UNIVERSITY OF LJUBLJANA

FACULTY OF ECONOMICS

MASTER'S THESIS

GREGOR TEHOVNIK

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FINANCIAL AND ENVIRONMENTAL IMPLICATIONS OF ENERGY RENOVATION: THE CASE OF A RESIDENTIAL BUILDING

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GREGOR TEHOVNIK

AUTHORSHIP STATEMENT

The undersigned Gregor Tehovnik, a student at the University of Ljubljana, Faculty of Economics, (hereafter: FELU), author of this written final work of studies with the title Financial and environmental implications of energy renovation: the case of a residential building, prepared under supervision of associate prof. Andreja Cirman, PhD.

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INTRODUCTION

The modern world is experiencing rapid and ongoing economic growth. According to the International Monetary Fund (2016), global gross domestic product (hereinafter: GDP) growth in 2015 is estimated at 3.1% and is predicted to increase in the years to follow. Economic growth is considered to be highly desirable as it has many positive impacts, including contributing to an individual's quality of life. However, it also comes with some negative impacts. As a result of the world’s economy being developed on the basis of fossil fuels, there is a high positive correlation between energy use and economic growth. Burning these fossil fuels emits greenhouse gases (hereinafter: GHG) which, over time have been emitted in such vast quantities that they have disturbed some of the crucial planetary systems and boundaries (Sachs, 2015). Potential negative impacts become even more alarming when future global developments are considered. As predicted by climate models, the pursuit of “business as usual scenarios” will lead to an unprecedented devastation inflicted on the environment (World Bank, 2012).

According to the International Energy Agency (2015, p. 20), greenhouse-gas emissions from the energy sector represent roughly two-thirds of all anthropogenic GHG emissions. Therefore, technology development in the sector and the energy choices that are made will play a crucial role in future scenarios. Sir Nicolas Stern (cited in Benjamin, 2007, p. 1) asserted that “climate change is a result of the greatest market failure the world has seen”. Markets have overproduced GHG emissions because the real social costs are not priced in the transaction. It is evident that the free markets alone will not solve this problem, and therefore governmental intervention and commitments on a global scale are needed.

To secure the lowest societal impact, decarbonisation of our economy should be gradual and efficient. According to McKinsey and Company (2009), the building sector represents one of the cheapest opportunities for abatement of GHGs. In developed countries, the majority of building stock has already been built, therefore the greatest potential lies in the reduction of emissions through retrofits of existing buildings. Rifkin (2011) even suggests that the whole building stock needs to be transformed into mini power plants, capable of generating renewable energy on site and sharing it through distributed energy networks.

According to Ministry of Infrastructure, Republic of Slovenia (2015, p. 14), around 72% of existing building stock in Slovenia is considered to be residential buildings. Many of the solutions in energy efficient refurbishment in the building sector offer a net economic benefit. This is due to high energy savings, which occur over the full lifetime of investment. The majority of economically viable energy-efficiency potential, however, remains unrealised (International Energy Agency, 2012, p. 291). The extent of this phenomenon is generally referred to as the energy efficiency gap, which is defined as the unexploited economic potential for energy efficiency (Hirst & Brown, 1990). Consideration of the underlying causes and barriers that are causing this gap is therefore of the utmost importance. Furthermore, the decarbonisation needs to happen on an individual-micro level basis. Therefore it is important to consider decarbonisation solutions from an individual investor's point of view.

The purpose of the thesis is to promote cost-efficient decarbonisation of residential buildings which have already been built. The thesis will therefore examine the relevant literature regarding environmental development, the potential for cost-efficient decarbonisation in the building sector, possibilities for onsite renewable electricity self-generation and the barriers to implementation of decarbonisation technologies. To verify the potential of energy renovation in the proposed areas, renovation potential of the specific residential building will technically and financially be examined. This will be done from the individual investor's point of view. The findings will aim to reduce the risk of investment and allow the investor/owner to make an informed decision and renovate the building in a manner that will be cost efficient, maximize wellbeing of residents and simultaneously reduce the dwelling's negative impact on the environment.

Furthermore, the thesis will serve as a facilitator for energy renovation of other residential buildings in a similar legal and geographical environment. It will provide an unambiguous review of contemporary energy efficiency and renewable energy microgeneration solutions, which can serve as basic information for other investors. Findings will therefore assist sustainable development and cost efficient GHG reductions at a household level. In order to make energy renovation of existing buildings efficient, identification of the most financially and environmentally viable solutions is of the utmost importance. The research aims to empower households to invest in financially sound solutions whilst reducing their carbon footprint.

The goal of the thesis is to examine the need for energy renovation of buildings and highlight the benefits it brings (with the emphasis on financial and environmental benefits). Furthermore, the goal is to identify and evaluate the most financially sound technical solutions to decarbonise the specific case study building. Findings and conclusions need to provide the most crucial information to the owner in order to make an informed decision regarding the building's energy renovation. The findings will also determine if the specific transformation to a carbon neutral building makes financial sense.

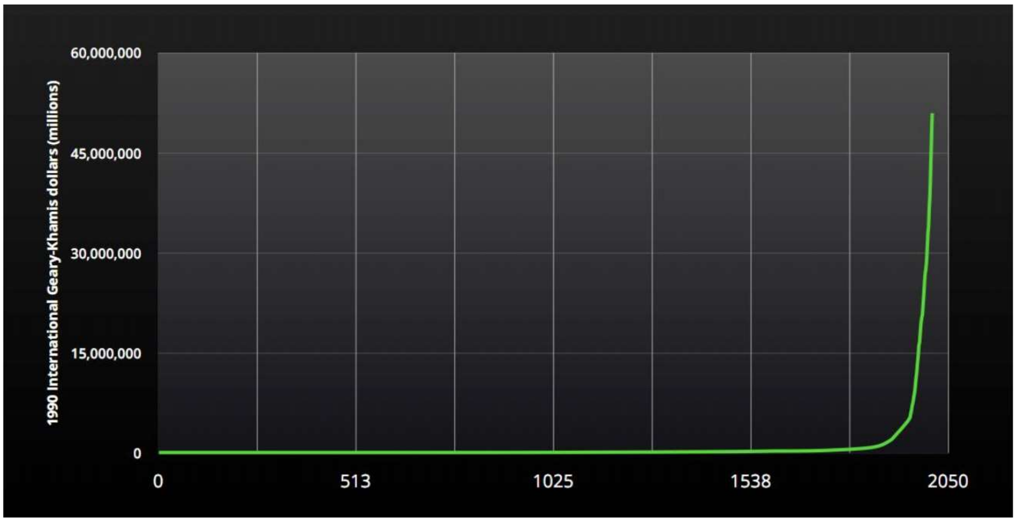
The thesis is composed of the introduction, theoretical part, empirical part and conclusion. In the introduction the problem is briefly described, followed by the purpose and goals of the thesis. The core of the thesis is composed of two theoretical chapters and one empirical chapter. The theoretical part examines the literature and recent developments in the research field, whereas the empirical part is the case study for the renovation of a specific residential building. The core of the thesis is followed by a conclusion, literature and attachments. The first chapter examines the problem of unsustainable development. It describes the basics of how human activity is impacting on the environment and projects future scenarios. Next, the development of international negotiations is examined and the most cost efficient methods of decarbonisation are described. Finally, the concept of net zero energy renovation of buildings is elaborated. In the second chapter, the focus is narrowed into a field of energy renovation of buildings in a geographic area of a specific country, Slovenia. Here, the national building stock is examined and national strategy is considered. Furthermore, the chapter examines the mechanism with which the country is addressing the energy efficiency gap, the country's "net-metering" regulation and takes local energy prices into consideration. The third chapter narrows the focus to a specific residential building in Slovenia. It describes the building and quantifies its total annual energy consumption patterns and resulting CO_2 emissions. Finally the energy renovation feasibility study is undertaken, which includes energy efficiency and on-site renewable energy generation measures. These are then further financially and environmentally examined. Theoretical findings will be supported by first-hand calculations. In order to estimate the financial effect of various renovation solutions, an unofficial energy performance certificate of the building will be used. The certificate for the household was developed as a part of an undergraduate thesis made by Domen Tehovnik on Faculty of Civil and Geodetic Engineering, University of Ljubljana. Primary data will be collected via quotations from various companies. Quotations were exclusively made for the selected residential building.

There are a number of drawbacks anticipated in the empirical part of the research. Firstly, calculations are based on many ambiguous estimates. Quotation price estimates and energy saving estimates given by sales staff are subjective and might be overly optimistic in order to promote sales. Furthermore, the price of different energy sources used in the calculations constantly fluctuates. Finally, the EKO Fund's (Sln. *Eko sklad*) financial assistance scheme is politically and bureaucratically uncertain. As a result, estimated financial savings and calculated financial indicators are subject to change and will be applicable for only a short amount of time.

1 THE AGE OF SUSTAINABLE DEVELOPMENT

Rapid sustained economic growth is a modern phenomenon. Throughout human history the whole world has been equally in economic poverty. Every part was rural and the population was mainly composed of small peasant farmers on the edge of famine, struggling to produce enough food to survive. Civilisation based on settled agriculture is roughly 10,000 years old and economic changes throughout history until now seem to be very negligible.

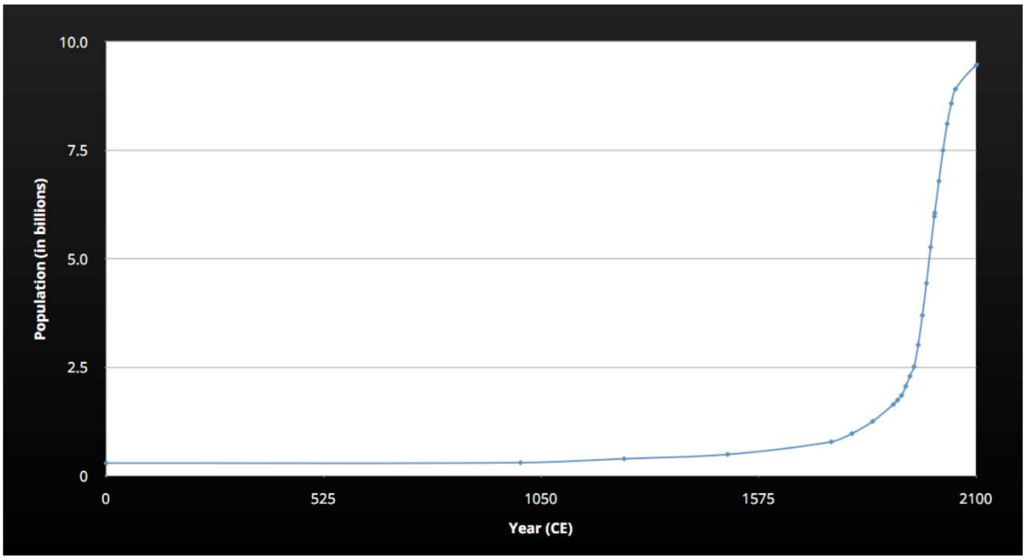
Figure 1. Global GDP Over Time (0-Present)



Source: J. Sachs, *The Age of Sustainable Development*, 2015, p. 72.

Figure 1 shows that economic output was relatively flat until recent economic take-off which began during the 18th century, with the industrial revolution. Similar to the economic expansion, there was also an expansion of population starting at the same period, as evident in Figure 2. Beforehand, the number of people on the planet remained stable for thousands of years. Minor exemptions that caused dents in global population count were the great famines, wars, plagues and so on. However, in line with economic growth and increasing ability to produce food, population has risen at apace never yet seen in history.

Figure 2. World Population since Year Zero



Source: J. Sachs, *The Age of Sustainable Development*, 2015, p. 73.

Dramatic change began in the Industrial Revolution. Since then, economic life has taken off and started spreading throughout the entire world. One of the underlying facilitators of the Industrial Revolution was the invention of the steam engine, which allowed society to harvest massive amounts of energy out of coal (Sachs, 2015, pp. 71-78).

Fast economic development has had many positive effects on society. It has increased the quality of life, fostered the development of science, and even allowed the survival of a high population which has not yet been witnessed in the past. However, the question of the sustainability of such rapid economic and population growth is a rising global concern. Likewise, humanity's impact on the environment is becoming increasingly more alarming.

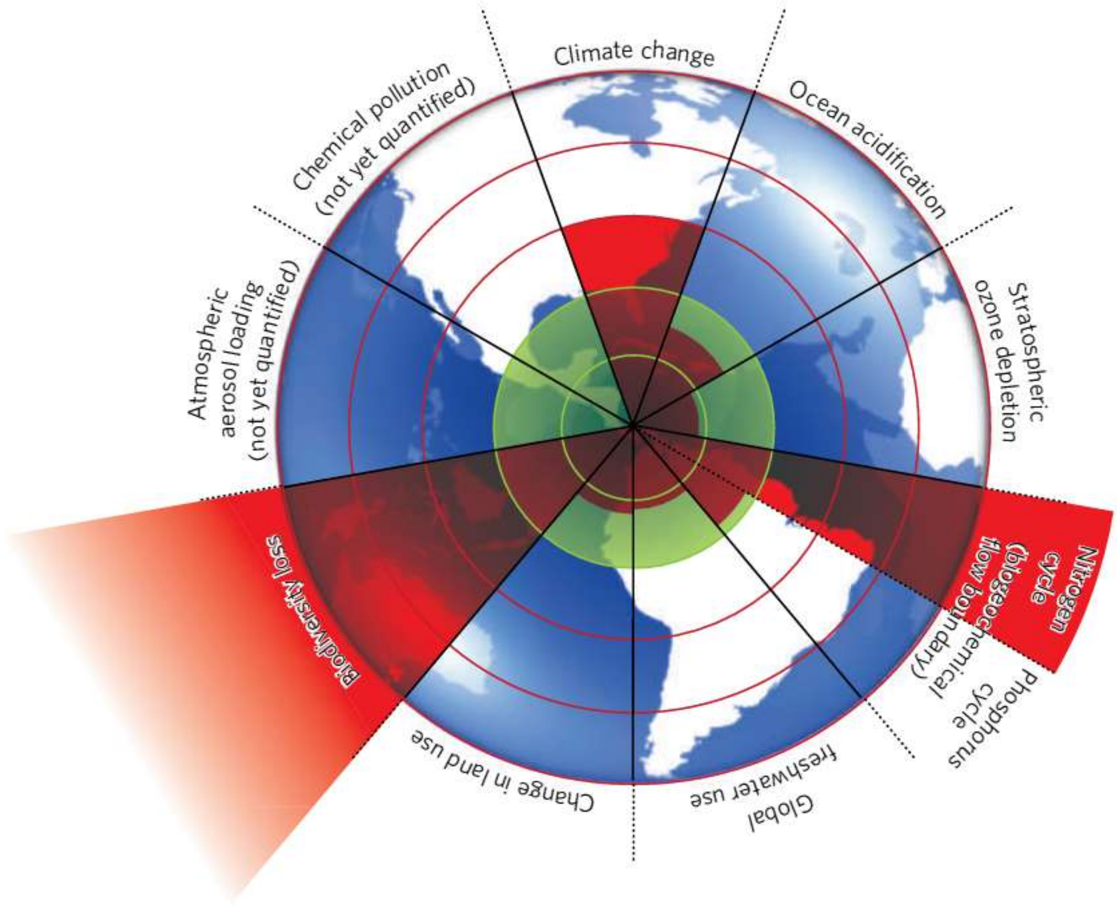
1.1 Trespassing the Planetary Boundaries

Some scientists mark the Industrial Revolution as the beginning of the Anthropocene or the so called "Age of humans". This epoch is not a formally defined and accepted geological unit within the geological time scale, nonetheless it is currently being considered by the working group on Anthropocene as a potential geological epoch. This period of Earth´s history marks the start of the significant global influence that humans have had on the Earth's ecosystem (Working group on the "Anthropocene", 2015). Anthropocene is a term commonly used in regard to global warming, however, it does not mark only that. Humanity has a significant impact on many of the planetary boundaries and it has the capacity to push the Earth's system outside the stable environment, or the so called state of the Holocene. This would lead to planetary states that would be far less conducive for human development (Rockström et al., 2009).

Planetary Boundaries is a new approach developed for defining preconditions for human development. It is about defining and quantifying the safe operating space for humanity with respect to the Earth's system, and is associated with the planet's biophysical processes or subsystems. Many of those subsystems react in a nonlinear way and can therefore cause abrupt changes on the planet Earth. If certain thresholds are crossed, it could shift some of the important Earth subsystems, such as monsoon systems or coral reef systems, in to a new undesirable environmental change. Identified boundaries are tightly linked together, meaning that if one boundary is crossed, then the other boundaries are also at a serious risk (Rockström et al., 2009).

In Figure 3 it is evident that certain thresholds have already been exceeded. According to Rockström et al. (2009, p. 472), "The inner green shading represents the proposed safe operating space for the planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity, climate change and human interface with nitrogen cycle), have already been exceeded."

Figure 3. The Current State of Planetary Boundaries.



Source: J. Rockström et al., *A Safe Operating Space for Humanity*, 2009, p. 472.

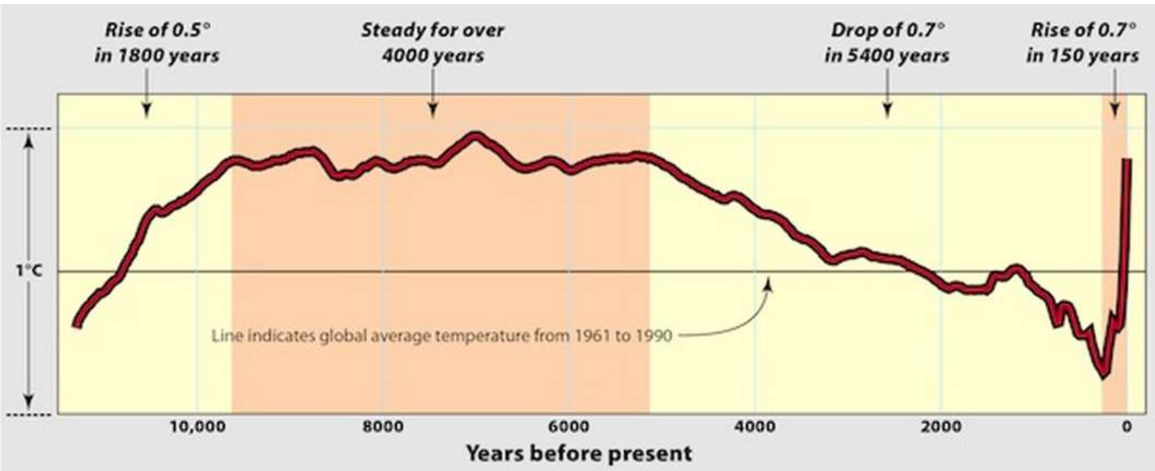
1.1.1 Climate Change

The most important and publicly recognised planetary boundary relates to human induced climate change. This is mainly caused by rising levels of greenhouse gases in the atmosphere. These gases include: carbon dioxide, methane, nitrous oxide and other industrial gasses. GHGs are necessary for normal functioning of the atmosphere. They work as an insulating layer in the atmosphere, keeping the heat within the atmosphere and preventing the Earth from freezing. Solar radiation, in the form of ultraviolet radiation, easily passes through the Earth's atmosphere, consequently warming the planet. Simultaneously Earth is re-radiating the heat in the form of infra-red radiation, which is cooling the planet. During the Holocene the process has been relatively balanced, however, the build-up of GHGs is causing our planet to warm-up and is pushing the planet to a new unprecedented climate (Sachs, 2015, pp 393-406).

Intergovernmental Panel on Climate Change (IPCC, 2013) concludes that the atmospheric concentrations of GHGs have increased to levels that have not been seen in the last 800,000 years. The most important GHG is carbon dioxide (CO_2). The main sources of CO_2 emissions are from burning coal, oil and gas. These fossil fuels have enabled the creation of the modern economy and the economy's functioning is now significantly dependent on fossil fuels. Due to fossil fuel emissions and net land use change emissions, CO_2 concentrations in the atmosphere have increased by 40% since preindustrial times (IPCC, 2013).

According to Cook (2014), our planet builds up heat at the rate of four Hiroshima atomic bombs per second. Most of that extra energy import in our climate system is stored in the oceans, accounting for more than 90% of the extra energy accumulated between 1971 and 2010 (high confidence). Furthermore, it is virtually certain that the upper ocean (0-700m) has warmed since the year 1971 (IPCC, 2013, p. 6). A much smaller percentage of net heat increase goes into the atmosphere. Nonetheless, each of the last three decades on the Earth's surface has been successively warmer than the other, as evident in Figure 4. With medium confidence it is estimated that in the Northern hemisphere, 1983-2012 was likely the warmest 30-year period of the last 1400 years (IPCC, 2013, p. 3).

Figure 4. First Global Reconstruction of Temperature for the Past 11,300 Years



Source: S. A. Marcott, J.D. Shakun, P.U. Clark, & A.C. Mix, *A Reconstruction of Regional and Global Temperature for the Past 11,300 Years,* 2013 p. 1198.

As a result of anthropogenic climate warming, sea levels are rising. The majority of the sea level increase is caused by thermal expansion of oceans. The second factor contributing to sea levels rising is the melting and discharge of ice from mountain glaciers and ice caps, as well as from much larger Greenland and Antarctic ice sheets (World Bank, 2012, p. 7). With high confidence it is estimated that "the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901 to 2010, the global sea level rose by 0.19 m" (IPCC, 2013, p. 9).

Heat waves and extreme temperature events are another effect of climate change. The past decade has seen an increasing number of those. These so called 3-sigma events were highly unusual until now, with monthly and seasonal temperatures generally more than three standard deviations (sigma) warmer compared to the local mean temperature. Without effect of the climate change, these 3-sigma events would be expected to occur only once in several thousand years. These events might not seem severe, but have in fact caused many heat-related deaths and harvest losses. For example, the heat wave in Russia in 2010 resulted in an estimated 55,000 fatal human casualties, more than 1 million hectares of burned land and grain harvest losses of 25% (World Bank, 2012).

1.1.2 Ocean Acidification

Oceans are one of the Earth's major CO_2 sinks, therefore this planetary boundary is closely related to climate change. As the atmospheric CO_2 concentrations increase, the oceans are becoming more acidic. They have absorbed about 25% of total anthropogenic CO_2 emissions in the period 2000-2006. CO_2 dissolves in the ocean, which produces carbonic acid (H2CO3). This acid further dissociates to an H+ ion and an HCO 3- ion. The rise of H+ signifies the increased acidity in the oceans. The PH of the oceans has already decreased by 0.1 units on the PH scale. This might not seem much, however, because the scale is logarithmic it signifies a 30% increase in the ocean's acidity. The rising acidity threatens various kinds of marine life. It decreases the ability for corals, shellfish, lobsters and small plankton to form protective shells. Even more alarming is the pace of this change currently observed and projected, which appears to be unparalleled in Earth’s history (World Bank, 2012, p. 11).

1.1.3 Atmospheric Aerosol Loading

When we burn coal, biomass, diesel fuels and other sources of pollution, small particles are emitted into the air. If these fuels are burned in outdated or inefficient combustion engines or heating systems, it can emit even larger quantities of aerosols. An additional factor that causes even greater emissions is insufficient regulation regarding emission control in some countries. Aerosols can be very damaging for lungs, can claim many lives and can significantly impact climate change dynamics. Some major Chinese cities have been experiencing extreme levels of aerosol pollution, leading to smog thickness that can make venturing outside very dangerous on certain days (Sachs, 2015, p. 190).

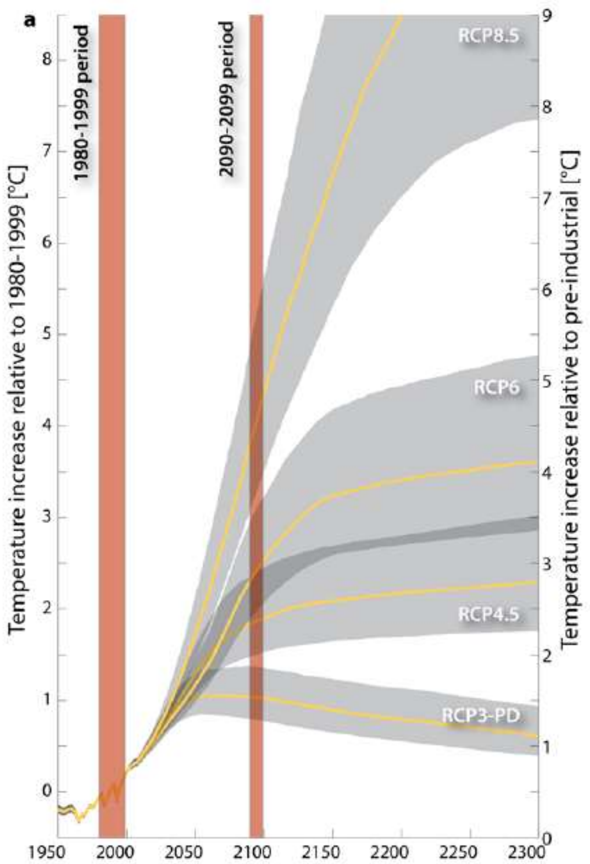
1.1.4 Other Boundaries

The other boundaries proposed in the model are: rate of biodiversity loss, global freshwater use, stratospheric ozone depletion, chemical pollution, phosphorus cycle, and change in land use (Rockström et al., 2009). However, due to the limited reach of the research topic these will not be further discussed in the thesis.

1.2 1st Century Projections

Projections overviewed below will compare the effects of strong mitigation actions, which could limit warming to 2°C above preindustrial levels, with low global mitigation efforts, which can result in net warming approaching 4°C by 2100. As mentioned previously, our climate is highly sensitive to the concentrations of GHG in the atmosphere. Based on a series of assumptions on driving forces (economic development, population growth, technology, political factors etc.), emission scenarios describe future release of GHG and other pollutants into the atmosphere. The following scenarios have been developed to project future climate change and develop mitigation scenarios (World Bank, 2012, p. 22).

Figure 5. Probabilistic Temperature Estimates for New IPCC Scenarios



Note. * Grey ranges show 66% ranges, yellow lines are the medians.

Source: World Bank, *Turn down the heat. Why a 4C warmer world must be avoided*, 2012, p. 23, Figure 21.

The Representative Concentration Pathways (hereinafter: RPC) in Figure 5 are based on carefully selected scenarios. The highest RCP scenario, RCP8.5, is the only non-mitigation scenario within the group. It projects warming close to 5ºC by the end of 2100. On the other side of the spectrum there is the RCP3PD scenario, which assumes relatively ambitious internationally coordinated mitigation efforts. As evident in Figure 5 and according to IPCC (2013, p. 8), "Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions". For more detailed regional warming and precipitation patterns see Appendix 1. In Figure 5 it is also illustrated that even after the 21^{st} century, the non-mitigation global mean temperatures are projected to increase significantly, which could threaten survival on Earth.

1.3 Climate Change as a Result of a Market Failure

According to Sir Nicolas Stern (cited in Benjamin, 2007, p.1): "Climate change is a result of the greatest market failure the world has seen. The evidence on the seriousness of the risks from inaction or delayed action is now overwhelming. We risk damages on a scale larger than the two world wars of the last century". Market failure is a situation where the allocation of goods and services is not efficient. It can be viewed as scenarios where individuals' pursuit of self-interests leads to inefficient results. An optimal allocation of resources is thus not attained and this results in a waste of these (market failure, n.d.).

Many components of our environment are considered to be public goods. Therefore, everyone should have the right to access nature, clean air, the weather, rivers, views and so on. Furthermore, it is argued that the environment should remain in public ownership, however, this right is usually formally not properly defined. With free access to these goods, some agents can excessively use them and cause negative externalities. Negative externalities exist if activities done by a certain agent causes costs (or loss of benefits) to another agent, who is not compensated for this loss. Unregulated markets have overproduced CO_2 because the real social costs are not priced in the transaction. CO_2 pollution is therefore a typical example of a negative externality, where overuse of the environment (public good) by some self-interest pursuing agents causes depletion of common resources, leading to climate change (Zorič, 2015).

Theoretically, there is an optimum level of pollution as the environment is able to absorb certain levels of pollution without causing any or only minimal harm to others. Also, sudden complete prohibition of pollution would in fact cause the whole economy to stop the production of goods. Therefore an optimum level of pollution should be found. At this level, benefits to all the agents involved would be maximised (Zorič, 2015). According to "Case theorem", this level of optimum pollution should gradually be achieved by negotiations between the polluters and aggrieved party. However, the underlying assumption in this theorem is not met. For example: rights to those goods are badly defined, there are high transaction costs and moreover people who will most severely be affected by pollution have not even been born yet. The impacts of such emissions do not fall on the polluters and free markets do not maximise society's welfare, therefore they are said to fail. In such cases, governmental intervention on an international level to increase the price of activities that emit GHG is needed to restore the balance and prevent overuse of the common good (Grantham research institute, & Clark, 2012).

1.4 International Negotiations

According to McKinsey and Company (2009, p. 56), "Effective policy and regulation will be at the core of the response to global warming. In fact, the transition to a low-carbon economy might be the first global economic transition of this scale to be driven largely by policy." Individual countries simply cannot cope with this issue by themselves. Therefore, a global consensus and global commitment to prevent extensive climate change and other environmental problems is needed.

A landmark agreement, was reached on December 12th, 2015, in Paris by the Parties to the United Nations Framework Convention on Climate Change, which virtually includes every nation on earth. Its goal is to limit global warming to a maximum of 2ºC above preindustrial levels by 2100 and moreover to strengthen efforts to limit the increase even further to 1.5 ºC by 2100 (Center for Climate and Energy Solutions, 2015). Many have expressed great optimism toward the Paris accord, marking it as the first significant attempt to reach a world-wide consensus on global warming. The new agreement combines a top-down and bottom-up approach, with the purpose to achieve both broad participation and stronger action. The top-down approach is where countries agree on a long-term goal and a formula for allocating legally binding emission reductions. Whereas the bottom-up approach allows countries to offer any commitment they like on a voluntary basis (Diringer, 2013). All countries are urged to come up with commitments on limiting GHG emissions, also known as Intended Nationally Determined Contributions (hereinafter: INDCs) (Center for Climate and Energy Solutions, 2015). The new agreement is said to have legal force, be applicable to all and take effect from 2020 (Center for Climate and Energy Solutions, 2014).

To enable entry into force, the agreement requires approval by at least 55 countries accounting for at least 55% of global GHG emissions. In order for an individual country to become a party to the agreement, it must express its consent to be bound through a formal process called "ratification". Each country has its own domestic procedure for deciding whether to join an international agreement. In some cases, depending on the individual country's legislation, the agreement has to be elected in the parliament. The agreement was opened for signature on April 22nd 2016, and will remain open until 21st April 2017. The three biggest climate polluters (People's Republic of China, United States and India) have all committed to join the agreement. (Goldenberg, 2016; Center for Climate and Energy Solutions, 2015)

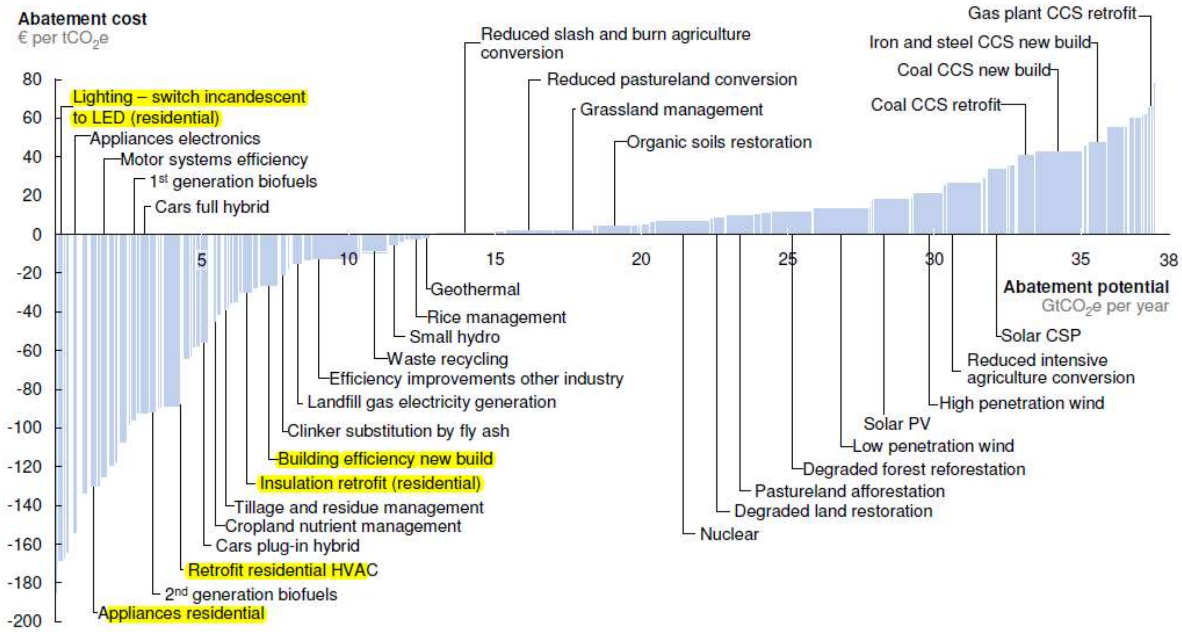
1.5 Cost Efficient Decarbonisation

In order to contain global warming to 2ºC, which was proposed by the science community and agreed at twenty-first session of the Conference of the Parties (hereinafter: COP21), deep decarbonisation of our economy is needed. GHGs cause our planet to build up extra heat. Out of those gasses, CO_2 causes around 2/3 of total warming. The majority of it is emitted from the way energy is used, by burning fossil fuels. Unfortunately energy is so deeply imbedded into the way society lives, into the economy, industry, and transport, that the transition cannot be done overnight. Sudden transition could cause catastrophic economic and social changes. This is making the challenge much more sensitive. Therefore, in order to have the lowest societal impact, the process should take from 30 to 40 years. To make this transition efficient and limit the negative impact on our environment, the process needs to start now and moreover every part of the world needs to be included (Sachs, 2015).

For efficient transition, options that are technically proven, commercially feasible and cost efficient should be implemented first. To provide a fact base on emissions-reduction opportunities and their associated cost and investment needs, McKinsey and Company (2009) is continuously researching the topic of abatement or mitigation. Their analysis found that there is a potential to effectively reduce GHG emissions by 35% by 2030 relative to emissions in 1990. According to the World Bank (2012) this would be sufficient to hold the global warming below the 2ºC threshold.

McKinsey and Company (2009) has developed the greenhouse gas abatement cost curve (Figure 6), which provides a quantitative basis for discussions about actions that would be most effective in delivering emission reductions and how much they might cost. The cost curve summarizes a global mapping of technical solutions needed to be taken in order to reduce the emission of GHGs ranging across regions and sectors. It includes technologies that are available today and technologies that offer a high degree of certainty about their future potential. Each bar represents the solutions opportunity to reduce GHG emissions in an individual year compared to the business-as-usual (hereinafter: BAU) development. Costs were calculated from a societal perspective (excluding taxes, excluding subsidies and with capital cost similar to governmental bond rates of 4%). Calculated costs also exclude transaction and program costs, which are largely dependent on an individual country's policy choices for implementation. Therefore, costs calculated from consumers' or investors' perspectives could be substantially different.

Figure 6. Global GHG Abatement Cost Curve – 2030



*Note. * The curve repre*sents an estimate of the maximum potential of all technical GHG abatement measures below 80 EUR per tCO_2e, if each lever was pursued aggressively.

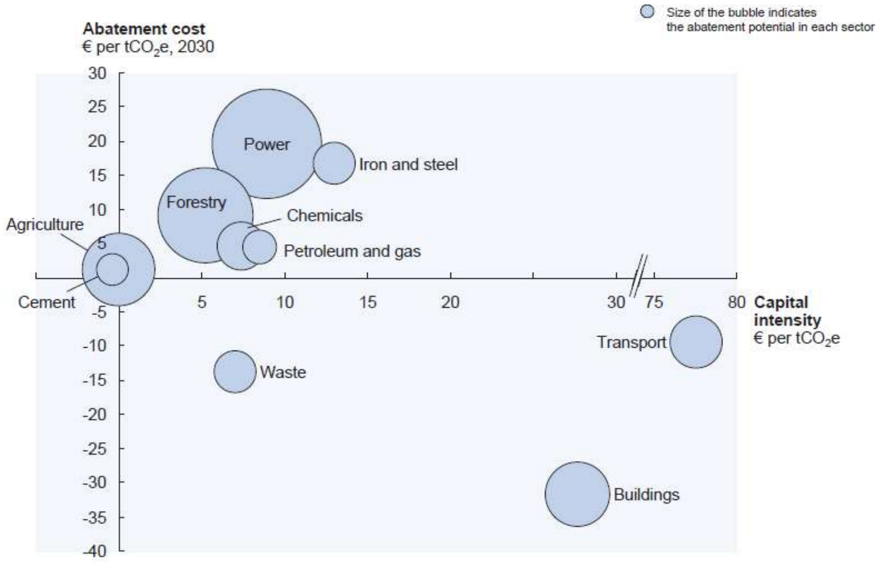
Source: adapted from P. Enkvist, J. Dinkel, & C. Lin, *Impact of the Financial Crisis on Carbon Economics: Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve*, 2010, p. 8, Exhibit 6.

The average abatement cost across all levers is about minus 6 EUR per tCO_2e, therefore mitigation would theoretically come with a net profit to society. Cost estimates for adaptation to climate change, under BAU scenario, lie in the range of 1 to 5% of global GDP on average across the globe. This would also represent significantly lower societal costs compared with the cost estimated for adaptation on climate change in non-mitigation scenarios. The projected future energy prices have a huge effect on the transport sector, the building sector and the industrial sector. The effect is accounted through savings from energy efficiency measures. Therefore, increases in energy price expectations can lead to more abatement technologies being net positive in the long term (Enkvist et al., 2010).

1.5.1 CO_2 Abatement Potential in the Building Sector

According to McKinsey and Company (2009), emissions in the building sector in 2005 accounted for about 18% of total global GHG emissions. In many developed nations they accounted for more than 30%. In the absence of abatement measures, global emissions from buildings are forecast to grow by 1.7% annually.

Figure 7. Capital Intensity and Abatement Costs



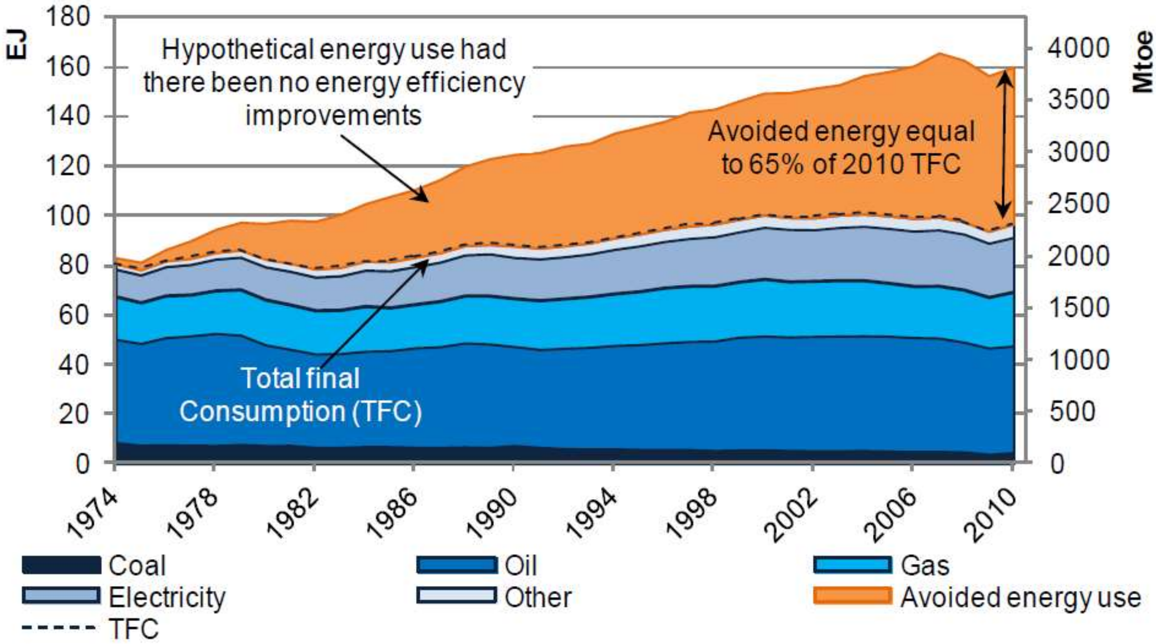
Source: McKinsey & Company, *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, 2009, p. 18, Exhibit 9.

In Figure 7, it is evident that the abatement of GHG emissions in the building sector represents the cheapest abatement potential. The costs are negative, meaning that the majority of investments will pay for themselves with net economic benefit. However, in Figure 7 it is also evident that capital intensity in this sector ranks as the second highest. The guiding principle in the buildings sector analysis, presented in Figure 7, was to reduce overall heat and electricity demand through energy-efficiency levers. As a result, the analysis of the building sector excluded solar photovoltaics (hereinafter: PV), combined heat and power (hereinafter: CHP), micro wind turbines and other microgeneration solutions that can be applied on a building for the purpose of self-consumption. This abatement potential is included in the power sector.

Buildings have an average lifespan of about 65-70 years in developed countries. This long lifecycle leads to low or negative lifecycle costs for many abatement opportunities. However, high upfront costs are creating barriers when initial investments in energy efficiency are considered. The long lifespan also means that decisions made during a building's construction have a strong lock-in effect for future emissions. Due to differences in the climate and an individual country's development levels, there are huge variations in emissions that the building sector produces. Therefore different regions and countries have significant differences in emission reduction potential. Developed countries generally have greater potential to reduce emissions through retrofits of existing buildings, whereas developing countries have greater opportunity to design new energy-efficient construction (McKinsey and Company, 2009).

To conclude and stress its importance, it must be added that energy efficiency has the biggest role in GHG abatement potential. Energy efficiency measures account for two-thirds of GHG abatement potential in 2020, with renewable energy contributing about 20%. Figure 8 clearly demonstrates the extent of avoided energy usage compared with total energy usage. Cumulative avoided consumption of energy due to energy efficiency (in the 11 countries included in the study) amounted to over 32 billion tonnes of oil equivalent. Between 1974 and 2010, energy efficiency or avoided energy use contributed more "fuel" than any other single fuel including coal, oil, gas or electricity (International Energy Agency, 2012).

Figure 8. Avoided Energy Use from Energy Efficiency in 11 IEA Member Countries



Source: International Energy Agency, *Energy efficiency market report 2013*, *Market trends and medium-term prospects*, 2013, p. 18, Figure ES.2.

1.5.1.1 Multiple Benefits of Energy-Efficiency

Even though energy efficiency solutions make up the majority of solutions that have negative abatement costs per tCO_2e, these solutions have long been pushed to the periphery (McKinsey and Company, 2009). Energy efficiency has long been viewed simply as a method of reducing energy demand and associated costs. However, in a recent study by Cooremans (2015) “Capturing the multiple benefits of energy efficiency”, it was found that investing in energy efficiency brings forth a range of areas going far beyond energy demand reduction and lower GHG emissions. In the study, clear benefits of energy efficiency have been documented in the following areas (Cooremans, 2015):

1. **macroeconomic development**. Benefits across the whole economy include an increase in economic activity, a decrease of unemployment, reducing energy prices and improving trade balance (especially for net energy importers).

2. **public budgets** of national and sub-sovereign entities. Energy efficiency measures increases governmental tax revenues through greater economic activity, reduces government expenditures on energy costs, as well as reduces the budget for unemployment payments (as energy-efficiency perusing policies lead to new job creation).

3. **health and well-being**: Energy efficiency retrofits in buildings, such as insulation retrofits and addressing indoor air quality, create conditions that support improved occupant health and well-being. This is particularly valuable among vulnerable groups such as children, the elderly and those with pre-existing illnesses. Realised health improvements also lower public health expenditures.

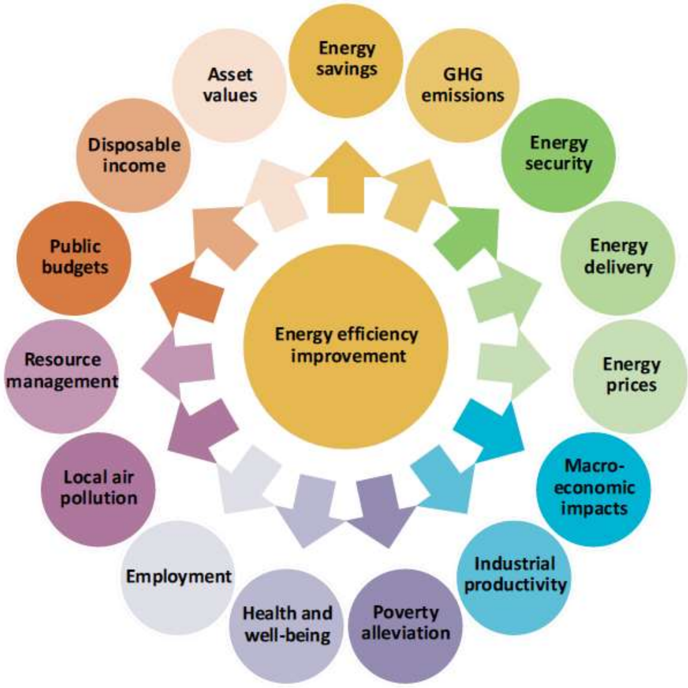
4. **industrial productivity**: In addition to energy cost savings, benefits can include increased productivity, competitiveness, profitability, working environment quality, product/service quality and so on. This can also be applied to rented residential apartments.

5. **energy delivery**: Utilities and other energy providers can gain from energy efficiency measures. Direct benefits include lower costs for transmission and distribution, dampened price volatility in wholesale markets, improved system reliability and the possibility of delaying or deferring costly system upgrades. The saving can then partially be passed from the energy provider to the final consumer.

6. **environmental sustainability**: Energy efficiency also significantly decreases local air pollution by reducing the quantity of aerosols emitted in the atmosphere. Furthermore, it reduces the amount of energy related GHG emissions.

To conclude, energy efficiency is the quickest and least costly way of addressing energy security, social development, environmental and economic challenges. Due to its broad portfolio of positive impacts, energy efficiency is considered to be one of the few "no-regret policies". In Figure 9, some of the most prominent benefits of energy efficiency are represented. It must be noted, however, that the list is not extensive. Furthermore, prioritisation by an individual country varies and different stakeholders will be interested by different benefits (Cooremans, 2015).

Figure 9. The Multiple Benefits of Energy Efficiency Improvements



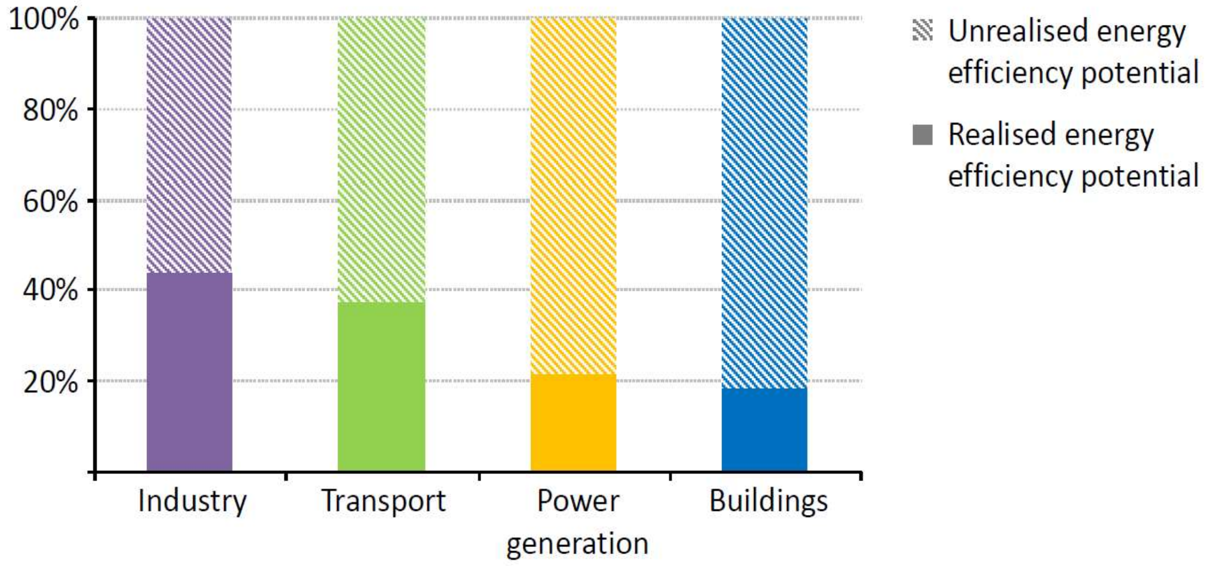
Source: C. Cooremans, Capturing the Multiple Benefits of Energy Efficiency, 2015, p. 21, Figure ES.2.

1.5.1.2 Energy-Efficiency Gap

Even though energy-efficient technologies offer an enormous opportunity to cost efficient reduction of environmental damages associated with energy use, a huge part of this potential is not being realised (Gerarden, Newell, Stavins, Stowe, & National Bureau of Economic Research, 2015; International Energy Agency, 2012). In public policy view, energy efficiency remains on the periphery. According to Maria van der Hoeven (2014), Executive Director of the International Energy Agency, roughly two-thirds of economically viable energy efficiency potential will remain unrealised under existing policies. This is also demonstrated in Figure 10, which shows the distinction between realised and unrealised energy efficiency potential.

Energy efficiency potentials in Figure 10 are based on the International Energy Agency New policies Scenario outlined in the World Energy outlook 2012. Investments which were classified as economically viable, have a payback period for the up-front investment that is less than the amount of time a potential investor might be reasonably willing to wait to recover the costs. These calculations were made using the value of undiscounted energy savings as a metric. The payback periods were always shorter than the individual asset's technical lifetime (International Energy Agency, 2012).

Figure 10. Long-Term Energy Efficiency Economic Potential by Sector



Source: International Energy Agency, *World Energy Outlook 2012*, 2012, p. 291, Figure 9.9.

This phenomenon is usually referred to as the energy-efficiency gap. Hirst and Brown (1990) defined the energy efficiency gap as the unexploited economic potential for energy efficiency. The gap accounts for the difference between the cost-minimising level of energy efficiency and the level of efficiency actually realised. In other words, it emphasizes the technically feasible energy efficiency measures that are cost-effective but are not being deployed. Various estimates of the energy efficiency gap and potentials offered by energy efficiency technologies vary considerably. This is a result of different and ununiformed definitions of the optimal level of energy efficiency levels. The gap estimates are further complicated by the heterogeneity of the issue. Relative contributions vary across different energy users and energy uses. The issue of the energy-efficiency gap has been debated in policy and academia for more than 30 years, however, the answer remains elusive, which is clearly indicating the complexity of the phenomenon (Gillingham & Palmer, 2013).

Gillingham and Palmer (2013) provided an extensive review on the explanations of the energy-efficiency gap. They segregated the explanations into market failures and behavioural anomalies. Furthermore they have expressed an opinion that the energy gap might not be as huge as it is generally proposed. The segregation of potential explanations was further expanded into three broad categories: market failures, behavioural anomalies, and model and measurement errors. **Potential market-failure explanations** include (Gerarden et al., 2015):

1. **principal-agent problem** can occur in renter-occupied buildings, as the owners lack incentive to invest in energy efficiency of the building. For example, a landlord who chooses the energy efficiency of the building pays for a new heating system, while the tenant uses the energy and pays for energy use. The energy efficiency attribute in this case might, however, be imperfectly observed when the rental contract is considered.

2. **asymmetric information or imperfect information** is another factor that can have a negative effect on the marketplace. Underinvestment can occur if buyers cannot evidently observe the efficiency of the products and are therefore unwilling to pay for its expected value. Furthermore, the seller might not be able to credibly convey the information to the customer, which can further contribute to the market failure.

3. **capital market failures,** such as liquidity constraints, could also be a possible explanation for the gap. Limited access to credit and high upfront costs of such an investment might prevent some potential investors from implementing energy-efficiency measures. Capital market failure issue is even more relevant in the least developed countries.

4. **energy market failures** include environmental and national security externalities and average-cost electricity pricing. Economic regulation of energy prices might result in prices that are different from marginal costs. If the regulated price falls below the marginal cost, then it might be contributing towards a greater than optimal usage of energy and consequently result in broadening the energy efficiency gap.

Potential behavioural explanations include (Gerarden et al., 2015):

1. **inattentiveness and salience issues**. According to this explanation, consumers simplify a complex decision by being inattentive to less salient or less important features, such as operating energy costs. This can be relevant especially for products that consume less energy, such as energy efficient lighting. Consequently, their energy-efficiency attribute remains neglected by potential buyers.

2. **myopia and short sightedness** suggest that in some cases excessive weight is placed on the near term financial implications of energy consuming products. Some buyers account for above average discount rates when considering the trade-off between upfront capital costs and operating costs. It was found that such implicit discount rates are perceived to be higher than market interest rates.

3. **bounded rationality and heuristic** refers to a simplified decision-making process that individuals often use, due to cognitive limitations, to simplify the formation of their judgments and decisions. In our case, suboptimal heretics can contribute to the energy-

efficiency gap by preventing individuals from optimising their decision in terms of net present value when purchasing energy-using capital goods.

4. **prospect theory and reference-point phenomena** suggest that in the case of uncertainty, potential investors might consider potential future losses to be more relevant than potential future gains. Such loss aversion can help explain the energy efficiency gap in the case of energy efficient renovation of buildings. When considering such a renovation, a potential investor is likely to be uncertain about the future household energy prices, how much energy will be required in the building and the actual efficiency improvement. In a case of a loss averse customer, few negative expectations about the future development might be heavily weighted, therefore resulting in a less ambitious renovation

5. **systematically biased beliefs** about future developments might also contribute towards widening the energy efficiency gap. Such beliefs can be connected to undervalued future savings potential of energy-consuming products as well as negatively biased beliefs about future energy prices.

Model and measurement explanations were added as a result of increasing assumptions that the observed rate of diffusion of energy-savings technology and the energy efficiency gap might not be as paradoxical as it first appeared. This category of potential explanations include: unobserved or understated costs of adaptation, ignored product attributes, exaggerated engineering estimates of energy savings, use of unappropriated discount rates, heterogeneity in beliefs and cost uncertainty (of adaptation across potential adopters), irreversibility and so on (Gerarden et al., 2015).

1.5.2 CO_2 Abatement Potential in the Power Sector

According to McKinsey and Company (2009, p. 59), “The power industry plays a unique role in climate change, being far the largest sector both in emissions and opportunities to reduce them”. In 2005 the power sector was responsible for around 24% of global GHG emissions. In the sector there are many opportunities to reduce emissions, which fall into four broad categories: renewable energy, carbon capture and storage, nuclear energy and demand reduction through energy efficiency. The biggest implementation challenges are largely related and rely on emerging technologies for which it is hard to estimate future costs and potential abatement potential.

1.5.2.1 Renewable Energy Technologies

A very promising category is renewable energy technologies, which include wind, solar PV, concentrated solar power, geothermal, biomass, and hydro. According to McKinsey and

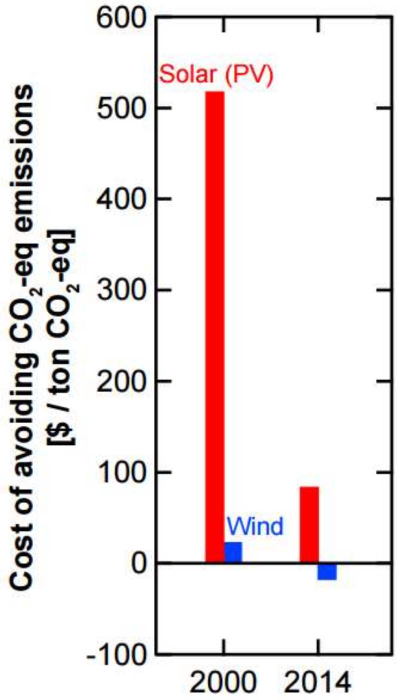
Company (2009), most of these renewable technologies are not yet cost competitive to traditional fossil fuel generation and they also face the challenge of effectively integrating into the existing energy systems. As a result, deployment of these technologies in many cases still strongly rely on governmental incentives to further push them down the technology and cost curve.

The more recent outlook for renewable energy technologies looks more optimistic. 2015 produced a new record year for investment in renewable energy. This happened despite the sharp fall in fossil fuel prices (oil, gas and coal). Renewables, excluding large hydro, made up around 53.6% of the gigawatt capacity of all installed energy technologies in 2015, which represents a majority of added electricity generation for the first time (Bloomberg New Energy Finance, UNEP SEFI, & Frankfurt School, 2016). The recent plummet in renewable power costs has caused many renewable sources to be cheaper than fossil fuels. Currently, onshore wind is one of the most cost-competitive sources of electricity of new capacity available. Individual projects, without financial support, are now generating electricity for USD 0.05 per kWh, compared to USD 0.045 to 0.14 per kWh for fossil based generation. Furthermore, solar photovoltaic is moving down the cost decline curve and heading toward a prospective future. The most competitive utility-scale PV projects are now delivering electricity for USD 0.08/kWh (International Renewable Energy Agency, 2015).

Trancik et al. (2016) notes that technology improvements and emission reductions have a mutually reinforcing effect. Economies of scale, research and development, and firm learning can drive down technology costs. In return, these open up new development opportunities which create a positive feedback or the so called “multiplier effect”. If countries pursue renewables expansion in implementing their INDCs, it is estimated, based on past trends, future technology development scenarios, and technology cost floors, that this expansion could achieve a further cost reduction of up to 25% for wind and up to 50% for solar PV. The falling costs of these technologies and resulting falling costs of emission reduction are demonstrated in Figure 11.

Cost estimates in Figure 11, however, do not take into account the high cost of energy storage addressing the intermittency issue, which is a consequence of mass adaptation of renewable energy technologies (Trancik et al., 2016). Nonetheless, World Energy Council (2016) forecast shows, that with many new energy storage technologies in the pipeline, storage costs are projected to fall as much as 70% over the next 15 years. Forecasted strong growth in global adaptation of energy storage will also give rise to many new innovations and business models which will arise from the new opportunities. Declining energy storage costs will therefore potentially ease the intermittency issue with renewables and allow for mass adaptation.

Figure 11. The Falling Costs of Reducing Emissions (Solar & Wind)



Note. * The cost of emissions abatement for solar PV fell by 85% since 2000. The cost of emissions cuts for wind become negative. All numbers refer to the U.S. average cost of replacing coal with solar PV or wind. Energy storage costs are not included in the calculations.

Source: J. Trancik et al., *Technology Improvement and Emissions Reductions as Mutually Reinforcing Efforts: Observations from the Global Development of Solar and Wind Energy*, 2016, p. 63, Figure 4.14.

1.5.2.2 A New Decentralised Energy Model

The integration of internet communication technologies and renewable technologies is giving rise to a new decentralised energy model. According to Jeremy Rifkin (2011, p. 37), who was also an advisor to the European Union (hereinafter: EU) and People's Republic of China on low-carbon economy, “In the twenty-first century, hundreds of millions of human beings will be generating their own green energy in their homes, offices, and factories and sharing it with one another across intelligent distributed electricity networks—an intergrid—just like people now create their own information and share it on the Internet.” Rifkin also believes that the construction and real estate sector are now teaming up with renewable energy companies to convert the building stock into countless mini power plants. This process, which will be happening over the next 3 decades, will also outset a building boom, creating millions of new jobs and business opportunities.

For successful energy and also economy transformation, a simultaneous development of 5 pillars is needed (Rifkin, 2011):

1. shifting energy production to renewable energy technologies.
2. transforming the building stock into mini power plants capable of generating renewable energy on site (buildings which are often called "net-zero" and "energy-plus buildings").
3. deploying energy storage technologies throughout the infrastructure and power generating buildings in order to store intermittent energies.
4. using and adapting internet technology to transform the power grid into an energy-sharing intergrid. This way, millions of people who generate their own energy can sell their surpluses back to their grid and share their electricity peer-to-peer.
5. transforming the transportation fleet into electric and fuel cell vehicles which can use and trade electricity on the interactive grid and simultaneously help with the issue of intermittent renewables.

One of the first cases of such energy models, to which Rifkin (2011) refers as intergrid, is being commercialised by "Sonnen GmbH", who is Europe's largest manufacturer of lithium battery storage. Its revolutionary peer-to-peer energy trading platform is called "the sonnenComunity". This is Europe's first online energy sharing platform. Through this platform, a community of decentralised energy producers, "sonenBatterie" owners and consumers share or trade their electricity. The surpluses produced by individual members are fed into the virtual pool that serves other members in times when they cannot produce enough energy to satisfy their own needs. A central software links and monitors all the members, while balancing supply and demand. Members are exclusively using the clean energy from the community, therefore there is no need for a conventional power provider anymore. This results in fairer electricity purchase and sales prices for all members in the community, altogether saving them the profit margin of the conventional energy companies (Sonnen GmbH, 2015)

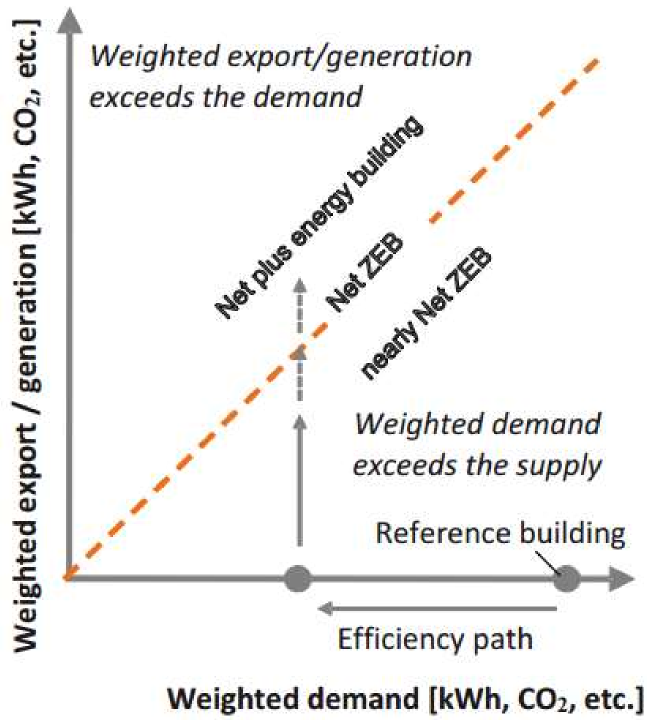
1.6 Net Zero Energy Renovation of Buildings

As evident and highlighted in Figure 6, CO_2 abatement potential in retrofitting existing buildings is among the cheapest, as many of the measures allow for a net return on investment. This goes especially for developed countries in which the majority of buildings have already been built and where the rate of construction of new buildings is decreasing (McKinsey and Company, 2009). Furthermore, as evident in Figure 11, the cost of reducing emissions through solar PV and wind electricity generation has decreased significantly and are set to decrease even further with mass deployment (Trancik et al., 2016). Combined measures of energy-efficiency and distributed on-site renewable energy generation could therefore provide for cost efficient decarbonisation of building, as well as the energy sector.

Energy renovation of a building is defined as a process of retrofitting energy features of an existing building. These measures can be undertaken in regard to the building envelope, the heating system, the ventilation systems, water heating systems, electrical appliances and electricity generation systems (Ministry of infrastructure, Republic of Slovenia, 2015).

There are various levels of energy renovation that can be undertaken. These depend on the depth of energy renovation, which include estimated primary energy savings as well as the level of energy self-sufficiency or self-generation. The level of renovation can range from implementing an individual measure to a more comprehensive renovation. At some point the building can reach a net zero energy building (hereinafter: Net ZEB) standard, as shown in Figure 12 (Voss, Musall, Sartori, & Lollini, 2013). When retrofitting more than one measure simultaneously, inter-optimization between individual measures is possible, therefore allowing the investor an advantage of wider economic potential and reducing the energy efficiency gap (Ministry of infrastructure, Republic of Slovenia, 2015).

Figure 12. Distinction between Nearly-zero, Net zero and Plus Energy Building



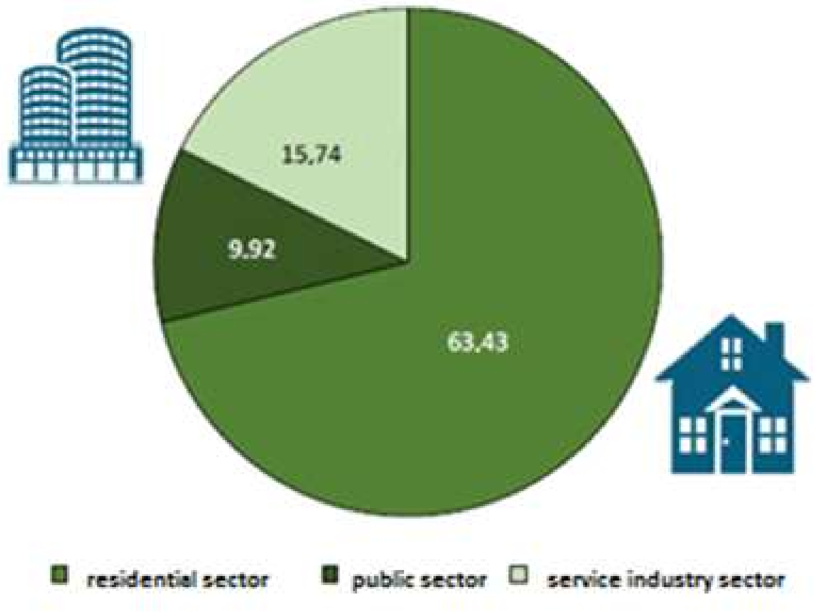
Source: K. Voss et al., *Nearly Zero, Net Zero, and Plus Energy Buildings - Theory, Terminology, Tools, and Examples*, 2013, p. 1, Figure 1.

Figure 12 demonstrates a path towards a Net ZEB standard, which can be achieved through energy efficiency measures and on-site generation. In practice, this means that the concept is targeting emissions covered in the building sector and the power sector, especially in the case of massive proliferation of net plus energy buildings (Rifkin, 2011). On site generation is typically done through renewable energy sources, such as micro wind turbines, micro solar PV system, CHP system, micro hydro system and so on. In general, Net ZEB is understood as a grid connected building, importing/exporting energy (electricity) when current self-production is in deficit/excess. The balance between weighted demand and weighted export can be, depending on the local regulation, done on an annual basis, monthly basis or with high resolution monitoring (including daily, hourly and simultaneous fluctuations) (Voss et al., 2013).

2 ENERGY RENOVATION OF RESIDENTIAL BUILDINGS IN SLOVENIA

In Slovenia, existing building stock represents the greatest potential for achieving energy efficiency gains, as existing buildings consume more than a third of the total energy. About 70% of the total existing residential surface area was built before the year 1985, representing a significant potential for energy renovation. The total size of Slovenian building stock in the year 2012 was 88 million m², out of which residential units represent a 71% share.

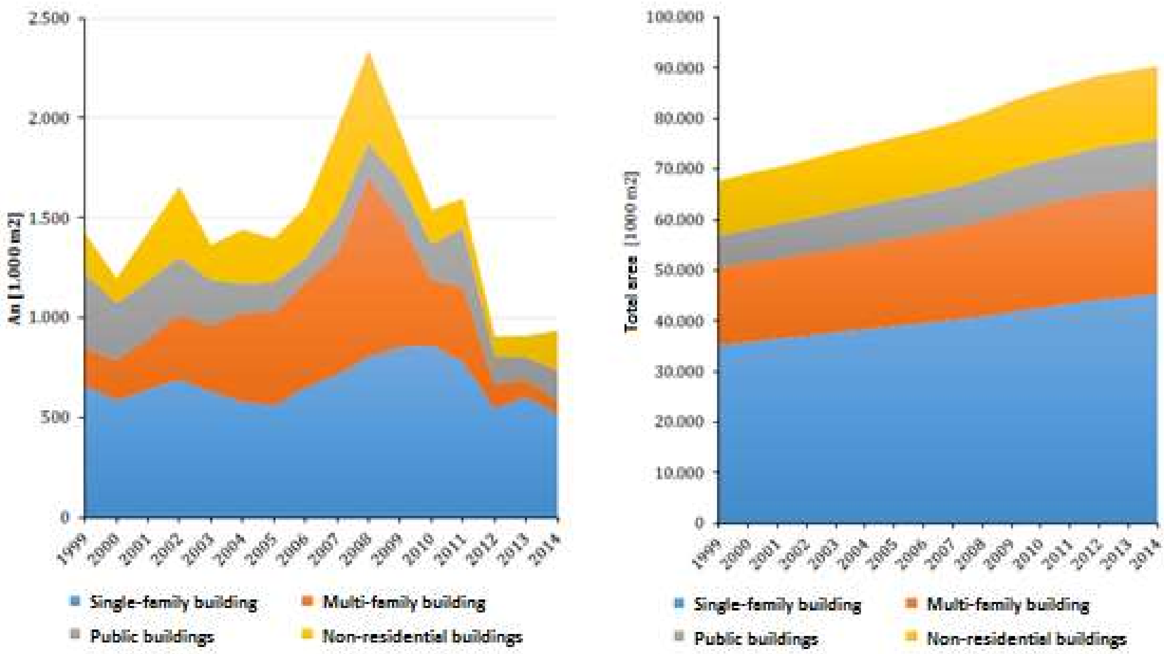
Figure 13. The Total Building Surface Area, Divided by Sectors (in Million m²)



Source: adapted from Ministry of infrastructure, Republic of Slovenia, *Dolgoročna strategija za spodbujanje naložb energetske prenove stavb*, 2015, p. 15, Slika 1.

The building stock in Slovenia is increasing constantly. However, due to the recession in the year 2008, the rate began to decrease. The decreasing rate stabilised in the year 2013. This is shown in the Figure 14.

Figure 14. The Total Area of New Buildings and the Total Area of the Building Stock



Source: adapted from Ministry of infrastructure, Republic of Slovenia, *Dolgoročna strategija za spodbujanje naložb energetske prenove stavb,* 2015, p. 15, Slika 2.

2.1 EU level Strategy

The European Union is an economic and political partnership among 28 member states located primarily in Europe. EU members have transferred part of their sovereignty to EU institutions, therefore many of the important political decisions are made at the EU level and the member states have to comply (Hix & Høyland, 2011).

Europe 2020 is a 10 year growth strategy, which is one of the crucial strategic documents that commits EU members to peruse smart, sustainable and inclusive growth. Three main climate and energy related targets to be reached by the year 2020 are (2020 Climate & Energy Package, 2015):

- 20% cut of GHG emissions (relative to 1990 levels),
- 20% of total energy consumption from renewable energy,
- 20% improvement in energy efficiency.

The 2030 climate and energy framework sets progressing targets for the year 2030, which will also enable EU to make a fair and ambitious contribution to the new international climate agreement, COP21 (2030 Climate & Energy Framework, 2015):

- at least 40% cut of GHG emissions (relative to 1990 levels),
- at least 27% of total energy consumption from renewable energy,
- at least 27% improvement in energy efficiency.

Furthermore, EU has set itself to reduce its GHG emissions progressively until 2050. This long-term approach should allow for a cost-efficient way to make the EU economy more climate-friendly and less energy-consuming. European low-carbon economy roadmap suggests that **by 2050 EU should cut emissions to 80% below 1990 levels** (2050 Low-Carbon Economy, 2015).

2.2 National Strategy

Slovenia has been an EU member country since 2004. As a member it is responsible to comply with regulations of the EU. One of the key laws regulating the development of renewable energy and energy efficiency is the new Energy Act (Sln. *Energetski zakon EZ-1*), which was published on 7.3.2014 in the Official Gazette of the Republic of Slovenia. With it, implementation and enforcement of 10 European directives was inserted into the national legislation. The law regulates the area of energy efficiency, renewable energy sources, energy infrastructure, the energy markets and so on (Energetski zakon EZ-1, Ur.l. RS, no. 17/2014, 81/2015, hereinafter: EZ-1).

2.2.1 Strategical Documents and Action Plans

With the new Energy Act, the legal basis for development and confirmation of national strategic documents was developed. These strategic documents will set and describe the long-term directions of the nation's future energy use. They will consist of the objectives, policy measures to reach them, providers, policy funding sources and so on. The following plans are applicable to the building sector and are related to energy supply and use (EZ-1):

- Energy Concept of Slovenia (Sln. *Energetski koncept Slovenije*),
- Long-Term Strategy to Mobilise Investment in the Renovation of Buildings (Sln. *Dolgoročna strategija za spodbujanje naložb energetske prenove stavb*),
- Energy Efficiency Action Plan (Sln. *Akcijski načrt za energetsko učinkovitost*),
- Action Plan for Nearly-Zero Energy Buildings (Sln. *Akcijski načrt za skoraj nič-energijske stavbe*),
- Renewable Sources Action Plan (Sln. *Akcijski načrt za obnovljivo energijo*).

The fundamental strategic document determining the long-term development of the Slovenian energy sector will be the Energy Concept of Slovenia, which is currently in preparation by the Slovenian Ministry of Infrastructure. With this document, the goals for competitive, sustainable and secure energy for the next 20 years and more will be set. Furthermore, a rough estimation for the next 40 year goals will be done. An effort will also be made to help the transformation of Slovenia into a low-carbon economy and to reduce its energy import dependency. This document, however, will not focus on individual projects. In contrast, it will merely set the strategical direction and the political framework to foster individual initiatives to develop the projects. The fundamental environmental goals of the Energy concept are (Energetski koncept Slovenije - Portal energetika, 2016):

- at least 40% cut of GHG emissions related to energy use by 2035 (relative to 1990 GHG emission levels),
- at least 80% cut of GHG emissions related to energy use by 2055 (relative to 1990 GHG emission levels).

2.2.2 National Goals in the Building Sector

As determined in the strategic documents and international obligations, Republic of Slovenia has set itself to pursue long-term decarbonisation of its economy. A considerable focus will be given to the building sector. The long-term national strategic goal is to **reach almost carbon-neutral energy use in the building sector by the year 2050.** Midway goals in the building sector by the year 2030 are (Ministry of infrastructure, Republic of Slovenia, 2015):

- reduce the use of final energy consumption in the buildings by 16% and 30% by the year 2020 and 2030 respectively (relative to 2005).
- increase the use of renewable energy to at least 60% and two thirds of total use in buildings by the year 2020 and 2030 respectively (relative to 2005).
- decrease GHG emissions in buildings by 58% and 70% by the year 2020 and 2030 respectively (relative to 2005).
- decrease particulate matter emissions from energy use in buildings by 20% and 50% in the 2015-2020 and 2015-2030 timeframe respectively.

In order to initiate the strategic move towards energy renovation of the national building stock and to set a positive example to the private sector, the government has set itself to progressively renovate buildings in the ownership and use by the public sector. Annually, 3% of these buildings will be renovated to reach or exceed the energy efficiency standards currently in use. Comprehensive energy renovations of the public building stock will strive to reach a nearly zero energy building standard (Ministry of infrastructure, Republic of Slovenia, 2015).

2.3 Supporting Mechanisms and Rules for Energy Renovation of Residential Buildings

For implementation of European directives, national strategies and goals, various facilitating mechanisms have been established. Among others, these mechanisms address the energy efficiency gap and support on-site renewable energy generation. In relevance to the energy renovation of the residential building, there are many measures and rules currently in action (Energy efficient products, 2016; Ministry of infrastructure, Republic of Slovenia, 2015):

- national rules on efficient use of energy in buildings,
- mandatory energy labelling of various home appliances in the EU,
- phasing out conventional incandescent light bulbs in the EU,
- mandatory energy performance certificates for selected buildings,
- financial support mechanisms for energy renovation of residential buildings,
- comprehensive energy renovation demonstration projects of private and public buildings (national housing fund, buildings in the public sector use etc.),
- energy renovation support scheme for impoverished residents,
- rules on dividing and billing heating costs in multiple-dwelling buildings (for buildings with four or more dwellings),
- free energy renovation consulting for residents,
- and numerous other measures.

Measures are being executed by various organisations, the Slovenian Environmental Public Fund (hereinafter: EKO fund) being one of the most relevant organisations in the field of energy renovation of residential buildings (Eko Fund, 2016), whereas Borzen is one of the main organisations supporting deployment of renewable energy sources. Furthermore, the relevant regulation is being enforced by a responsible inspectorate, who carry out inspections of its implementation (EZ-1).

2.3.1 Slovenian Environmental Public Fund

EKO fund is an independent legal entity under the Ministry of the Environment and Spatial Planning. Its purpose is to manage assets, secured by the Republic of Slovenia, which are designated for preservation of public interest in the field of environmental protection. The fund offers soft loans or/and grant financing programs to individuals (households), legal entities and municipalities. The grant financing programs are in the form of non-repayable subsidies, whereas the soft loans are offered at lower interest rates than prevailing commercial market rates. Furthermore, they can be approved for longer periods compared to loans approved by commercial banks. The largest share of EKO fund's resources are reserved for residential buildings. In fact, 78.63% of its subsidies are earmarked for that purpose in the financial framework from 2016 to 2020. The financial support scheme for residential buildings include soft loans and /or grants which can be used for investments in energy efficiency measures, use of renewable energy, measures in sustainable water management and residues management (EZ-1; Eko Fund, 2016).

The most recent public call for investments in energy efficiency measures and renewable energy use measures applied on residential buildings, lists the measures subsidised by EKO Fund and all the relevant conditions. Furthermore, the call sets the amount of the subsidy available to investors as (Javni Poziv 37SUB-OB16, Ur.l. RS, no. 18/2016, 26/2016):

- up to 20% of the investment on implementation of individual measures for residential buildings in Republic of Slovenia.
- up to 30% of the investment on simultaneous implementation of three or more measures for residential buildings in Republic of Slovenia.
- up to 50% of the investment on implementation of individual measures for residential buildings in municipalities that have adopted the Air Pollution Control Ordinance (Sln. *Odlok o načrtu za kakovost zraka*).

2.3.2 ENSVET

Households have access to ENSVET, which is organised in cooperation between EKO fund and interested local communities. ENSVET is a network of independent energy consultants, who offer free, unambiguous and individually tailored consultancy service to individual investors (Eko Fund, 2016; EZ-1).

2.3.3 Energy Performance Certificate

An Energy Performance Certificate (hereinafter: EPC) is a document, which among others, contains information regarding energy efficiency and calculated CO_2 emissions of a specific building. This gives a potential buyer or a tenant the relevant information to compare different buildings in terms of efficiency and resulting energy costs. Furthermore, the EPC includes recommendations for energy renovation and their calculated energy savings, which are specifically made for the building. The certificate is obligatory for buildings which will be sold or rented out and for all new buildings (EZ-1).

2.3.4 Centre for RES/CHP Support

One of the functions of the Borzen (the Slovenian Power Market Operator) is running the Centre for RES/CHP Support (Sln. *Center za podpore proizvodnji zelene energije*). The Centre administers the electricity feed-in support scheme for renewable energy sources (RES) and high-efficiency cogeneration (CHP) power plants. Currently there are roughly

3,700 power plants included in the scheme of which total capacity is about 500MW. Generally these plants receive support in the form of guaranteed purchase or feed in tariffs. After 22 of September 2014, all RES and CHP plants which want to get the support have to apply on the basis of a call for tender. The call will be issued by Energy Agency, which is a national regulatory authority in the Slovenian energy market (About Center for RES/CHP, 2016).

In September 2015 the Government of RS approved 10 million euros, however, the call for tender was not issued yet. This was due to necessary preliminary approval of the European Commission and the fact that the government still has not implemented complementary legislation, which will define necessary rules for allocation of public funds (Energy Agency, 2015). Out of all RES and CHP sources included in the scheme, solar PV plants received the highest financial support, which accounted for about 46.3% of total. However, the investment into new PV plants has come to a complete halt. In the year 2014 there were 44 new PV plants connected to the grid, whereas in the year 2015 only 3 PV plants were connected (PV Portal, 2015).

2.3.5 The New Net Metering Regulation

A potential reason for optimism in the field of small renewable energy sources in Slovenia, is the newly passed Decree on Self-Supply of Electricity from Renewable Energy Sources (Sln. *Uredba o samooskrbi z električno energijo iz obnovljivih virov energije*). The law has been in effect since 15. January 2016, however, the actual effect is still not evident as some complementary regulation is still lacking. It is also worth mentioning that these rules do not apply for power generating sources, which are currently receiving the national feed-in support scheme by the Centre for RES/CHP support (Sln. *Center za podpore proizvodnji zelene energije*), unless they decide to leave the scheme (PV Portal, 2015; Uredba o samooskrbi z električno energijo iz obnovljivih virov energije, Ur.l. RS, no. 97/2015).

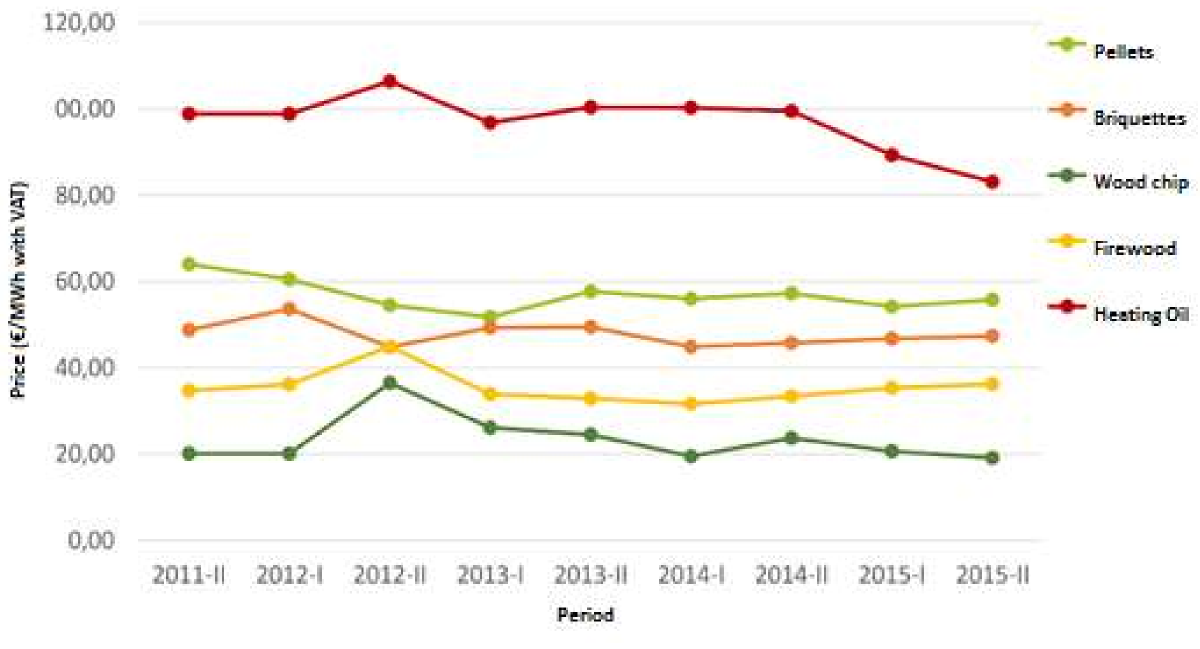
The net-metering concept allows a consumer who is generating their own electricity, which is generally intermittent or non-dispatchable, to use self-generated electricity at the agreed place independently of its generation time. The type of consumer is sometimes referred to as "prosumer" (Rifkin, 2011). Primarily, the produced electricity is used to cover the building's total electricity needs. The surplus is transmitted to the electricity grid and can be transmitted back to the prosumer at a time when there is not sufficient electricity being self-generated (Energy Reconstruction Agency, n.d.).

The newly passed regulation also allows for simplified construction of small power plants utilising the power of the sun, water and wind. The individual plant's power generating capacity must not be bigger than 11 kW. To enter into the scheme, the prosumer will also need to install a bidirectional smart meter. The balance between weighted demand and weighted export will be settled on an annual basis, which will enable the prosumers to receive just one electricity bill annually. The net metering settlement mechanism is only meant to support self-generation and self-sufficiency. Therefore, the excess electricity produced on the annual basis will not necessarily be financially compensated. The prosumer will still have to pay network charges to compensate the electrical grid, which will serve as the form of a free battery capable of accepting and dispatching electricity in line with the prosumer's needs (EZ-1; Energy Reconstruction Agency, n.d.).

2.4 Household Energy Prices

An important factor for consideration of energy renovation of buildings are prices of various energy sources. With high and increasing prices there is a greater potential for energy renovation. To determine future financial implications of various technologies, price trends for electricity and other sources generally used for heating (pellets, briquettes, wood chip, firewood and heating oil), will be considered.

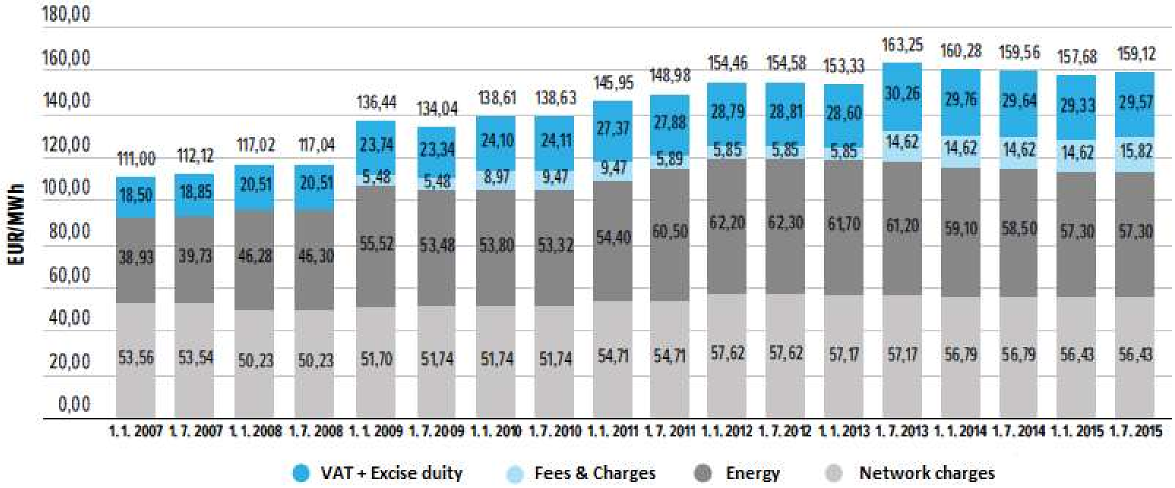
Figure 15. Prices of Wood-Based Fuels and Heating Oil (in EUR/MWh).



Source: adapted from Slovenian Forestry Institute, *Cene lesnih goriv,* 2015, Slika 1.

Figure 15 indicates that the prices of wood-based fuels remained relatively stable from 2011 to 2015. Furthermore, it is evident that the price of generated energy from wood-based fuels is considerably cheaper than energy generated by heating oil (in EUR/MWh). In general, wood-based fuels are about 40% cheaper than heating oil.

Figure 16. Household Electricity Prices (EUR/MWh) in Slovenia



Source: adapted from Javna agencija RS za energijo, *Poročilo o stanju na področju energetike v Sloveniji v letu 2015*, 2016, p. 59, Slika 43.

Figure 16 shows the electricity price structure and an increase in electricity prices for households. From 1.1.2007 to 1.7.2015 the price per kWh has increased by about 43%. It is also evident from Figure 16 that network charges have remained relatively stable, whereas other charges have increased.

3 ENERGY RENOVATION OF THE CASE STUDY BUILDING

The thesis has so far focused on theoretical aspects of unsustainable development, international and national political developments, cost-efficient decarbonisation methods and energy renovation of buildings in Slovenia. From a societal point of view, energy renovation of buildings seems to be one of the "no regret" policies, especially in the net-energy-importing countries and countries where the majority of building stock was already built (Cooremans, 2015).

This part will, however, examine more practical aspects of the energy renovation of a specific case study building. It will determine the feasibility of individual investments, some of the benefits they bring and resulting financial implications. All of this will be done from the owner's / investor's point of view. The measures which will be examined range from energy efficiency measures and onsite renewable energy generation. The amount of CO_2, which can be offset by individual measures, will also be considered. The findings will determine the most financially sound technological solutions for decarbonisation of the case study building.

3.1 Profile of the Dwelling

The building, for which the energy renovation feasibility study is undertaken, is a duplex residential building located in Medvode, Slovenia. The building was built in 1985 and is composed of a first floor, ground floor and a basement. Part of the basement is unheated and used as a garage, whereas the other part was retrofitted into a studio apartment in 2014. The total useful floor area (heated floor area) of the building is 271 m². The building has a gable roof covered with concrete tiles. The roof pitch of 30° and south facing side sizing slightly above 100m² is also making the roof convenient for solar thermal collectors or solar PV panels. The building, however, does not have access to other renewable energy sources also supported by the new net metering regulation (micro-wind and micro-hydro). External walls are built out of concrete blocks and insulated with 5 centimetres of polystyrene. The external part of the basement area and the basement floor are not insulated, neither is the ground floor/basement ceiling. Furthermore, the studio apartment is not insulated against the unheated basement area, which is causing significant heat losses due to space heating of the studio apartment. The attic floor is insulated with 15 centimetres of glass wool and is relatively well insulated compared to other elements of the building envelope. The building has wooden doors, windows and frames (Tehovnik, 2015). Windows are double glazed and some of them cannot properly be closed due to various defects. The central heating system is composed of a combined wood/oil boiler (Ferrotherm 40kW), 150l hot water reservoir and a heat distribution system with conventional high temperature radiators and individual radiator thermostats. Sanitary hot water is prepared with firewood all year long. The efficiency of the boiler is estimated at around 65% (Krajnc et al., 2009). The building is not connected to a district heating system or gas supply system, nor has access to it. The photograph of the front, south facing side, of the described case study building is included in Figure 17.

Figure 17. South-Facing Side of the Case Study Building

Source: D. Tehovnik, *Izdelava računske energetske izkaznice dvostanovanjske stavbe in analiza upravičenosti priporočil za energetsko sanacijo*, 2015, p. 14, Slika 2.

Currently, the building is occupied by three tenant families. Therefore, the **principal-agent problem** might occur, as the investor will not be able to capture the full benefits of a proposed energy renovation. Rent costs are fixed, whereas the heating costs are variable. Tenants heat the building and hot sanitary water with firewood, which they buy by themselves. Therefore, in order to capture the financial benefits of the proposed energy renovation, the contract (rent increase) would have to be renegotiated. On the other hand, electricity costs are fixed (assuming normal consumption), therefore it would be easier for the investor to capture financial benefits in this area (reduced electricity consumption and on-site generation).

Due to the fact that many technical aspects of the building have worn-away, there are regular complaints from the tenants. The major issues are: windows' defects, air leaks, heating system defects, energy inefficiency of the building, and inconvenience of sanitary hot water preparation during the non-heating period (which requires manual log loading every second day to secure hot water). Overall this is negatively impacting the satisfaction of the tenants and furthermore is causing unnecessary energy cost expenditures. Due to these reasons, renovation of the building should be considered. The question of which technical measures will be undertaken, however, mainly remains dependent on the financial implications of the considered measures, as well as the ability of the investor to pass the costs of renovation to tenants or to capture the financial benefits of proposed solutions.

3.1.1 The Building's Energy Performance Certificate

For the purpose of facilitating the renovation of the case study residential building, an energy performance certificate has been produced. This was done by Domen Tehovnik (2015), as part of the undergraduate thesis on the Faculty of Construction and Civil Engineering. The recommendations provided by the certificate will be financially and environmentally examined.

As concluded in the Energy performance certificate, the residential building is very wasteful in terms of energy expenditures for heat generation. According to Ministry of Environmental and Spatial planning, Republic of Slovenia (2010), the national building code sets requirements for heating expenditures at 61.98 kWh/m^{2}a, whereas the calculated building's expenditures are about three times higher, at 184.16 kWh/m^{2}a. This classifies the building as an energy label F, as seen in Figure 18. The Figure represents the first page of the unofficial energy performance certificate, which is translated from Slovenian into English. Nonetheless, the building is meeting the national building code requirement regarding renewable energy generation, as it is generating more than 50% of energy, used for space heating, cooling and water heating, from firewood (Tehovnik, 2015).

Figure 18. Energy Performance Certificate for the Case Study Building (Page 1/4)

Energy Performance Certificate (EPC)

Dwelling Information

No. of the certificate: 1 Valid until 1.9.2025

Clasification: Multi-dwelling unit
Year of construction: 1985
The adress: Dimčeva ul. 4, Medvode

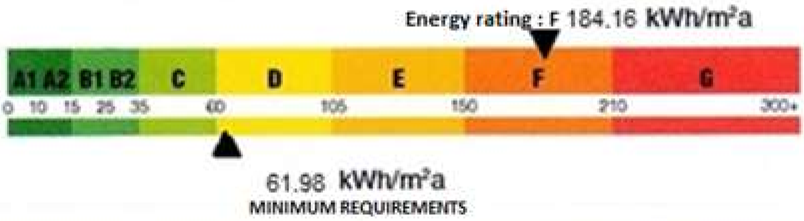
Total floor area: 270,88
Parcel number: 208/5

Type of the Certificate: Calculated

Dwelling type: Residential building

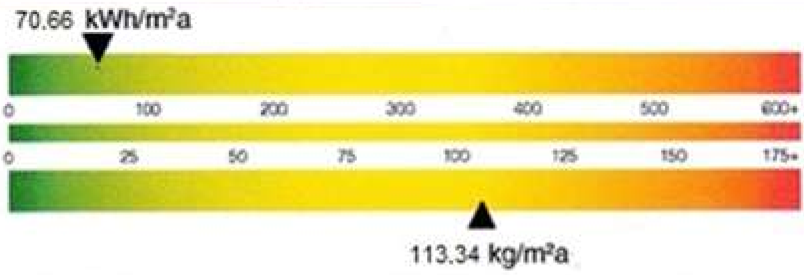
Photograph of the building:

Annual space heating demand



Building energy consumption

Primary energy use and CO2 emissions



Producer: Domen Tehovnik

Date of certificate: 1.9.2015

page 1/4

Source: adapted from D. Tehovnik, *Izdelava računske energetske izkaznice dvostanovanjske stavbe in analiza upravičenosti priporočil za energetsko sanacijo,* 2015, p. 35, slika 19.

3.1.2. Current Firewood Costs and its Structure

The building consumes firewood for space heating and sanitary hot water preparation. Cost and emission reduction potential in this area will be considered through efficiency measures and consideration of other heating systems. Furthermore, as a support to the central heating system for sanitary hot water heating during the non-heating period, various technologies for sanitary hot water heating will be considered.

Table 1. Structure of Annual Consumption of Firewood and Relating Costs

	Usage of Total	Quantity (m^{3st})	Price per unit (EUR/m^{3st})	Costs (EUR)
Annual Consumption of Firewood	100%	30	60	1,800
Heating period	80%	24	60	1,440
Non heating period	20%	6	60	360

Table 1 notes the consumption patterns of firewood and related costs. According to the observation made by tenants and the owner, the average consumption of firewood over the last three years was about 30 stacked (25-30cm) cubic meters (m^{3st}) per annum, which costs around 60 EUR per m^{3st}. Out of total firewood consumption, 20% is consumed for the soul purpose of hot water preparation during the noneating-period, usually ranging from May till the end of August. The rest (80%) is consumed during the heating season for space heating and hot water preparation.

3.1.3 Current Electricity Costs and its Structure

The building consumes electricity for lighting and use by other electrical appliances. Costs and emission reduction potential in the area of electricity use will be considered through efficiency measures (lighting retrofit) and on-site generation measures. For this purpose marginal costs of electricity use, needs to be calculated.

Table 2. Electricity Costs and its Structure

	Monthly average (EUR)	Annual average (EUR)	Costs per kWh (EUR)
Average costs of electricity	109.50	1,314.05	0.126606609
Fixed costs	13.74	164.88	0.015886255
Variable costs	95.76	1,149.17	0.110720355

From Table 2 it is evident that electricity costs are divided into fixed and variable costs, which together amount to 1314 Euro per year for the case study building. The annual costs were calculated from electricity bills issued in the last 12 consecutive months. The variable costs were calculated by deduction of fixed charges from the total annual electricity costs and division of that number with total kWh consumed in the period (10,379 kWh). If the household were to consume 0 kWh of electricity, the monthly charge of 13.74 EUR would still have to be paid. However, in Table 2 it is also evident that around 84% of electricity costs are variable, therefore the reduction of electricity usage or on-site generation should result in substantial financial savings.

Table 3. Annual Consumption of Electricity, Costs and Emissions for Lighting

	Usage of total	Consumption (kWh)	Related variable costs (EUR)
Total consumption	100%	10,379	1,149.17
Consumption for lighting	11.52%	1,196	132.38

In Table 3, the average annual consumption of electricity for the building is noted and its related variable costs are calculated. An average Slovenian household usage of electricity for lighting, not taking into account electricity usage for heating from the period 2009 to 2014, was 11.52%. The same percentage is also used as a relative share of electricity used in the building for lighting. Estimated annual variable electricity expenditures for lighting are 132 EUR.

3.1.4 Total Consumption of Energy and Related CO_2 Emissions

The use of energy generally results in CO_2 emissions. Different sources of energy relate to different net CO_2 emissions per kWh. Therefore, to estimate emission reduction potential of various solutions, CO_2 emissions of particular energy sources per unit of consumed energy needs to be determined. Furthermore the total carbon footprint of the energy use in the building needs to be calculated.

Table 4. Total Annual Consumption and Related CO_2 Emissions

	Total annual consumption (toe)	Total annual consumption (kWh)	CO_2 emissions' factor (kg/kWh)	Annual CO_2 emissions (kg)
Electricity use	0.89	10,379	0.49	5,085.71
Firewood use	6.19	71,940	0	0
Total	7.08	82,319		5,085.71

In the calculation in Table 4, the assumed calorific value of a m^{3st} of firewood is 2,398 kWh (Krajnc et al., 2009, p. 22). According to Decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015), the emissions' factors for determining the specific CO_2 emissions when consuming biomass (wood) is 0.00 kg of CO_2/kWh, whereas the emissions factor when consuming electricity is 0.49 kg CO_2/kWh.

Based on the observed total energy consumption of the building, there are around 7.08 toe (tonne of oil equivalent) used annually, which results in around 5,086 tonnes of CO_2 equivalent emissions annually (Table 4). A vast majority of the energy is used for building space and water heating, whereas all of the CO_2 emissions are attributable to the electricity use in the building.

It is assumed that **wood based fuels are CO_2 neutral** when they are sourced with sustainable foresting, as is the practice in Slovenia. CO_2 neutrality, however, should not be assumed when unsustainable foresting, such as deforestation, is in progress (Krajnc et al., 2009). For those reasons it will be assumed that the current heating and hot water preparation in the building is carbon neutral. Therefore, a reduction of CO_2 emissions cannot be assumed when retrofitting certain features of the building which result in a decrease of firewood consumption.

On the other hand, small combustion heating systems, such as the one in use in the building, are a major source of particulate matter (PM) emissions. They represent 79.4% of PM2.5 and 66.3% of PM10 emissions in Slovenia (Ministry of infrastructure, Republic of Slovenia, 2015, p. 95). The particulate emissions issue is especially exacerbated with old/inefficient wood boilers and in the case of burning firewood with higher moist content (Ministry of infrastructure, Republic of Slovenia, 2015). Nonetheless, due to the limited reach of the thesis, the PM emissions and the reduction potential will not be quantified.

3.2 Energy Renovation Feasibility Study

In this chapter, various technical measures will be introduced and examined. Initially, the current state of a specific area will be described and the need for renovation examined. After that, the feasibility study and estimation of energy savings potential will be made. Technical measures which will be taken into account include measures recommended by the BPC (Tehovnik, 2015), measures subsidized by the EKO fund and other measures sourced from the relevant literature.

3.2.1 Building Envelope & Heat Recovery

These technical measures have been recommended by BPC (Tehovnik, 2015) and their main goal is to decrease the required energy for building heating. Most of them also qualify for EKO fund's subsidy and green loan. As concluded in the BPC and annual firewood consumption log, a vast majority of the building's energy use is attributable to the building's heating requirements. Furthermore, measures which improve energy efficiency are generally advised to be implemented first, as demand reduction is supposed to be the most financially viable and cost efficient way to reduce CO_2 emissions. Furthermore, these measures later allow for proper sizing of the heating system if it is to be retrofitted (Thorpe, 2010).

3.2.1.1 Building Envelope

The building envelope is composed of walls, floors, roof, doors, and windows. In general these are structures that enclose the building, which creates its internal microclimate. Most of the energy loss is a result of insufficient insulation properties of the building envelope (Beltrán, Kochova, Pugliese, & Sopoliga, 2010). The individually examined technical measures suggested are (Tehovnik, 2015):

- **retrofitting windows and doors.** The thermal conductivity of the building's windows and doors is exceeding the national building code standards by double the recommended amount, meaning that a lot of energy is being lost through the windows. Furthermore, the tenants complain about air leaks which are resulting in decreased comfort and energy loss. These leaks are a result of worn-away compression seals around the frames and in some cases damaged windows which cannot be properly closed. It is recommended to retrofit the windows to triple glazed aluminium-wood windows and replace the weather-stripping of the existing doors' frames. These measures would decrease the annual heating demand by 24.84%.

- **additional insulation of external façade.** The façade was built in 1987 and is a bit worn-away. Therefore it is in need of renovation due to aesthetic and energy-efficiency reasons. The BPC recommends an additional 13 centimetres of insulation with expanded polystyrene. The retrofit includes the addition of a decorative waterproof finish to the outside wall. This measure alone would reduce the heating demand by 13.43%.

- **external insulation of the look-out basement.** The basement of the building extends over the ground floor and is occupied by a tenant family. Originally the basement was not intended as a residential area, therefore it was not insulated during the construction phase. Adding 13 centimetres of insulation (Fragmat Stirocokl) would reduce the annual heating demand by 14.14%. It must be noted, however, that the additional insulation of the external façade and the external insulation of the look-out basement would be done simultaneously, due to aesthetic reasons.

- **insulation of the internal wall in the basement.** The wall separating one of the heated residential apartments and an unheated garage/cellar is not insulated and is therefore causing unwanted heat loss (this again is a result of subsequent retrofit of the basement area for residential purposes). The added insulation of 12 centimetres of expanded polystyrene would result in a 5.35% reduction of annual heating demand.

- **basement ceiling insulation.** The ceiling divides the unheated garage space and heated residential area. As the ceiling is not insulated, there is heat loss occurring from the residential area. If the ceiling would be insulated with 10cm thick expanded polyester, the annual heating demand would be reduced by 2.42%. The measure does not qualify for EKO fund subsidy as its requirements are to add 15 cm of insulation. This level of thickness, however, would reduce the height of the basement below the national building code requirements, making it unsuitable for taller vehicles and people.

3.2.1.2 Heat Recovery

As we retrofit and improve the efficiency of the building's envelope, the house is approaching a passive standard. With it, the annual heating demand is significantly decreased. At some point, a building can obtain much of its heat requirements from solar gains, occupant's body heat and use of appliances (cookers, fridges and other). In such cases, the rest of the heat requirements can be met by Mechanical Ventilation with Heat Recovery (MVHR). On the negative side, approaching the passive standard (especially when retrofitting airtight windows, glazing and doors) can cause extreme airtightness. In such cases, natural air infiltration to provide fresh air decreases, which can also lead to moisture and mould issues (Thorpe, 2010). Furthermore, the BPC (Tehovnik, 2015) concluded that if the measures under the chapter "Building Envelope" are retrofitted, the annual cooling requirements will significantly increase. Due to the above mentioned reasons, when retrofitting the building's envelope, the automatic ventilation system should be considered:

- **Mechanical Ventilation with Heat Recovery** (hereinafter: MVHR). A well-insulated and air-tight building's envelope could cause overheating, lack of natural ventilation, excessive moist and health hazardous mould. For those reasons, MVHR is recommended which would control the internal climate, air quality, air humidity and would promote the health of the occupants (Thorpe, 2010). The proposed system is a central heat recuperation system and its core unit is Helios KWL EC 500. The measure would decrease the annual heating demand by 23.96%. It would also offset the increase of the annual cooling requirements, which is a negative aspect of a well-insulated building (Tehovnik, 2015).

Table 5. Building Envelope Retrofit Measures

Measures	Estimated Energy Savings	Annual Savings (EUR)	Investment (EUR)	Investment including EKO subsidy (EUR)	Technical lifetime (years)
Retrofitting windows and doors	24.84%	358	22,454	19,454	30
External facade insulation	13.43%	193	10,129	8,103	30
Look-out basement insulation	14.14%	204	2,683	2,146	30
Insulation of internal wall	5.35%	77	825	825	30
Basement ceiling insulation	2.42%	35	1,995	1,995	30
Recuperation	23.96%	345	9,979	7,983	17

Annual savings potentials (in Table 5) are calculated if the current central heating system is in use and the cost of firewood would remain the same. An individual measures' energy saving potential is calculated when assuming only the individual measure is implemented (in the case of comprehensive renovation, the saving potential of an individual measure would be slightly different). However, this is not the case with "Recuperation", where savings are calculated after, but not including, windows and doors are retrofitted (resulting in greater air-tightness of the building). Investment costs from Table 5 were gathered through acquiring quotes from various suppliers. For the calculation, the most cost competitive quotes for a comparable quality were taken. Some measures qualify for EKO fund's subsidy, therefore the proposed subsidy (generally up to 20% of the investment) was discounted from the investment costs. The lifetime of individual measures was sourced from the decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015)

3.2.2 Space Heating & Sanitary Hot Water

The main task for a household heating system is to provide thermal comfort in the internal space for residents. The recommended temperature is 19-24ºC. In cold climates, such as Slovenia, central heating is generally used. In buildings with central heating, the same source is generally used for heating and sanitary hot water preparation. During the heating period, which lasts for around 8 months, sanitary hot water needs and space heating needs are met by the same central system, whereas during the non-heating period the system is solely used for sanitary hot water preparation. As a result, the whole input of the boiler is not used during the non-heating period and this can result in a significant drop in a boiler's efficiency. Modern heaters can, however, switch into summer mode and maintain their efficiency at 80% or higher (Beltrán et al., 2010).

Currently the building's heating and hot water needs are being met by a central heating system with a combined wood/oil boiler and an additional 150 litres sanitary hot water reservoir. The system has a 40kw power, is 30 years old and its efficiency has dropped to around 65%. According to the repairman, the system should last a few more years, however, a new system should be considered in case the current system brakes down permanently. The boiler is also equipped with a heating-oil burner, however, due to the damaged heating oil reservoir and prohibitive prices of heating oil, this source of heating has not been used for years.

3.2.2.1 Central Heating System

The proposed central heating system upgrades will examine annual energy costs of various systems. Another important aspect is the seizing of the system. If measures under "Building Envelope & Heat Recovery" are implemented, the required power of the proposed new system could be significantly reduced. Therefore, it is generally recommended to consider a central heating system retrofit after the building envelope renovation and heat recovery is implemented (Thorpe, 2010). Nonetheless, for the purpose of the thesis, the calculations are based on the current actual firewood consumption (71,940 kWh/annually) and the **calculated building's heating requirements and sanitary hot water heating requirements** of about **46,761 kWh/annually** (65% efficiency of the boiler is assumed).

In Table 6, various heating systems, which can be applied on the building, are listed. Furthermore, the costs of energy in EUR per kWh of useful heat are calculated and annual savings of various energy sources compared to the current system (under the building's current heating requirements) is estimated. The proposed factors and energy source prices were adapted from various sources and are distinguished in Table 6. It must be noted, however, that a slight change in the value of the proposed factors and energy prices would considerably change the calculation.

In Table 6, it is evident that the current already system already ranks as one of the most economic methods of heat generation. It must be noted, however, that the labour costs of manual log loading are not accounted for in the calculation. At current prices, of listed energy sources, only a woodchip boiler, a new log gasification boiler and heat pump systems with an overall efficiency of (Seasonal Performance Factor) of 2.88 or more, would generate cheaper useful heat. Therefore, only systems which generate cheaper heat will further be examined, with the exception of an air source heat pump system (as its running costs are only slightly more expensive):

1. **new log boiler.** These types of boilers produce space and water heating. Loading by hand is required at least once every three days in the summer and up to 3 times a day in the winter. The old boiler's estimated efficiency is at 65%. Investing in a new efficient system would increase the efficiency to 90% or more. The main components in the proposed system includes, a 20 kW wood gasification boiler (Wvterm GT 20) and a thermal storage tank (1,000 litres). The system also qualifies for EKO subsidy and a low interest loan, which would result in savings in log consumption by around 30% or more. Furthermore, the system would reduce the PM emissions, reduce the needed frequency of manual log loading and provide constant heat to the residents (Krajnc et al., 2009, p. 17; Tehovnik, 2015).

2. **wood-chip boiler.** Wood chip boilers generally provide space heating and sanitary hot water heating. They are commonly used in a larger context, such as district heating systems, as well as in multi-occupancy dwellings. The system is fully automatic, however, it is fairly expensive and requires a lot of space to store wood chips and a chip feeding station (Thorpe, 2010). The main components in the proposed system includes, a 26 kW wood-chip boiler (HDG Compact 25), an automatic feeding station and a

thermal storage tank (1000l). Investment in the system with a 90% or above efficiency, would decrease annual energy expenditures by around 39% as evident in Table 6. The investment also qualifies for EKO subsidy and a low interest rate loan.

3. **heat pump system (HPS).** This type of system can typically satisfy both heating and cooling requirements of the building. It transforms low-grade heat from the environment into high temperature heat that can be used for space and sanitary hot water heating. In contrast to the current system, a heat pump system does not require any manual work as it is fully automatic. According to Thorpe (2010, p. 122), these systems are most efficient when the output temperatures are low and the heat distribution system requires lower delivery temperatures, such as an underfloor heating system and low temperature radiators. The building, however, has conventional radiators, which require significantly higher delivery temperature to sufficiently heat the building. Therefore, the proposed heat pump systems might not reach the estimated SPFs. The proposed systems are (Beltrán et al., 2010):

    a. **air-water HPSs** take heat from the external air and transfers it into a building. These pumps are less efficient compared to ground and water heat pumps, however, their installation costs are considerably lower. The source is easily accessible and does not directly influence the external environment, as the heat taken from the air is gradually put back due to envelope heat losses. The main components of the proposed system is a 17.9 kW compact external heat pump (Atec 18). The system also qualifies for EKO subsidy and a low interest loan. At the estimated average price of electricity, the annual heating costs would increase by 2.7%.

    b. **ground-water HPSs** take heat from the ground and transfers it into a building. It requires a network of underground pipelines usually filled with refrigerant to extract the heat from the ground. The output depends on the ground temperature, ground moisture content, the length of the pipeline and other factors. The main components in the proposed system includes, a 17.2 kW ground-water heat pump (Diplomat Duo Optimum G3 17) and around 900 m of underground piping. The proposed system also qualifies for EKO fund subsidy and a low interest loan. At the estimated average price of electricity, the annual heating costs would be reduced by around 18%.

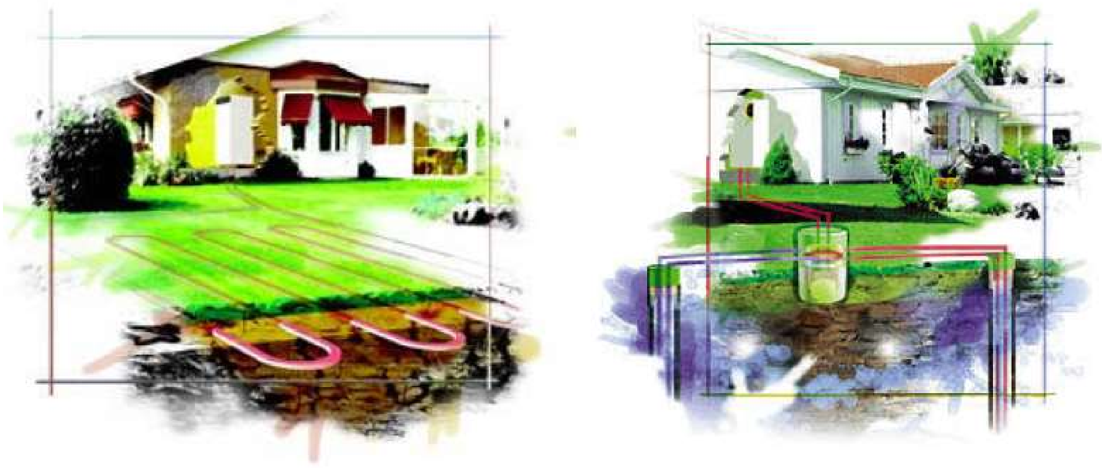
    c. **water-water HPSs** take heat from a nearby body of water (if available) and transfers it into a building. The water, however, needs to be clean and its lowest temperature should be 8ºC. The main components in the proposed system includes, a construction of two 30 m deep wells (one for collection and the other for infiltration) and a 21.1 kW water-water heat pump unit (Diplomat Duo Optimum G3 17). The system also qualifies for EKO fund subsidy and a low interest loan. At the estimated average price of electricity, the annual heating costs would be reduced by around 28%.

Table 6. Energy Cost Calculator and Energy source Usage

	LPG	Electricity heating	Heating oil	Natural gas	Wood pellets	Heat pump (air-water)	**Firewood (current)**	Heat pump (ground-water)	Firewood (new)	Heat pump (water-water)	Wood chips
Unit of the energy source	kWh/l	kWh	l	kWh/Sm3	kg	kWh	**m^3**	kWh	m^3	kWh	kWh/m^3
Calorific value (kWh/unit)	7.23	1.00	10.08	9.47	4.73	1.00	**2,398.00**	1.00	2,398.00	1.00	800.00
Annual efficiency of the system	0.90	0.96	0.88	0.95	0.85	2.80	**0.65**	3.50	0.90	4.00	0.90
Cost of the energy source (EUR/unit)	0.94	0.11	0.86	0.73	0.25	0.11	**60.00**	0.11	60.00	0.11	17.00
Costs of useful energy (EUR/kWh)	0.144	0.115	0.097	0.081	0.062	0.040	**0.038**	0.032	0.028	0.028	0.024
Quantity used (units of the energy source)	7,186.26	48,709.38	5,271.58	5,197.69	11,630.64	16,700.36	**30.00**	13,360.29	21.67	11,690.25	64.95
Annual energy costs (EUR)	6,755.09	5,393.12	4,533.56	3,794.31	2,907.66	1,849.07	**1,800.00**	1,479.26	1,300.00	1,294.35	1,104.08
Annual Savings (EUR)	-4,955.09	-3,593.12	-2,733.56	-1,994.31	-1,107.66	-49.07	**0.00**	320.74	500.00	505.65	695.92

Source: Adapted from *Izberite cenejše ogrevanje*, 2016.

Figure 19. Ground Source (left) and Water Source (right) Heat Pump System



Source: adapted from S. Beltrán et al., *Building Energy Efficiency, Student Handbook,* 2010, p. 28.

In Table 7 the proposed methods of heating are listed. Financing costs are not included in the calculation. All of the proposed solutions would annually generate cheaper heat, except for the air source heat pump system. All of the systems would also significantly reduce the amount of physical labour which is currently required. It must be noted, however, that the estimates of the proposed system efficiency are normative and are very dependent on various unpredictable factors, therefore the actual efficiency at implementation might vary significantly. Furthermore, it is also recommended that before the heating system, the building's envelope is to be retrofitted, as this would allow for proper downsizing of the heating system and consequently reducing the investment costs and environmental impact. The prices were sourced from various quotes, which were made specifically for the building, whereas the proposed lifetime of systems were sourced from the decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015)

Table 7. Costs of Proposed Heating Solutions in Comparison with the Current System

Measures	Investment (EUR)	Investment including EKO subsidy (EUR)	Costs of Useful Energy (EUR/kWh)	Annual Savings (EUR)	Technical lifetime (years)
Current System	0	0	0.0385	0.00	0
Log Gasification Boiler	9,270	7,416	0.0278	500.00	20
Wood-Chip Boiler	14,170	12,170	0.0236	695.92	20
Air-water HPS	12,522	13,522	0.0395	-49.07	20
Water-water HPS	14,232	16,732	0.0277	505.65	20
Ground-Water HPS	14,268	16,768	0.0316	320.74	20

3.2.2.2 Sanitary Hot Water Heating

During the non-heating periods, which last for around 4 months in the summer, the log boiler is solely used for hot water preparation. This causes a decrease in the efficiency of the boiler and an inconvenience to residents, as they have to manually start the system every 2 days to prepare hot water. Furthermore, burning firewood in summer can cause discomfort for tenants and neighbours, as the smoke sometimes tends to descend and pollute the area in the proximity. On the other hand, preparation of hot water during the winter is relatively cheap and requires almost no extra manual labour. Therefore, only auxiliary systems which can provide hot water (especially during the non-heating period) will be examined. These can simply be plugged into the current central system, providing water heating throughout the summer months and therefore eliminating the need for manual log loading during the non-heating period (Thorpe, 2010).

Solar hot water heating. According to Thorpe (2010), solar hot water heating for hot water supply should be installed whenever possible. However, the sun alone will not provide sufficient heat all year round. Therefore solar hot water is generally done in combination with a gas or biomass boiler and a heat exchanger, which can be placed in a buffer tank. The building has a south facing roof and sufficient physical space in the boiler room for a storage tank. Investment into solar hot water heating systems also qualifies for EKO subsidy and green loans. Proposed systems for the building are (Thorpe, 2010):

- **flat plate solar panels.** The technology is mature and cheap, however, the collectors will not produce heat during the colder months in the winter. The main components in the proposed system includes, a 500 litre boiler and 5 flat plate panels (Prosun TS 201). Annually, the system should generate enough heat to minimise the need for usage of the wood burning boiler during the non-heating period.

- **evacuated tube collectors** are usually more efficient, require less surface area and can produce heat all year round (even during the cold winter months), however, they are more expensive. The main components in the proposed system includes, a 400 litre boiler and 2 evacuated collectors (NSC-58-30). It would generate enough heat to minimise the need to use the wood boiler during the non-heating period and should also provide additional heat all year long.

Table 8. Costs of Proposed Solar Hot Water Heating Solutions

Column1	Investment (EUR)	Investment including EKO subsidy (EUR)	Annual useful heat generation (kWh)	Annual savings (EUR)	Technical lifetime (years)
Flat plate solar collectors	4,300.00	3,440.00	3,706	142.65	20
Evacuated collectors	5,032.78	4,026.22	3,712	142.88	20

In Table 8, costs of useful heat in EUR per kWh are calculated. The investment prices were sourced from various suppliers and made especially for the building and its sanitary hot water requirements. Financing costs are not included in the calculation. Annual system yield is calculated with Valentin Energie Software (Appendix 2; Appendix 3). The proposed lifetime of both systems is 20 years, as suggested in the Decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015). The proposed systems would minimise the need for manual labour during the non-heating months, however, as evident in Table 8, the cost of auxiliary heating is significantly higher than the current heating cost of 0.038 EUR/kWh. Therefore it is not possible to consider financial benefits of these investments and its payback period.

Sanitary hot water heat pump (hereinafter: SWHP): This type of heat pump uses indoor or outdoor air to generate sanitary water up to 65ºC. Usually they are placed in the boiler room where they simultaneously cool down the room. Units can be connected to an existing external hot water tank or independently be installed with an integrated boiler tank. However, the existing hot water tank capacity is only 150 litres, which is not sufficient to satisfy the non-heating period needs for hot water. The proposed system for the building is a heat pump integrated with a 270 litre hot water tank (Logaterm WPT 270 I-S). Additionally, the installation would also integrate the old 150 litre hot water tank with the new one. Combined capacity would amount to 420 litre, which together with the heat pump could cover the hot water needs during the non-heating period.

As evident in Table 9, the costs of useful heat depends on the assumed efficiency of the same system. According to the supplier, the overall efficiency would be almost impossible to calculate as it is too dependent on usage patterns and other vague factors. The most favourable coefficient of performance (hereinafter: COP) of 4.2 is achieved with preparation of hot water from 15ºC to 45ºC, with an air temperature of 20ºC (Attachment 5). Generally these conditions could only be assumed during the summer. Financing costs are not included in the calculation and the proposed lifetime of the system is 20 years, as suggested in the Decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015). Furthermore, as the system consumes electricity, future financial risks are likely to increase due to the constant rise of household electricity prices.

Table 9. Payback of the SWHP System When Considering Various Assumed Efficiencies

Efficiency according to the EN 255-3 standard	COP	Investment (EUR)	Cost of useful heat (EUR/ kWh)	Annual savings (EUR)	Technical lifetime (years)
A20/W15-W45	4.2	1,981	0.0282	64.42	15
A15/W15-W45	3.6	1,981	0.0330	20.17	15
A15/W10-W54	2.66	1,981	0.0446	-89.28	15

3.2.3 Micro-CHP

Micro Combined Heat and Power (CHP) is a promising new technology of small units for individual homes. These units can run on biomass (wood pellets, wood chips, and biogas), natural gas and hydrogen. The system produces heat and electricity simultaneously with very high overall efficiency. Generally they are more appropriate for buildings with a larger heat demand, therefore limited benefits are offered to smaller and newer dwellings (Thorpe, 2010).

CHP power plants are not included in the new net metering scheme. Furthermore, the electricity feed-in support scheme for high-efficiency cogeneration (CHP) power plants organised through the Center for RES/CHP support is currently not yet active. CHP plants which will potentially want to get the support will have to apply on the basis of a call for tender. The exact conditions and the amount of the fed-in support scheme are not determined yet, therefore it is impossible to determine financial implications of Micro-CHP unit for the building at this moment (About Center for RES/CHP, 2016).

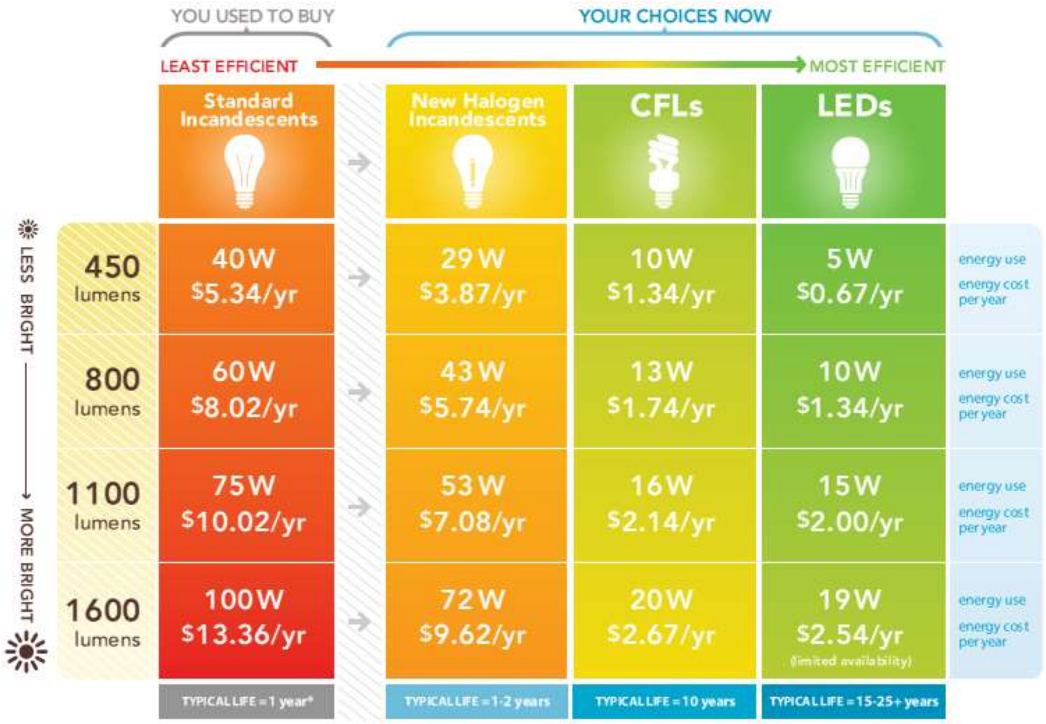
3.2.4 Lighting & Electricity Use Reduction

Before looking into onsite self-production of renewable energy sources, the reduction of electricity consumption should be considered. Measures that can potentially reduce electricity consumption are: monitoring and conservation, voltage optimization, advanced metering (demand response), reduction of phantom loads, usage of energy efficient home appliances, efficient lighting and so on (Thorpe, 2010). For the specific building, only lighting retrofit will be considered due to the complexity of calculations.

LED lighting retrofit: Lighting can account for up to 30% of electricity use in the building. It is possible to cut that figure by 90% through introducing energy efficient lighting. Electricity wasteful incandescent lamps can be replaced with light-emitting diode (hereinafter: LED) lamps. LED lamps use a tiny amount of electricity and can last for over 25,000 hours, whereas incandescent lamps can last for about 1000 hours (Thorpe, 2010).

Even though the incandescent lamps for residential purposes were phased out from the EU market by the EUs' Ecodesign Directive, a vast majority of the lighting bulbs in the building are still standard-incandescent lamps. This is due to the sizeable stock held by the owner. In the building 40-100W light bulbs can be replaced with 5-19W LED bulbs. This would, according to Figure 20, not result in decreased light output, however, it would result in about 80% decreased electricity consumption for lighting and an 8 to 10 times longer lifetime period of the light bulbs (Thorpe, 2010).

Figure 20. A Comparison of Watt and Lumen Output for Different Types of Bulbs and Relating Annual Energy Cost Expenditures.



Source: Natural Resource Defence Council, *Your Guide to More Efficient and Money-Saving Light Bulbs*, n.d., p.1.

The calculation in Table 10 includes a retrofit of 78 old incandescent bulbs with new efficient LED bulbs (EMOS 5-10W bulbs), which would decrease the consumption of electricity currently used for lighting by 80%. The cost of investment, however, does not include manual labour. The installations do not require a qualified expert or a contractor as it can be done by residents themselves in just a few hours. The proposed technical lifetime of a LED light bulb is 15 years. The efficient lighting retrofit is not included in the EKO funds financial support scheme for residential buildings.

Table 10. LED-Lighting Retrofit

Consumption for Lighting (kWh)	Variable costs for Lighting (EUR)	Investment (EUR)	Estimated Energy Savings	Annual Savings (EUR)	Technical lifetime (years)
1,196	132.38	546	80%	105.90	15

3.2.5 Solar PV with Net-Metering

On average there are 10,379 kWh of electricity consumed in the building annually. Due to the big south facing roof and the newly passed Decree on self-supply of electricity from the renewable energy sources (Uredba o samooskrbi z električno energijo iz obnovljivih virov energije, Ur.l. RS, no. 97/2015), the annual consumption could be met by self-production of electricity with solar PV. The electricity costs are composed of a fixed and a variable part. Therefore, even in the case of 100% self-sufficiency annually, the fixed part of 13.74 EUR per month (for the case study building) would still have to be paid. The average variable cost of electricity paid for the household is 0.11 EUR/kWh.

The main components in the proposed system includes, 34 PV panels (Canadian Solar 265.27 W) and a 9 kW inverter (SM-STP 9000TL-20) The investment qualifies for EKO fund credit and should, according to EKO funds financial plan (Eko Fund, 2016, p 19), soon be eligible for a subsidy. However, due to the uncertainty of this amount and the time the program is initiated, the subsidy will not be included in the calculation. There is enough roof space in the south facing roof for installation of 9 kW PV system and the proposed solar hot-water heating collectors simultaneously.

Table 11. Annual Electricity Production and Savings of the Solar PV System

Measure	Investment (EUR)	Annually displaced electricity (kWh)	Annual savings (EUR)	Technical lifetime (years)
9 kW PV system	14,322.60	10,260	1,135.99	15

The investment cost and annual production of the system was taken from the most competitive quote, for a comparable system, which was produced for the building. In Table 11, however, the decrease in efficiency of the panels over their lifetime and the constantly increasing household electricity prices are not included (as it is presumed that the two factors would offset one another). The warranty of individual components range from 2 to 25 years. The supplier also gives a warranty that panels will still generate 80% of its output after 25 years.

3.3 Financial and Environmental Implications of Individual Measures

To evaluate and compare individual measures from a financial and environmental perspective, various indicators will be calculated. It must be noted, however, that these indicators do not capture all the benefits that individual measures might bring, such as increased comfort or aesthetics of the building. The environmental indicators considered are the total CO_2 emissions and change CO_2 emissions, whereas the financial indicators considered are the Internal Rate of Return (hereinafter: IRR) and the payback period:

- the **IRR** is a metric used to measure profitability of potential investments. It is a discount rate that equals the net present value of all cash flows from a particular investment to zero. In general, the higher the investment's IRR the more financially desirable the project is (Internal Rate of Return – IRR, n.d.). The following IRR calculations include only cash flows which would be generated in investments' technical lifetimes.

- the **payback period** is a length of time required to recover the investment costs. Typically, the longer the payback period, the less desirable the investment. This indicator, however, ignores the time value of money in contrast to IRR (Payback Period, n.d.).

Table 12. Financial and Environmental Implications of Individual Measures (Current Usage of Electricity).

	Annual savings (EUR)	Investment (EUR)	Technical lifetime (years)	CO_2 emissions change (kg)	Total CO_2 emissions (kg)	Payback period	IRR
Current	0		0	0	5,086	0.00	0.00%
LED retrofit	106	546	15	586	4,500	5.16	17.72%
9 kW PV system	1,136	14,323	15	5,027	58	12.61	2.25%

Table 12 lists the measures which would reduce annual electricity expenditures in the building (excluding electricity use for space heating and sanitary hot water preparation). The payback period and IRR indicates that the measure, LED retrofit of lighting bulbs, is financially very appealing. Nonetheless, annual savings of 106 EUR hints toward inattentiveness and a salience issue (a potential behavioural explanation of the energy efficiency gap) as the actual savings seem negligible. The installation of a PV system, however, does not seem as financially appealing (according to PB and IRR), therefore it might be reasonable to wait until the EKO Fund's subsidy is available. Overall implementation of both measures would result in offsetting all of the buildings net CO_2 emissions.

Table 13. Financial and Environmental Implications of Individual Measures (Current Usage of Firewood).

	Annual savings (EUR)	Investment including EKO subsidy (EUR)	Technical lifetime (years)	CO_2 emissions change (kg)	Total CO_2 emissions (kg)	Payback period	IRR
Current	0	0	0	0	0	0.00	0.00%
Retrofitting Windows and Doors	358	19,454	30	0	0	54.39	-3.48%
External Facade Insulation	193	8,103	30	0	0	41.90	-2.03%
Look-out Basement Insulation	204	2,146	30	0	0	10.54	8.71%
External Facade & Look-Out basement insulation	397	10,249	30	0	0	25.82	1.00%
Insulation of Internal Wall	77	825	30	0	0	10.71	8.54%
Basement Ceiling Insulation	35	1,995	30	0	0	57.25	-3.75%
Recuperation	345	7,983	17	0	0	23.14	-3.23%
New Log Gasification Boiler	500	7,416	20	0	0	14.83	3.03%
Wood-Chip Boiler	696	12,170	20	0	0	17.49	1.31%
Heat Pump (water-water)	506	16,732	20	5,728	5,728	33.09	-4.38%
Heat Pump (ground-water)	321	16,768	20	6,547	6,547	52.28	-7.81%
SWHP A20/W15-W45	64	1,981	15	1,097	1,097	30.75	-7.87%
SWHP A15/W15-W45	20	1,981	15	1,279	1,279	98.19	-17.62%
Flat plate solar panels	143	3,440	20	0	0	24.07	-1.70%
Evacuated collectors	143	4,026	20	0	0	28.18	-3.06%

Table 14. Financial and Environmental Implications of Individual Measures (Fictional Current Consumption of Heating Oil).

Column1	Annual savings (EUR)	Investment including EKO subsidy (EUR)	Technical lifetime (years)	CO_2 emissions change (kg)	CO_2 emissions (kg)	Payback period	IRR
Current	0	0	0	0	13,152	0.00	0
Retrofitting Windows and Doors	1,126	19,454	30	3,267	9,885	17.28	4%
External Facade Insulation	609	8,103	30	1,766	11,385	13.31	6%
Look-out Basement Insulation	641	2,146	30	1,860	11,292	3.35	30%
External Facade & Look-Out basement insulation	1,250	10,249	30	3,626	9,526	8.20	12%
Insulation of Internal Wall	243	825	30	704	12,448	3.40	29%
Basement Ceiling Insulation	110	1,995	30	318	12,833	18.18	4%
Recuperation	1,086	7,983	17	3,151	10,000	7.35	11%
New Log Gasification Boiler	3,234	7,416	20	13,152	0	2.29	44%
Wood-Chip Boiler	3,429	12,170	20	13,152	0	3.55	28%
Heat Pump (air-water)	2,684	13,522	20	8,183	4,968	5.04	19%
Heat Pump (water-water)	3,239	16,732	20	5,728	7,423	5.17	19%
Heat Pump (ground-water)	3,054	16,768	20	6,547	6,605	5.49	17%
A20/W15-W45	641	1,981	15	1,097	12,055	3.09	32%
A15/W15-W45	597	1,981	15	1,279	11,872	3.32	30%
Flat plate solar panels	359	3,440	20	1,042	12,109	9.57	8%
Evacuated collectors	360	4,026	20	1,044	12,108	11.19	6%

Table 13 lists all the measures which would reduce annual expenditures on space and hot water heating in comparison to the current annual expenditures on firewood. The EKO subsidy is already subtracted from investments which qualify. As calculated, only insulation of the look-out basement and insulation of the internal wall would yield somewhat appealing financial benefits. Nonetheless the measures are exclusive, as the potential savings of the individual measure would significantly be reduced if the other measure would already be implemented. Furthermore insulation of the look-out basement would, due to aesthetic reasons, be done with external façade insulation. Therefore, the only financially appealing and technically feasible measure is insulation of the internal wall, achieving a payback in 10.71 years and an IRR of 8.71%. Due to carbon neutrality of the current source (firewood) of energy for space and sanitary hot water heating, the measures do not reduce CO_2 emissions. The contrary goes for measures which use electricity for their operation, which would actually increase the CO_2 emissions.

As mentioned earlier, the building's central heating system has the capacity to use heating oil as an energy source. Due to the fact that heating oil hasn't been used in the building for more than 5 years, the annual heating oil expenditures were calculated in Table 6. Table 14 lists all the measures which would reduce net CO_2 emissions and annual expenditures on space and hot water heating, if heating oil was used in the building as an energy source. CO_2 factor 0.27 kg CO_2/kWh is sourced from the decree on the method of determining energy savings (Pravilnik o metodah za določanje prihrankov energije, Ur.l. RS, no. 67/2015). The EKO subsidy is already subtracted from investments which qualify. The calculations indicate that majority of the measures are financially appealing and would simultaneously reduce CO_2 emissions. The measure offering the highest IRR, the shortest payback period and would simultaneously offset the most of CO_2 emissions is the investment in a new log gasification boiler. It must be noted, however, that after retrofitting the heating system, measures to retrofit the building envelope would not be as financially appealing.

CONCLUSION

In the **theoretical part**, it is evident that extensive research and reliable knowledge supports the need to transform the global economy towards carbon neutrality. The transformation should also be done as quickly as possible to prevent the worst from happening. The decarbonisation of the global economy will not take place by market forces alone, as the climate change is a result of one of the greatest market failures ever seen. The scientific consensus is gradually being acknowledged by the public and the political leaders. COP 21 produced a clear international commitment among 195 countries to curb the greenhouse gasses and limit the global warming to at least 2ºC compared to preindustrial levels, as well as to aim for zero net emissions in the second half of the century. To achieve that, mass proliferation of decarbonisation technologies is needed. Therefore governments should use various tools to speed up the process. The tools/measures need to be implemented to neutralise the market failure and to allow the free market to pursue cost efficient decarbonisation. EU is progressively passing the regulation to offset the market failure, the energy efficiency gap and to support mass adaptation of technologies for decarbonisation. This is directly influencing Republic of Slovenia, which is gradually introducing regulation and support mechanisms to speed up the adaptation.

Space heating, sanitary hot water heating and the electricity used by various appliances in buildings are an overall major source of energy use and consequently a major source of CO_2 emission. Furthermore, buildings do not just offer low-cost abatement opportunities through energy-efficiency measures, they also offer an opportunity for integration of distributed renewable energy sources with ever decreasing CO_2 abetment costs. Altogether, implementation of these measures can transform CO_2 emitting buildings into net energy plus buildings in a cost efficient way. Therefore an opportunity for the mass proliferation of energy-efficient solutions and distributed renewable energy sources applied on the building stock should be perused. This will not only decarbonise the building sector, but also the power sector as well as other carbon intensive sectors. In this way, the building sector can play a major role in the global mass decarbonisation process, which will take place for decades to come.

The **empirical part** concluded that most of the measures aiming to reduce the consumption of firewood or measures to retrofit the heating system did not make any financial or environmental sense. The only exception was the measure, Insulation of internal wall, which separates the heated studio apartment and unheated garage. The poor financial and environmental performance of the listed measures is mainly due to the fact that firewood is currently used in the building, which is one of the most cost efficient energy sources, as well as carbon neutral energy sources. This is further indicated in Table 14, which demonstrates a fictional case where the building would use heating oil as its energy source. In this case, most of the measures make environmental and financial sense.

For the renovation of the building (apart from measures reducing electricity costs) a holistic strategy needs to be determined and perused. The financial implications suggest that the proposed measures do not achieve an appealing financial return (when other benefits brought forth with energy renovation are not included). Nonetheless, the current (30 years old) central heating system might default, therefore the decision will soon have to be made to either retrofit the envelope of the building (energy conservation/efficiency) or to focus on the more efficient heating system (low-cost/efficient heat generation). From the calculations, the latter seems more financially appealing, as the investment in a new wood gasification boiler would further reduce the cost of kWh of heat, which would make measures to retrofit the building's envelope even less appealing. On the other hand, retrofitting the envelope would add value in other areas, such as increased aesthetics and increased comfort to the residents. Both strategies, however, face the issue of the principal agent problem, meaning that for the owner/investor to capture the financial benefit of the renovation, a lease contract (rent increase) will have to be renegotiated with the tenants. For the time being, the most reasonable thing to do is to prolong the current state of the building, as long as the central heating system is working properly and tenants are willing to manually heat the building.

On the other hand, the two measures aiming to reduce electricity use in the building made more financial and environmental sense. Furthermore, the principal agent problem is not an issue as electricity costs paid to the owner are fixed (under normal conditions). The retrofit of incandescent light bulbs to energy efficient LED bulbs achieved the fastest payback and IRR out of all listed measures in the thesis. Nonetheless, absolute savings were not as substantial, as the measure would save only slightly above 100 EUR annually on electricity costs. Electricity use in the building is the only source of net CO_2 emissions, assuming that carbon neutral firewood is used in the central heating system (this does not include PM emissions). With simultaneous implementation of the LED retrofit measure and the micro PV plant for self-consumption, all of the remaining emissions would be offset. Furthermore, this would still come with a (small) financial benefit to the owner.

To conclude, it is **possible to achieve carbon neutrality and even a net plus energy building standard in a financially sound way** for the specific building. The main measures to achieve it are installation of LED lighting and installation of micro PV plant for self-consumption. The economics of these measures are also projected to improve, as the PV market in Slovenia matures. Furthermore, the EKO subsidies for renewable energy self-consumption, projected in the EKO financial plan (Eko Fund, 2016, p 19), should further improve its financial implications. The findings also suggest that old-inefficient buildings in Slovenia could potentially achieve carbon neutrality in a financially sound way.

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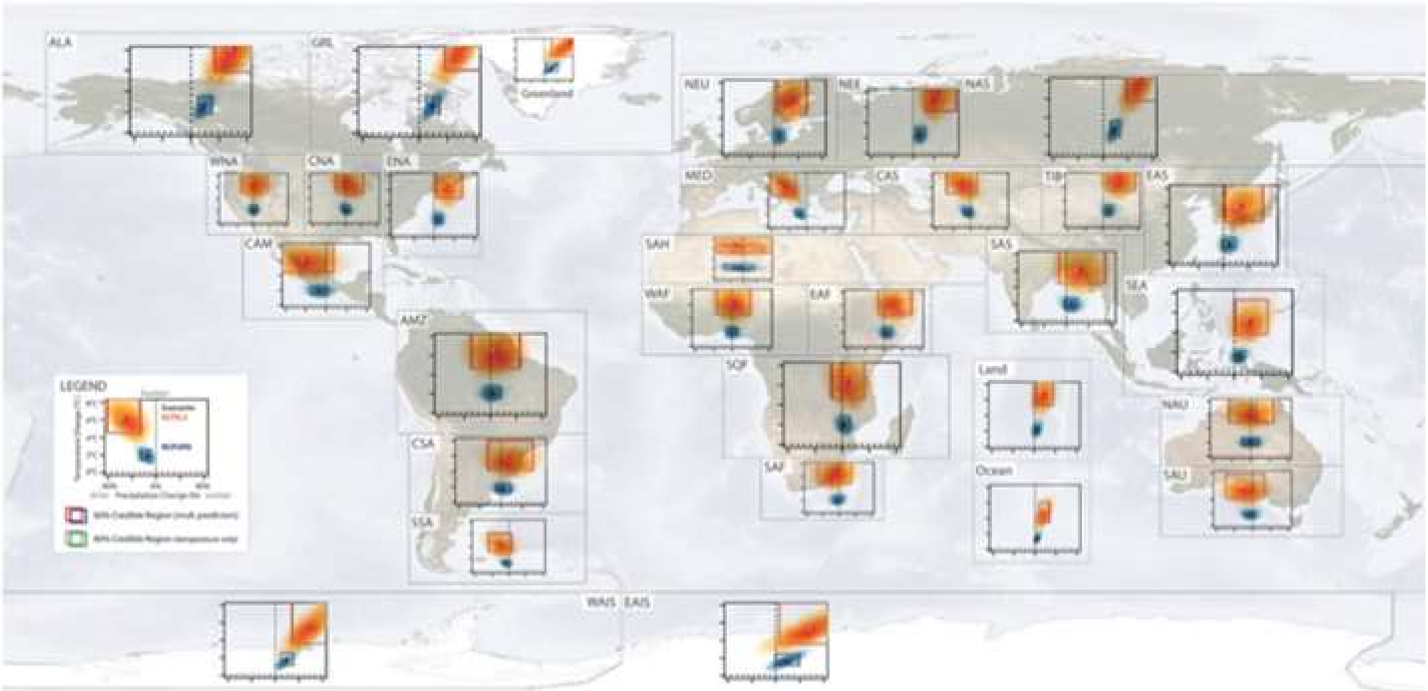
APPENDIXES

TABLE OF APPENDIXES

APPENDIX A: The correlation between regional warming and precipitation changes.

Figure 1. Distributions of mean regional temperature and precipitation changes in 2100.

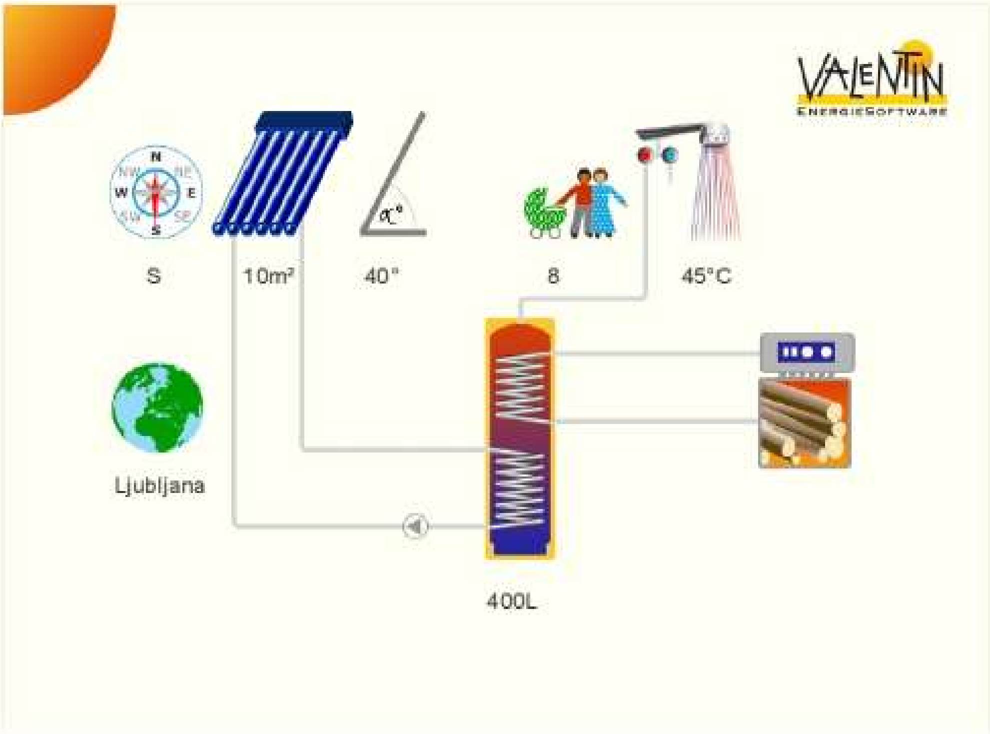


Note: The correlation between regional warming and precipitation changes in the form of joint distributions of mean regional temperature and precipitation changes in 2100 is shown for the RCP3-PD (blue) and RCP8.5 (orange) scenarios. The boxes indicate the inner 80% of the marginal distributions and the labelling of the axes is the same in all subpanels and given in the legend. The region definitions are based on Giorgi and Bi (2005) and are often used to describe large-scale climate changes over land areas. Here, they are amended by those for the West and East Antarctic Ice Sheets separated by the Transantarctic Mountains.

Source: World Bank, *Turn down the heat. Why a 4C warmer world must be avoided*, 2012, p. 25, Figure 23.

APPENDIX B: Solar Thermal Calculation for the Proposed Tube Collectors

Figure 2. Solar Thermal Calculation for the Proposed Evacuated Tube Collectors



Results

Irradiation:	12.217 kWh/a
System yield:	3.712 kWh/a
Solar fraction:	77 %
CO² savings:	0 kg/a

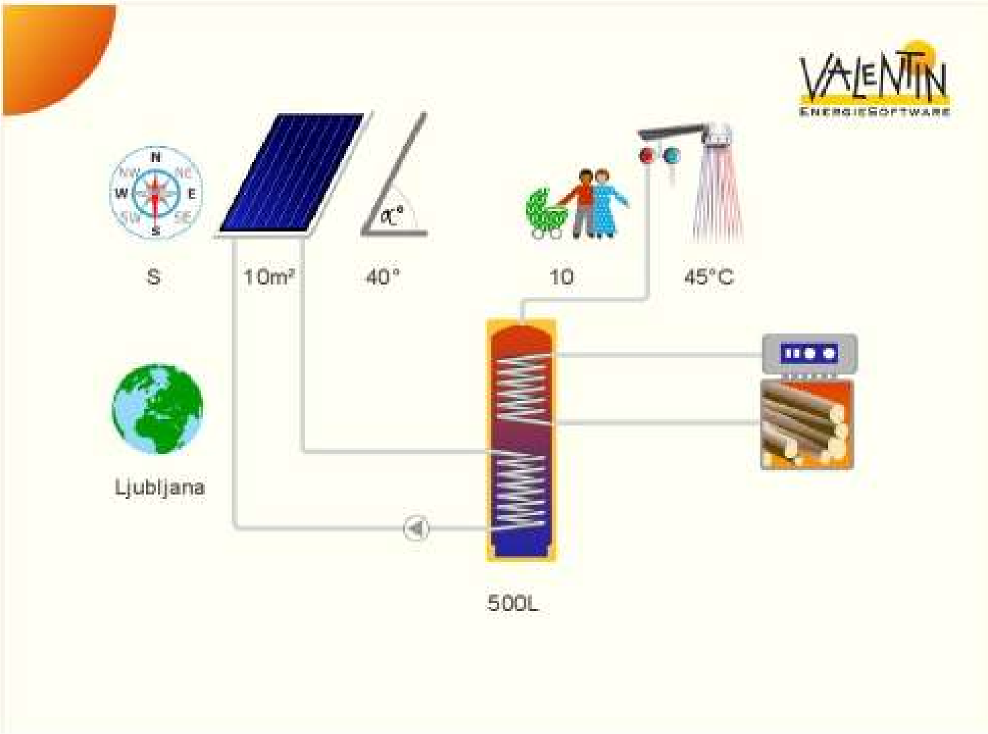
Irradiation:	Solar radiation onto the tilted surface of the collector absorber surface, over one year
System yield:	Solar system's available energy
Solar fraction:	Percentage of the total energy requirement produced by the solar system (= system yield)
Efficiency:	System yield/irradiation
CO² savings:	Emissions avoided by use of the system in kg/year

T*SOL Professional is available for detailed calculation and simulation of solar thermal systems.
Full information: www.valentin-software.com

Source: Adapted from *Online Solar Calculation and Simulation of Solar Thermal Systems*, 2016.

APPENDIX C: Solar Thermal Calculation for the Proposed Flat Plate Solar Collector

Figure 3. Solar Thermal Calculation for the Proposed Flat Plate Solar Collector



Results

Irradiation:	12.217 kWh/a
System yield:	3.706 kWh/a
Solar fraction:	65 %
CO^2 savings:	0 kg/a

Irradiation:	Solar radiation onto the tilted surface of the collector absorber surface, over one year
System yield:	Solar system's available energy
Solar fraction:	Percentage of the total energy requirement produced by the solar system (= system yield)
Efficiency:	System yield/irradiation
CO^2 savings:	Emissions avoided by use of the system in kg/year

T*SOL Professional is available for detailed calculation and simulation of solar thermal systems.
Full information: www.valentin-software.com

Source: Adapted from *Online Solar Calculation and Simulation of Solar Thermal Systems*, 2016.