy saving scenario overview for the EU food and beverage sector [Chan et al., 2015]

Scenario	ESOs	Relative Energy Savings		Total Energy Savings	
		2030	2050	2030	2050
Economic Scenario 1	42	5%	10%	1.4 Mtoe	2.4 Mtoe
Economic Scenario 2	61	6.5%	14.5%	1.7 Mtoe	3.2 Mtoe
Technical Scenario	93	26%	24%	6.8 Mtoe	5.7 Mtoe

All of the above seven sectors that were analyzed by ICF International displayed one similar characteristic. The technically available ESOs of each sector were all ready for usage by 2015. This leads to the conclusion that the study does not see further large technical development that would possibly increase energy savings even more. The economic readiness of the ESOs on the other hand is displayed in such a way that it is estimated to increase slowly up to 2050. This means that many of the technologies that were already technically viable in 2015 will be able to reduce their capital cost through a constant learning curve of the technology providers and hence make certain ESOs economically viable. The highest impact for energy savings will be reached in 2050 for all the sectors through the economic scenario 2 and ESOs with a pay-back period of up to 5 years.

The machinery and food and beverage sectors reach the highest relative economic energy savings, with 13.3% and 14.5% of energy savings, respectively towards their BAU energy consumption. These are both in relation to relatively small total BAU energy consumptions and therefore solely present 2.5 Mtoe and 3.2 Mtoe of saved energy, respectively. The highest total values of saved energy are attained in the iron and steel and the chemicals sector in 2050. The former is estimated to yield 6.8 Mtoe of saved energy and the latter around 7.4 Mtoe.

2.4.1.1. Heat Recovery Strategies

Heat recovery represents the recycling of heat through using waste heat that would have otherwise been lost to the environment. This can mean that a stream needs to be cooled down and hence the heat of this formerly hot stream is used elsewhere, e.g. to heat up a cold stream that needs to be warmed up. As well, this entails the usage of waste heat to generate mechanical power or even electricity in the follow-up step [Banerjee et al., 2012].

There are two main benefits of heat recovery. The first being an economic benefit, which is yielded through different factors. The recovered heat can directly replace energy that would have been bought otherwise and hence reduces the cost of purchased energy. Through the usage of waste heat the capacity requirements for the heat generating device can decrease and therefore save capital costs, because a smaller heat generating system can be installed. The second benefit is of environmental nature, as the increased efficiency through heat recovery provides a lower energy consumption, which decreases the amount of GHG and other environmental pollutants [Nexant Inc., 2009].

Table 17 shows an overview of the most relevant heat recovery strategies. They are based on a study by ICF International, which calculated the estimated annual technical energy savings potential up to 2030 and 2050 for each ESO. Five main heat recovery ESOs were identified and are briefly described. The abbreviated sectors are the non-metallic mineral products

(NMM) and the non-ferrous metals (NFM) sectors. The largest ESO in terms of total quantity is the “low temperature heat recovery”, which has a large potential especially in the chemicals sector. In terms of relative energy savings potential per sector, the “exhaust gas and low temperature heat recovery” within the non-metallic minerals products have the largest potential with each around 13% to 14% up to 2030 and 2050, respectively. The “exhaust gas heat recovery” is most applicable to different sectors, as it has a technical energy savings potential in six different sectors.

Table 17: Most relevant heat recovery strategies [Chan et al., 2015]

ESO	Description	Sector	Technical Savings Potential			
			2030		2050	
			ktoe/a	of sector	ktoe/a	of sector
Exhaust gas heat recovery	Increases efficiency through extracting energy from the exhaust gases and reusing it	Iron & steel (furnace)	900	6%	816	4%
		Pulp & paper (dryer)	465	6%	438	8%
		NMM products (kiln & furnace)	904	13%	872	14%
		NFM (furnace)	70	4%	70	5%
		Food & beverage (oven)	139	2.2%	118	2.1%
		Machinery	234	4.4%	161	3.3%
Inter-plant process integration	Applies pinch analysis for resource conservation. Several plants may be integrated to maximize resource recovery through inter-plant integration	Iron & Steel	1941	12%	2010	11%
		Pulp & Paper	374	5%	236	4%
		Chemicals	1441	8%	1312	7%
		Food & beverage	528	8%	449	8%
CHP plant	Raises the conversion rate of fuel use (fuel efficiency level) through using waste heat for other applications	Pulp & paper	360	5%	235	4%
		Chemicals	299	2%	296	2%
		Food & beverage	258	3.8%	232	4%
Basis oxygen furnace waste heat and gas recovery	Either recovers sensible gas in a waste heat boiler when combustion takes place in the converter gas duct, or gas is cleaned, cooled and stored in a gas holder for further use	Iron & steel	1227	8%	1180	6%
Low temperature heat recovery	Uses additional waste heat that is available from kiln gasses and cooler exhaust gas. Principally, for drying other materials like slag or secondary fuels or production of steam / power through organic rankine cycles from heat as low as 80°C	NMM products	900	13%	859	14%
		NFM	41	2%	32	2%
		Chemicals	1946	12%	2182	12%

The exact heat recovery systems that stand behind the five ESOs will be laid out in the following to give a clearer insight into which kind of technologies are applicable to generate the named energy savings. There are four main heat recovery systems, which are displayed in *Table 18*. These are recuperators and regenerators, waste heat boilers, feed-water economizers and the heat recovery from boiler blowdown.

Recuperators and regenerators are generally applied to high temperature exhaust gas heat recovery, such as incineration and thermal oxidation. Generally, for both methods, gas that is coming into the process is pre-heated by high temperature exhaust gas that is going out of the process. The design of a recuperator consists of tubes and plates that transfer heat from the exhaust gas to the incoming combustion air without mixing them. Two regenerators are required for a properly working heat recovery process, because one provides energy to the combustion air that the other is recharging. Regenerators are generally bulkier, heavier and more expensive than recuperators [Nexant Inc., 2009].

Waste heat boilers use the heat from exhaust gases to generate steam or warm water. The exhaust gas is passed over parallel tubes containing water, which is heated or even vaporized and collected. To generate steam with the boiler the exhaust gas should be above 400°C. To generate warm water at least 200°C are sufficient [Nexant Inc., 2009].

A feed-water economizer uses the waste heat of the exhaust gas to heat a feed-water stream of a boiler through a gas-to-liquid heat exchanger and hence reduces the heat loss. Generally, there are two different types of feed-water economizers. Firstly, in fire-tube economizer the exhaust gas flows through tubes surrounded by water, which is then heated. Secondly, water-tube economizers heat up water, which flows through a bundle of tubes, by the surrounding exhaust gases [NEXANT INC., 2009].

Heat recovery from boiler blowdown can be applied to boilers that need periodic or continuous removal of water from the boiler to remove solids or sludge. To recover the energy from the boiler blowdown a relatively low-pressure receiver is used. The saturated liquid high-pressure blowdown is discharged into the receiver, which is at relatively lower pressure. Hence, part of the liquid blowdown evaporates to steam, which can then be used to pre-heat the boiler feed-water. The remaining liquid can be used in a liquid-to-liquid heat exchanger to pre-heat the makeup water. In this way a heat recovery ratio of up to 90% can be achieved [NEXANT INC., 2009].

NEXANT INC. conducted an assessment of the above mentioned heat recovery systems, presented in *Table 18*. The cost savings are annual and in reference to the case without waste heat recovery. Despite relatively large annual cost savings that can be attained through the usage of recuperators or regenerators of 20% – 40%, their pay-back period is the longest in relation to the other presented methods, with 2 – 4 years. This means that their capital cost is relatively high. The shortest simple pay-back time of up to 1 year is reached by applying heat recovery to boiler blowdown. This is mainly because up to 90% of heat can be recovered.

Table 18: Main heat recovery systems [NEXANT INC., 2009]

Method	Waste Source	Application	Cost Savings	Simple Pay-back
Recuperators/ regenerators	Exhaust gases from incineration or thermal oxidation processes	Incoming product preheating	20% - 40%	2 - 4 years
Waste heat boilers	Exhaust gas from gas turbines, reciprocating engines, incinerators, furnaces	Steam generation, water heating	5% - 20%	0.5 - 2 years
Feed-water economizer	Exhaust gas from fuel-fired burner	Feed-water, make-up water preheating	2% - 20%	0.5 - 2 years
Heat recovery from boiler blowdown	Steam boiler blowdown	Steam generation, feed-water pre-heating	-	0.5 - 1 year

2.4.1.2. Retrofitted Systems

Next to the above presented heat recovery strategies, a large part of the ESOs involve retrofitting and changing the process heat generating systems. The most relevant of these opportunities are displayed in *Table 19*. They yield a larger energy savings potential than the above presented heat recovery strategies. The largest technical energy savings potential is reached through an “integrated control system” in the iron and steel and chemicals sectors, just as through the usage of “improved catalysts” in the chemicals sector with around 1500 to 1900 ktoe per year. The largest relative energy savings per sector are attained through an “integrated control system” as well, with around 14% to 15%, in each the pulp and paper, non-metallic mineral products and the machinery sectors. “Integrated control systems” and “flue-gas monitoring” systems are the most applicable to the overall industry, as they stand for energy savings in seven different industrial sectors.

Table 19: Most relevant retrofitting opportunities [CHAN ET AL., 2015]

ESO	Description	Sector	Technical Savings Potential			
			2030		2050	
			ktoe/a	of sector	ktoe/a	of sector
Integrated control system	Adapts the process conditions, based on artificial intelligence, mathematical or neural networks and "fuzzy logic" models of industrial process through information of sensors used in control systems	Iron & Steel	1775	11%	1789	11%
		Pulp & Paper	987	14%	821	15%
		NMM Products	998	14%	925	15%
		Chemicals	1579	10%	1797	10%
		NFM	235	13%	201	13%
		Food & beverage	676	10%	563	10%
		Machinery	766	14.4%	706	14.6%
Flue-gas monitoring	Maintains a proper air-to-fuel ratio to optimize fuel combustion efficiency through stacking thermometers, fuel meters, make-up feed water meters, oxygen analyzers, run-time recorders and energy output meters	Iron & Steel (furnace)	982	6%	850	5%
		Pulp & Paper (boiler & dryer)	707	10%	625	11%
		NMM Products (kiln & furnace)	358	5%	320	5%
		Chemicals	1049	6%	1189	7%
		NFM (furnace)	86	5%	84	5%
		Food & beverage (boiler)	266	3.9%	199	3.5%
		Machinery (furnace)	116	2.2%	77	1.6%
High efficiency burner	Increases efficiency at high temperature applications through commercialization of self-recuperative and self-regenerative burners to achieve flameless combustion, which results in more uniform heating, lower peak flame temperatures, improved efficiency and lower NOx emissions	Iron & Steel (furnace)	1207	7%	1049	6%
		NMM Products (kiln & furnace)	306	4%	222	4%
		Chemicals	271	1.5%	248	1.5%
		NFM (furnace)	89	5%	76	5%
		Food & beverage	227	3.6%	189	3.3%
		Machinery (furnace)	140	2.6%	97	2%
Black liquor gasification	Allows improved use of wood residues through the extension of a pulp plant into a bio-refinery, because chemical pulp plants are favorable for the production of "green" chemicals and biofuels	Pulp & Paper	225	3%	152	3%
Combustion optimization	Improves combustion efficiency by frequent adjusting of the air-to-fuel ratio to reduce excess air, which carries away excessive amounts of heat	Iron & steel (furnace)	634	4%	549	3%
		NMM Products (kiln & furnace)	240	3%	218	3%
		NFM	57	3%	56	3%
Advanced heating and process control	Reduces energy losses by governing aspects such as material handling, heat storage and turndown	NMM Products (kiln & furnace)	351	5%	304	5%
		Chemicals	358	2%	421	2%
		NFM (furnace)	94	5%	77	5%
		Food & beverage	118	1.7%	93	1.6%
		Machinery	151	2.8%	114	2.4%
Optimization of kiln efficiency	Saves energy through an optimized kiln design, which includes the selection of the best melting/heating techniques for the specific application	NMM Products	375	5%	286	5%
Improved catalyst	Increases process performance and reduces energy consumption	Chemicals	1627	10%	1869	11%
Improved design of distillation column	Increases efficiency of distillation/ separation reaction. Can include advanced separations such as Divided Wall Column distillation or Heat Integrated Distillation Column	Chemicals	373	2%	464	2%
Optimization of distillation column operation	Reduces distillation energy consumption through operational improvements (reflux ratios, avoid over-purifying products, pressure adjustment, etc.)	Chemicals	339	2%	380	2%
Increased recycling	Recycles aluminum and consumes approximately one third of the energy required to produce primary aluminum.	NFM	150	8%	130	8%

ESO	Description	Sector	Technical Savings Potential			
			2030		2050	
			ktoe/a	of sector	ktoe/a	of sector
Inert anode technology	Reduces downtime period for replacing anodes for the aluminum reduction process and hence increases efficiency, because unlike carbon anodes, inert anodes are not corroded and will not release CO2 but pure oxygen	NFM	121	6%	105	6%
Improved cleaning equipment efficiency	Optimizes cleaning process through efficient nozzles on hoses, water use at ideal temperature instead of steam and optimized flushing operations	Food & beverage	227	3.3%	177	3.1%
Boiler air preheat	Increases efficiency by roughly 1% for every 5°C increase in the combustion air temperature. Changes in combustion air temperature directly affect the amount of combustion air supplied to the boiler and can increase or decrease the excess air	Food & beverage	178	2.6%	140	2.4%

2.4.2. Renewable Heat

Next to ESOs that consist of either heat recovery strategies or retrofitting process heat systems in an energy efficient way, there are several renewable heat technologies that generate process heat. The increased deployment of these technologies mitigates emissions of carbon containing fossil fuel sources as well. As mentioned in Chapter 2.2, the share of renewables in European industry applications is fairly small up to present. Solely biomass has a considerable share of 10% of the European process heating and cooling demand. Further renewables account for less than 1%.

A study on the long-term potential of renewables in the global industry up to 2050 concluded that around 50 EJ/year of the final industrial energy consumption could be of renewable origin, representing around 21% of the total global industry share. 37 EJ/year (~16%) standing for biomass feedstock and process energy and 10 EJ/year (~4%) for process heat from solar thermal systems and heat pumps [TAIBI ET AL., 2010].

These three technologies are the most applicable for process heat generation in the industrial sector. The main focus in this chapter will be on solar thermal energy and biomass systems though, as these are direct renewable energy sources. Heat pumps basically depend on the power mix of the national electricity grid, as they are furnished with electricity.

This overview will explain the technologies and some of their basic technical aspects, just as their future deployment potential. In the following Chapter 3 cost data on solar thermal systems will be laid out, as solar thermal systems will be the main technical reference system within this thesis work.

Biomass

As for the moment biomass is mainly used in the food, drink and tobacco and the pulp and paper sectors, just as in the wood industry [REN21, 2016]. The further sectors, like the iron and steel, non-metallic mineral products, chemicals, non-ferrous metals, machinery and the textile, leather and clothes sectors use almost no process heat from biomass. In 2015 around 77% of global heat that was generated from biomass stemmed from solid biomass, 18% from municipal solid waste, 4% from biogas and 1% from biofuels [REN21, 2016].

Different biomass types are available and already commercialized. They are separated depending on their state of aggregation:

- Liquid biofuels: ethanol is produced through the fermentation of sugar and biodiesel through transesterification of vegetable oils
- Solid bioenergy: charcoal and pellets are made from wood and could both replace coal as a fossil fuel source
- Gaseous biofuels: biogas is obtained from anaerobic fermentation and producer or synthetic gas (syngas) from biomass gasification

Biogas that is obtained through anaerobic fermentation is very similar to natural gas and can be used in gas engines. Syngas from gasification can be used for process heat applications, but as well for power generation [TAIBI ET AL., 2010]. A graphical presentation of these different types of bioenergy and some others is to be found in *Figure 22*. It shows that liquid biofuels are mainly made from sugar or oil crops, solid biofuels on the other hand basically from wood.

A first example for the specific application of biomass as process heat source is the co-combustion of biomass waste especially in cement kilns. The cement industry is well suited for the combustion of biomass waste, because clinker and the limestone feedstock act in a gas-cleaning way. Through adding biomass waste into cement kilns with conventional fuels, the production costs, dispose of waste, CO_2 emission and fossil fuel usage can be reduced.

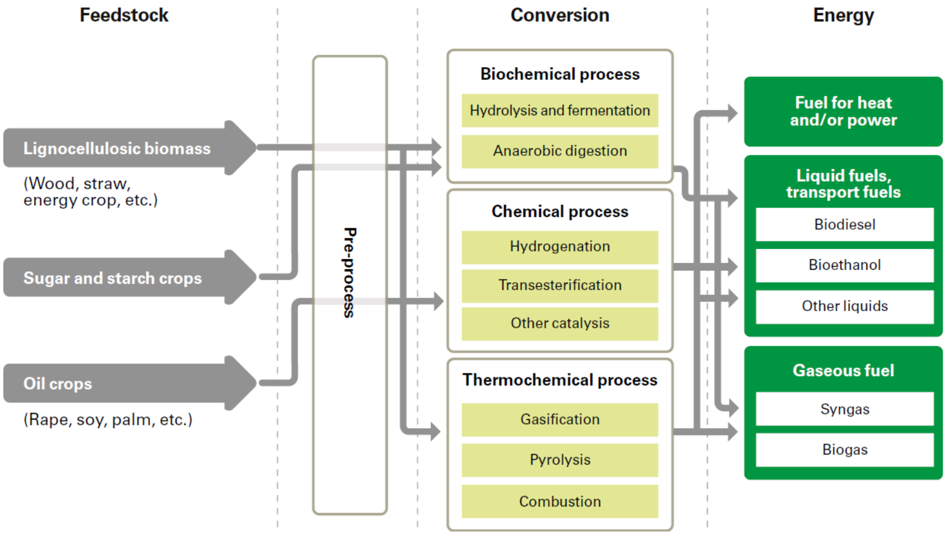


Figure 22: Schematic overview of bioenergy production [DAVIS ET AL., 2014]

A further possible application of biomass is in blast furnaces, through the usage of charcoal. It has similar chemical properties as coke, which is currently still the most widely used fuel for the iron and steel sector [TAIBI ET AL., 2010]. In terms of long-term environmental potential through the usage of charcoal in blast furnaces, research indicates that around 18% to 40% of CO_2 could be mitigated [FELICIANO-BRUZUAL, 2014].

A third example is the gasification of biomass in form of risk husk or other agricultural residues, which can be used for thermal applications [TAIBI ET AL., 2010]. Most of the currently operational biomass gasifiers run on wood-based feedstock, e.g. forest residue, bark, waste wood and wood pellets. They are mainly applied to co-firing purposes and for fuel and chemicals production. There are few currently running plants and the largest ones can be found in Finland.

One of the largest applications of biomass usage is in recovery boilers that are mainly used in the pulp and paper sector. This occurs mainly after the chemical pulping process, when organic residue, in form of black liquor, remains and is burned in a recovery boiler. On a global level, recovery boilers represent about a quarter of total industrial biomass usage [VAKKILAINEN ET AL., 2013].

Regarding solid biomass sources, the heating appliances based off these sources are well developed in Europe. Wood pellets for the European market are mainly supplied from within Germany, Sweden and Latvia. The worldwide trade of wood pellets was focused on Europe as the largest importer in the past, though quite recently Japan and South Korea have become further important importers.

The liquid biofuels industry has been full of uncertainty in 2015, especially because future regulatory frameworks are uncertain and large biofuel plants were running with 35% spare capacity. Despite the current uncertainties in the liquid biofuels sector, the predictions up to 2050 forecast around 16% of the total global industrial energy share to be based on biomass [TAIBI ET AL., 2010].

Solar Thermal

There are two broad technologies when considering solar thermal systems for process heat.

- Solar dryers
- Solar collectors

Solar dryers are mainly used in the food sector and use natural-circulation or forced-convection in drying applications. Solar drying techniques are considered to be either direct or indirect and active or passive. Indirect techniques avoid the direct UV radiation and an eventual loss of food quality and passive systems use natural convention for the drying process instead of using fans, like the direct techniques [IRENA ET AL., 2015].

The main solar collector technologies for low temperature levels (below 80°C) are unglazed flat plate, glazed flat plate (FPC) and evacuated tube collectors (ETC). Flat plate collectors are made of plastic or copper tubing that is laid through an insulated and weather-proof box with a dark flat plate absorber on its top surface and insulated material on its backside.

The evacuated tube collectors are made of parallel glass tubes with a vacuum inside. The vacuum enables lower heat losses. The heat transfer fluid, mostly water, flows through the tubes and is surrounded by the vacuum. Some of the evacuated tube collectors have circular absorbers in the tubes. They enable the sun rays to stay perpendicular to the absorbers and hence increase the solar yield [PHILIBERT, 2006].

For temperatures up to 200°C new technologies like ultra-high vacuum flat plate collectors or evacuated tube collectors with concentrators placed behind the tubes have been developed. The concentrators are called compound parabolic concentrators (CPC). Temperature levels up to 400°C can be generated by solar concentrators, such as parabolic dish and parabolic through collectors or linear Fresnel collectors. The concentrating solar thermal technologies can use different heat transfer fluids. Basically, they can be designed as a direct or indirect system. The former is also referred to as open-loop system and uses water or air, which is heated in the solar system and then directly used in the process. The latter is named closed-loop system and uses a heat transfer fluid different to the process fluid. Possible heat transfer fluids for the indirect systems are glycol, hydrocarbons, refrigerants or molten salt. They finally heat up the process fluid through a heat exchanger [IRENA ET AL., 2015].

Next to meeting heating demands, solar thermal systems can as well be used for cooling applications. In absorption and adsorption chillers solar energy can be used to regenerate the absorber fluid, which contains the refrigerant of the chiller, after it has been evaporated throughout the cooling process. Current improvements to thermally-driven chillers have decreased the working temperatures required in a chiller and hence increased the possibility of applying solar energy [IRENA ET AL., 2015].

Including all possible global applications for solar thermal technologies, the total annual energy output of solar thermal heat systems exceeded the output of geothermal, photovoltaic and CSP systems with around 68 TWh in 2005, based on an installed global capacity of 115 GW. However, within the industrial sector there were only 85 industrial solar thermal heat applications identified in 2005, which accounted for around 25 MW of installed capacity [Philibert, 2006].

By the end of 2015 the total global installed capacity of solar thermal systems reached around 435 GW, which provided a total energy output of 357 TWh [Ren21, 2016]. Hence, the current installed capacity is around four times the capacity of 10 years ago, in 2005. The majority of these systems though are used for domestic hot water and space heating and very small amounts are used on an industrial scale. In fact only around 3% of the new installed capacity of solar thermal systems in the EU and Switzerland in 2015 was for district heating, process heat or cooling processes [Ren21, 2016].

Promising applications for industrial solar thermal systems are for example the desalination of water, especially in areas with high water scarcity and high solar radiation, and drying of agricultural goods. Hay drying is done with unglazed flat plate collectors in Switzerland. Solar technologies can as well be applied to cooling processes, especially in the food, drink and tobacco sector, in which mainly electric chillers are currently in charge of product cooling.

Industrial applications with higher temperature requirements will require concentrating and solar tracking technology, such as parabolic through collectors or high temperature concentrating solar collectors that can be installed on roofs [Philibert, 2006]. Parabolic through collectors are the dominating technology for medium temperature process heat applications, just followed by linear Fresnel collectors. The majority of concentrating solar thermal manufactures is located within Europe [Ren21, 2016].

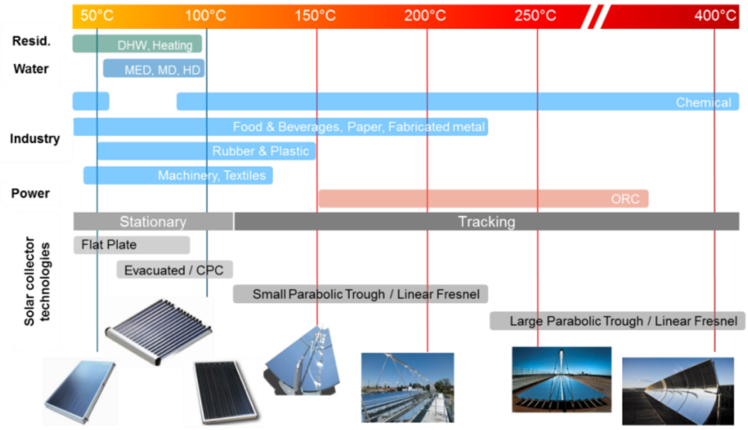


Figure 23: Solar thermal technologies and their temperature levels [Horta et al., 2016]

The key industrial sectors that should be addressed by solar thermal process heating technologies are the food, drink and tobacco; the transport equipment; the textile, leather and clothing; the machinery and the pulp and paper sectors. Around 60% of the heating need in these sectors is at temperatures below 250°C [Irena et al., 2015]. *Figure 13* and *Figure 23* show further and more specific sectors and applications that can be served by solar thermal technologies and their temperature ranges. Especially large parabolic through collectors and linear Fresnel collectors have the potential to provide high temperature process heat to the chemicals sector.

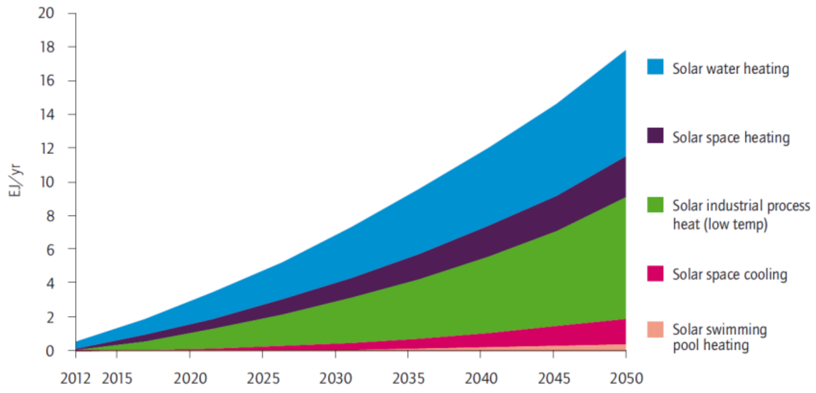


Figure 24: Solar heating and cooling roadmap vision up to 2050 [IEA, 2012b]

In regard to future installations of solar thermal systems the IEA estimates that up to 2050 especially solar process heat technologies are going to gain a larger share of the total installed capacity of solar thermal systems, reaching up to around 7.2 EJ of newly installed capacity in 2050 (*Figure 24*).

3. Investment Analysis and Third-Party Funding

Chapters 2.4.1 and 2.4.2 have laid out the potential that energy efficiency measures and renewable heat generating technologies for process heat have in different European industry sectors. Despite this potential, the funds that are invested into revamping process heat technologies, making them more energy efficient or renewable, remain insignificant. Especially in comparison with the funds that are available for renewable power generating technologies like wind and solar PV (Chapter 1.1.2). Already back in the 1970s, due to the fact that many companies bypassed profitable energy efficiency investments, this problem has been coined the "efficiency gap", and remains an issue up to date [JACKSON, 2010].

The extensive usage of the pay-back period as investment criterion is part of the problem [JACKSON, 2010]. The lack of standardization throughout the assessment process of investments into energy efficient and renewable process heat technologies and the lack of risk mitigation for investments are further key issues. Especially energy efficiency improvements go along with relative high costs for project development, finance documentation and transaction costs [SULLIVAN, 2015].

The implementation of the TrustEE platform in the scope of the Horizon 2020 program aims at tackling these problems, to enable a quick technical and economic assessment of an investment possibility. Within the scope of this thesis the impact of risk mitigation on the investment analysis is the main focus. Hence, this chapter will present the main parameters that are needed for a thorough investment assessment. As well, a risk assessment model will be developed. Furthermore, it will present which are the different risk mitigation measures and their influence on risk perception. As well, third-party funding options and platforms that are already put in place for process heat applications will be shown.

3.1. Investment Analysis Parameters

Investment analyses can be used to assess either a portfolio consisting of bonds and stocks, or an investment into a new business idea or even large corporate projects. In this thesis it is used to assess the profitability of an investment into more energy efficient and renewable process heat generating systems. The use of this analysis is beneficial for either a third-party investor or the final end-user, depending on who is seeking to invest, in helping them to compare such an investment to other options available. The following Chapter 4 though will strictly focus on analyzing third-party investments into solar thermal process heat systems. The investment approach is applicable to all the above mentioned energy efficiency measures and renewable energy technologies, such as biomass, biogas and solar thermal.

The main values that are generally used to assess the profitability of energy projects are the LCOE (levelized cost of energy) or in this case the LCOH (levelized cost of heat), the pay-pack period, the NPV (net present value) and the IRR (internal rate of return) [JESÚS BAEZ ET AL., 2015]. Especially the LCOH can be used to compare energy projects of different lifetimes based on their energy costs. It is therefore often used in the energy sector. Though, in this case the objective is to have measures that can compare an investment into an improvement of a process heat generating system with other non-energy related investment options. Therefore, the following strictly financial output parameters will be considered to assess different investment options:

- Pay-back period
- NPV (net present value)
- IRR (internal rate of return)

The pay-back period is defined as the amount of time that is needed to earn the invested amount of money through the incoming annual cash flows of the investment. For a project that yields constant annual cash flows of €1000 and has invested €2000, the total pay-back time will be two years. The pay-pack period criterion does not consider the time value of money. It considers that €100 in the third year of an investment have the same value as in the first year, which in reality is not the case due to inflation.

A further issue (Chapter 1.1.2) is that the pay-back period criterion does not differentiate between different investment lifetimes. It considers an investment of 10 years to be equal to an investment of 20 years and simply focuses on the amount of time needed to return the investment. By this it disregards the cash flows of the investment that are attained after the pay-back period, which are likely larger for a 20 year investment than for a 10 year investment. Though, the 10 year investment most likely reaches a shorter pay-back period and will therefore be preferred [JACKSON, 2010].

Both the IRR and the NPV take into consideration the time value of money and are therefore regarded as superior criteria towards the pay-back period criterion. Both are based on the following Equation (1):

$$NPV = -I + \frac{\sum_{t=1}^{T_I} CF_t}{(1+i)^t} \qquad (1)$$

The NPV is the sum of the discounted cash flows over the investment lifetime minus the invested amount of money. If the NPV is positive the investment pays back more than it invested. In other words, if the sum of the discounted cash flows is larger than the initial investment, then the investment is profitable [JACKSON, 2010].

The IRR is equal to the discount rate i when the NPV is zero and hence is calculated through the same equation from above, setting the equation equal to zero. This can be done through a trial and error method, by trying to get the equation with the given investment and cash flows equal to zero. The IRR stands for the maximum discount rate at which the project remains profitable. If the discount rate is increased further the NPV becomes negative and hence the project is not profitable. A relatively lower discount rate always increases the NPV, as the cash flows are discounted less.

As an evaluation criterion the NPV is generally considered as superior in comparison to the IRR. Because the IRR method cannot yield a single conclusion for projects which have negative cash flows, as the proper calculation will yield multiple IRRs [JACKSON, 2010]. Both IRR and NPV will lead to the same conclusion for an independent project decision. If mutually exclusive projects are analyzed, meaning if the decision has to be for either one of two projects, it can happen that both metrics will have different conclusions, one suggesting the first project is to be preferred and the other voting for the second one. This mainly occurs when project sizes or the cash flow timing is very different for each of the investment option.

The three presented criteria are by far the most used for investment assessments within firms. Often multiple criteria are used. A study by RYAN ET AL. found that 75% of firms used the NPV, IRR and pay-back criteria, while a further study from GRAHAM ET AL. revealed that 90% of firms that either use the NPV or the IRR criterion, as well use the pay-back period criterion [JACKSON, 2010; GRAHAM ET AL., 2001; RYAN ET AL., 2002]. Even though, the investment assessments that have been using NPV and IRR have been increasing over time, the use of the generally less suitable pay-back period criterion has not been diminishing [RYAN ET AL., 2002], which stands in contrast to the recommendations of the financial academic community.

To be able to calculate the pay-back period, the NPV and the IRR and to assess the financial viability of an investment through them, the parameters from Equation (1) and further input parameters are needed. The main input parameters are the following:

- Investment I or capital expenditure (CAPEX)
- Investment lifetime T_I
- Discount rate i
- Cash flow CF

The amount of invested money depends on the cost of the system components and the installation cost. The system layout of the solar thermal reference system will be a key issue here to assess the investment. Historical cost data for solar thermal systems will be laid out in Chapter 4.1.1 and used for the simulations. The investment lifetime will range from about 10 to 20 years, depending on the type of risk mitigation measures that are presented in Chapter 3.2.3.

The discount rate has an influence on the output parameters of the investment analysis. It can be defined as the opportunity cost of capital, which means it theoretically represents the return on another investment that was not considered by the investor [KHATIB, 2015]. This interpretation regards the discount rate as a cost of equity, in other words the return that equity from a third-party investor should at least have to be considered by the investor. Often investments are financed through equity and credit, in these cases the weighted average cost of capital (WACC) is used as discount rate, because it considers the cost of equity and the cost of debt from a financial institution [KHATIB, 2015]. To account for risk that comes along with an investment, the discount rate needs to be adjusted by a risk premium, which will be further explained in Chapter 3.2.1.

Depending on the investment option and the perspective, the incoming cash flow stands for something different. There are basically two different investment perspectives and investment options regarded here.

- Investment perspective:
  - End-user standpoint
  - Third-party investor standpoint
- Investment options:
  - Energy efficiency measures for process heat
  - Renewable process heat

Within this thesis the perspective will be from a third-party investor standpoint for investments into renewable process heat, namely from solar thermal systems. *Table 20* explains what the main incoming cash flows consist of, depending on the investment option or perspective.

From the end-user perspective for an investment into a more energy efficient system, the incoming cash flow will consist of the annual amount of energy saved E_S, in comparison to the former reference system, multiplied by the price per kWh of the conventional fuel P_C of the reference system. For a renewable system of process heat that replaces a conventional energy source, or part of its produced energy, the incoming cash flow will consist of the annual amount of energy produced by the renewable system E_R multiplied with the price of energy P_C of the conventional system.

Table 20: Incoming cash flow differences for investment analysis

		Investment Perspective	
		Third-Party Investor	End-User
Investment Option	Energy Efficiency	$E_S * P_C(1-P)$	$E_S * P_C$
	Renewable System	$E_R * P_C(1-P)$	$E_R * P_C$

For a third-party investor, who might be the new owner of the energy generating systems, the perspective is different. His cash flow from a new energy efficiency measure will pertain of payments for the saved energy E_S from the end-user. The price for the saved energy depends on a premium P of the conventional fuel price and is multiplied with the conventional fuel price. If the investor funds a renewable process heat source to replace part of the conventionally produced energy, the incoming cash flow will be the total energy produced by the new renewable system E_R multiplied by a reduced price of the conventional source. Through the deduction of a premium P of the conventional fuel price, the end-user is ensured to have a benefit from the investment as well.

The incoming cash flow presented in *Table 20* is deducted by different kinds of operational costs and taxes and positively influenced by financial and fiscal benefits to yield the final cash flow. These are mainly the following ones:

- Residual value (RV): is the value of the asset at the end of the investment lifetime, it depends on the remaining system lifetime after the end of the investment and can be calculated by dividing the investment lifetime through the product lifetime and multiplying it with the CAPEX. There are other ways of calculating or defining the RV though, for example it could simply be negotiated in the beginning of the investment
- Inflation (Inf): is a macroeconomic parameter that depends on the general market conditions and will therefore be defined through different scenarios in Chapter 4.1
- Operational expenditure (OPEX): is the cost of operations and maintenance for the installed system, it is often defined as percentage OM of the CAPEX and is adjusted annually by inflation
- Financial incentive: is basically an investment grant, which is defined as a percentage of the CAPEX and granted in the year of investment
- Credit repayments: are done annually at a constant rate over the credit lifetime
- Interest rate payments on credit: are dependent of the interest rate by the credit giver, and decrease each year due to the credit repayments
- Depreciation (Dep): is assumed to be linear over a certain amount of years and decreases the taxable income
- Taxes (Tax): are defined as a corporate tax on the taxable income from the investment

The above presented further parameters basically split up into four different annual cash flow categories that are represented in *Table 21*. The sum of these cash flows is the total cash flow CF.

Table 21: Annual cash flow categories for investment analysis

Cash Flow	Equations
Investment	$CF_{Inv,t} = -I_t + RV_t$
Operational	$CF_{Op,t} = E_{R,t} * P_{C,t}(1-P) - I * OM * (1 + Inf_t)^{t-1}$
Financial	$CF_{Fin,t} = Inc_t - FC_t$
Fiscal	$CF_{Fis,t} = -(CF_{Inv,t} + CF_{Op,t} + CF_{Fin,t} - Dep_t) * Tax$

The investment cash flow basically is set up by the CAPEX in the year of investment and by the residual value in the last year of the investment lifetime. The operational cash flow is the main income represented by the investment and consists of the sold energy from the solar thermal process heat system, which is only deducted by the annual OPEX. The financial cash flow consists of the positive financial incentive Inc and the cost for the repayments and interest rate payments for the credit FC, if the investment is credit financed. Lastly, the fiscal cash flow is the corporate tax rate applied to the taxable income; that is the sum of the three initial cash flows deducted by the annual depreciation. The taxable income has to be positive and will be regarded from the first year of operation on.

3.2. Risk Assessment and Mitigation Measures

In Chapter 3.1 the different parameters essential to an investment analysis have been presented, especially those that are obtained through an investment analysis and based on which different investment options are assessed. This chapter will focus on developing a risk assessment approach for process heat investments and on laying out different risk mitigation measures. The measures basically aim at securitizing investments into energy efficient and more renewable process heat technologies. They try to change the risk perception of investors, towards this kind of investments, through mitigating risk. This will be applicable to process heat investment into energy efficiency and renewable technologies, though the focus in the analysis that will follow in Chapter 4 will lay on solar thermal process heat systems.

In general energy efficiency has been regarded and promoted as a risk management tool, as it has the capability of decreasing the exposure towards volatile energy prices [JACKSON, 2010; NAUMOFF ET AL., 2007]. The usage of energy efficiency measures leads companies to fewer expenses for conventional energy resources. The same counts for an increased usage of renewable process heat sources. Over the last decade the gas and especially the oil price have been highly volatile. Especially for very energy-intensive companies an increase in energy prices had a direct negative impact on its financial bottom line, as they had to cope with largely increasing expenses for energy resources. The usage of price volatile fossil fuel sources hence represents an enterprise risk, which can be mitigated through energy efficiency measures and more renewable sources.

Therefore, applying energy efficiency measures and renewable heat technologies to a company's process heat equipment already represents risk mitigation towards a company's profitability. This aspect is not the main focus of this thesis though. The aim is to analyze how far mitigating the risk of an investment that aims at revamping process heat technologies has an impact on the profitability of an investment project itself. The risk assessment and perception of both third-parties and end-users towards this kind of investment is supposed to be changed. Up to now both regard investments into new process heat technologies as rather risky in comparison to other investment options.

A rather well known way of securing investments and likewise enhancing access to capital markets is called securitization. It generally refers to a process in which an institution pools a part of its assets to form a consolidated financial instrument which can then be issued to investors as a special purpose vehicle (SPV). In other words, it refers to the process of transforming illiquid assets into standardized, tradable and risk segmented instruments with a different risk perception. The assets normally yield future cash flows, which get transferred to the investors in tranches that are segmented depending on their risk and future yield. Securities are said to enhance liquidity, as they help companies to raise funds through selling off assets that were perceived as rather risky. In general assets can be all sort of things, such as machines, equipment, buildings and stocks. In the framework of the TrustEE project assets refer to energy generating systems, within this thesis this will be solar thermal systems.

The first time securitizations were applied was back in the 1970s, as U.S. government agencies started pooling real estate mortgages [JOBST, 2008]. The market for securitizations has grown extensively in the recent past and an increasing amount of renewable energy assets has been securitized. The solar industry in the USA pioneered the process of securitizing renewable assets back in 2013, when SolarCity was able to sell distributed solar assets with a value of $54.5 million in a securitization deal. In 2016, SolarCity has already been able to sell $235 million worth of solar bonds, a securitization in form of bonds [ROSELUND, 2016]. Basically these solar securitization deals are based on power-purchase-agreements (PPAs) that SolarCity sells to their customers, enabling them to put solar panels on their roofs with little to zero upfront payment. The payments from the customers are secured through the PPA and are sold on to an investor [ECKHOUSE, 2016]. The PPA hence represents the risk mitigation measure, as it ensures that the end-user will buy a certain amount of power over time.

In Europe a project finance boutique called Independent Debt Capital Markets (IDCM) created its first solar bond in 2013 through The Renewable Finance Company (TRFC) by pooling small solar PV projects to give them access to the capital markets. The French energy utility EDF followed up in the same year by issuing their first green bond, which was twice oversubscribed and brought in €1.4 billion [LINDSAY, 2014]. This enabled EDF to provide more funds to other renewable energy projects. The bonds were sold to fund managers, central banks, insurances, pension funds and banks. Even before creating TRFC in 2013, IDCM was able to securitize several different non-rated large-scale solar PV projects in the UK in 2012 and 2013 through two bond issuances of £40 and £60 million [LINDSAY, 2014]. Further securities have been brought to the market since then through TRFC, focusing on aggregating multiple smaller projects into one bond [TRFC, 2016].

Though, solar thermal and energy efficiency projects have not been securitized up to now. For the latter it is mainly due to a lack of standardization of projects. This stands in contrast to renewable power projects that have been pooled, securitized and sold mainly in the USA and Europe. In general green securitizations have a large potential of allocating funds from the capital markets to smaller scale renewable energy or energy efficiency projects, especially in the industrial process heat sector, and decreasing their capital costs [CLIMATE BONDS ET AL., 2015]. Next to the above mentioned options and initiatives some of the largest research institutions of the UK, such as the Climate Bonds Initiative, the London School of Economics and Political Science, the Centre for Climate Change Economics and Policy and others, met for a “Green Securitization Roundtable” in 2015 to work on a policy brief for European policymakers showing the opportunities that green securitization offers [CLIMATE BONDS ET AL., 2015].

The above introduced securitizations are often based on standardized agreements, which ensure that the asset will be repaid. They function as risk management tools and are supposed to convince investors that there is little risk associated to a project. The above mentioned PPA is such an example and is widely deployed by SolarCity in the USA. It is the main pillar of the securitization deals that SolarCity has brought to the capital markets in the recent years. In the following sub-chapters risk mitigation schemes, similar to PPAs, will be presented. Furthermore, the impact of risk mitigation measures on the risk assessment and hence the total investment analysis will be laid out.

There are different ways of how to include a risk analysis into assessing investment options. Mainly the following techniques are known as risk assessment tools [GOSWAMI ET AL., 2015; OXERA, 2011]:

- Capital asset pricing model
- Expected value analysis
- Mean-variance criterion and coefficient of variation
- Certainty equivalent technique
- Monte Carlo simulation, decision analysis
- Real options analysis
- Risk-adjusted discount rate technique (RADR)

For investments into energy efficient and renewable process heat generation the RADR technique has been analyzed to be the most appropriate and will therefore be presented and used to assess risk and the impact of risk mitigation measures on risk perception. The measures through which investments are supposed to be securitized are presented in the following two Chapters 3.2.2 and 3.2.3. Most of the other techniques from above only allow determining a probability, with which future cash flows might occur. Hence, they make it more difficult to include all the impacts from the different risk mitigation measures. Or they yield a risk premium that is mainly based on systemic market risk and therefore represents exposure to market risk, but not to project risk. Especially for new markets, such as energy efficiency and renewable energies, this is critical, as there is little data available on the systemic risk of these markets [OXERA, 2011].

3.2.1. Risk-Adjusted Discount Rate

The discount rate is one of the most important factors regarding the economics of a project, especially in capital intensive energy projects [KHATIB, 2015]. The RADR technique accounts for risk through the discount rate, which is determined by using the risk-free discount rate (RFDR) plus a risk premium that is in relation to the volatility and risk of the investment [PARK ET AL., 2011]. When a project is riskier than normal, the risk premium increases by the amount of risk that has been assessed. The RADR technique can account for both risk exposure and risk attitude. Though it only provides an approximate adjustment of the real risk and does not measure the risk that comes along with a variation in cash flows [GOSWAMI ET AL., 2015].

The mainly used discount rate to assess investments is the WACC, which is calculated from the cost of equity and the cost of debt. Both equity and debt are generally used to finance projects. Therefore, the risk premium needs to be applied to the risk-free values of cost of equity and of cost of debt. If a third-party investor perceives a relatively low project risk, he will finance the project at a low cost of equity. The same counts for banks that hand out credits, the lower they perceive the risk of a project, the less costly their credit will be. For example, the cost of debt for onshore wind projects differs from country to country, especially because banks perceive a different legislative risk per country [NOOTHOUT ET AL., 2016].

The risk of a creditor is generally lower than for an equity investor, because interest rate payments and debt repayments are rather secure, especially in comparison to dividends that are paid to an equity investor. The interest rate payments and debt repayments are ensured through the credit agreement, dividend payments though only occur if a project or company is making a profit. Furthermore, interest rate payments bring along a tax benefit, as they reduce the amount of taxes that need to be paid. Hence, the cost of equity is generally higher than the cost of debt.

For both the cost of debt and the cost of equity a risk-free rate needs to be defined, on top of which the risk premium will be added. The approach chosen in this thesis, to obtain the risk free cost of debt and equity, is in reference to NOOTHOUT ET AL. and is based on a study by EURELECTRIC. It sets the risk-free rate for the cost of debt and equity equal to the average annual yield of a 10-year government bond [EURELECTRIC, 2012]. Hence, each country obtains its risk-free rate from the yield of a government bond. The average annual yield of 10-year government bonds was calculated out of 12 months of data from August 2015 to July 2016. Hence, the risk-adjusted cost of debt C_D and cost of equity C_E are calculated through following Equation (2) and (3). They are basically the risk-free rate r_{RF}, which is the 10-year government bond yield of the respective country, plus the risk premium of debt r_{RPD} and of equity r_{RPE}, respectively:

$$C_D = r_{RF} + r_{RPD} \tag{2}$$

$$C_E = r_{RF} + r_{RPE} \tag{3}$$

The final RADR, or to be exact the risk-adjusted after-tax WACC, is going to be calculated through the risk-adjusted cost of debt and cost of equity, the tax rate Tax and the capital structure. The tax rate is included to correct and further decrease the cost of debt. The after-tax WACC is calculated after the following Equation (4), in which DR is the debt ratio and ER is the equity ratio:

$$WACC = C_D * (1 - Tax) * DR + C_E * ER \tag{4}$$

The way risk premiums are generally calculated in the financial industry is not applicable to the energy efficiency and renewable sectors, because it is calculated in reference to past stock performances within a certain country and industry. Instead of referring to the financial industry, in this case the idea of how to calculate the risk premium for investments into energy technologies was taken from the mineral industry and a paper by Park et al. In their approach five different steps are used to calculate the risk premium [Park et al., 2011]:

1. Identifying risks
2. Developing rating scales
3. Determining risk values
4. Calculating risk scores
5. Determining the risk premium

The adapted method of how to calculate the risk premium is represented in *Table 22*. As the first step three main risk categories were identified in the process heat technology sector: technology, economic and political or policy risk [IRENA, 2016b; Park et al., 2011]. Each of them has sub-categories that have been chosen and apply to investments into energy efficiency measures and renewable process heat technologies. If possible the energy contracting schemes in Chapter 3.2.2 and the risk mitigation strategies in Chapter 3.2.3 will be able to decrease the impact of the presented risks and make an investment less risky and more viable.

Table 22: Calculation scheme for risk score of investments into energy efficient and renewable process heat technologies [Park et al., 2011]

Category	Risk	Probability	Impact	Risk Score
Technology Risk	Uncertainty of Energy Savings/Output	Low, Medium, High	Low, Medium, High	Probability x Impact
	Energy System Failure	Low, Medium, High	Low, Medium, High	Probability x Impact
	Incorrect Deployment of Energy System	Low, Medium, High	Low, Medium, High	Probability x Impact
	Uncertainty of Resource Availability	Low, Medium, High	Low, Medium, High	Probability x Impact
Economic Risk	Payment Timing Mismatches	Low, Medium, High	Low, Medium, High	Probability x Impact
	Payment Difficulties from End-User	Low, Medium, High	Low, Medium, High	Probability x Impact
	Decreasing End-User Demand	Low, Medium, High	Low, Medium, High	Probability x Impact
Political or Policy Risk	Radical Political Events	Low, Medium, High	Low, Medium, High	Probability x Impact
	Change of Incentive Scheme	Low, Medium, High	Low, Medium, High	Probability x Impact
	Change of Permitting Policies	Low, Medium, High	Low, Medium, High	Probability x Impact
	Change of Taxation Laws	Low, Medium, High	Low, Medium, High	Probability x Impact
Total				**Total Score**

For the technology risks, the uncertainty of energy savings or energy output refers to the fact that it is difficult to assess the exact amount of energy that will be saved by an energy efficiency measure or the amount of energy that a renewable system will produce, as both are very dependent of a correct system layout that accounts for the load profile of the application. The risk of system failure needs to be assessed as well, as it is likely to have a large impact on the investment analysis when occurring. Further, there is a risk that the installed energy technology is deployed incorrectly, due to unskilled labor workers that are in charge of the installation. These three risks are rather dependent of the energy system and their direct consequence is that they system provides less or no energy output or savings. The final technology risk is the uncertainty of the resource availability, this especially accounts for solar thermal systems and biomass systems. These four risk factors have a direct effect on the contractor who generally stays in charge of the energy system throughout its lifetime.

Regarding the economic risks there are basically three different risk factors. The risk that liquidity issues might occur through payment timing mismatches basically refers to short-term revenue defaults from the end-user because there is a timing difference between planned and real payments. The risk that an end-user comes into payment difficulties relates to the possibility that the borrower or end-user is unable to pay his annual energy payments at some moment over the investment lifetime. The demand risk stands for the possibility that the end-user at one point might have a decreased demand of energy and hence will not want to pay for additional energy.

The last category, the political or policy risk has four sub-categories. There is the risk of political events that can heavily impact the value of investments, such as radical changes in governments or even coups. Then there is the risk that incentives for certain technologies run out or are suddenly changed or banned. Furthermore, there is a risk of having a change of permitting policies for certain technologies that could make it harder or longsome to permit a new installation. Lastly, there is the risk that taxation laws for energy appliances can change and make an investment less favorable [IRENA, 2016b].

As second step after PARK ET AL. each probability and impact per risk factor needs to have a rating scale. These are defined as low, medium or high on a scale from 0 to 1 in reference to PARK ET AL. With 11 different risk factors this gives a maximum possible risk score of 7.04.

- Low probability and impact: 0.1
- Medium probability and impact: 0.5
- High probability and impact: 0.8

In steps three and four the total risk score TRS of an investment is then calculated based on all these risk factors and their probability P_{rf} and impact I_{rf}. For 11 different risk factors, as chosen in this assessment, the following Equation (5) represents the way the total risk score is obtained:

$$TRS = \sum_{i=1}^{11} P_{rf,i} * I_{rf,i} \tag{5}$$

With this, the first four steps for calculating the risk premium are achieved. The last and fifth step is to convert the total risk score into a risk premium that can be used to adjust the cost of debt and equity. In reference to PARK ET AL. different risk score levels were chosen, as displayed in *Table 23* and *Table 24*, that correlate to a risk premium value. The risk premium values will differ though for banks and for investors, as they regard risk from different perspectives. Banks as creditors have the guarantee that their credit and their interest rates will be paid back on an annual, semi-annual or even quarterly basis. A certain risk will be regarded and evaluated with a different risk premium, than from the standpoint of an investor.

To define the risk premium values for the cost of debt and equity for process heat investments in *Table 23* and *Table 24*, reference values from onshore wind were used. Due to the fact that onshore wind and solar thermal systems are both rather developed on a technical level, they are used as equivalent values. NOOTHOUT ET AL. calculated risk-adjusted values for the cost of debt and equity for each European country in 2014 and validated them through interviews with equity providers, project developers and banks. The costs are based on a risk-free rate plus the risk premium from the year 2013. The risk-free rate was chosen to be equal to a 10-year German government bond yield in 2013, which then was at 1.57% [NOOTHOUT ET AL., 2016]. The costs of equity and debt for onshore wind, which were evaluated by NOOTHOUT ET AL., are displayed in *Figure 25* and *Figure 26.*

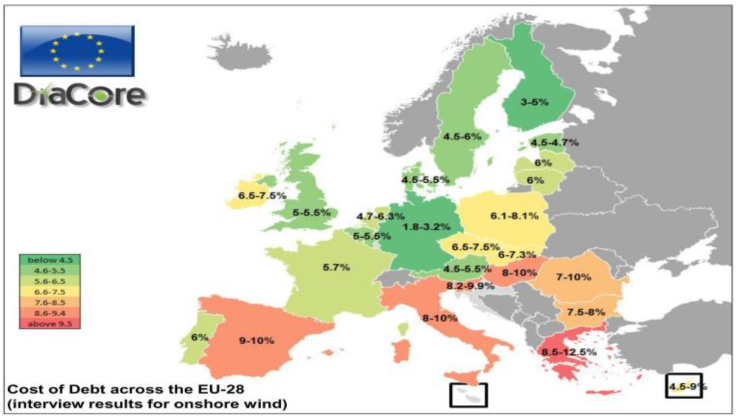


Figure 25: Cost of debt for onshore wind projects in 2014 [NOOTHOUT ET AL., 2016]

The highest risk-adjusted cost of debt was evaluated for Greece at 12.5%, deducted by the German risk-free rate in 2013 this is equal to a maximum risk premium of 10.93%. This value is rounded to 11% and hence stands for the maximum possible risk premium for the cost of debt (*Table 23*). The lowest risk-adjusted cost of debt is in Germany at 1.8%, which is basically the same as the risk-free rate of 1.57%. Hence, the lowest risk premium for the cost of debt is rounded from 0.23% to 1% in *Table 23*. The further risk premium values for the other risk score levels between the minimum and maximum level are set in accordance to PARK ET AL. This means that especially for projects with a high risk, the leverage through risk mitigation measures could be rather large, as the risk-free rate is comparatively small.

Table 23: Risk premium for cost of debt of investments into energy efficient and renewable process heat technologies [PARK ET AL., 2011; NOOTHOUT ET AL., 2016]

Expected Risk Score	Risk Premium for Debt
5.71 – 7.04	**11.00%**
5.11 – 5.70	**9.00%**
4.56– 5.10	**8.00%**
4.01 – 4.55	**7.50%**
3.51 – 4.00	**6.50%**
3.01 – 3.50	**6.00%**
2.66 – 3.00	**5.50%**
2.26 – 2.65	**5.00%**
1.91 – 2.25	**4.50%**
1.51 – 1.90	**4.00%**
1.21 – 1.50	**3.50%**
0.91 – 1.20	**3.00%**
0.61 – 0.90	**2.50%**
0.31 – 0.60	**2.00%**
0.15 - 0.30	**1.50%**
0 – 0.14	**1.00%**

Regarding the cost of equity, the same procedure as above was conducted to set the risk premium values for each risk score level of *Table 24*. The highest risk-adjusted cost of equity, calculated for onshore wind projects by NOOTHOUT ET AL., was of 20% in Estonia. Subtracting the risk-free rate of German government bonds from that, the final maximum risk premium is of around 18.5%.

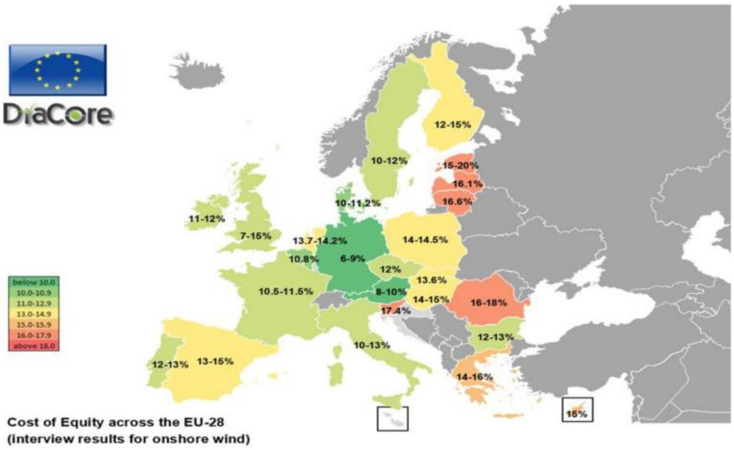


Figure 26: Cost of equity for onshore wind projects in 2014 [NOOTHOUT ET AL., 2016]

The lowest risk premium is set to 4.5%, after the same assumptions. The further risk premium values between the minimum and maximum values are set after the scheme applied by PARK ET AL.

Table 24: Risk premium for cost of equity of investments into energy efficient and renewable process heat technologies [PARK ET AL., 2011; NOOTHOUT ET AL., 2016]

Expected Risk Score	Risk Premium for Equity
5.71 – 7.04	**18.50%**
5.11 – 5.70	**16.50%**
4.56– 5.10	**15.50%**
4.01 – 4.55	**14.50%**
3.51 – 4.00	**13.50%**
3.01 – 3.50	**12.50%**
2.66 – 3.00	**11.00%**
2.26 – 2.65	**10.00%**
1.91 – 2.25	**9.00%**
1.51 – 1.90	**8.00%**
1.21 – 1.50	**7.00%**
0.91 – 1.20	**6.50%**
0.61 – 0.90	**6.00%**
0.31 – 0.60	**5.50%**
0.15 - 0.30	**5.00%**
0 – 0.14	**4.50%**

To calculate the WACC from the costs of equity and debt through Equation (5), the average capital structure per country is needed. It refers to the equity E and debt D ratios that a project uses in general to finance itself. Capital intensive industries usually try to fund their projects with primarily debt, as it is mostly cheaper [NOOTHOUT ET AL., 2016] and permits using a larger leverage on lower cost capital. The main differences between different countries generally stem from the economic and political stability of a country. Normally, this leads to different average debt-to-equity ratios per country. As well, certain projects that have a proven track record will generally have less difficulties attracting debt funding. In this thesis the differences in debt-to-equity ratios per country will be neglected though, as they have a rather large influence on the WACC and their analysis is not a main objective of this thesis. Therefore three different options will be considered for the following calculations. They are presented in *Table 25* and represent a low-, medium- and high-leverage option, high leverage means being able to utilize a high amount of debt that is available at a lower cost than equity.

Table 25: Capital structure options

Option	Debt/Equity Ratio
Option 1	30/70
Option 2	50/50
Option 3	70/30

3.2.2. Energy Contracting

Energy contracting is the general term currently used for energy services that are offered based on certain risk mitigation measures. Generally a contractor offers different kinds of contract types to an end-user to make his energy consumption more energy and cost efficient. An ESCO or another type of energy related company can be the contractor. This is mostly done by offering a full package of services including planning, construction, operations and maintenance, optimization and financing. Most of the contract types are based on performance based compensation and performance guarantees, which consequently means that the supplier often has technical and economic project risk transferred to him [BLEYL-ANDROSCHIN ET AL., 2013].

This makes energy contracting especially attractive to end-users, though it brings along additional risks for contractors or the investors that finance the projects. The different kind of risks that occur in connection to process heat projects, and which are presented in *Table 22*, hence need to be mitigated through risk mitigation measures. These measures are often referred to as guarantees or risk mitigation instruments. Applying risk mitigation measures to sustainable projects on a global level is supposed to realize additional $100 – 165 billion of private sector investment throughout the next 15 years [IRENA, 2016b].

The following five contract types are the mainly used contracts in the energy service business as of now. Partially they can be found as combined versions as well, one of them actually already represents a combined version. The contracting schemes themselves already represent a way of risk mitigation, though there are additional risk mitigation measures that can be applied to mitigate risk, which are presented in Chapter 3.2.3.

Energy performance contracting (EPC) is an arrangement that leads to an improvement of the beneficiary's energy system through energy efficiency measures [SCHUBERT ET AL., 2014; BLEYL-ANDROSCHIN ET AL., 2013; PANEV ET AL., 2014]. In an EPC arrangement a contractor is responsible as a provider for optimizing energy service systems. Though, the provider does not supply energy, meaning that the end-user continues to procure its own energy from an energy utility. The main service provided is energy savings over a defined period of time. EPC is furthermore known under the following names [BEA ET AL., 2013]:

- Performance contracting
- Energy services agreement [KIM ET AL., 2012]
- Securitized energy savings [LIN, 2013]
- Guarantee of results contracting [FRAUNHOFER ISE ET AL., 2016]
- "Energie Einspar Protect" [B2B PROTECT GMBH, 2016]

The service provider mainly starts by calculating the savings potential of an existing energy generating system and then he plans the different measures to save energy and designs the retrofitted system. Generally he takes care of financing as well and often maintenance contracts are included into the deal. Therefore, mostly there is no end-user investment required up front. The upfront CAPEX is basically paid back from the end-user to the provider throughout the time of a long-term contract of 10 to 20 years [Bea et al., 2013].

The payment by the end-user is results-based and hence depends on the amount of energy saved. The contract defines an energy cost baseline that can be based upon the energy consumption of the past years and which will be used as reference to calculate the energy savings. Mostly the payments are only a proportion of the energy cost savings that are attained through the energy efficiency measures, which is referred to as shared savings EPC [Bea et al., 2013]. This represents the incentive towards the end-user, as he will save more through the energy cost savings than he spends on the payments. In most cases a certain minimum amount of energy cost savings is guaranteed through the contract [Bea et al., 2013; Schubert et al., 2014].

The German start-up b2b Protect GmbH (also referred to as “KlimaProtect”) has recently started offering a performance contracting scheme on the German energy efficiency market and refer to it as “Energie Einspar Protect” (EEP). The main difference to the other mentioned performance contracting schemes is that in this scenario the technology risk is not with the contractor, but neither with the tech-supplier. There is a backup insurance company integrated into the contracting scheme that insures against the technology risk, so against the risk that the system does not provide the energy savings as promised [b2b Protect GmbH, 2016].

Energy supply contracting (ESC) provides the end-user with guaranteed heating out of an energy supply system. On the other hand the end-user agrees to buy a certain minimum amount of energy. The main difference towards procuring heat from a local utility is that the heat generation system is installed on-site and can include an emergency generator [Bea et al., 2013; Panev et al., 2014]. This type of contract comes very close to PPAs that are widely used in the power generation sector. Where a utility or end-user agrees to purchase the generated power from conventional, renewable, large-scale or distributed generation plants [Kim et al., 2012]. ESC is called in the following ways as well [Bea et al., 2013]:

- Guarantee of solar results (GSR) [Ademe et al., 2006; Medved et al., 2007]
- Guarantee of results contracting [Fraunhofer Ise et al., 2016]
- Supply contracting
- Facility contracting
- Useful energy supply
- Chauffage
- Delivery contracting
- Contract energy management
- Guaranteed purchase agreement [Fraunhofer Ise et al., 2016]
- Energy output performance protect [b2b Protect GmbH, 2016]

Next to supplying the final energy to the end-user, the contractor takes care of procuring the primary energy if a conventional energy source is used and of planning and constructing the energy supply system. The initial financing of the system is covered or arranged by the contractor as well, which has the end-user repay this upfront cost through a use-based charge of the supplied energy over the contract lifetime. After the lifetime the installed system can be acquired and further used by the end-user. The contract lifetime is generally set so that the contractor obtains a positive return on their initial investment [Bea et al., 2013].

One of the above mentioned contracting types is specifically for solar applications, the guarantee of solar results (GSR). For the investment analysis that will be conducted in this thesis and which will only be using solar thermal system, this contracting type is especially interesting. The contractor takes the responsibility and guarantees that a system yields a certain amount of energy per year. He as well agrees to penalty payments if the guaranteed solar energy yield is not reached

[ADEME ET AL., 2006]. GSR as a contracting method entails the promotion of high quality solar thermal system with high long-term yields, though often additional equipment, such as monitoring systems, is needed [MEDVED ET AL., 2007].

Just as for performance contracting the German start-up from above as well offers supply contracting, which they call energy output performance protect. In this case again, there is a risk transfer to the insurance company, which takes over the technology risk if the system does not supply the output that was planned [B2B PROTECT GMBH, 2016].

Energy operations contracting (EOC) is based on contractors delivering technical services that ensure economic, environmental and efficient system operation. The contractor basically is in charge of operations and maintenance of the energy system. An exemplifying remuneration scheme can be through a basic fee plus a result-based bonus, depending on the downtime of a system. EOC is also named in the following way [BEA ET AL., 2013]:

- Technical facility management
- Operations contracting

Contract lifetime can be very short, such as in cases of needed refurbishment, or the arrangement can go hand in hand with an ESC or EPC agreement and have the same lifetime.

Integrated energy contracting (IEC) is an innovative delivery mechanism that aims at combining energy efficiency measures and renewable energy projects. The aim is to provide both measures after the paradigm “energy efficiency first”, so that there is no incentive to produce more energy than needed through the renewable energy generating system [BEA ET AL., 2013; PANEV ET AL., 2014]. It is based on the limitations of the two main contracting arrangements, the ESC and the EPC. The ESC scheme includes an incentive to sell more energy, as it is paid on the basis of the amount of energy provided. And the EPC is often only financially attractive for projects with a very high cost baseline, where energy savings lead to relatively large cost savings.

The payment scheme is therefore based on a fee for the energy provided and a service fee for the supply and efficiency measures. The energy fee is equal to the profit-neutral marginal price per energy unit, this means the price is equal to the cost of each energy unit and hence producing and selling additional energy will not lead to additional profit. The profit of the contractor is attained through the service fee that is based on performance and paid for providing efficiency measures and hence saving energy.

Third-party financing (TPF) or equipment leasing is a contractual arrangement involving a third party for financing reasons. In addition to the contractor and the beneficiary of the energy service, a third-party is involved through providing capital for energy service measures [BEA ET AL., 2013; PANEV ET AL., 2014]. This framework is basically what risk mitigation projects are based on and what is supposed to be implemented in the scope of the European Commission Horizon 2020 project TrustEE. The third-party financing aspect can generally be combined with all of the above contracting schemes. Mainly this will make the energy service projects be equity funded, instead of being funded solely by own funds or by debt. The fee that the end-user is paying for the supplied energy or the saved energy will partially be forwarded to the third-party investors as his dividend [SCHUBERT ET AL., 2014].

Guarantee of solar results (GSR) is the contracting and guarantee scheme that this thesis will focus on to assess investments into solar thermal systems for process heat applications in the industry. It is chosen in reference to ADEME ET AL. and MEDVED ET AL. and basically is equal to the ESC scheme. Though it will directly include EOC and TPF. Hence, O&M will automatically be included into this contract type, so that the contractually guaranteed energy supply is ensured. The main goal is to attract increasing amounts of third-party investors from the capital markets and to analyze the effect of energy contracting and risk mitigation on the risk perception of third-party investors. That is why a third-party financing method is as well included into the GSR scheme. Basically the technology risk is swapped from the contractor or third-party investor to the tech-supplier who will take care of O&M and guarantee that the system functions adequately.

The GSR arrangement is hence presented in *Table 26* to display its effect on the probability and impact of the different risk factors for investments into energy efficient and renewable process heat technologies. It is assumed that neither of the contracting methods (including GSR) is using extensive standardization methods, monitoring devices or any guarantees and insurances in their basic versions. Hence, the assessment in *Table 26* represents the basic version of GSR. The effect of further risk mitigation methods is analyzed below.

Table 26: Effect of GSR on technology and economic risk

Category	Risk	Factor	GSR
Technology Risk	Uncertainty of Energy Savings/Output	Probability	◇
		Impact	
	Energy System Failure	Probability	◇
		Impact	
	Incorrect Deployment of Energy System	Probability	◇
		Impact	
	Uncertainty of Resource Availability	Probability	◇
		Impact	
Economic Risk	Payment Timing Mismatches	Probability	
		Impact	
	Payment Difficulties from End-User	Probability	
		Impact	
	Decreasing End-User Demand	Probability	◇
		Impact	

GSR does not have an effect on political or policy risk from the investor standpoint, though it shifts all the technology risk from the investor or contractor to the tech-supplier, who receives and annual O&M fee to guarantee a certain energy output of the system. The contract scheme is based on two main agreements:

- Tech-supplier guarantees a fixed minimum amount of energy or energy savings to the end-user through payments from the investor or contractor
- End-user procures a fixed minimum amount of energy or energy savings from the investor or contractor

Therefore, the GSR contract type decreases the probability of all four technology risk factors and it decreases the probability that the end-users energy demand decreases.

3.2.3. Risk Mitigation Measures

Additionally and next to the above presented contracting types, the following risk mitigation measures can be applied to a project to further positively influence the risk perception through decreasing the risk-adjusted discount rates. The measures are divided into three groups, depending on the risk factor they are mainly mitigating. The exact impact each measure has on a certain risk factor will be presented per group in *Table 27*, *Table 28* and *Table 29*.

Technology Risk

Standardization is one of the most commonly used measures to increase investor confidence into projects. A known document simply creates more trust than a document that is put on one's table for the first time. Next to this effect, standardization of contracts and documents generally tends to shorten certain bureaucratic working processes. Standard specifications, such as the ones presented below, help as well in decreasing the risk perception of investors, as they provide an independent and generally trustworthy certification. Establishing system layouts, processes and contracts in coherence with standard certifications and definitions hence directly creates an additional trust level, which is especially in favor of decreasing the existing technology risk. Furthermore, due diligence is facilitated for investors and hence speeds up the contracting process. The following standards provide definitions and requirements around energy services, so their usage ensures that a system or contract is laid out in a standard and proven way [BEA ET AL., 2013].

- DIN EN 15900: is a standard on energy efficiency services and includes definitions, essential requirements and examples of energy efficiency service measures
- DIN 8930 Part 5: regards contracting and therefore includes definitions and fields of application of key types of ESCO services
- DIN EN ISO 50001:2011-12: is about energy management systems and presents requirements with guidelines for the use and establishment of systems and procedures to improve energy efficiency
- IREE™ - Investor Ready Energy Efficiency™ certificate: is an international certification that ensures best practices and third-party validation to deliver energy efficiency projects for the building renovation sector, it is based on the ICP (Investor Confidence Project) framework [ICP, 2016]

Asset quality is ensured through equipment and installer certifications and makes sure that an adequate amount and quality of assets are in place to service the contract obligations. This often helps overcome the lack of track record of many renewable technologies. Making sure the originator and servicer quality is up to the standards, as well leads to an appropriate and qualitative functioning of the asset. This is done through evaluating the operator and servicer capabilities, competences and processes, to establish confidence in the management of all aspects of the asset. The adequate performance of the assets is ensured in this way [IRENA, 2016b].

Surveillance and monitoring is done through detailed and frequent asset monitoring, reporting and energy accounting. This should show that installed systems will perform as expected and it should help in anticipating new technology risks [IRENA, 2016b]. Especially for solar thermal heating systems monitoring is important and helpful in keeping a clear overview of the performance of the systems, as the performance and energy output change depending on weather conditions and the consequent temperature levels [ADITYA MANGAL, 2014]. Next to keeping track of the actual system performance, a main objective of monitoring is to validate the predicted and calculated system outputs. If they are not validated this generally means that either the calculations have not been done appropriately or that faults have been detected. In this case correcting measures have to be taken through maintenance and optimization actions. All of the above leads to confidence building towards a third-party investor that is considering an investment in such a system and it decreases technology risk by making sure that the system performs as it was calculated [ADITYA MANGAL, 2014].

Insurance of equipment makes sure that a system is insured against extreme weather conditions (such as windstorms, lightning, flooding), thievery and vandalism, fire and public liability against damage done to humans or the environment. Especially for the case of extreme weather conditions precise weather specifications have to be set as limits, for to know when the insurance starts to cover damage [SCHUBERT ET AL., 2014]. This kind of insurance helps to mitigate risk of extreme occurrences, such as the above named.

Weather derivatives are used to secure projects against the uncertainty of weather conditions at a given time. They enable to hedge against unfavorable weather conditions by using a wide variety of available exchange-traded products. Mainly there are temperature, wind and precipitation based products on the market [UNEP-DTIE, 2004]. For solar energy applications temperature based derivatives have been used most recently and are seen to be most effective in summer months [BHATTACHARYA ET AL., 2016].

Table 27: Effect of risk mitigation measures on technology risk [IRENA, 2016b; ADITYA MANGAL, 2014; SCHUBERT ET AL., 2014]

Category	Risk	Factor	Standardization	Asset quality	Surveillance & monitoring	Insurance of equipment	Weather derivatives
Technology Risk	Uncertainty of Energy Savings/Output	Probability	◇	◇	◇		
		Impact				◇	◇
	Energy System Failure	Probability	◇	◇	◇		
		Impact				◇	
	Incorrect Deployment of Energy System	Probability	◇	◇	◇		
		Impact					
	Uncertainty of Resource Availability	Probability					
		Impact					◇

Table 27 displays which risk mitigation measures have a risk-mitigating effect on the different technology risk factors. The measures either decrease the probability or the impact of a risk factor. If either probability or impact is positively influenced through a risk mitigation measure, this means that they decrease by one level from their initial risk level, which will be assessed later on in Chapter 4.1.2. If the probability of “uncertainty of energy savings/output” has been evaluated as “high” for a project, using standardization generally leads to decreasing its risk probability to “medium”.

Through the usage of standardized and proven contracting methods, energy management systems, energy efficiency systems and renewable energy systems the probability of having uncertain or unknown energy savings or outputs decreases. Just as the probability of system failure and incorrect installation of the system decreases, because installers will utilize proven system layouts. Obtaining and using installer and equipment certifications to ensure proper asset quality and surveilling and monitoring the energy system has the same positive effect on the risk factor as the usage of standardization.

When insuring a system against extreme natural disasters, such as storms, lightning and fire it is not possible to influence the probability of this kind of events, but to decrease the impact they will have on the investment. Insurances cover for the damage that is done to the system and for the most likely occurring performance outage.

Weather derivatives are able to hedge against the risk of uncertainty of resource availability and a consequent uncertainty of energy savings or output. They decrease the impact of the risks of bad weather conditions through covering for the losses that occur if the weather is not as expected.

Especially insurances and monitoring are costly though and increase the OPEX of an investment. The consequence is a decreased final revenue and cash flow.

Economic Risk

Financial structure refers to the payment priority that can be settled in regard to the risk and return expectations of the handed out tranches of a securitization deal. If a standard securitization method is chosen, the assets will be pooled into different segments depending on their risk and return expectations. Low risk tranches are settled with a higher payment priority, which means they are paid first by the cash flow of the project. The higher the risk, the lower the payment priority will be set to. This means the likelihood that investors with high risk tranches will receive their dividend, in case of a default of the project, is lower. This financial structure must be sufficiently designed to repay principal dividends in full by the legal maturity date [IRENA, 2016b].

Credit enhancement ensures that a default of the asset does not lead to project losses. This is done by increasing the credit worthiness of the project by giving additional collateral or further insurances. Adding too much credit enhancement to a project can lead to an increased financing cost and can therefore have a net negative impact on the project rating [IRENA, 2016b].

Currency hedging instruments can be used to take an offsetting position on a security, such as a secured process heat investment. This is known as hedging and can help protect the investment against adverse price movements and mitigate commercial risks. Currency hedging instruments allow projects to remove eventual currency fluctuations. This is needed if a project developer wants to borrow in a foreign currency, he can then lock in the currency difference in advance through a forward contract. It can be attractive for developers to apply for foreign credits, especially when the cost of credit is lower abroad. Though, the cost of currency hedging can offset the benefit of hedging, especially when it is too high [IRENA, 2016b].

Currency risk guarantee funds can help address the high cost issue for currency hedging. The fund would cover the difference in exchange values between the local and foreign currency. The fund would generally be led by a government entity that charges developers an hedging fee per energy unit and which covers against a depreciation of the local currency [IRENA, 2016b].

Internal liquidity facilities can be used to support payments that bridge short-term cash flow problems and help ensure on-time payments to investors. The following risk mitigation measures represent some examples [IRENA, 2016b].

- Debt service accounts help with a source of funding for a limited period of time of insufficient cash flows
- Excess spread accounts save cash flow amounts, which are higher than necessary, for debt service, in the case that cash flows decrease in another moment
- Over-collateralization means that additional assets are provided as collateral for the credit, which leads to a lower cost of capital
- Contingent equity is supposed to protect project owners of an unexpected increase of costs. Equity is put aside to have a safety buffer if emergency funding is needed

Liquidity guarantee is supposed to lengthen the lifetime of a credit, so that the borrower does not become unable to refinance part of the outstanding loan midway through the life of a project. This can happen if the credit lifetime is too low and therefore repayments in the initial years are relatively high. In this case a credit structure of two loans that lend to the project can be established. The liquidity guarantee makes sure that the lending bank has enough funds to make the second credit [IRENA, 2016b].

The risk mitigation measures presented in *Table 28* show their influence on the probability or impact of the economic risk factors in the same way as shown above for *Table 27*.

Table 28: Effect of risk mitigation measures on economic risk [IRENA, 2016b]

Category	Risk	Factor	Financial structure	Credit enhancement	Currency hedging instruments	Currency risk guarantee funds	Internal liquidity facilities	Liquidity guarantee
Economic Risk	Payment Timing Mismatches	Probability						
		Impact	◇	◇	◇	◇	◇	
	Payment Difficulties from End-User	Probability						◇
		Impact	◇	◇			◇	
	Decreasing End-User Demand	Probability						
		Impact	◇	◇			◇	

Using a proper financial structure, credit enhancement or internal liquidity facilities all leads to decreasing the impact of the liquidity, refinancing and demand risk. An appropriate financial structure ensures that even if there is lacking liquidity, due to a shortfall of payments from the end-user, the senior debt and equity givers will be serviced. Junior equity givers with higher yields might fall short in this case, which is compensated through their higher yields though. Credit enhancement makes sure that additional collateral and insurances cover for debt service when the assets default. The internal liquidity facilities as well make sure to decrease the risk impact on the investment, through the usage of debt service accounts or other means.

Both risk mitigation measures related to currencies are mostly needed in developing countries and most likely will not be needed within project finance for Europe. Though, both measures ensure that sufficient project liquidity stays available when the local currency value depreciates.

The liquidity guarantee is mainly supposed to aid increasing credit lifetimes, especially in areas where credit tenor is often too short to properly finance energy projects. This can lead to a lack of repayment capability for the end-user, who might see himself incapable of refinancing his high debt repayments early on into the investment. Through a second credit, which directly follows the first credit, the following refinancing is ensured.

Especially credit enhancement and currency hedging instruments come along with a relative high cost, internal liquidity facility partially as well. This entails a counter-effect on the investment, which can make it less favorable.

Political or Policy Risk

Government guarantees are taken against risk that governments can better mitigate. For example, they can mitigate currency, regulatory and energy-off taker risk through their treasury or finance ministry. If these guarantees do not seem sufficient, because the government entity does not provide enough creditworthiness, public finance institutions (central bank, state-level bank) can go ahead and set up a guarantee fund instead [IRENA, 2016b].

Political risk insurance is provided because investors are highly sensitive to the potential impact of political risk, especially in countries with unstable political systems. Political risk insurance is mainly issued by public finance institutions and covers risks related to government action. The Multilateral Investment Guarantee Agency (MIGA) is part of the World Bank and one of the largest providers of political risk guarantees. Other official bilateral insurers that provide such insurances are OPIC, NEXI, HERMES, Coface and ECGD [UNEP-DTIE, 2004]. They provide insurances against losses that may arise due to war, terrorism, civil disturbance, currency inconvertibility, breach of contract by a government utility, expropriation and non-honoring of financial obligations by a government utility [IRENA, 2016b; FRISARI ET AL., 2015].

Partial risk guarantee is sold especially to mitigate policy and regulatory risks. It can be provided to investors to ensure a government's obligation to compensate for loss of revenues resulting from regulatory changes that influence the incoming cash flows of the investment. This mainly happens when the government or the regulatory agency changes or repeals part of the regulatory framework on which the initial investment was based on, or when government ensured infrastructure actions needed for a successful investment are cancelled [IRENA, 2016b; FRISARI ET AL., 2015; UNEP-DTIE, 2004].

Partial credit guarantee can be used to cover part of a debt default by the borrower, regardless of the cause of default for a period of the debt term for a public investment. This makes a partial credit guarantee be more flexible than political risk insurances or partial risk guarantees, as it can cover a wider range of risks. For renewable energy projects, partial credit guarantees can be used to address currency transfer and convertibility risk that might be caused by government actions. For example, if a currency becomes inconvertible the guarantee will cover the debt service that is due for a certain time frame [IRENA, 2016b; UNEP-DTIE, 2004].

The partial credit guarantee can be used as well to mitigate technology risk, which is especially valuable for nascent technologies. If the technology defaults, the guarantee covers up to a certain amount of the credit repayments. This kind of guarantees are mostly granted from public or central banks [IRENA, 2016b].

Country credit default swaps (CDS) can be helpful when a government or a government entity is not able or willing to continue its promised incentive schemes. If a government defaults in meeting their financial support obligations a CDS can be used to hedge the risk of not receiving the incentives. The promised financial incentive can be seen as a credit obligation, if it is not meet and defaults, the CDS pays off the defaulted credit [IEA-RETD ET AL., 2011].

Table 29: Effect of risk mitigation measures on political or policy risk [IRENA, 2016b; IEA-RETD ET AL., 2011; FRISARI ET AL., 2015]

Category	**Risk**	**Factor**	Government guarantees	Political risk insurance	Partial risk guarantee	Partial credit guarantee	Country CDS
Political or Policy Risk	Radical Political Events	Probability					
		Impact		◇			
	Change of Incentive Scheme	Probability	◇				
		Impact			◇	◇	◇
	Change of Permitting Policies	Probability	◇				
		Impact			◇	◇	
	Change of Taxation Laws	Probability					
		Impact				◇	

In the same way as above for the technology and economic risk, *Table 29* shows how the risk mitigation measures addressing political or policy risk are impacting the risk factors by decreasing their probability or impact in comparison to the basic risk case.

Government guarantees, which are normally handed out by local governments, help in decreasing the probability that incentives and the permitting processes are cancelled or delayed. The partial risk guarantee addresses the same risk factors, though aims at the case in which a governmental regulatory agency has already changed the incentive and permitting scheme to a disadvantage of the project. The government obliges itself to compensate for an eventual loss of revenues due to such changes.

The political risk insurance is thought to mitigate the effects of severe political events that entail contract breach, for example through war, civil disturbance or expropriation. It is mainly provided by global public finance institutions that cover for the damage done by such government actions.

The partial credit guarantee is even more flexible than the partial risk guarantee and covers part of the debt in case the assets default through negative changes in the incentive, permitting or tax scheme. Partially it can as well cover for technology risks.

A country CDS is used to hedge against changes in the incentive scheme. If promised incentives do not occur, the incentive is seen as a kind of credit obligation which has defaulted. Hence, the CDS will cover for the amount that was lost through the missing incentive scheme.

The political risk insurance and the country CDS entail certain costs that need to be considered for within the OPEX. The same accounts for some of the above mentioned risk mitigations measures. Their extra cost might mitigate the positive and risk-decreasing effect of these measures.

3.3. Third-Party Funding

The above described manifold of energy contracting schemes and risk mitigation measures are thought to attract third-party investors to fund increasing amounts of retro-fitted process heat systems. Next to risk mitigation, there are other things that can enhance additional investment into energy efficiency and renewable technologies for process heat applications. ESCOs, contractors and investment funds have created a diverse mixture of different platforms to facilitate the process of bringing together end-users, technology suppliers and potential third-party investors. An ESCO generally tries to take care of most of the processes involved and represents somewhat of a central element in a potential investment, they mostly use internal platforms and communication strategies to organize themselves. Investment funds rather try attracting financing at the capital market and then leave the development and procurement of systems to contractors. Generally, an investment fund focuses on equity or debt investment. As an equity investor one buys shares or assets of a company by financing it, the benefit comes with dividend payments, which depend on the performance of the company. A debt investor gives a loan and will receive constant and fixed payments over the lifetime of the loan, this is often referred to as a bond issuance. Next to these main entities there are further platforms that exist and try to enhance investment into energy efficiency and renewable energy.

3.3.1. ESCOs

ESCOs have been increasing the deployment of energy efficiency measures and renewable technologies through service contracting in several sectors. An ESCO is defined as a "[…] natural or legal person who delivers energy services or energy efficiency improvement measures in a final customer's facility or premises", by the European Energy Efficiency Directive [EP, 2012; MED-ENEC, 2014]. Another definition states that an ESCO is "[…] a company that offers energy services which should include implementing energy efficiency projects and other sustainable energy projects […]", mostly on a turn-key basis. Basically ESCOs are supposed to follow these three characteristics [PANEV ET AL., 2014]:

- Guarantee energy savings or provide the same level of energy services at a lower cost
- Remuneration is directly tied to energy saved or supplied
- Help in financing or arranging finance for the energy system

Basically, an ESCO offers a transfer of financial risk from the end-user to the ESCO, by providing guarantees and offering service contracting [MED-ENEC, 2014]. This is generally done by not just acting as a simple contractor, but as a project manager, guarantor and financier as well [PANEV ET AL., 2014]. The contracts that are mainly used to execute an ESCO's business proposal are those mentioned above in Chapter 3.2.2. In comparison to investment funds, the main approach of an

ESCO is to organize, realize and finance one or a couple projects at a time. The process mostly starts with a proposal of an energy efficiency or renewable energy project.

3.3.2. Investment Funds

Funds for general energy efficiency measures or renewable energy technologies have been available for some years now. There are funds based on equity, debt or a combination of both. Mostly they are attractive to socially and environmentally responsible investors. Though, they have become more and more accepted and interesting for other investors too, due to their financial attractiveness. They can be an interesting catalyst for increased investment into new process heat technologies [SULLIVAN, 2015]. Most of the current funds are developed to finance either energy efficiency measures or renewable energy technologies for the power sector.

Especially institutional investors, such as pension funds, insurance companies, endowments and sovereign wealth funds can play an important role in scaling up investments into these technologies [IRENA, 2016b]. After an estimate from the OECD there are around $2.8 trillion available annually for clean energy investments from pension funds and insurance companies [KAMINKER ET AL., 2012]. Some of the existing funds for energy efficiency and renewable energy are presented below. Next to these investors, other players exist that can help in pushing investments, such as major or municipal utilities, infrastructure and private equity funds [GCF ET AL., 2013].

The Swiss company SUSI (Sustainable Investments) Partners AG just recently announced that they will create the SUSI Energy Efficiency Fund (SEEF) together with the EPC company Pöyry Switzerland Ltd. The objective is that SUSI finances energy efficiency projects and Pöyry takes care of procuring them. The SEEF claims to be one of the leading European investment vehicles for energy efficiency funding, with around €250 million of equity available [SUSI PARTNERS AG, 2016b]. Next to the SEEF there is a renewable energy fund consulted by SUSI as well, the SUSI Renewable Energy Fund II (SUSI RE II), which has recently reached an investment volume of more than €100 million. The fund has invested this money into solar and wind parks in Germany, France, UK, Portugal and Italy and is aiming for a total volume of €400 million [SUSI PARTNERS AG, 2016a].

A further measure of equity funding has evolved in 2013 and is generally referred to as yieldco structure. It has been largely used from utilities, independent power producers or project developers with renewable energy assets on their balance sheets, to outsource these assets and gain new means of financing. This is basically done through creating a new publicly traded company or platform as a yieldco, owning the renewable energy assets and their cash flows [FRANKFURT SCHOOL, 2016]. Shares of this company can then be sold to investors and the gained funds can be reinvested into other projects [IRENA, 2016b]. This structure enables investors to obtain rather predictable dividend income [FRANKFURT SCHOOL, 2016].

The Renewable Financing Company (TRFC) was set up in 2011 and has mainly debt financed solar PV projects up to now. Long-term bond issuances of up to a maximum of £66 million have been used to refinance loans to solar projects. Basically, TRFC acts as an aggregator for small and large renewable energy assets that need funding, thereby giving access to the debt capital market to especially smaller sized renewable energy assets, which would have larger difficulties otherwise accessing the capital markets [TRFC, 2016]. TRFC is basically selling green bonds to investors that are interested in environmental and climate-friendly investments. Green bonds are fixed income securities which come along with an annual coupon, which is an ensured fixed annual payment. It always stays the same, no matter how the asset performs [IRENA, 2016b].

3.3.3. Platforms

German start-up Thermondo has started to digitalize the heating market a couple of years ago. They created an online platform for direct interaction with B2B customers, which improves the sales process, but as well facilitates the planning and installations processes of the heating systems. Their main customers are one-family households, though such a platform could be used for other appliances and customers. After a good amount of input parameters have been provided the platform calculates and plans the system and gives a cost estimate [EPP, 2016a].

The Joint Research Center (JRC) of the European Commission has recently created the European Energy Efficiency Platform (E3P) as a tool to facilitate data gathering and online knowledge exchange amongst experts from different energy efficiency sectors. The aim is to gather data and knowledge in the E3P to improve the energy efficiency policy design process. This is supposed to be done through a data hub, a wikEE, community and calls. The data hub can be used to collect data related to energy efficiency. In the wikEE experts can collaborate, especially those in charge of developing energy efficiency policies. The community can be used to discuss specific topics in working groups and if any data is needed a call can be published [JRC ET AL., 2016].

3.3.4. Investor Expectations

The majority of sustainable investments, by the above mentioned institutions, into energy efficiency measures or renewable energy technologies has been focused on the power sector [FRANKFURT SCHOOL, 2016]. As a consequence most of the above mentioned investors have developed clear expectations towards the return they aim on achieving through an investment. The presented return expectation or IRR expectations in *Table 30* are therefore mainly based on investments into renewable energy technologies that are power generating and are supposed to be used as reference values. Next to the return expectations, *Table 30* as well shows at which investment stage most investors like to make their investment and for how long they tend to hold the acquired assets. Furthermore the average investment size is displayed. Most investors, besides the private equity fund investors, tend to invest over a long-term timeframe of up to 30 years. The private equity investors as well have the highest return expectations with an IRR of up to 25%. Pension funds clearly aim at investing the largest amount with a ticket size of up to €250 million.

Table 30: Investor expectations for renewable energy investments [GCF ET AL., 2013]

Investor Type	Expected IRR	Investment Stage	Holding Length	Ticket Size
Major utilities	Market average	All stages, many at development stage	Long-term	> €50 million (estimated)
Municipal utilities	7-9% after tax	All stages, many at development stage	20-30 years	€5-20 million or larger with joint investment vehicles
Independent power producers	Varied	Primarily greenfield projects	-	-
Infrastructure funds	6-15%	Late construction or operational stage	20-25 years (hold-to-maturity)	€10-30 million
Private equity funds	15-25% after tax	Development and late construction stage	3-7 years	> 50 MW
Pension funds	5-10% after tax	1-2 years after commissioning	20-30 years	€100-250 million
Insurance companies	5-10% after tax	1-2 years after commissioning	20-30 years	€20-100 million

4. Impact of Risk Mitigation Measures on Investment Analysis

Chapter 3 has laid out the basics of how to assess investments into process heat technologies. This includes naming the essential input parameters that are needed, showing how the risk of the investment will be assessed, laying out possible energy contracting schemes and presenting risk mitigation measures that decrease the risk perception of an investment. Furthermore, important third-party investors and their expectations were presented.

The investment analysis is going to be done in the following for solar thermal systems that can replace conventional energy sources in process heat applications at the locations presented in *Table 31*. The four countries were chosen, as the project partners from TrustEE are from these four countries. Firstly, the finally used input parameters and three macroeconomic scenarios will be described. Secondly, risk assessments for a basic and securitized investment will be done, to obtain the WACCs for each country in both cases. Finally, the results will be presented.

Table 31: Locations for investment analysis

Country	Cities			
Austria	Graz	Innsbruck	Klagenfurt	Vienna
Germany	Berlin	Düsseldorf	Freiburg im Breisgau	Hamburg
Portugal	Évora	Faro	Lisbon	Porto
Spain	Barcelona	Madrid	Seville	Vigo

4.1. Input Parameters and Macroeconomic Scenarios

This chapter will mainly focus on assessing the risk of a solar thermal process heat system based on the above presented risk assessment method, through a risk-adjusted discount rate in each of the locations. Throughout the assessment the influence of energy contracting and risk mitigation measures on the risk of each location will be assessed and laid out. Furthermore, the macroeconomic parameters, which will be largely influenced by market development, are going to be defined and used in three different scenarios.

4.1.1. Input Parameters

The input parameters have been introduced above in Chapter 3.1 and most of them are constant and hence stay the same for all the chosen locations. Basically, five parameters can change for each location:

- Financial incentives
- Tax rate
- Solar yield
- Cost of debt
- Risk-adjusted WACC

The financial incentives, the tax rate and the solar yield change depending on the country. The cost of debt is influenced by the risk assessment and will be introduced in Chapter 4.1.2, just as the risk-adjusted WACC. The OPEX (cost for operations and maintenance) will change if the energy contracting scheme is applied, because in this case the tech-supplier will charge a higher fee for the maintenance and an availability guarantee. Furthermore, the OPEX changes according to the annual level of inflation. The macroeconomic parameters, such as inflation and conventional energy cost, are going to be taken into consideration through three different scenarios in Chapter 4.1.3. The overview of all input parameters is given in *Table 32*.

The equity ratio of an investment, which is connected to the debt ratio of an investment, is a special case within the constant parameters. There were three possible options defined for the debt-to-equity ratio that will be included for this parameter.

Table 32: Input parameters for investment analysis

Constant	Country	Risk	Macroeconomic
Residual Value	Financial Incentives	Cost of Debt	Inflation
Credit Lifetime	Tax Rate	WACC	Conventional Energy Cost
Investment Lifetime	Solar Yield	OPEX	
Product Lifetime			
Depreciation			
Premium			
Equity			
CAPEX			

Financial Incentives and Tax Rate

The two parameters that only change depending on the respective countries are the existing financial incentives and the corporate tax rate. The tax rates for companies in Austria and Spain are both at 25%, Germany at 30% and Portugal at 21% of the taxable income (*Table 33*) [KPMG, 2016].

Table 33: Financial incentive and tax rate [KPMG, 2016; KFW, 2016; EPP, 2016b; BMLFUW, 2016]

Country	Financial Incentive	Taxes
Austria	< 44%	25%
Germany	< 50%	30%
Portugal	35%, €2,500	21%
Spain	-	25%

Incentives for solar thermal process heat systems in Germany can go up to a maximum of 50% of the net system cost, excluding VAT. There are two government subsidies that can be applied for with a solar thermal system providing process heat. One is granted through the German government-owned development bank ("KfW – Kreditanstalt für Wiederaufbau") and is part of a credit of up to €10 million that companies can apply for. It comes along as a redemption grant of the credit, which means a part of the credit does not have to be repaid [KFW, 2016]. The second is granted by the German Federal Office for Economic Affairs and Export Control and as well covers up to 50% of the net system costs. It is not handed out as a redemption grant of a credit, but as a simple grant [BAFA, 2015].

In Austria the Federal Ministry of Agriculture, Forestry, Environment and Water Management ("BMLFUW – Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft") is running an incentive program for industrial solar thermal systems larger than 100 m^2. With a EU co-financed option an investment grant of up to 30% of the system cost can be obtained [BMLFUW, 2016]. In regions like Upper Austria there is even the possibility of receiving an additional regional grant. In sum with the national grant this can go up to a maximum of 44% of the system cost [O.Ö.ENERGIESPARVERBAND, 2010].

The Portuguese Energy Efficiency Fund has recently launched the "Aviso 20" incentive scheme for energy efficiency measures, including solar thermal systems, for residential and commercial buildings. The total budget is €1.1 million and commercial customers can cover up to 35% of their solar system cost. Per system the maximum amount is capped at €2,500 though [Epp, 2016b]. Spain currently does not have any incentive scheme available for solar thermal installations.

CAPEX

Larger-scale solar thermal systems have been installed since the 1980s. In general, the larger a system is, the cheaper the investment cost per kW or m^2 turns out. As well, the cost for standard FPCs and ETCs with a single collector size of 2 – 2.5 m^2 has halved from 1995 to 2010 [Stryi-Hipp, 2013].

Of the total cost per system around 50 – 70% can be allocated to capital costs, the remaining 30% – 50% account for installation and integration. Of the capital cost around 50% are for the collectors, 20% for piping, 11% for buffer storage and heat exchanger and around 5% for control systems [Irena et al., 2015].

Solar thermal applications for higher temperature levels are mostly concentrated systems. Mainly these are CPC vacuum tubes, parabolic through collectors and Linear Fresnel collectors. These systems are clearly more expensive than the conventional collectors, but offer higher temperature levels.

In the near future prices for conventional solar thermal technologies are expected to further decrease. After Ivancic et al. non-concentrating systems are supposed to reach investment costs of around 250 €/kW$_{th}$ and higher temperature, solar concentrating systems around 300 €/kW$_{th}$ by 2020 [Ivancic et al., 2014]. These economic parameters are mainly supposed to be reached through thorough R&D on self-carrying and modular collector structures, improved large-scale collector arrays and improved reflectors for concentrating, just as through standardized certification schemes and additional financing models [Ivancic et al., 2014].

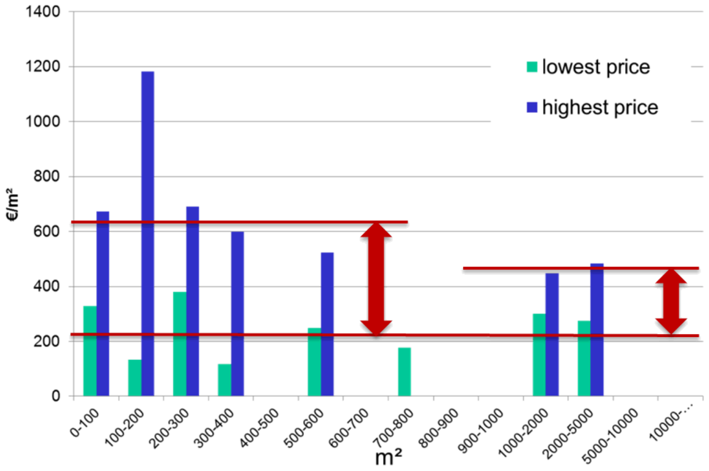


Figure 27: Price scales for solar thermal systems [Horta et al., 2016]

The calculations done within this thesis used general and up-to-date cost data for solar thermal systems on a square meter basis. The data was extracted from the data base of the SHC (Solar Heating & Cooling Program) by the IEA, which has summarized the prices of different solar thermal systems (*Figure 27*). The average size of solar thermal systems for process heat applications is defined at around 500 m^2 and therefore the average system price used in the calculations is going to be 400 €/m^2.

Solar Yield

The solar yield data for solar thermal systems in the respective locations was obtained from the TrustEE project partners. The displayed solar yield in *Figure 28* is the net output at the solar field outlet under the assumption of a constant load and no energy dumping. Furthermore, a system layout without thermal energy storage, but with heat exchanger was chosen. The latter is considered through a conversion factor of 80% at the output of the solar field. The southern locations in Portugal and Spain clearly have higher annual solar yields than the locations in Austria and Germany, partially the solar yield is three times that of one of the northern countries, such as Düsseldorf and Seville in comparison to each other. The average annual solar yield in Austria and Germany is 299 kWh/m^2 and in Portugal and Spain it is 605 kWh/m^2.

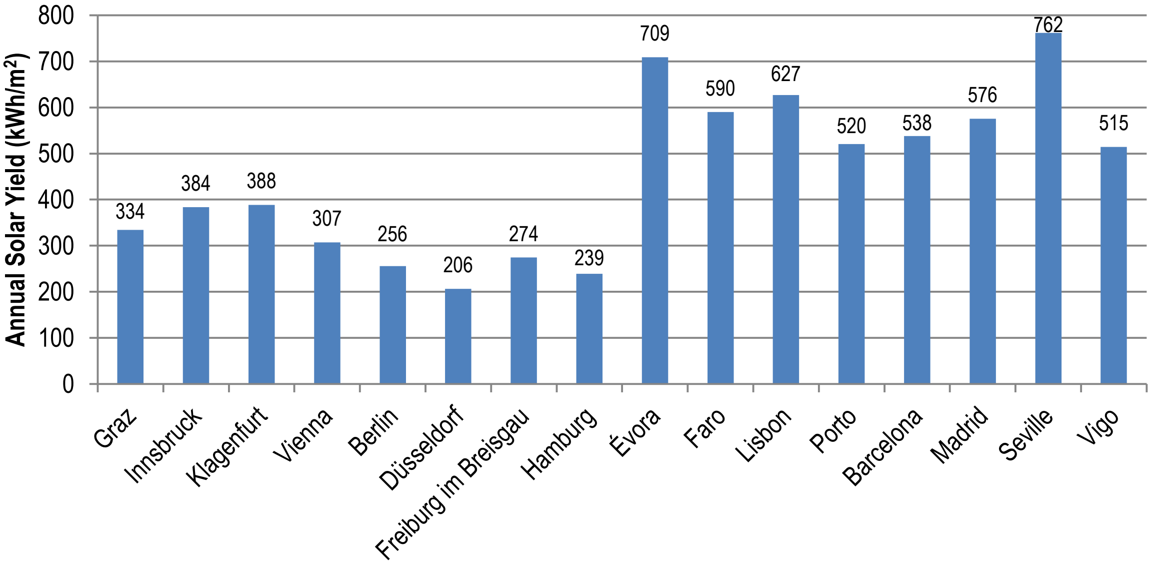


Figure 28: Annual solar yield per location

4.1.2. Basic and Securitized Risk Assessment

The following *Table 34* and *Table 39* exemplify how to obtain the risk-adjusted cost of debt and WACC for both assessments with (securitized) and without (basic) an energy contract and risk mitigations measures. This will be done through the risk-adjusted discount rate method specifically for solar thermal systems providing process heat in Austria, Germany, Portugal and Spain. The risk assessment is done for the basic and securitized scenario. The basic risk assessment is done for the reference case in which the energy system is installed, run and maintained by a contractor over the whole investment lifetime. In the securitized risk assessment the system maintenance is handed over to a tech-supplier, who provides an availability guarantee.

Basic Risk Assessment

The way the total risk score is calculated with the risk-adjusted discount rate method is shown in Chapter 3.2.1. Summed up briefly the method is the following: the probability and impact of each risk factor are assessed and defined, either as low, medium or high. Then the risk score for each risk factor is calculated by multiplying the probability with the impact. The sum of the 11 risk scores can be on a scale from 0 to 7.04. The risk premiums for debt and equity are derived from the total risk score in reference to *Table 23* and *Table 24*.

Table 34: Calculation of basic risk premiums

Category	Risk Factor	Probability				Impact				Risk Score			
		Austria	Germany	Portugal	Spain	Austria	Germany	Portugal	Spain	Austria	Germany	Portugal	Spain
Technology Risk	Uncertainty of Energy Savings/Output	0.5	0.5	0.5	0.5	0.8	0.8	0.8	0.8	0.40	0.40	0.40	0.40
	Energy System Failure	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.08	0.08	0.08	0.08
	Incorrect Deployment of Energy System	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.08	0.08	0.08	0.08
	Uncertainty of Resource Availability	0.5	0.5	0.1	0.1	0.5	0.5	0.5	0.5	0.25	0.25	0.05	0.05
Economic Risk	Payment Timing Mismatches	0.2	0.2	0.5	0.5	0.5	0.5	0.7	0.7	0.10	0.10	0.35	0.35
	Payment Difficulties from End-User	0.3	0.3	0.5	0.5	0.8	0.8	0.8	0.8	0.24	0.24	0.40	0.40
	Decreasing End-User Demand	0.3	0.3	0.5	0.5	0.8	0.8	0.8	0.8	0.24	0.24	0.40	0.40
Political or Policy Risk	Radical Political Events	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.08	0.08	0.08	0.08
	Change of Incentive Scheme	0.0	0.0	0.0	0.0	0.8	0.8	0.2	0.1	0.00	0.00	0.00	0.00
	Change of Permitting Policies	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	0.00	0.00	0.00	0.00
	Change of Taxation Laws	0.5	0.1	0.8	0.8	0.8	0.8	0.8	0.8	0.40	0.08	0.64	0.64
Total Risk Score										**1.87**	**1.55**	**2.48**	**2.48**
Risk Premium Debt										**4.0%**	**4.0%**	**5.0%**	**5.0%**
Risk Premium Equity										**8.0%**	**8.0%**	**10.0%**	**10.0%**

The technology risk factors are defined almost equally for all four countries. There is a medium probability that the energy output is not as expected and a low probability that the system fails or that it is not deployed correctly. The impact though, if any of the three risk factors occur, is going to be high because it directly means that the system owner, generally the contractor, has a liability towards the end-user. Regarding the possibility of low solar radiation, the probability that this occurs is medium in Austria and Germany and low in Portugal and Spain, as solar radiation can be assumed more constant in southern countries. Its impact though is medium in all countries, because a lack of solar radiation would affect a systems performance equally in each country.

Regarding the economic risk, there are quite some differences in the assessment per country, which is mainly due to the different economic situations of each country. The probability that an end-user runs late with his payments is regarded as relatively low in Austria and Germany, but medium in Portugal and Spain. The impact will be rather higher in Portugal and Spain as well, as the payments will likely be late not just by a couple days. The risk that an end-user is in a position of being insolvent and of having a decreased energy demand is considered medium in Portugal and Spain, because economic reasons will more likely lead to such situations than in Austria or Germany, where this risk probability is assessed to be medium to low. The impact of both risk factors (payment difficulties and decreasing demand), if they occur, would be equally high in all four countries.

All the political risk factors generally will have a high impact if they occur in any country. With exception if incentive schemes in Portugal and Spain change. As there is a really low incentive scheme in Portugal and none in Spain, the impact will be relatively low in both countries, because the situation cannot worsen in regard of incentive schemes. The probability that radical political events occur in any of the four countries is low. Due to the fact that incentives for solar thermal systems are normally grants that are given at the beginning of the investment and solely reduce the CAPEX, there is a zero probability for the risk related to incentive schemes. While planning an investment the investor will know for sure if he can obtain an incentive and there will be little time between planning and starting the investment. Hence, the risk that the incentive is not granted within that timeframe can be neglected. In cases where incentives have a large impact on the operational income of the systems, such as with feed-in-tariffs for solar PV systems, the probability that incentive schemes are changed is higher. The same counts for permitting policies, while planning a solar thermal investment an investor can be sure of obtaining permission for the system without it being revoked shortly after. Therefore, here as well the probability of changes in the permitting policies is zero for all countries. Germany, with high taxation policies in place already, has a low probability of an increase of taxes. Though, the other three countries are more likely to change their policies. Hence, in Portugal and Spain the probability is considered to be high, due to the economic situation.

The risk premium for debt and equity that are yielded through these calculations in *Table 34* are rather close to each other for the four countries. Austria and Germany obtain risk premiums for debt that are 1% lower than for Portugal and Spain and risks premiums for equity that are 2% lower. To obtain the finally risk-adjusted cost of debt and equity, Equation (2) and (3) need to be applied and the risk-free rates are needed. As mentioned above the average value of each respective 10-year government bond is used for the risk-free rate (*Table 35*).

Table 35: 10-year government bond returns [EUROSTAT, 2016a]

Country	Risk-Free Rate
Austria	0.62%
Germany	0.31%
Portugal	2.83%
Spain	1.66%

With these risk-free rates, the respective risk-adjusted cost of debt and equity can be obtained through Equation (2) and (3) and are displayed in *Table 36*.

Table 36: Risk-adjusted cost of debt and equity for basic risk assessment

Country	Risk-Adjusted Cost of Debt	Risk-Adjusted Cost of Equity
Austria	4.62%	8.62%
Germany	4.31%	8.31%
Portugal	7.83%	12.83%
Spain	6.66%	11.66%

Austria and Germany each yield around 4-5% risk-adjusted cost of debt and around 8-9% risk-adjusted cost of equity. Portugal has slightly higher final risk-adjusted values than Spain at around 8% cost of debt and around 13% cost of equity, mainly because it has a higher government bond yield (risk-free rate) that is added on top of the risk premium, which is equal for Portugal and Spain. In regard to the assessment done by NOOTHOUT ET AL. for onshore wind the risk-adjusted values for cost of debt and equity calculated here for solar process heat systems are rather similar in their dimensions. Austria and Germany yield comparatively low values for each the cost of debt and equity in comparison to Portugal and Spain.

Out of these risk-adjusted cost values for debt and equity the final WACC can be calculated after Equation (4), using the risk-adjusted cost of debt and equity from *Table 36*, the debt and equity ratios from *Table 25* and the tax rates from *Table 33*. As there are three options for the debt-to-equity ratio, three different WACCs are displayed for the respective countries in *Figure 29*. Option 1 stands for 30% financed by debt, option 2 stands for 50% and option 3 represents the most leverage with 70% financed by debt. The clear conclusion is that the more debt leverage is available, the lower the WACC turns out. Equal to the cost of debt and equity, Germany yields the lowest values, just followed by Austria. Portugal and Spain yield around 3% - 4% higher WACCs.

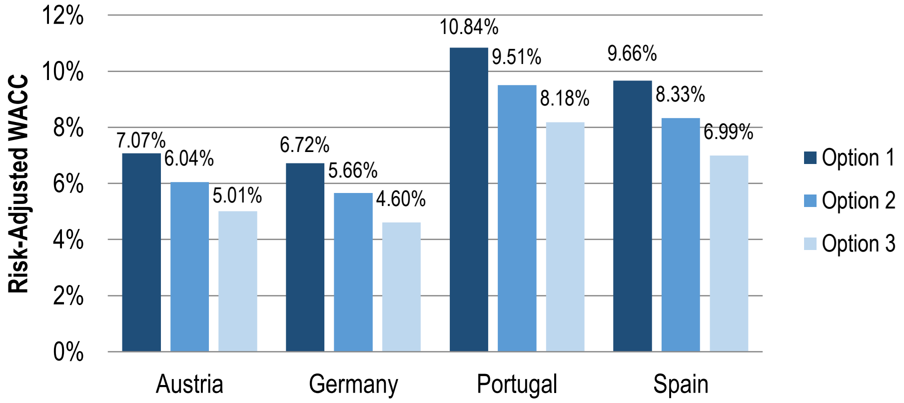


Figure 29: Risk-adjusted WACC for basic risk assessment

Securitized Risk Assessment

The next step is to mitigate the risk factors of an investment in each respective country into solar thermal process heat applications. This is done through the usage of a final selection of the above mentioned contracting schemes and risk mitigation measures. The used contracting scheme and the risk mitigation measures for solar thermal systems are shown in *Table 37*. The chosen GSR energy contract basically mitigates the entire technology risk from the investor perspective, as its makes sure that the tech-supplier agrees to guarantee a certain energy output from the solar thermal system. The tech-supplier is paid an additional fee for this availability guarantee, which increases the O&M cost for the investor. Though, in this way the probability of the technology risk factors are mitigated to zero.

Table 37: Risk mitigation measures

Type	Name	Description
Energy Contract	Guaranteed solar results	Guarantees a certain amount of solar heat to the end-user; the end-user agrees to buy a certain minimum amount of energy
Risk Mitigation Measures	Financial structure	Ensures timely, but consecutive, payments to creditors through payment priorities settled in regard of the risk and return expectations of the handed out tranches. Low-risk tranches have a high payment priority, high-risk tranches have a lower priority
	Internal liquidity facility	Helps ensure on time payments to investors when short-term cash flow problems arise; through debt service accounts or excess spread accounts
	Liquidity guarantee	Ensures that the borrower can refinance the credit through lengthening the lifetime of a credit with a second credit
	Partial credit guarantee	Helps to cover part of a debt default by the borrower, regardless of the cause of default for a period of the debt term for a public investment

Out of the presented risk mitigation measures in Chapter 3.2.3 several measures are not used, as their usage is not adequate for this case or because another measure already mitigates the same risk factor.

- **Standardization, asset quality, surveillance and monitoring, insurance of equipment and weather derivatives**: These are all factors that mitigate technology risk, which is obsolete with GSR, as the technology risk shifts entirely to the tech-supplier
- **Credit enhancement**: Generally is expensive and credit service accounts can be cheaper and have the same effect
- **Currency hedging instruments and currency risk guarantee funds**: Not useful in Europe, especially not in the chosen countries, as they have the same currency
- **Government guarantees and country CDS**: Are not useful for solar thermal systems that have no risk due to changes of the incentive or permitting schemes
- **Political risk insurances**: Generally can be considered not adequate or useful in Europe, as risk of radical political events is minimal
- **Partial risk guarantees**: Can be totally covered by the partial credit guarantee, as the latter is more flexible and mitigates the same risk factors

Some of the chosen risk mitigation measures come along with an extra cost. These are especially the insurances and the hedging instruments. As most of these are not used in this case though, the associated cost of the risk mitigation measures can be neglected. The guarantees and certifications need to be negotiated but generally do not cause relevant additional costs. The only extra cost is generated by the energy contracting scheme, which comes along with an additional cost for the availability guarantee.

When applying the GSR scheme, the technology risk is transferred to the tech-supplier, who provides an availability guarantee for the energy system on top of operations and maintenance. This kind of guarantee was primarily used for the wind power sector [NPS, 2016; FROESE, 2016] and has established itself in the solar PV sector as well [FIRST SOLAR, 2016; SMA, 2016]. Up to now there is no literature available stating that availability guarantees have been deployed on a large-scale in the solar thermal sector. Due to lack of data on the cost for availability guarantees for solar thermal systems, the assumption in this thesis will be that the annual O&M cost increases by 50% in comparison to its usual cost level. This means that it is around 1.5% of the total CAPEX, instead of 1%.

With the remaining risk mitigation measures and the energy supply contracting scheme GSR the risk factors from *Table 38* are going to be positively influenced and partially mitigated. The assumption in this thesis is that each risk mitigation factor decreases the probability or impact of a risk factor to the same level for all countries, no matter if it was initially higher in another country. As mentioned above the entire technology risk is mitigated through GSR contracting. Furthermore, the impact of the economic risk factors is decreased mainly through the financial structure, the internal liquidity facility and the liquidity guarantee. They, and GSR, as well decrease the probability that the end-user has payment difficulties or a decreased energy demand. As for the political or policy risk factors, besides the risk of radical political events, the partial credit guarantee is able to decrease the impact of possible changes to incentive schemes, permitting and taxation laws. Though, in the case of solar thermal systems there is no risk of changes in incentive and permitting schemes, so this would not be needed.

Table 38: Effect of risk mitigation measures on risk factors

Category	Risk Factor	Probability	Impact
Technology Risk	Uncertainty of Energy Savings/Output	◇	
	Energy System Failure	◇	
	Incorrect Deployment of Energy System	◇	
	Uncertainty of Resource Availability	◇	
Economic Risk	Payment Timing Mismatches		◇
	Payment Difficulties from End-User	◇	◇
	Decreasing End-User Demand	◇	◇
Political or Policy Risk	Radical Political Events		
	Change of Incentive Scheme		◇
	Change of Permitting Policies		◇
	Change of Taxation Laws		◇

With this the new and securitized risk score and premiums are calculated (*Table 39*). Through the GSR contracting and the applied risk mitigation measures the risk premium are decreased essentially in relation to the basic risk assessment.

Table 39: Calculation of securitized risk premiums

Category	Risk Factor	Probability				Impact				Risk Score			
		Austria	Germany	Portugal	Spain	Austria	Germany	Portugal	Spain	Austria	Germany	Portugal	Spain
Technology Risk	Uncertainty of Energy Savings/Output	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	0.00	0.00	0.00	0.00
	Energy System Failure	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	0.00	0.00	0.00	0.00
	Incorrect Deployment of Energy System	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	0.00	0.00	0.00	0.00
	Uncertainty of Resource Availability	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.00	0.00	0.00	0.00
Economic Risk	Payment Timing Mismatches	0.1	0.1	0.6	0.7	0.1	0.1	0.1	0.1	0.01	0.01	0.30	0.35
	Payment Difficulties from End-User	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.05	0.05	0.25	0.25
	Decreasing End-User Demand	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.05	0.05	0.25	0.25
Political or Policy Risk	Radical Political Events	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.08	0.08	0.08	0.08
	Change of Incentive Scheme	0.0	0.0	0.0	0.0	0.5	0.5	0.1	0.1	0.05	0.05	0.05	0.05
	Change of Permitting Policies	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.05	0.05	0.05	0.05
	Change of Taxation Laws	0.5	0.1	0.8	0.8	0.5	0.5	0.5	0.5	0.25	0.05	0.40	0.40
Total Risk Score										**0.44**	**0.24**	**0.64**	**0.65**
Risk Premium Debt										**2.0%**	**1.5%**	**2.5%**	**2.5%**
Risk Premium Equity										**5.5%**	**5.0%**	**6.0%**	**6.0%**

The risk premiums of debt are at least halved for all four countries through the risk mitigation. The risk premiums for equity are not halved, but decreased by 3 – 4%. In the same way as for the basic risk assessment, the risk-adjusted cost of debt and equity can be calculated out of the risk premium plus the risk-free rate. These values are displayed in *Figure 30* and *Figure 31*. They include the values from the above basic risk assessment for sake of comparison.

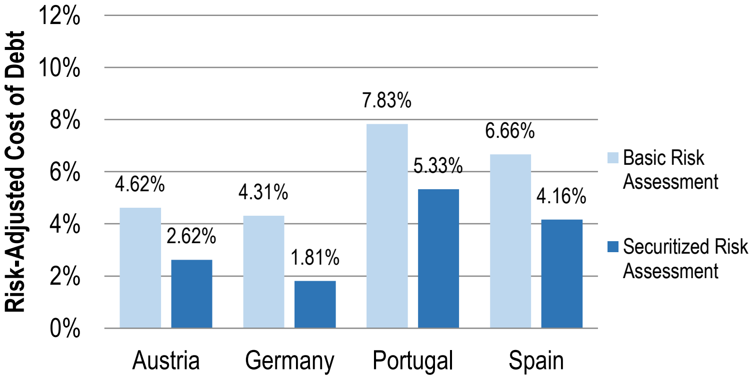


Figure 30: Risk-adjusted cost of debt for basic and securitized risk assessment

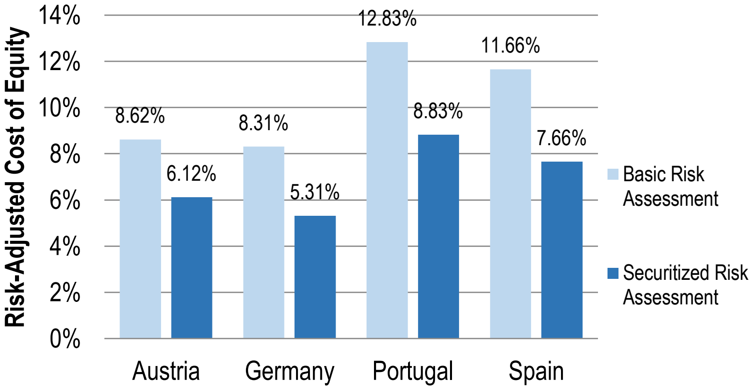


Figure 31: Risk-adjusted cost of equity for basic and securitized risk assessment

As expected the risk-adjusted values decrease for all four countries when applying GSR and further risk mitigation measures. Especially the cost of equity of Portugal is decreased by 4% down to 8.83%. Germany attains a cost of debt of only 1.81%.

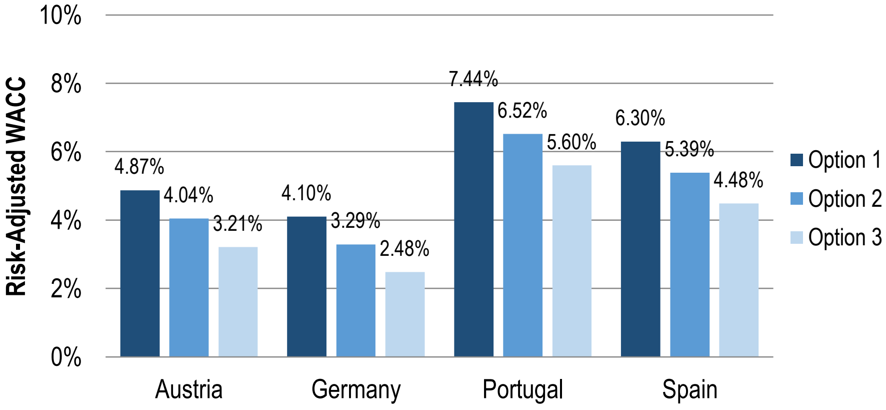


Figure 32: Risk-adjusted WACC for securitized risk assessment

The WACC can then be obtained out of the above cost of debt and equity from *Figure 30* and *Figure 31*. Just as in the basic risk assessment displayed in *Figure 29*, Spain attains a lower WACC in all three options with risk mitigation than Portugal (*Figure 32*). This is because it obtained the same securitized risk premiums as Portugal (*Table 39*) and has a lower risk-free rate than Portugal. Coherent to the WACC values for the basic risk assessment, the WACC for each country decreases with more debt leverage. Germany attains the lowest WACC with 70% of debt leverage at 2.48%.

In coherence with NOOTHOUT ET AL., both the basic and the securitized risk assessments yield lower WACCs for Austria and Germany than for Portugal and Spain. Though, and this is contrary to NOOTHOUT ET AL., Spain is regarded as relatively less risky than Portugal.

4.1.3. Macroeconomic Scenarios

An investment analysis often depends on external factors that are influenced by the current market conditions. These factors are so called macroeconomic factors. In this case there are two main macroeconomic factors that have an influence on the assessment, the conventional energy cost and the inflation. The latter as well has an influence on the OPEX. Through the GSR contracting scheme there will already be an agreement for operations and maintenance in place, which will generally be settled at the beginning of an investment. In this case, the OPEX increases annually with the inflation rate.

Because almost 40% of European process heat is currently based on natural gas (*Figure 7*), the conventional energy price scenario will be derived from the spot market price of natural gas. The European Energy Exchange (EEX) in Leipzig, Germany trades natural gas through a central gas trading platform called PEGAS for predominantly Germany, France, Belgium, the Netherlands, Italy and the UK. The daily spot market price for natural gas on the 12th of September 2016 was at 1.14 €ct/kWh and has been on an average level of around 1.30 €ct/kWh throughout 2016 [EEX, 2016]. The retail gas market price for industrial end-users in the Euro area was around 3.5 €ct/kWh in the second half of 2015 though [EUROSTAT, 2016b].

The British Department of Energy & Climate Change (DECC) published a study on fossil fuel price developments up to 2040, on which this thesis will base its macroeconomic scenarios for the conventional energy cost of the next 20 years. As the prices represented in the study refer to the spot market prices though, they were adjusted to the retail market level with the above mentioned retail market price from the second half of 2015.

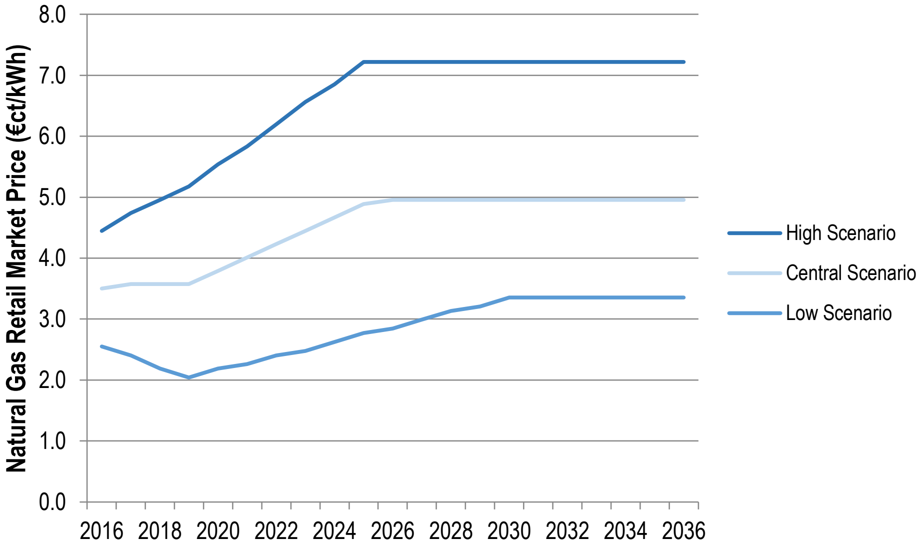


Figure 33: European natural gas retail market scenarios [DECC, 2015]

There are three different scenarios that were developed by DECC, they are named after the different price levels they yield and are therefore called high, central and low price scenarios (*Figure 33*). The exact numerical values can be found in Appendix A2. Macroeconomic Input Parameters The study was conducted in 2015 and hence has its reference point in that same year, which is why in 2016 there are already price differences between each scenario. The low price scenario gas price is estimated to decrease slightly the upcoming years up to 2019, where it begins to rise up to its maximum of 3.35 €ct/kWh. The central price scenario will stay constant at around 3.57 €ct/kWh up to 2019 and then increase to 4.96 €ct/kWh. The high price scenario directly is predicted to increase from around 4.45 €ct/kWh in 2016 to 7.22 €ct/kWh [DECC, 2015].

The low price scenario is based on the assumption that European demand for natural gas will be decreasing. Mainly due to additional energy and climate policies that facilitate a market shift towards more renewable sources. At the same time liquefied natural gas (LNG) will be available more abundantly and hence the total supply capacity of natural gas is going to increase. Russia being the largest importer of natural gas to Europe will seek to maintain this position against the LNG-supplying competitors by pricing its gas lower. A further assumption is that Russia would only decrease its price to a minimum that would still cover the marginal costs and the transportation costs [DECC, 2015].

The central price scenario reflects the assumption that LNG from North America, especially from the US, will be the marginal source of supply for the European gas market by the latest in 2025, especially due to its relatively low gas price levels. The prices are hence assumed to be equal to the price level of the Henry Hub (U.S. distribution hub and pricing point for natural gas) plus the delivery price to Europe, including liquefaction, shipping and re-gasification [DECC, 2015].

The high price scenario represents increasing natural gas demand in Europe, which cannot only be saturated by Russian natural gas, internal European sources and additional North American LNG. Furthermore, Australia is assumed to be the largest exporter of LNG by 2020. In a tight market with high worldwide demand Australia will be acting as price setter, which will as well reflect on European natural gas prices [DECC, 2015].

As for the inflation expectations in the upcoming years, there are only forecasts on inflation rates for the upcoming two to three years available. The inflation scenarios will therefore be developed based on these forecasts. To stay coherent to the above mentioned scenarios in *Figure 33*, the inflation scenarios were defined according to the assumed developments of the three scenarios for the conventional energy cost.

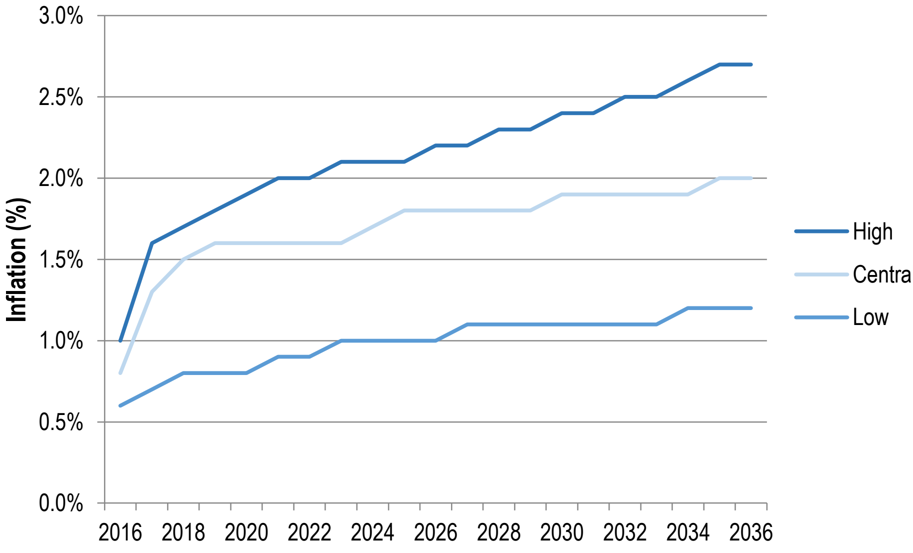


Figure 34: European inflation scenarios [EC ET AL., 2016]

The central inflation scenario of *Figure 34* is based on the forecast for the upcoming years by the Ec et al. and the Ecb (European Central Bank) and is in reference to the central price scenario of the natural gas prices, which represent the conventional energy cost [Ecb, 2016; Ec et al., 2016]. The exact numerical inflation values can be found in Appendix A2. Macroeconomic Input Parameters The increase of energy cost in general has an influence on inflation as well, because inflation represents an index of consumer price development. Hence, the higher the energy price, the higher inflation can be expected. As the energy price in the central price scenario from *Figure 33* rises slowly, so does inflation, up to around 2%, which is the ideal inflation value defined by the European Central Bank.

Accordingly, the low and high inflation scenarios have values below and above that, respectively. They represent the same trend as the energy price scenarios. The low inflation scenario slowly rises to a maximum inflation of 1.2% and represents a market with relatively low energy demand and prices. In the high inflation scenario, similar to the central price scenario, a strong initial increase is displayed for the next few years, which is in reference to the forecast from the European Commission [Ec et al., 2016].

4.2. Results

The results were attained using all the above mentioned input parameters. An overview of the used input values can be found in the Appendix A1. Constant Input Parameters An investment calculation was conducted, which yielded the most important investor parameters. These key performance indicators (KPI) are the simple pay-back period, the IRR and the NPV. They were calculated for all 16 chosen countries, for three macroeconomic scenarios, for the basic and securitized risk assessment and for the three debt-to-equity ratios. Hence, for each of the three KPIs 288 values were yielded. The high price scenario clearly yielded the most positive values, showing that certain investments will be financially viable. Hence, these results will be graphically displayed below in *Figure 35*, *Figure 36* and *Figure 37*. All the further results can be found in the Appendix A3. Results

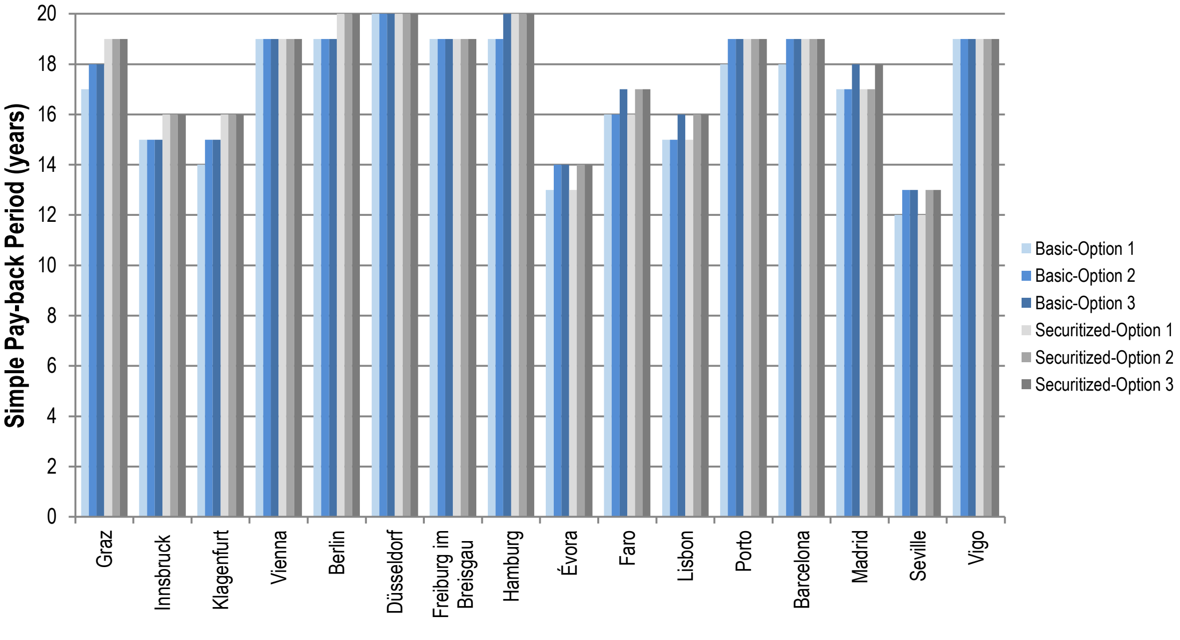


Figure 35: High price scenario simple pay-back period results

Figure 35 shows the high price scenario simple pay-back period in years for all the 16 locations for each the basic and securitized assessment and for each option 1, 2 and 3. Seville has the best pay-back values, which go down to 12 years.

Évora, Innsbruck and Klagenfurt come close to that with optimum values of 13 to 16 years of pay-back period. The German locations yield the worst values, especially Düsseldorf has a pay-back period of 20 years in all scenarios, almost double that of Seville. In Austria and Germany the securitized pay-back periods are always at least higher than those from the basic assessment. In Portugal and Spain option 1 mostly leads to better pay-back periods than option 2 and 3. In Graz and Klagenfurt the low debt leverage option 1 as well leads to better pay-back periods for the basic risk assessment.

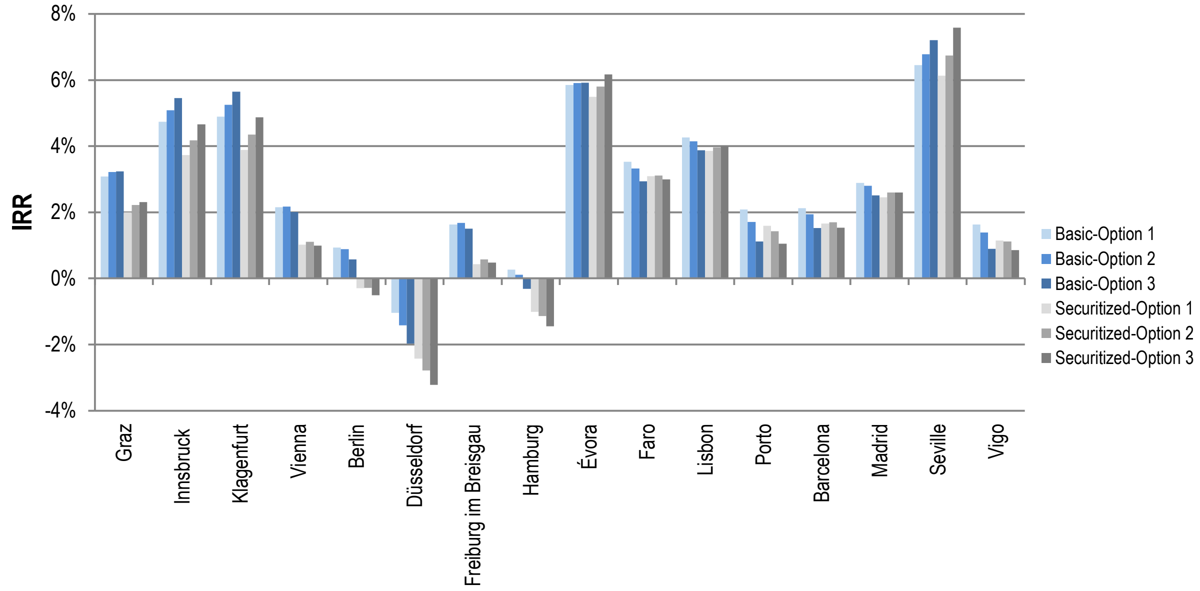


Figure 36: High price scenario IRR results

Figure 36 displays the obtained IRR results. The majority of locations have positive IRRs, with the highest values at around 6% to 7% for Évora and Seville. Innsbruck and Klagenfurt come close to that and have IRRs of around 5%. Düsseldorf has negatives IRRs, just as Berlin and Hamburg with securitized risk. In Austria, besides in Vienna, option 3 always has a higher IRR than option 1 and 2. For all the 8 locations in Austria and Germany the IRRs are always higher through the basic risk assessment. In Portugal and Spain, besides for Porto and Vigo, the IRRs of option 3 are always higher with securitized risk than with basic risk.

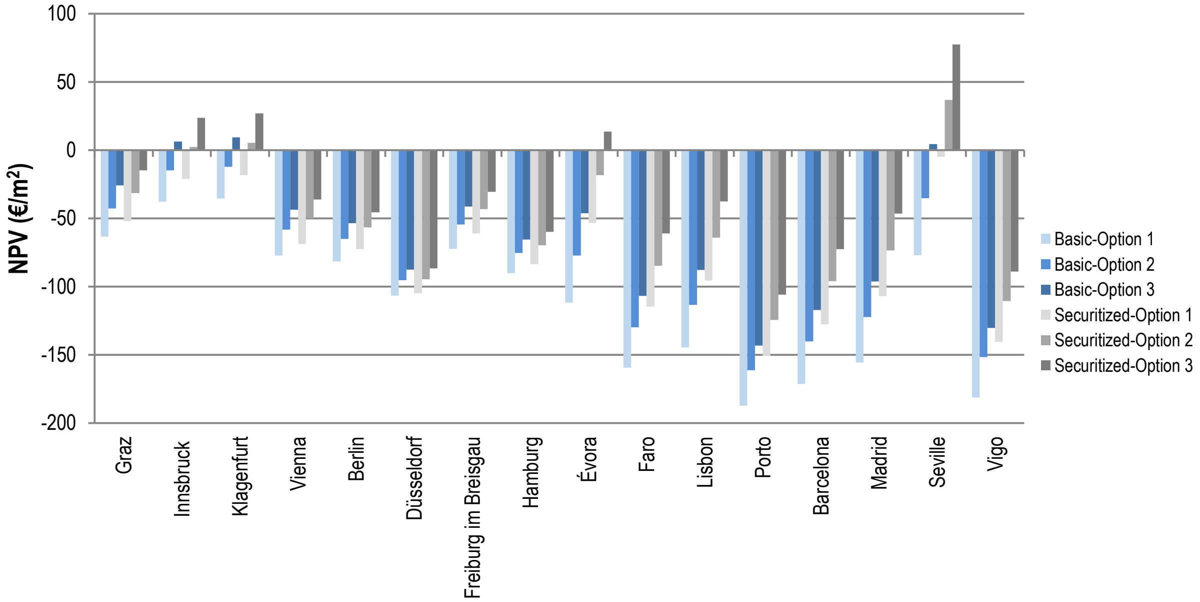


Figure 37: High price scenario NPV results

Figure 37 shows the high price scenario NPV results for all macroeconomic scenarios and the debt-to-equity ratio options. Strictly positives NPVs throughout all scenarios and options are not attained for any location. In Seville the maximum NPV value is obtained, at around 77 €/m², with a securitized assessment of option 3. Otherwise only Évora, Innsbruck and Klagenfurt attain further positive NPVs. For all locations option 3 and the securitized assessment represent the highest values.

4.2.1. Critical Input Parameters

Through the different scenarios and options that were assessed, a kind of sensitivity analysis for important input values has already been done. Further input parameters are assumed to have a rather large influence on the KPIs as well. Therefore, in the following an assessment of the impact of changing incentives and the CAPEX will be done. The question is which value would these two key input parameters have to have so that the investments at each location would be financially viable, which is defined as having at least a critical NPV of zero. Hence, they are supposed to be adjusted in a way that each location attains a NPV of at least zero. Each of these two input parameters will be changed one by one, while all the remaining parameters stay as in the above assessment. The assessment will be done at high debt leverage, so at option 3. The NPV will be used as criterion, because it allows one to see financial viability directly through a positive NPV. The assessment is done with each basic and securitized risk and for each of the three scenarios.

4.2.1.1. Critical Incentives

The initially used incentives for the four respective countries were all investment grants, which were 44% of the CAPEX in Austria, 50% in Germany, 1.25% in Portugal (calculated out of the maximum payout of €2,500 at a system size of 500 m² and a system cost of 400 €/m²) and 0% in Spain. To obtain financial viability conditions in each of the locations of the respective countries these incentive values had to be increased.

The following *Figure 38* represents each of the needed incentive values and the difference to each initial incentive scheme per country in the low, central and high price scenario. The incentive in each country was increased so long until each location attained at least a NPV of zero. The respective marginal locations per country were Vienna, Düsseldorf, Porto and Vigo. This means that they set the incentive to its displayed value, because they were the least favorable investment option.

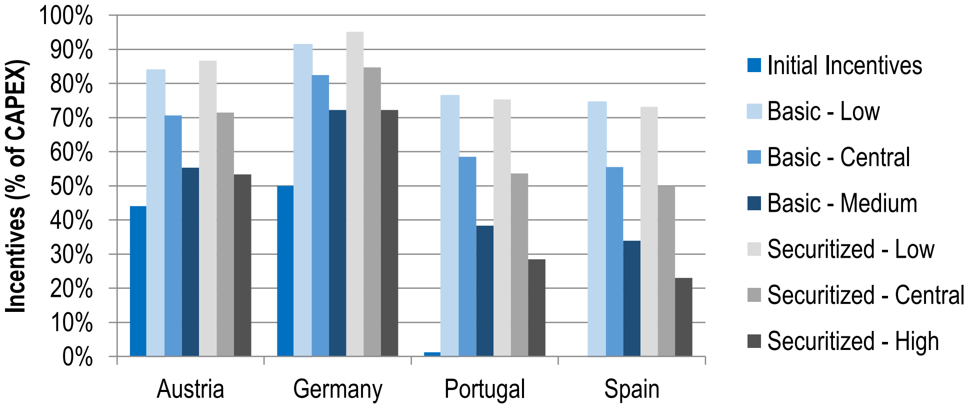


Figure 38: Critical incentives for financial viability conditions (NPV = 0)

Within the low price scenario the incentives for Austria would have to be almost doubled both with basic and securitized risk and those for Germany come close to that. Portugal and Spain each currently have almost no incentives and hence would need an investment grant of up to around 75% to have all locations be financially viable. In Austria and Germany risk mitigation does not seem to help in pushing for lower incentives, as both cases need higher incentives with securitized risk to be financially viable.

The central price scenario looks rather similar to the low price scenario, only that incentives could be around 10% to 15% lower. Risk mitigation still does not seem to be of advantage in Austria and Germany, as the incentives that would be needed with securitized risk are slightly higher than with basic risk.

In the high price scenario Portugal and Spain would only need an investment grant of around 20% to 35% to have financially viable locations. In Austria and Germany risk mitigation would pay off within the high price scenario, as the incentives theoretically needed with securitized risk are lower than with basic risk. Still the incentives need to be at an additional 20%, in comparison to the current values, for both countries to be viable.

Germany seems to have the lowest viability conditions, because it would need the highest amount of incentives to be financially viable. Austria follows with a maximum incentive scheme of 87% in the low price scenario. Both Portugal and Spain would need rather low incentives in comparison to Austria and Germany.

4.2.1.2. Critical CAPEX

In the initial assessment a CAPEX of 400 €/m^2 was used. It leads to many locations not being financially viable even in the high price scenario. Hence, the CAPEX value would need to be decreased to yield financial viability. The CAPEX was decreased per country so that each location in the respective country would be viable. The results are displayed in *Figure 39*. They clearly show that through risk mitigation a higher CAPEX is possible within each of the three scenarios and all the countries. Just as for the critical incentives, Vienna, Düsseldorf, Porto and Vigo are the marginal locations for all the cases. This means that at the presented critical CAPEX values a solar thermal system in these four locations would be just about viable and hence the NPV is zero. All the other locations would yield a lot larger NPVs with these critical CAPEX values.

The highest CAPEX values from *Figure 39* show the most viable investment locations. In this case this is clearly Austria, which in the high price scenario with securitized risk would be financially viable for all its four locations at a CAPEX of 348 €/m^2. This only represents a 13% decrease towards the initial CAPEX. The lowest value would be reached by Germany with basic risk at the low price scenario and a CAPEX of 108 €/m^2. This would mean a cost reduction of solar thermal panels of 73% would have to be achieved. After Austria it is Spain that can handle the second highest CAPEX values to reach financial viability.

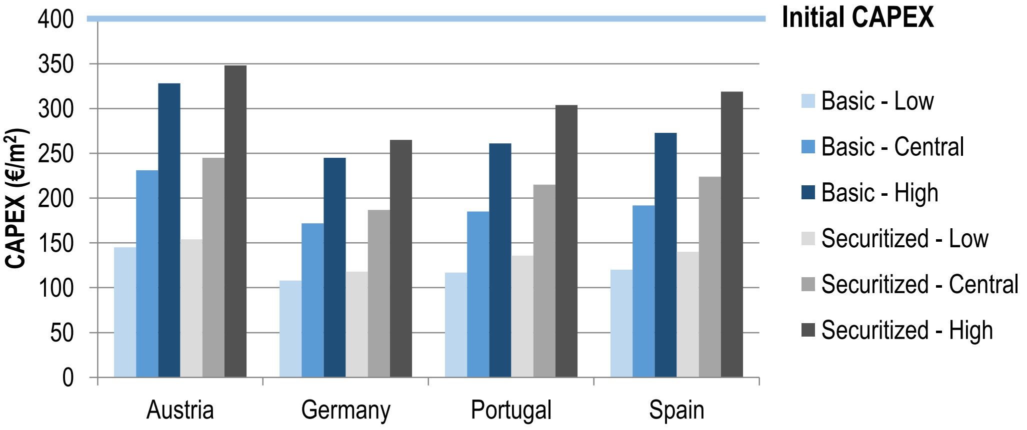


Figure 39: Critical CAPEX for financial viability conditions (NPV = 0)

4.2.2.Analysis of Results

As most investment options, the ones presented above can be analyzed by means of different KPIs. Here these are the pay-back period, the IRR and the NPV, as introduced above. The main question within this thesis is how far the risk mitigation measures can impact the assessment of an investment, so how far they influence the KPIs. Interestingly enough the KPIs are impacted quite differently. The same counts for other important input parameters, which influence the KPIs when changed. The effect of the debt-to-equity ratio and two constant input parameters, the CAPEX and the incentives, will therefore be analyzed as well.

Effects of Risk Mitigation Measures

The impact of the risk mitigation measures was implemented into the investment assessment through the RADR method. The main positive influence was a reduced WACC, which would bring along a lower discounting effect on the final annual cash flows. The risk mitigation measures though have an effect on two other main parameters as well: the cost of debt and the O&M cost. The former is reduced through risk mitigation measures and hence reduces the costs that stem from interest rate payments, which directly reduce the financial cost. The latter is increased through risk mitigation measures, particularly through the GSR, because the tech-supplier charges extra fees for providing an availability guarantee. An increase of O&M costs directly increases the operational cost.

Hence, the decreased WACC is the only parameter influencing the discounted cash flows and hence the NPV, because the sum of the discounted cash flows plus the initial CAPEX yield the NPV (Equation (1)). The other two KPIs are not affected by the WACC. The pay-back period is calculated from the initial investment and the annual cash flows that are not discounted. It does not consider the time value of money. The IRR is calculated through Equation (1) as well, it represents the discount rate that makes Equation (1) and the NPV be equal to zero. When calculating the IRR, Equation (1) is solved for the discount rate. Hence, the positive influence of the WACC, as a discount rate, is not considered. The pay-back period and the IRR therefore solely account for direct changes that occur to the cash flows, such as the net decrease of cash flow through the increased O&M costs for securitized risk. This leads to four main takeaways, which are as well displayed in *Figure 40*:

1. There are three main influencing parameters of the RADR method. These are the cost of debt, the O&M cost and the WACC. The cost of debt and the WACC are both decreased through risk mitigation. The O&M cost though increases. The securitized cost of debt decreases the financial cost and the WACC increases the discounted final annual cash flows. The O&M cost increases the operational cost.

2. The positive effects of risk mitigation measures are not displayed by the pay-back period and the IRR. Although the decreased cost of debt is considered through the financial cash flow, it is outweighed by the increase in O&M costs. Hence, the impact of risk mitigation on investments is displayed as negative by the pay-back period and IRR criteria, because they only consider the decreased final cash flow but not the positive discounting effect.

3. The positive effects of risk mitigation measures are directly displayed by the NPV. This is because a decreased WACC increases the discounted annual cash flows in comparison to the basic risk assessment. Although the final cash flow decreases through the risk mitigation measures, this decrease is mostly outweighed by the positive discounting effect of the decreased WACC.

4. There are exceptions to the third takeaway, especially when the final cash flows are negative. This is because the positive discounting effect of a securitized WACC is turned around with negative cash flows. The decreased WACC

leads to larger negative discounted cash flow values, just as it leads to larger positive discounted cash flow values. This makes the investment less favorable. This can especially be seen for the low and central price scenarios in Germany (Appendix A3. Results).

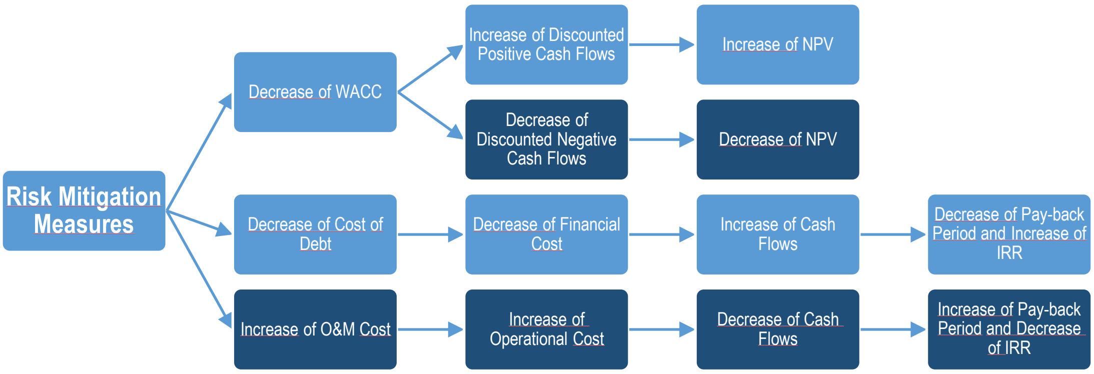


Figure 40: Effects of risk mitigations measures through risk-adjusted discount rate method

As the NPV is the KPI that shows the most essential information, it as well clearly displays the advantages that risk mitigation, in form of energy contracting schemes and further risk mitigation measures, brings along. And most importantly it shows that the positive effects of the decreased WACC and cost of debt outweigh the increased O&M cost. For the high price scenario *Figure 41* shows the Δ NPV from a basic to a securitized risk assessment. In other words, it is the difference in €/m² from the NPV with basic risk to the NPV with securitized risk. It can be noted that in the locations with rather high solar yield risk mitigation has the most positive impact. *Figure 41* actually resembles a lot to *Figure 28*, which shows the annual solar yields of each location. Seville with the highest solar yield is the most advantageous location for risk mitigation of solar thermal systems. And on the contrary Düsseldorf with the lowest solar yields has almost no benefit from risk mitigation. Putting this into perspective to the initially invested amount, or at least the initial monetary value of the investment, this means that Seville yields an additional NPV through risk mitigation, which represents 18% of the CAPEX (*Figure 41*). Risk mitigation in Évora leads to an increased NPV of 15% of the CAPEX under the high price scenario. The further locations yield lower values.

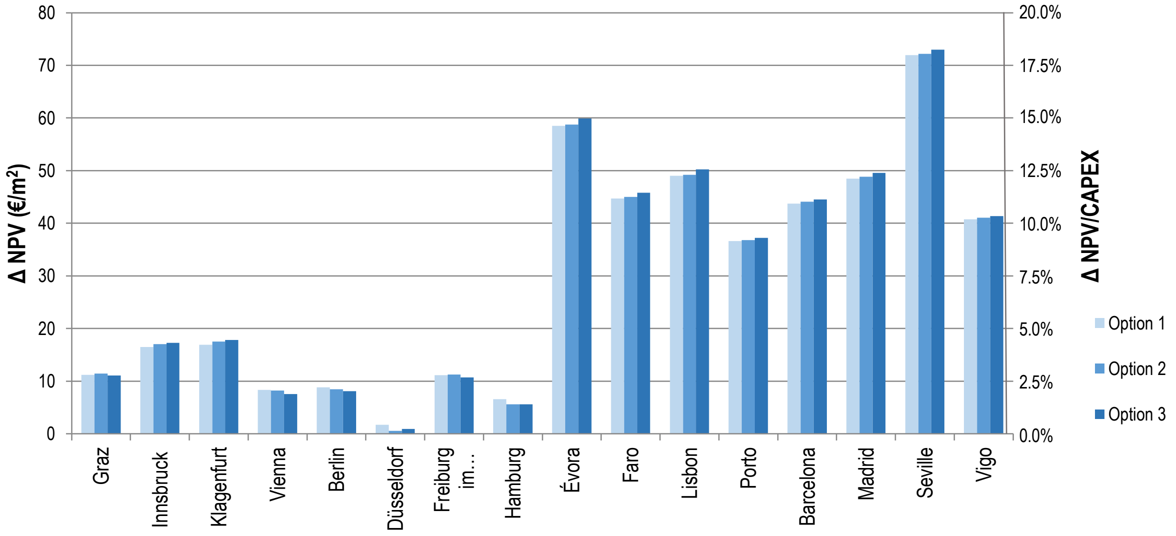


Figure 41: High price scenario Δ NPV

Effects of Debt Leverage

A further analysis regarding the different options of debt leverage shows that increasing the debt leverage has three direct consequences: the initial CAPEX on the balance sheet is reduced, the financial cost is increased and the WACC is decreased. The former two generally lead to a higher pay-back period (*Figure 35*). The effect of a reduced CAPEX and an increased financial cost on the IRR depends on the final cash flows. In rather positive conditions, with positive final cash flows, such as in Austria, Évora and Seville (*Figure 36*) the effect of higher debt leverage is a higher IRR. In the other, rather unfavorable, locations a counter effect of higher debt leverage takes place though. Especially the increase of the financial cost impacts the IRR negatively. Hence, smaller IRRs are obtained through higher debt leverage in rather unfavorable locations. The NPV as well includes the third direct consequence of higher debt leverage, a decreased WACC. Its impact is shown in *Figure 37* and makes clear that higher debt leverage leads to higher NPVs.

Effects of Critical Input Parameters

Regarding the critical input parameters *Figure 39* shows that the marginal location of Austria, which is Vienna, is the most viable out of the marginal locations in the four countries. The presented critical CAPEX values are primarily in reference to these four locations: Vienna, Düsseldorf, Porto and Vigo. The other locations are going to be yielding a lot more favorable values and are hence not directly represented by the critical values.

Furthermore, *Figure 38* shows the values of incentives and the differences to the initial incentives that are needed for financial viability conditions, while all the other input parameters stay exactly the same as in the initial assessment. If only considering the quantitative total amount of incentives Austria and Germany would be the least viable option to invest into. The currently available amounts of incentives in Austria and Germany make a difference though. In comparison to the current situation, Austria and Germany need less additional incentives to become viable than Portugal and Spain.

In a first thought more incentives to decrease the CAPEX by one unit should have the same financial effects as decreasing the CAPEX by one unit through improved manufacturing processes. When comparing *Figure 38* and *Figure 39* it becomes clear that this is not entirely true. Even if the incentives are an investment grant that decreases the CAPEX and one could assume that an incentive of 40% is equal to a 40% reduction of the CAPEX. Austria for example, needs additional incentives of around 10% to 40%, depending on the scenario, to become financially viable. Though, it needs a decrease of around 15% to 60% of the CAPEX to reach the same viability conditions. The same can be concluded for Germany, which needs additional 20% to 45% of incentives, but a decreased CAPEX of around 35% to 70%. On the other hand in Portugal and Spain the effect of decreasing the CAPEX is equal to increasing incentives.

A conclusion of this is that in Austria and Germany a further increase of incentives is more effective to make an investment viable, because a unit increase of the incentive leads to a larger increase of NPV than a unit decrease of CAPEX. The reason for this is the incentive scheme that is already in place in Austria and Germany. In Germany for example, decreasing the CAPEX by 10% only represents a decrease of 10% from the final CAPEX value, which is already deducted by the 50% incentive in Germany. At an initial CAPEX of 400 €/m^2 the final CAPEX value is 200 €/m^2, therefore a 10% decrease of the CAPEX stands for 20 €/m^2 instead of 40 €/m^2. The same counts for Austria. In Portugal and Spain there are no incentives that could have a similar negative impact.

5. Conclusions and Further Steps

This thesis was conducted with the main objectives to define a risk assessment model for investment analyses and to analyze, by means of this model, the impact of risk mitigation measures on investments into solar thermal systems for process heat generation. This was done in a multiple-step approach, by firstly defining and articulating the problem that is supposed to be addressed through this thesis. The second step was to lay out the potential for energy efficiency measures and renewable energy sources within the European industrial process heat sector and to show which technologies and measures could be most suitable. In a third step the risk assessment model was developed and explained. Furthermore, energy contracting schemes and risk mitigation measures were presented. The final step concluded by conducting the risk assessment for both basic and securitized risk and integrating it into the investment analysis.

From the first part of the thesis it can be concluded that next to the widely addressed power generation sector, the process heat sector needs to be increasingly focused on to decrease a large amount of future carbon emissions from this sector. The reasons for the lack of investment into more energy efficient and renewable process heat systems are mainly economic, because the technologies are available on the market and are proven. A main issue is that such investments create relatively small energy cost savings in comparison to their initially needed investment, which results in relatively long pay-back periods. The extensive usage of the pay-back period criterion therefore lets investors perceive investments into refurbished process heat systems as rather risky. Furthermore, in most countries there is little public funding available for investments into less carbon emitting process heat systems. As an example, in 2014 public European funding for energy efficiency measures in the industry was only 9% of the available funding for energy efficiency improvements in buildings. Based on these problems, this thesis had as an objective to see how risk mitigation would improve the essential KPIs, such as the pay-back period criterion, to increase the amount of funds that are invested into low carbon process heat technologies.

Throughout the work on this thesis a main finding was that the current European process heat demand makes up of around 25% to 28% of the total European energy consumption and the large share of it stems from conventional and carbon emitting sources. Actually only around 10% are from renewable sources, namely biomass. In 2012 alone 57% of process heat was generated from natural gas and coal. The European industrial sectors of iron and steel, non-metallic mineral products, chemicals, pulp and paper, food, drink and tobacco and refineries all have a process heat share of larger than 50% of their total energy consumption and hence present a large potential for new process heat technologies. Especially the iron and steel and the chemicals sectors are estimated to increase their energy consumption up to 2050. For low and medium temperature heat that can especially be provided by renewable sources, the chemicals, the food, drink and tobacco and the pulp and paper sector have a large potential which could most likely be provided by biomass and solar thermal systems. The latter was concluded to generate a large share of energy for process heat in 2050. As for energy efficiency the iron and steel and the chemicals sector were estimated to have the largest economic energy savings potential of up to 7.4 Mtoe in 2050.

A further conclusion is that more and more investors have already been investing into both energy efficiency and renewable energies, though mainly in the power sector. Securitization deals have been part of this recent development. They have mainly been backed through PPAs, which come very close to energy contracting schemes such as the GSR scheme. Hence, the RADR method was used to assess the impacts of the GSR scheme and other risk mitigation measures on solar process heat investments. It led to having a risk premium for debt and for equity. The assumption behind this was that investors and financial institutions could use this risk assessment method in their evaluation schemes of new solar thermal process heat systems to respectively define their cost of debt and equity. The risk assessment method was based on assessing the impact and probability of several risk factors. The assessment of these risk factors could theoretically be claimed to be the largest uncertainty to the subjectivity of the person or institution conducting the assessment. Simply defining slightly different probabilities to the risk factors could change the final output, the risk premium. The risk assessment yielded the WACC as final value, to be used as input parameters for the investment analysis. Under the least debt leveraged option the WACC was able to be decreased through risk mitigation on average by 2.90% (in absolute terms).

The investment analysis and the three main KPIs (pay-back period, IRR and NPV) lead to following conclusions: Even in the high energy price scenario, with accordingly high operational profits from the solar thermal system, the pay-back period was on average around 15 years. Seville yielded the most optimal value with only 12 years under low debt leverage. Most of the yielded IRRs were positive and went up to a maximum of around 8% in Seville. Düsseldorf obtained the worst IRRs, going down to -3%. As for the NPVs, only Innsbruck, Klagenfurt, Évora and Seville yielded positive NPVs in the high energy price scenario. In regard of the IRR expectations of several investors, the yielded values represented what pension and infrastructure funds and insurance companies were looking for and hence give a rather positive outlook towards being able to attract further investment to the process heat sector.

As one of the final conclusions, the highest impact of risk mitigation was analyzed in locations with high solar yield. Seville yielded an NPV that was 73 €/m^2 (to be compared with the CAPEX of 400 €/m^2) higher through risk mitigation. That means the NPV was improved by this amount through using the GSR scheme and the other risk mitigation measures. The other two KPIs, the pay-back period and the IRR did not display the positive impact of risk mitigation, because they did not consider the discounted cash flows, which were positively influenced by the WACC. They were calculated from the undiscounted cash flows, which were slightly decreased through the increased O&M costs. The conclusion is that when using the RADR method as risk assessment tool, the pay-back period and the IRR will yield less favorable results when applying risk mitigation measures. Companies and investors hence would have to shift their focus on using the NPV as KPI and they would have to lay less focus on the pay-back period and the IRR. This would mean a serious shift in how financial analysts and investors do their business, as mostly they consider several KPIs when assessing an investment.

A further conclusion in regard to critical input parameters, which is as well confirmed through *Figure 41*, is that the impact of risk mitigation is strongly dependent on the solar yield of a location. This can be exemplified through the needed decrease of the CAPEX, through improvements in the manufacturing processes, up to reaching financial viability. For example, Seville under the neutral price scenario (less dependent on external factors than high and low price scenarios) and high debt leverage would need a decrease of technology cost (CAPEX) from 400 €/m^2 to 284 €/m^2 at basic risk. With risk mitigation, so securitized risk, the technology cost decrease would only have to be decreased to 332 €/m^2, so that Seville reaches financial viability under the neutral price scenario. In Düsseldorf on the contrary the decreased values for financial viability would be 172 €/m^2 and 187 €/m^2, respectively with basic and securitized risk. This means that the risk mitigation tools render investments into solar thermal process heat systems more attractive under good solar irradiation conditions and that a smaller technology cost reduction is needed to reach financial viability.

The most critical input values for the evaluation of the effects of risk mitigation are the impact and probability of each risk factor under basic and securitized risk. For further validation of the developed risk assessment model these values would need to be verified through industry expert interviews. This would enable to see how accurate the values used in this thesis can be considered. Furthermore, industry experts could give feedback regarding the structure of the risk assessment model and how far they would consider only using the NPV as evaluation parameter.

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Appendix

A1. Constant Input Parameters

Table 40: Constant input parameters for investment analysis

Parameter	Value
CAPEX	400 €/m²
Premium for End-User	98%
Linear Depreciation	4 years
Investment Lifetime (max. 25 years)	20 years
Credit Lifetime (Debt)	10 years
Product Lifetime (max. 30 years)	25 years
Equity	30%
Residual Value	20%

A2. Macroeconomic Input Parameters

Table 41: Natural gas retail market price scenarios (€ct/kWh)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	2.6	2.4	2.2	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.8	3.0	3.1	3.2	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Central	3.5	3.6	3.6	3.6	3.8	4.0	4.2	4.4	4.7	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
High	4.4	4.7	5.0	5.2	5.5	5.8	6.2	6.6	6.9	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2

Table 42: Inflation scenarios (%)

Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Low	0.6	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Central	0.8	1.3	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	2.0	2.0
High	1.0	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.7

A3. Results

Table 43: Overview of total results

City	Criterion	Basic Risk									Securitized Risk								
		Option 1			Option 2			Option 3			Option 1			Option 2			Option 3		
		Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High
Graz	Pay-back (year)	20	20	17	20	20	18	20	20	18	20	20	19	20	20	19	20	20	19
	IRR	-4%	0%	3%	-5%	-1%	3%	-5%	-1%	3%	-5%	-2%	2%	-6%	-2%	2%	-6%	-3%	2%
	NPV (€/m²)	-161	-114	-63	-154	-101	-43	-150	-92	-26	-169	-113	-52	-162	-101	-31	-158	-93	-15
Innsbruck	Pay-back (year)	20	19	15	20	19	15	20	19	15	20	20	16	20	20	16	20	20	16
	IRR	-3%	1%	5%	-4%	1%	5%	-4%	0%	5%	-4%	0%	4%	-5%	0%	4%	-5%	-1%	5%
	NPV (€/m²)	-149	-96	-38	-140	-80	-15	-135	-69	6	-154	-91	-21	-146	-76	2	-141	-65	24

Klagenfurt	Pay-back (year)	20	19	14	20	19	15	20	19	15	20	20	16	20	20	16	20	20	16
	IRR	-3%	1%	5%	-3%	1%	5%	-4%	0%	6%	-4%	0%	4%	-5%	0%	4%	-5%	-1%	5%
	NPV (€/m^2)	-147	-94	-35	-139	-78	-12	-134	-67	9	-153	-89	-18	-145	-73	5	-139	-62	27
Vienna	Pay-back (year)	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19
	IRR	-4%	-1%	2%	-5%	-2%	2%	-6%	-2%	2%	-6%	-3%	1%	-6%	-3%	1%	-7%	-3%	1%
	NPV (€/m^2)	-167	-124	-77	-161	-113	-58	-158	-105	-44	-177	-125	-69	-171	-115	-50	-167	-108	-36
Berlin	Pay-back (year)	20	20	19	20	20	19	20	20	19	20	20	20	20	20	20	20	20	20
	IRR	-5%	-2%	1%	-6%	-3%	1%	-6%	-3%	1%	-7%	-4%	0%	-7%	-4%	0%	-8%	-5%	-1%
	NPV (€/m^2)	-157	-120	-81	-151	-111	-65	-149	-105	-54	-166	-122	-73	-161	-113	-57	-158	-107	-45
Düsseldorf	Pay-back (year)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	IRR	-6%	-4%	-1%	-7%	-4%	-1%	-8%	-5%	-2%	-8%	-5%	-2%	-8%	-6%	-3%	-9%	-6%	-3%
	NPV (€/m^2)	-169	-140	-107	-165	-133	-95	-164	-129	-88	-182	-147	-105	-178	-140	-95	-176	-136	-87
Freiburg im Breisgau	Pay-back (year)	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19
	IRR	-5%	-2%	2%	-5%	-2%	2%	-6%	-3%	2%	-6%	-3%	0%	-7%	-3%	1%	-7%	-4%	0%
	NPV (€/m^2)	-152	-113	-72	-147	-103	-55	-144	-96	-41	-161	-113	-61	-155	-104	-43	-151	-97	-30
Hamburg	Pay-back (year)	20	20	19	20	20	19	20	20	20	20	20	20	20	20	20	20	20	20
	IRR	-5%	-3%	0%	-6%	-3%	0%	-7%	-4%	0%	-7%	-4%	-1%	-7%	-5%	-1%	-8%	-5%	-1%
	NPV (€/m^2)	-161	-127	-90	-156	-119	-75	-154	-113	-65	-172	-131	-84	-167	-123	-70	-164	-117	-60
Évora	Pay-back (year)	20	19	13	20	19	14	20	19	14	20	19	13	20	19	14	20	19	14
	IRR	-3%	2%	6%	-4%	1%	6%	-5%	0%	6%	-3%	1%	5%	-4%	1%	6%	-5%	0%	6%
	NPV (€/m^2)	-271	-195	-112	-259	-171	-77	-254	-155	-46	-258	-161	-53	-247	-137	-18	-241	-121	14
Faro	Pay-back (year)	20	20	16	20	20	16	20	20	17	20	20	16	20	20	17	20	20	17
	IRR	-4%	0%	4%	-5%	-1%	3%	-6%	-2%	3%	-5%	-1%	3%	-6%	-1%	3%	-7%	-2%	3%
	NPV (€/m^2)	-294	-229	-159	-284	-210	-130	-281	-199	-107	-287	-204	-115	-278	-186	-85	-274	-175	-61
Lisbon	Pay-back (year)	20	19	15	20	20	15	20	20	16	20	20	15	20	20	16	20	20	16
	IRR	-4%	0%	4%	-5%	0%	4%	-6%	-1%	4%	-4%	0%	4%	-5%	-1%	4%	-6%	-1%	4%
	NPV (€/m^2)	-287	-218	-145	-276	-197	-113	-273	-185	-88	-278	-191	-96	-268	-171	-64	-264	-158	-38
Porot	Pay-back (year)	20	20	18	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19
	IRR	-5%	-1%	2%	-6%	-2%	2%	-7%	-3%	1%	-6%	-2%	2%	-7%	-3%	1%	-8%	-4%	1%
	NPV (€/m^2)	-307	-249	-187	-299	-233	-161	-297	-225	-143	-304	-230	-151	-296	-215	-125	-294	-207	-106
Barcelona	Pay-back (year)	20	20	18	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19
	IRR	-5%	-1%	2%	-6%	-2%	2%	-7%	-3%	2%	-6%	-2%	2%	-7%	-3%	2%	-7%	-3%	2%
	NPV (€/m^2)	-302	-238	-171	-292	-219	-140	-289	-208	-117	-296	-214	-128	-287	-196	-96	-283	-185	-73
Madrid	Pay-back (year)	20	20	17	20	20	17	20	20	18	20	20	17	20	20	17	20	20	18
	IRR	-5%	-1%	3%	-6%	-1%	3%	-7%	-2%	3%	-5%	-1%	2%	-6%	-2%	3%	-7%	-3%	3%
	NPV (€/m^2)	-294	-227	-156	-283	-205	-122	-280	-193	-96	-286	-200	-107	-276	-179	-73	-271	-167	-47
Seville	Pay-back (year)	20	18	12	20	19	13	20	19	13	20	19	12	20	19	13	20	19	13
	IRR	-2%	2%	6%	-3%	2%	7%	-4%	1%	7%	-3%	2%	6%	-4%	2%	7%	-4%	1%	8%
	NPV (€/m^2)	-257	-171	-77	-242	-141	-35	-233	-119	5	-238	-128	-5	-223	-97	37	-214	-75	78
Vigo	Pay-back (year)	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19	20	20	19
	IRR	-5%	-2%	2%	-6%	-3%	1%	-7%	-4%	1%	-6%	-2%	1%	-7%	-3%	1%	-8%	-4%	1%
	NPV (€/m^2)	-307	-245	-181	-297	-227	-152	-295	-218	-130	-302	-224	-141	-293	-207	-111	-290	-197	-89