Lithuanian Least-Cost Heating Strategy

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Masters' Thesis of Sustainable Energy Planning and Management

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Synopsis

Title: Lithuanian Least-Cost Heating Strategy

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This study identifies the least-cost heating strategy in the future energy system, by investigating to which extent heat should be saved rather than supplied. Lithuanian case is analysed due to the current energy-inefficient building stock and thereby too much money wasted on heating as well as dependency on imported natural gas, which threatens insecurity of supply.

First, the Lithuania's energy system for 2030 is constructed applying future prospects, where the key focus in the heating sector is given to the transition from natural gas to local biomass resources. Second, heat saving measures in the building stock, both multi-apartment buildings and individual houses separately, are looked into. The essential point in this study is that the cost of investment strongly depends on whether it is heat conservation in existing buildings or an additional investment in new buildings. For the existing buildings, it is also important whether an investment is made solely for the heat conservation purpose or as a part of renovation, which will be carried out anyways.

By comparing marginal heat production cost with marginal heat saving cost, it is concluded that a suitable least-cost heating solution is a reduction in heat demand for space heating down to 44-51% of current level for multi apartment buildings, whereas for individual houses much more effort is identified to be crucial to reduce heat demand from current level. Also, investments should be primarily made for new buildings and buildings being renovated anyways.

Afterwards, the main existing barriers towards successful buildings renovation are looked into, with a case of multi-apartment buildings. An analysis of private expenditure reveals that renovation might impose a significant financial burden for dwelling owners, if there is no financial support. In order to investigate other potential obstacles, a brief stakeholders' analysis is made and interviews with the main recognised actors are conducted. It is concluded that a crucial factor in the process is a motivation of dwelling owners, since they have the highest influence. Apart from other identified barriers, mostly legal and organisational, lack of craftsmen turned out to be one of the most significant issues as far as renovation of the building stock in Lithuania is concerned. Finally, recommendations to the identified issues are given.

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Preface

This Master's thesis is written by a 4th semester student from the Master of Science programme *Sustainable Energy Planning and Management*, from the Department of Development and Planning, Aalborg University. The title of the project is "Lithuanian Least-Cost Heating Strategy". It is carried out in the period from 1st February 2015 to 3rd June 2015.

Reading Guide

The report is divided into 10 chapters. The following structure is used: Chapters (1, 2, 3…), Sections (1.1, 1.2, 1.3…) and Subsections (3.1.1, 3.1.2…). Also, there is a distinction between figures and tables. Tables are used to present numerical data while figures are used for visual material, such as graphs. Figures and tables are numbered continuously regardless the placement in chapters, e.g. Table 1, Table 2, etc.

The Harvard – Anglia 2008 Style is used for referencing the sources in this report, i.e. references are done in the following style: (Author, Year). In case of more than one references for the same author in the same year, they are distinguished by a letter, e.g. (LEI, 2014a), (LEI, 2014b) etc. Personal communications, i.e. interviews, are also referred to in this style. As far as bibliography is concerned, if title of reference is in Lithuanian, English translation is given in angle brackets.

Furthermore, there are appendixes attached in this document, which are named by capital letters, e.g. A Appendix. Finally, a CD is attached to the project in which *EnergyPLAN* summaries, interview records and transcripts and electronic version of the project can be found.

Acknowledgements

Thanks are given to the student's supervisor, Henrik Lund, for his supervision throughout the semester. Furthermore, thanks are given to the interviewees for the inputs to the project.

The picture used in the front page is taken from the following source: www.technologijos.lt

Abbreviations

CHP – combined heat and power

DH – district heating

DHW – domestic hot water

EPS – expanded polystyrene

EU – European Union

IP – investment plan

LEI – Lithuanian Energy Institute

LDHA – Lithuanian District Heating Association

SH – space heating

Definitions

Expression	Definition
District heating	*"<…> a network of pipes connecting the buildings in a neighbourhood, town centre or whole city, so that they can be served from centralised plants or a number of distributed heat producing units"* (Lund, et al., 2014)
Dwelling	A self-contained unit of accommodation used by a person or a group of persons as a home; a place of residence
Household	A person living alone or a group of persons who share the same dwelling and expenditure
Individual heating	A system when heat is supplied from a local heating source, i.e. individual boilers or other type of individual heating (stove, fireplace), equipped in a building or a dwelling
Individual house	Building for one or two dwellings
Marginal cost	In this paper, the change in total cost of heat production or implementing heat saving measures when one additional unit of saved energy is achieved
Multi-apartment building	Building for more than two dwellings
Renovation	In this paper, a process of returning a building to a good state as well as improving its energy performance, by adding insulation or new systems, such as heating system, that a building did not have before
Specific heating demand (kWh/m^2)	In this paper, total annual heat energy needed for 1 m^2 of dwelling for the purpose of space heating or domestic hot water

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1 Problem Formulation

Today the European Union (EU) is facing challenges of increased dependence on energy imports, which threatens both EU's economy due to negative EU energy trade balance, and security of supply due to oil and gas imported to a large extent from politically unstable regions. Moreover, there is a sound need to mitigate climate change, which arises from extensive use of fossil fuels for energy production (EC, 2012).

To fight those challenges, a substantial focus and effort is put on improving efficiency of energy supply systems and expanding energy production from renewable sources, i.e. wind, solar, biomass, etc. However, the demand side is a determinant factor and should not be overlooked when designing sustainable future energy solutions. Energy conservation and efficiency measures can *"<…> ease the pressure on biomass resources and investments in renewable energy* <...>*"* (Lund, et al., 2014).

As a fact, energy use in buildings amounts for the biggest share of the total primary energy use in the EU and thereby causes large amount of carbon dioxide (CO_2) emissions. Both space heating and domestic hot water constitute a significant share of final buildings energy consumption (IEA, 2013). With regard to this, the EU has recognised that *"<…> the existing building stock represents the single biggest potential sector for energy savings"* (EC, 2012). The question is how to realise these savings in the near future in the most cost-effective way.

1.1 Heat Consumption Trends

In 2013, the existing building stock was responsible for 41% of the total EU's final energy consumption and 36% of CO_2 emissions in the EU (Eurostat, 2015). According to International Energy Agency (IEA), the overall energy consumption in EU buildings increased by 0.9% per year between 1990 and 2010 and, if no action is taken to improve energy efficiency in the building stock, it is expected to increase by 50% by 2050 (IEA, 2013)[pp.10;72].

The demand for space heating and domestic hot water in the building stock is a major component of the buildings final energy consumption in the Union, accounting for about 80% in residential buildings and 52% in non-residential buildings, leaving the rest for space cooling, lightning, cooking and other purposes. Space heating is of particular importance, amounting for 66% of residential energy use and about 40% of services energy consumption. (IEA, 2013) The distribution is illustrated in Figure 1.

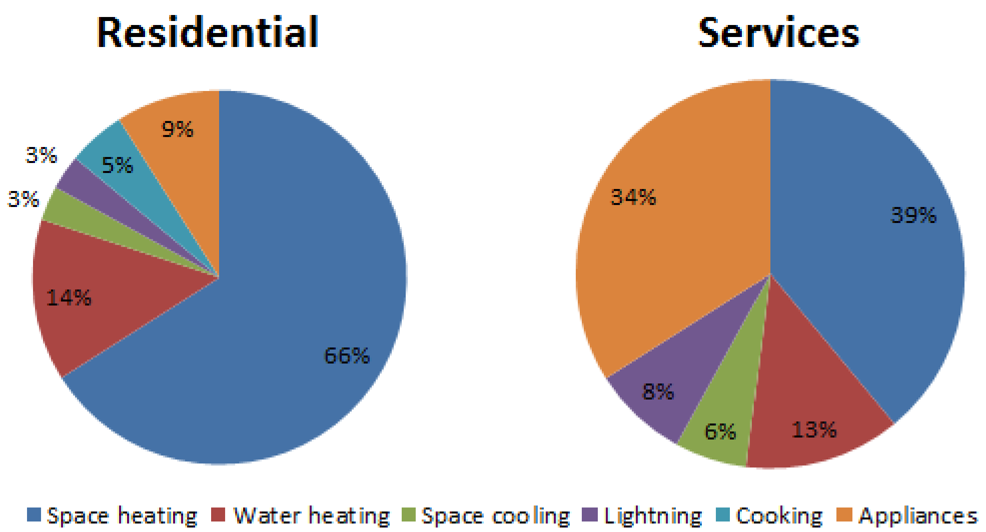

Figure 1: Energy consumption in residential and services sub-sectors for EU27 (2010)

Source: (IEA, 2013)

While domestic hot water demand is assumed to be equally intense in most EU countries, accounting for 10-15% of the final buildings energy consumption (IEA, 2013), space heating varies considerably by several factors.

Firstly, it depends on region and its climatic conditions. The colder Nordic states and Eastern Europe regions with the drier continental climate tend to have higher number of heating degree days[1] comparing to the rest of Europe. Western Europe coastal regions tend to have the milder climate, whereas warmer Mediterranean regions have growing demand for space cooling. (IEA, 2013)

Secondly, energy use is strongly linked to the buildings' age. The EU's building sector is characterised by a high share of old and inefficient buildings, imposing a burden of high heat demand (IEA, 2013). Almost 40% of all residential buildings in the EU were built before 1960 and nearly 84% are at least 20 years old (IEA, 2013), suggesting that the majority of building stock might not meet recent building codes or provide adequate indoor climate conditions, as well as might threaten higher heating bills.

Finally, the building sector tends to expand over the years, which is bound to increase its energy consumption further (EC, 2010). Therefore, an increasing EU's attention is given to achieving energy savings in the future, as described in the following section.

[1] Heating degree days – the dimension designed to reflect the energy demand needed to heat a building. It is the number of degrees that a day's average ambient temperature is below comfort temperature inside the building, i.e. the temperature below which a building needs to be heated.

1.2 EU Policy

Improvement in buildings' energy efficiency and thereby achieving energy savings have been recognised by the EU as a crucial factor in attaining the Union's goal of reducing greenhouse gas (GHG) emissions by 80-95% by 2050 compared to 1990 (EC, 2012).

In this connection, designing low-energy buildings, such as energy-efficient buildings or nearly zero-energy buildings (ZEBs), is significantly emphasised by the EU. The Energy Performance of Buildings Directive (EPBD), introduced in 2002, set the requirement for the EU member states to enhance building regulations by establishing minimum energy efficiency requirements and to introduce energy certification schemes. Furthermore, with a recast in 2010, the EPBD requires all new public buildings and all other buildings to be nearly zero-energy by the end of 2018 and 2020 respectively. (IEA, 2013)

However, considering that half of the currently existing building stock is expected to still be standing in 2050 and taking into account that buildings can last for over 100 years (IEA, 2013), actions should not be limited to tightening regulations on new constructions. Since large potential exists in existing buildings to achieve energy savings, the rate of implementing renovations and upgrading the existing building stock has to be increased. It is outlined in Energy Efficiency Directive (EC, 2012), which sets the obligation for member states to *"<…> establish a long term strategy for mobilising investment in renovation of the national stock of residential and commercial buildings <…>"*. It is up to member states to identify a cost-effective approach to renovations, considering building types and climatic conditions, as well as to ensure effective policy measures to stimulate the transition, thereby reducing extensive heat consumption in the existing building sector.

The main steps to exploit potentials of reducing heat demand is to improve envelopes of existing building stock and upgrade heating equipment (EC, 2012), which will then reduce the burden of the heat supply side and thereby primary energy use as well as CO_2 emissions. However, heat conservation measures involve significant investments (Connolly, et al., 2013)[p.112]. Therefore, it is crucial to analyse to which extent heat should be saved within the building by involving such an investment rather than supplied by the future energy system, thereby indicating the least-cost heating strategy.

Strategies can vary a lot from country to country regarding their climate, condition of the building stock as well as energy supply systems. Heat saving strategy has been discussed for Denmark's case in (Lund, et al., 2014), where it is concluded that a suitable least-cost heating strategy for Denmark's future smart energy system is to reduce heat demand for space heating and domestic hot water by approximately 50% for new buildings and existing buildings which are being renovated anyways.

In this paper, it is attempted to uncover the least-cost balance between end-use heat savings and heat production in the future energy supply system for Lithuania, which is shortly presented in the following section.

1.3 Case of Lithuania

Lithuania is a member state of the EU located in the North-East Europe with moderately cold climate. The country tends to have a high number of heating degree days (IEA, 2013), which accounted for 3,931 in 2009 (to compare, for the same year in Denmark it accounted for 3,235 due to milder climate, while in colder Sweden it reached 5,291) (Eurostat, 2015). In Lithuania, the final energy consumption for heating purposes in the building sector is a particular issue due to the following reasons.

First of all, one of the main problems in the heating sector in Lithuania is inefficient heat consumption in the building sector and thereby too much money spent on heating. The average annual heat consumption in Lithuanian buildings reaches 209 kWh/m^2, which is significantly higher comparing to Scandinavian countries where it accounts for 128 kWh/m^2 (Ministry of Energy, 2012). The issue is closely related to energy performance of Lithuania's building stock. For instance, the majority of multi-apartment buildings in Lithuania were built before 1993 according to already outdated building codes. Therefore, most of these buildings are uneconomical and consume a significant amount of heat. (Alchimovienė, et al., 2011)

Secondly, the Lithuania's heating sector lacks diversification and is heavily dependent on imported natural gas from Russia. In 2012, around 70% of district heating in Lithuania was based on natural gas (Ministry of Energy, 2012), which is a great threat to Lithuania's security of energy supply. Moreover, natural gas prices regulated by the single gas supplier "Gazprom" are unpredictably increasing over the years. As a fact, in the period 2005-2011 natural gas prices increased 3.5 times, which threatens the population with high heating bills (Murauskaitė, et al., 2013). As a result, in the period of 2006-2010, district heating prices grew from 34.7 to 66.6 EUR/MWh (LRP, 2011) and have currently reached over 72 EUR/MWh (LDHA, 2015).

The latter is a particular threat due to rather low disposable income in Lithuania (Eurostat, 2015), causing a risk of fuel poverty, which defines *"<…> the inability of people to keep their home adequately warm, to pay their utility bills and to live in a dwelling without defects* <...>*"* (BPIE, 2014). In 2012, over 30% of people in Lithuania were identified to be at risk of fuel poverty, which is above the EU28 average (25%) and takes the fifth place regarding the worst situation. Moreover, 38.2% of population is unable to keep their dwellings adequately warm. (BPIE, 2014) To make things worse, household expenses for space heating in Lithuania are significantly higher compared to other EU countries: for 50 m^2 dwelling, it accounts for 13.3% of total household expenses in Lithuania, while it reaches 8.0% in Estonia and only 1.5% in Scandinavian countries (Ministry of Energy, 2015).

With regard to this, the Lithuanian government has taken initiatives to promote heat savings within the building stock as well as to ensure a well-functioning and more sustainable heating supply system, which is also in line with the EU policy. However, the above mentioned issues stress the need to find the least-cost way of reducing heat demand in the building sector in Lithuania, thereby reducing dependency on imported fuel as well as financial burden faced by end-users.

1.4 Research question

The previous sections have shown that 41% of final energy consumption in the EU is due to the building sector, where heat demand for space heating and domestic hot water constitutes the major part of end-use energy demand. Due to a high share of existing old and inefficient buildings, there is a large potential of heat savings within the building sector, stressing a need for heat conservation. However, heat saving measures require significant investments and therefore, it should be analysed to which extent heat should be saved rather than supplied, in order to indicate the least-cost heating solution for the future energy system.

This paper analyses the case of Lithuania, where the heating sector is of particular importance due to considerable share of energy inefficient buildings, resulting in significant heat losses and therefore a substantial amount of money wasted on heating. Moreover, it causes an extensive use of fuel, which currently leads to the dependency on single fuel supplier, thereby imposing energy supply insecurity. As a solution to the above, the least-cost heating strategy is attempted to be found for the future energy supply system in Lithuania, for 2030 optionally.

Based on the findings, the following research question is formulated:

"What is the least-cost heating strategy in the future energy system in Lithuania, comparing marginal cost of heat production with marginal cost of heat savings in both existing and new buildings, and what are the barriers towards successful buildings renovation?"

In order to clarify the research question, the following questions arise:

1. What is the current situation of the Lithuania's heat supply system, the building stock and its heating characteristics?
2. What are the future prospects of the energy supply system and growth of the building stock?

3. What are the marginal costs of future heat supply and end-use heat saving measures?
4. What are the social, financial and legal barriers to implementing successful renovation of existing buildings as a part of the least-cost heating strategy in Lithuania, with a focus on multi-apartment buildings?

It should be emphasised that in this paper, heat savings always refer to *end-use* heat savings, i.e. measures implemented within the buildings. Also, only reductions in heat demand for space heating are analysed, since it represents a considerable potential of heat energy savings.

1.4.1 Delimitations

In order to limit the extent of this research, the following boundaries are set:

- End-use heat savings related to domestic hot water are not looked into and the sole focus is given to reduction of heat demand for space heating.
- District heating infrastructure expansion is not analysed in the report and the same current level is assumed in the future scenarios.

2 Methodology

In order to find the least-cost heating strategy in the future energy system, a balance between heat demand and heat supply has to be defined. Heat conservation is vital and should be carried out not only for energy-related benefits, but also for improved indoor climate, *"<…> increased living comfort and operating ease, protection against external noise, additional safety, lower occurrences of respiratory illnesses, and improved leasing potential or betterment"* (Jakob, 2006). However, implementation of energy saving measures is feasible until the price of saved energy is lower than that of the purchased one. If this point is reached, further investments in heat saving measures only increase energy consumption costs.

To identify an optimum point in the study, marginal heat production costs are analysed and then compared to marginal heat saving costs, following a similar methodology as described in (Lund, et al., 2014), where the investigation is carried out for the Denmark's future energy system.

Marginal cost represents the change in total cost of heat production or implementing heat saving measures, when one additional unit of saved heat energy is achieved. In general, total annual cost of heat production is decreasing along with heat savings implementation, since less fuel is consumed and lower heat production plant capacity is needed, whereas investment in energy-efficient renovation is increasing as more heat savings are achieved.

For the analysis, a few questions need to be considered though. Firstly, heat production cost depends on which energy system is addressed. It is important that heating strategies should be constructed for the future energy system and not for the present one. Moreover, the results largely depend on the future energy system context and thereby, which path of the energy sector development is chosen as well as how the building sector is expected to evolve in the future. Due to the Union's goal of reducing dependency on fossil fuels and thereby GHG emissions, today's energy systems have to undergo a major transition towards more sustainable and renewable energy based systems in the future. It is argued that such future systems, supplemented by energy savings, can have significantly positive socio-economic results (Lund & Mathiesen, 2009). In this study, Lithuania's energy system in 2030 is modelled in relation to the consultative study for the upcoming National Energy Strategy, which has been formulated by Lithuanian Energy Institute (LEI) and which focuses on rational deployment of local renewable energy sources and security of energy supply (LEI, 2014a).

Secondly, it is very important how costs of heat saving measures are defined. Since heating strategy is designed for the future energy system and due to extensive lifetime of the building stock, both existing and new buildings are taken into consideration. The important point in the study is that the cost of investment highly depends on whether it is heat conservation in existing buildings or an additional investment in new buildings. Moreover, for the existing buildings, it is important whether an investment is made solely for the heat conservation purpose or as a part of renovation, which will be carried out anyways. It is assumed that in case of buildings being renovated anyways, only material cost and marginal labour force cost is relevant, whereas for buildings which are not planned for renovation, total cost including expenses on energy-efficient renovation as well as supplementary works is taken into consideration (Wittchen, 2009). The idea is that adding insulation in the buildings which are being renovated anyways (marginal) is cheaper than paying for all the costs (total). For new buildings, marginal heat saving costs are represented as additional investments.

Furthermore, there is a difference which building type and heating solution is addressed. As can be seen later in Table 5, individual houses and multi-apartment buildings are evenly typical residential buildings in Lithuania. Moreover, it is common that individual houses have individual heating solutions while multi-apartment buildings are connected to district heating systems (see Section 3.2), and therefore it is relevant to analyse them separately. As far as public buildings are concerned, in (Lund, et al., 2014) it is argued that these buildings might show sufficient energy efficiency. Therefore, heat saving analysis is based on individual house and multi-apartment building types, which are expected to be the most expensive to renovate. Thereby, for the total building stock, more buildings are expected to be feasible to renovate.

Currently, in Lithuania a significant focus is being given to multi-apartment buildings and their renovation, yet no solid forecasts are present for individual houses. The Lithuanian government has a vision to reduce heat consumption in multi-apartment buildings built before 1993 by 20% by the year 2020 (LRP, 2011). More detailed prospects for renovation of multi-apartment buildings are indicated in the above-mentioned study prepared by LEI, where until 2030 renovation is expected to be implemented for nearly entire stock of old buildings, 70% of buildings that consume substantial amount of heat and 40% of buildings that consume moderate and low amount of heat (LEI, 2014b)[pp.80-81] (division of multi-apartment buildings are described in Table 7). However, the fact that in the period of 2004-2011 only 760 multi-apartment buildings (around 2% of total amount) have been fully renovated (Biekša, et al., 2011), indicates a huge improvement needed in implementing these goals. Even though a number of small-scale renovations have been carried out over the last decade, where around 60% of windows and door has been changed, 30% of balconies have been glazed and 80% of district heating substations have been renovated and equipped with automatic heating control devices (LRP, 2011), larger-scale renovations need to take place.

Figure 2 contains an overview of different steps carried out throughout the analysis. The overall analysis is divided into *supply* and *demand* sides, where heat production and heat savings are analysed respectively. To identify marginal heat production costs in the future energy system, future energy system scenario is designed in the *EnergyPLAN* software. For the modelling, reference data of energy system in 2010 is used, while future prospects are based on the above-mentioned consultative study. Calculations of marginal heat saving costs include an analysis of heat saving measures for different types of buildings and their contribution to reducing heat demand, taking reference heat demand as a point of departure and using *Microsoft Excel*. Finally, the costs of heat supply are compared to the costs of heat demand reductions in terms of annualised marginal costs.

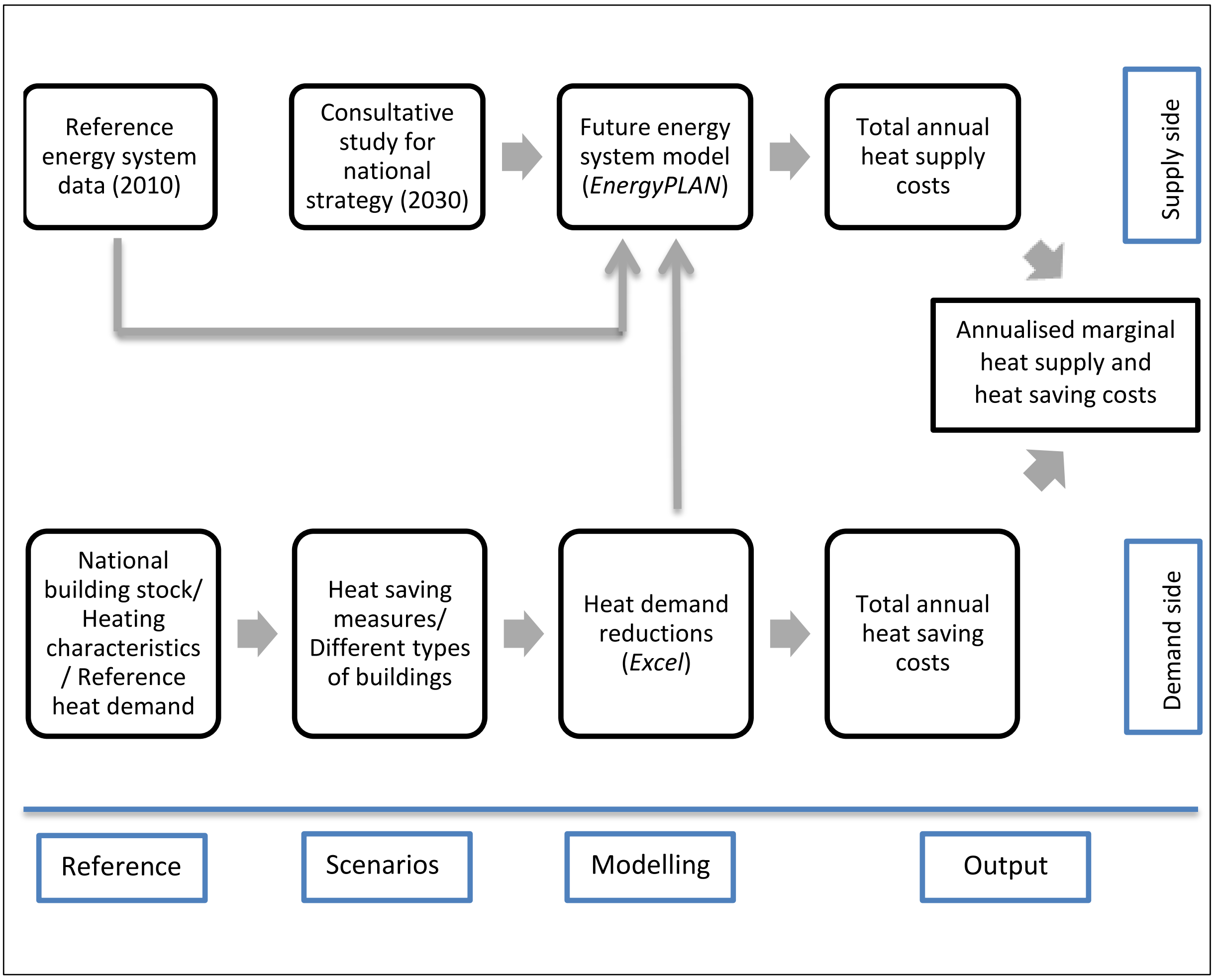

Figure 2: Methodology carried out in the analysis

After identification of the least-cost heating strategy, the analysis of potential barriers towards its successful implementation is carried out, with a focus on multi-apartment buildings renovation.

In the following sections, the methodology needed to answer the research question and used throughout the study is presented in more detail.

2.1 Energy System Analysis

To evaluate the effect of heat savings in the future energy system and to identify marginal cost of heat production, the future energy system is defined first and modelled afterwards applying the *EnergyPLAN* software.

The software is designed to make an integrated analysis of the national energy system operation, simulating and optimising the dynamics between the supply and demand sides of heat, electricity, industry and transport sectors on an hourly basis. Apart from technical energy system analysis, the software enables to do an economic evaluation. One of the reasons of choosing this software is that previously *EnergyPLAN* has been utilised in a number of energy system analyses, such as simulation of a 100% renewable energy system for Denmark, described in (Lund, et al., 2011), or identification of the least-cost heating strategy in the future Danish energy system, described in (Lund, et al., 2014). Figure 3 represents a schematic overview of the *EnergyPLAN* model and the interconnections between energy sources (left side), energy conversion units (centre) and demands (right side).

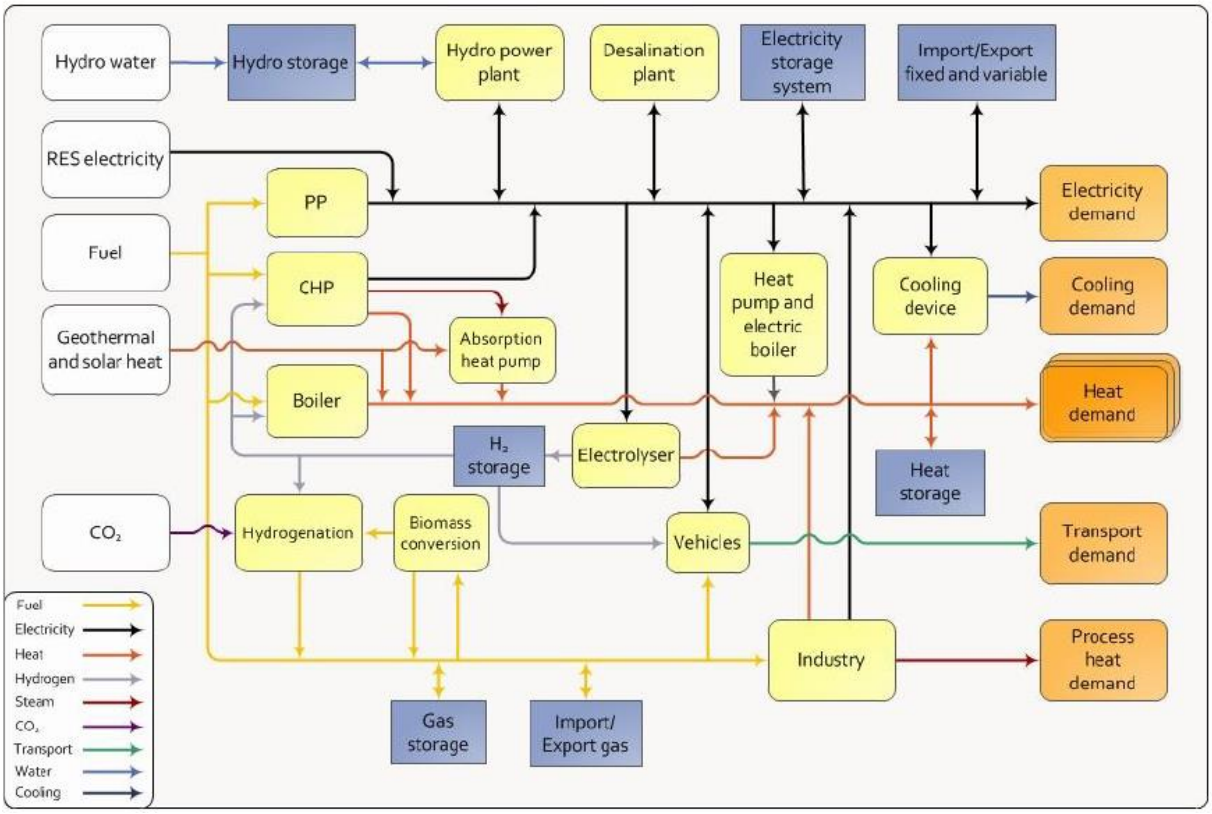

Figure 3: Schematic diagram of the *EnergyPLAN* model

Source: (Lund, 2015)

EnergyPLAN is an input/output model. Inputs include energy demands and energy productions from renewable energy sources, which are expressed as actual hourly distribution curves (typically found as historical data), as well as energy plant capacities, relevant costs, etc. The main outputs are annual energy productions, fuel consumptions, CO_2 emissions, import/exports and total costs. (Lund, 2015)

The software enables to analyse the consequences in terms of technical and market-economic simulations. Market-economic simulation identifies the least-cost solution based on the short term business-economic costs of each production unit. Meanwhile, in case of using technical simulation strategy, combination of technical and cost data for different technologies makes it possible to identify the least-cost solutions for the whole energy system in a long-term perspective. (Lund, 2015) Therefore, technical simulation is carried out in this analysis, where units operate to continuously meet and balance heat demands.

By using the *EnergyPLAN* software, the socio-economic feasibility is calculated as annual costs of investment, fuel and operation and maintenance, taking into account certain lifetime and interest rate. The equation of total annual costs for a production unit is described as following (Lund, 2015):

$$A = A_{investment} + A_{FOC} + A_{fuel} = I \cdot \frac{i}{1-(1+i)^{-n}} + I * P_{FOC} + A_{fuel} \tag{1}$$

Here: $A_{investment}$ – annual cost of investment;

A_{FOC} – annual fixed operational cost;

A_{fuel} – annual fuel cost;

I – total cost of investment, found by multiplying the number of units by the cost of one unit (e.g. the unit for CHP is MW and the cost is given in EUR/MW);

i – interest rate;

n – lifetime given in years;

P_{FOC} – annual fixed operation and maintenance share of the investment cost.

In the analysis of the future energy system, investment and fixed operational costs as well as lifetimes of production units are taken from Danish Technology Data catalogue (Energistyrelsen, 2012a) for large power plants and from catalogue (Energistyrelsen, 2012b) for individual heating plants, for the year 2030. Prices of individual boilers are verified with Lithuanian prices; however there is no available data regarding costs of large energy conversion units in Lithuania.

Fuel prices are essential in this study and are taken from the report published by LEI for the year 2030 (LEI, 2014b)[pp.106-110], which is the same report used to define Lithuania's future energy system scenario. Due to extensive dependency on natural gas supply and sensitivity to its price fluctuations, in the document two different natural gas future price scenarios for Lithuania are applied: 1) high price scenario and 2) moderate price growth scenario. Further, it is shortly described how the prices in the scenarios are defined by LEI.

In the first scenario, long-term fuel price forecasts are based on the U.S. Energy Information Administration report *Annual Energy Outlook 2013* main scenario, where crude oil and oil products price trends are outlined. Natural gas prices are then calculated by using the existing contractual formula, which is directly linked to the price of fuel oil and diesel in the world's oil market. Biomass price trends are estimated on the basis of several internal and external factors, such as:

- Increasing biomass demand in the domestic market;
- Deployment of more expensive types of biomass due to increased overall demand;
- National obligations to increase the use of renewable energy sources, thereby increasing the demand in international markets.

The temperate price growth scenario is based on International Energy Agency report *World Energy Outlook 2013*, where the growth in oil and especially natural gas prices is less intense than in the previous scenario. Consequently, lower natural gas prices are expected to have an impact to biomass competitiveness and its prices as well. Fuel prices in 2030 of both high price and moderate price growth scenarios are given in Table 1.

Table 1: Fuel prices in 2030

Fuel	Fuel price, [EUR/GJ]	
	High price scenario	**Temperate price growth scenario**
Fuel oil (non-sulphurous)	16.7	16.4
Natural gas	14.1	12.0
Wood biomass	7.0	6.1
Wood waste	4.6	4.3
Coal	6.6	6.4
Peat	3.8	3.4
Firewood	5.0	4.9

Source: (LEI, 2014b)

The average price of wood biomass and wood waste is used in calculations for district heating plants, since it is the most common types of biomass to date; 5.8 EUR/GJ and 5.2 EUR/GJ in two above mentioned scenarios respectively. For individual houses, firewood price is used. Since a shift from natural gas to local biomass in the Lithuania's future energy system is essential, these two prices are of the highest importance. As can be seen, biomass price is 2-3 times lower than natural gas.

As far as electricity prices are concerned, the Nordic power market (*Nordpool)* is expected to shape electricity price in Lithuania the most, once Lithuanian electricity system is connected to Sweden in 2020. Based on LEI predictions, electricity price in the *Nordpool* market is expected to reach 50 EUR/MWh in 2030 in the basic scenario. (LEI, 2014b)[pp.156-157]

Since it is a socio-economic calculation, taxes are disregarded. CO_2 cost of 30.6 EUR/t is used for 2030 and taken from (Lund, et al., 2011)[p.61].

Socio-economic costs are calculated with a discount rate of 3%, since it is argued that *"<…> a low discount rate should be applied for investments in infrastructure with a long lifetime and positive socio-economic effects"* (Sperling & Möller, 2012). 3% discount rate is used in a number of studies, such as Denmark's 100% renewable energy system analysis, and is thus applied in this paper as well.

2.2 Heat Saving Analysis

As far as heat saving analysis is concerned, to find the least-cost heating strategy for the building stock in Lithuania in 2030, both existing and new buildings are analysed. Multi-apartment buildings and individual houses are investigated separately due to the difference in their heat supply solutions. Calculations are done in *Microsoft Excel*.

First, two models are constructed: a typical five-storey multi-apartment building, taken from (Ruzgys, et al., 2013), and a typical two-floor individual house. Their characteristics are presented in Table 2.

Table 2: Characteristics of chosen multi-apartment building and individual house

Areas of building's elements		
Heated floor, [m^2]	2,300	126
External walls, [m^2]	2,000	149
Roof, [m^2]	620	72
Windows, [m^2]	450	20

Source: (Ruzgys, et al., 2013)

Further elaborates on the main equations that are used in heat saving calculations. Firstly, according to Lithuanian Technical Construction Regulation (LRP, 2008), heat losses related to space heating are calculated as a sum of losses through outer walls, roof, floor, windows as well as heat losses related to natural ventilation.

Heat losses through envelope Q_{en}, [kWh/year], are calculated as follows:

$$Q_{en} = \sum (A_i \cdot U_i) \cdot \Delta T \cdot t \cdot 24 \cdot 10^{-3} \cdot 1.1 \qquad (2)$$

Here: A_i – area of i part of envelope (i can be wall, roof, floor, window), [m^2].

U_i – heat transfer coefficient of i part of envelope, [$W/m^2 \cdot K$]. In the study, correction factors for U value are neglected due to their minor significance, which otherwise should be included following the methodology given in (LRP, 2005a).

ΔT – difference between indoor temperature and ambient temperature during heating season, [°C]. Used values: indoor temperature – 18°C, average ambient temperature – 0°C (LR, 1995), temperature of basement – 5°C.

t – duration of heat demand for space heating, [days]. Normally, heating season lasts for ~220 days (LR, 1995).

1.1 – coefficient to evaluate heat losses through thermal bridges, which usually add around 10%. According to (LRP, 2005a), it can be found in a detailed way, taking into account each type of thermal bridges, yet in this study there is no need to do that.

Heat losses due to natural ventilation Q_{nv}, [kWh/year], are calculated as follows:

$$Q_{nv} = n \cdot V \cdot \mathrm{c} \cdot \rho \cdot \Delta T \cdot t \cdot 24 \cdot 10^{-3} \qquad (3)$$

Here: n – change of air due to natural ventilation, [h^{-1}]; normally n = 0.67 h^{-1}.

V – volume of living area (area multiplied by room height, which is usually 2.7m), [m^3];

c – specific heat of air; $c = 0.279$ Wh/kg·K.

ρ – density of air; $\rho = 1.2$ kg/m^3.

After adding additional insulation for envelope elements (wall, roof or floor), new heat transfer coefficients are found according to the following equation:

$$U_{new} = \frac{1}{R_{old} + R_{new}} = \frac{1}{\frac{1}{U_{old}} + \frac{1}{U_{new}}} \quad (4)$$

Here: R – thermal resistance, inversely proportional to heat transfer coefficient, [$m^2 \cdot K/W$].

Nowadays, the biggest focus is given to heat savings related to thermal resistance improvement and heating system upgrading. However, mechanical ventilation is another measure which can achieve heat savings and is discussed further.

Fundamentally, ventilation is a tool to ensure adequate air change in buildings, which falls in the range of 0.5 and 1.0 h^{-1} for residential buildings (Gudzinskas, et al., 2011). According to norms (LRP, 2005b), 1.8 m^3/h per m^2 is recommended in living and dining rooms in residential areas, which is around 0.67 h^{-1}. Moreover, ventilation is particularly necessary after the envelope renovation, when lack of air change and moulded walls become an issue (Staskevičius, 2015).

Natural ventilation is the most common in existing residential buildings and the simplest solution that does not require any investments and installations, meaning that the normative air change rate is ensured by opening windows or air vents regularly. Also, in case of low energy efficiency buildings, fresh air gets into buildings through thermal bridges, leaky windows and door, and is then extracted through natural draft ventilation channels in inner walls or by case-by-case installed mechanical exhaust from toilet, bathroom or kitchen. Natural ventilation however requires regular residents' attention (opening windows regularly) and causes additional heat consumption from radiators due to the need to heat the incoming colder air.

Therefore, mechanical ventilation is an alternative solution to ensure adequate air change and at the same time to reduce heat demand by recovering a considerable amount of heat used to warm up the incoming air. It is indicated that at a certain point, further heat savings can be achieved only if natural ventilation is replaced by mechanical ventilation (Aggerholm, 2013).

When it comes to the heat saving analysis in this study, a few considerations arise based on the above. One is whether the whole investment cost should be appointed to heat saving measures, if mechanical ventilation is installed, since ventilation also provides other benefits in terms of improved indoor climate. The second consideration is whether the mechanical ventilation should be included in renovation packages at all, since to date these systems in Lithuanian residential buildings are uncommon due to required investments. As it is calculated and concluded in (Lund, et al., 2014), the marginal cost of the step of including mechanical ventilation creates a bulge that it never pays to pass. The similar phenomenon is also expected in Lithuania, yet it is not verified due to lack of time and difficulty to obtain investment costs of mechanical ventilation in residential buildings.

Based on the above, mechanical ventilation is considered neither in existing buildings, nor in new buildings. However, it should be taken into account that in the future, buildings have to meet high energy efficiency requirements, which call for mechanical ventilation with heat recovery, as one of possible measures to achieve it.

2.2.1 Existing Buildings

In reality, the extent of renovation depends on each building individually and therefore a detailed analysis is needed to find the most energy- and cost-efficient solution for each case. In this study though, calculations are simplified. The following building elements and the most common energy efficiency improvements according to (Sistela, 2014) are considered when looking into renovation, for both multi-apartment buildings and individual houses:

- Wall insulation (including socle) – 200 mm expanded polystyrene (EPS) (EPS is chosen as the most common insulation material in residential buildings, cheap and easy to install);
- Roof insulation – 160 mm EPS;
- Floor insulation – 60 mm EPS;
- Windows – efficient windows with heat transfer coefficient of 1.2 $W/m^2 \cdot K$.

Renovation prices are taken from an issue *Recommendations for price calculation of building renovation (modernisation)* (Sistela, 2014), which is published by *Sistela*, a leading construction pricing company in Lithuania. The issue is prepared in accordance with national Technical Construction Regulations and their calculation principles, is recommended for economic assessment of investments and has to be followed for public procedures in the country. This is a simplified version, where agglomerated renovation prices are presented. The prices are given in 2014 value without VAT and are based on primary information from country's manufacturers, wholesalers and construction contractors. Therefore, the prices are expected to reflect rather real market situation.

In the document, different renovation measures of individual envelope elements and engineering systems are described. In each case, 1 m^2 renovation cost is given, which is divided into the following:

- Material (including all purchase and delivery costs);
- Machinery operation;
- Labour force and social insurance;
- Costs related to building lot.

The given costs include a complete renovation work, meaning not only the energy efficiency improvement part, but also supplementary works, i.e. preparation and completion works, such as cover layer, decoration, etc.

It is therefore important to notice that for buildings being renovated anyways, only the costs of material and marginal labour force are taken into account in calculations, as they reflect the cost of additional energy efficiency improvements. Whereas for buildings which are not being renovated, initialising and closure of the renovation should be also considered and therefore total costs are relevant in calculations. However, distribution of costs in (Sistela, 2014) is rather general and thus the costs of material as well as marginal labour force related to energy efficiency improvements for the buildings being renovated anyways are identified as an approximation. A total given material cost is used in calculations, assuming that a certain part of material cost, which is not related to energy efficiency improvements, is replaced with equal marginal labour force cost.

Investment costs as well as lifetimes of each improvement are given in Table 3. The same lifetimes as in (Lund, et al., 2014) are used and taken from (Aagaard, et al., 2013). To find the annual cost of investments, the annuity formula is applied again, as for the investments of energy conversion units (see Equation 1), with the interest rate of 3%.

Table 3: Costs of renovation related to envelope improvements

Measure	Characteristics	Material and marginal labour cost, [EUR/m^2] material	Total cost, [EUR/m^2] material	Lifetime, [years]
Wall	200 mm EPS	36.03	75.10	60
Roof	160 mm EPS	42.17	65.34	40
Floor[2]	60 mm EPS	13.89	27.57	60
Windows	1.1-1.3 W/ m^2·K	0	139.14	40

Sources: (Sistela, 2014), (Aagaard, et al., 2013)

It is seen in Table 3 that total costs are higher than material and marginal labour costs. Material and marginal labour cost for windows is equal to zero, since replacement of windows, which is being carried out anyways, at the same time includes energy efficiency improvements.

Apart from heat reductions due to improved thermal resistance of existing buildings envelope, heating system renovation might be also carried out to improve heating efficiency, including a number of measures such as renovation of district heating substations, replacement or improvement

[2] Insulation is put on basement ceiling

of pipes insulation, replacement of radiators, system balancing and installation of thermostats to ensure individual heat flow regulation and individual metering.

As far as multi-apartment buildings are concerned, the most needed measure is balancing the heating system. Today, older one-pipe heating systems encounter a problem of unequal heat flows in risers (vertical pipes). Consequently, dwellings close to district heating substation are overheated, whereas the ones far from substation are not warm enough. Balancing the system can be ensured by, e.g. installing automatic flow limiters (Danfoss, 2013).

Another needed measure is individual heating control, since today in the majority of multi-apartment buildings one-pipe heating system does not enable to do this. To date, individual heat consumption is found as the total heat consumption in a multi-apartment building, divided proportionally among apartments according to their heated area, which though does not reflect actual heating in each dwelling (Juodis, et al., 2009); even though corner apartments might face higher heat losses compared to inner apartments, their countable heat consumption is the same if heated area is identical in both apartments. A solution is an installation of thermostats and individual metering, which today are present only in new buildings and some of those which have undergone renovation (Juodis, et al., 2009).

To solve the above mentioned problems, *Danfoss* solutions are analysed in the brochure of already implemented renovations in Lithuanian multi-apartment buildings (Danfoss, 2013) and an installation of thermostats and automatic flow limiters are chosen. Based on the actual implemented renovation for similar five-storey building, the approximate investment cost is 6.22 EUR/m^2 (excluding VAT) of heated area and reduction in heat consumption is 30%. However, 30% refers to the building without improvements in thermal resistance. In this study, it is assumed that heating system renovation is carried out after improved insulation and therefore, around 15% reduction in heat demand for space heating is achieved. The lifetime of heating system elements such as valves or thermostats is 15 years (Ministry of Environment, 2001). Balancing the heating system and installing thermostats can be fully attributed as a measure for the heat conservation purpose, which is not regarded as a measure that one would carry out anyways. Therefore in both cases, for buildings being renovated anyways and not being renovated, full cost is included.

For individual houses, heating system imbalance is expected to be minor due to small-scale systems and therefore, heating system renovation is not included in the renovation packages.

2.2.2 New Buildings

For new buildings, marginal heat saving costs are calculated as additional investments. Energy efficiency improvements due to better insulation of outer walls, roof and floor as well as installation of more efficient windows are analysed. Investment costs of insulation (EPS) are taken from *Lemora* website (Lemora, 2015), which is one of the biggest wholesalers of construction material in Lithuania. Costs of efficient windows are found in (TavoLangai, 2015). Prices without VAT are shown in Table 4. To find the annual costs of investments, the same annuity calculations with 3% interest rate are carried out.

Table 4: Costs of envelope improvement in new buildings

Measure	Characteristics	Material cost, [EUR/m^2] material	Lifetime, [years]
Wall insulation (EPS 70)	100 mm	3.97	60
	150 mm	5.94	60
	200 mm	7.93	60
Roof insulation (EPS 80)	100 mm	4.37	40
	150 mm	6.55	40
	200 mm	8.74	40
Floor insulation (EPS 70)	100 mm	3.97	60
Windows	0.95 W/ $m^2 \cdot K$	61.23	40
	0.74 W/ $m^2 \cdot K$	85.65	40

Source: (Lemora, 2015), (TavoLangai, 2015)

2.3 Barrier Analysis

In the study, barrier analysis is carried out with relation to multi-apartment buildings renovation. Individual houses are not investigated though, due to the time restriction. To identify the main potential barriers, a stakeholders' analysis is done first and interviews with identified actors are conducted afterwards. These methods are described in the following subsections.

2.3.1 Stakeholders' Analysis

A short stakeholders' analysis is made to point out the relevant actors, when considering the renovation process of multi-apartment buildings, taking into account the existing governmental renovation programme, presented in Subsection 7.1.2. Analysis is done in order to get an idea of actors' interests and goals, role and possible influence to the renovation process and thereby to find the key actors and problems they might create or encounter.

14 stakeholders are identified due to long value chain of the process and are described in Section 7.1. These are not necessarily the only actors who might be considered as relevant, yet the most obvious. Stakeholders are also assessed in terms of their influence and interest in the process and placed in the diagram, which can be found in F Appendix. It should be emphasised that the decision of interest/influence rates is subjective and based solely on the author's opinion.

Information about stakeholders' characteristics and relations is found through the literature study, based on conducted interviews and author's general knowledge.

2.3.2 Interviews

Conducting interviews is a common and useful tool to get the primary data. In the study, communication with relevant actors and opportunity to hear their experience and opinion gave an insight into the actual renovation process, which otherwise would be difficult to obtain from secondary sources.

It is interesting to assess, what issues are pointed out by different stakeholders with different backgrounds and functions in the whole process. For this reason, the following stakeholders are chosen to interview: investment plan maker, chairman of the community, responsible consultancy BETA and Lithuanian Building Association. In general, more stakeholders could have been interviewed if given more time. For instance, other investment plan makers or chairmen of communities as well as residents and municipalities might provide different information due to the difference in their experience. Also, less involved but competent stakeholders, such as the president of Lithuanian District Heating Association, could have been contacted in order to hear an objective opinion about the renovation process as well relevant issues of the heating sector in Lithuania.

The conducted interviews are semi-structured, meaning that the main questions are prepared for the interview, but the whole process is flexible and depends on the flow of conversation. In this way, the discussion between the interviewer and the respondent is created, giving enough time to elaborate on the topic as well as give broader and more detailed answers.

Two interviews were conducted via Skype, while two other stakeholders requested to answer the questions by email. It is a pity though, since more detailed information could have been obtained by carrying out verbal communication. The transcripts of the interviews, which are verified by the interviewees, can be found in the attached CD.

3 Current Situation

In this chapter, the current situation of the energy supply system in Lithuania is presented first and the building stock is introduced afterwards. A focus is given to the heating sector as well as buildings' heating characteristics that are essential to further analysis.

3.1 Energy Supply System

As it is discussed, the least-cost heating strategy should be modelled for the future energy system and not for the existing one. However, it is essential to understand the current energy system situation in Lithuania before analysing the future vision. Therefore, in this section the energy supply system is briefly presented. Subsection 3.1.1 shortly describes the electricity sector, while Subsection 3.1.2 presents the heating sector in more detail.

3.1.1 Electricity Sector

After the closure of Ignalina nuclear power plant in 2009, which had provided the country with cheap electricity for several decades, the Lithuanian electricity sector has radically changed from being self-sufficient and an exporter to being an importer. Even though there is a sufficient electric capacity installed in the country to meet the domestic demand, high prices of imported natural gas cause the situation that the cost of domestic electricity production in these plants is too high to compete with the cost of imported electricity. Thereby, more than half of gross inland electricity consumed is currently imported from neighbouring countries (e.g. 51% in 2010, 65% in 2014), to the largest extent from the Eastern neighbour – Russia. However, new connection lines with Sweden (*Nordpool*) and Poland are planned to be implemented during upcoming years, which will improve the security of supply. (LEI, 2014b)

Regarding domestic electricity generation, in reference year 2010 the majority of electricity was generated in thermal power plants (69%), with the rest covered by hydro power and hydro pumped storage plants (23%), wind power plants (4%) and industry (4%) (LEI, 2011).

3.1.2 Heating Sector

As far as heating sector is concerned, in Lithuania all cities have well developed district heating (DH) systems, which are a heritage of planned economy times. Most of the systems are implemented more than 40 years ago (Murauskaitė, et al., 2013) and serve more than 50% of final heating demand in total, which has remained fairly constant over the last years (Ministry of Energy, 2012). Even though DH system offers a number of advantages over individual heating solutions, such as possibility to utilise waste heat, better environmental pollution control, higher efficiency, convenience for end-users, etc., in Lithuania it currently faces several issues described below.

First, around 70% of DH production is based on natural gas, which is fully imported from the single country – Russia, threatening insecurity of supply. In relation to this, the current focal area is how to reduce the consumption of natural gas and thereby dependency on imports. It is restricted though by the biggest DH plants in Vilnius, Kaunas, etc., which operate natural gas CHP plants. (LEI, 2014b)

In smaller cities though, biomass in DH production is the dominant fuel and its share is increasing constantly. In total, biomass share in the DH production grew from 2% in 2000 up to 27.2% in 2012. Wood is the most common type used, including chips, wood waste, etc. By utilising local biomass resources rationally, the share could be increased further. (LEI, 2014b)

Apart from increasing share of biomass, another measure to fight the issue of dependency on Russian natural gas and to ensure higher level of diversification of fuel sources is floating liquefied natural gas (LNG) terminal, which has been implemented at the end of 2014 and which enables natural gas import from Norway. However, it seems that today the terminal plays a back-up role to improve security of supply, in case problems with natural gas import from the East occur.

Second, a significant part of district heat is produced in DH boilers, whereas the rest comes from CHP plants located in the main cities (43% and 56% of heat production in 2010 respectively (LEI, 2011)). Thus, an increasing focus is being currently given to promotion of CHP plants, which produce both heat and electricity and provide substantial advantages in terms of efficiency, reduced pollution, etc.

Third, an important issue in the DH sector is old and outdated distribution pipe network, reaching the age of over 30 years. However, during the last decade modernisation of DH distribution system has been carried out and heat losses have been reduced from 25.1% in 2000 down to 15.7% in 2010 (LEI, 2014b).

Finally, too slow buildings renovation, both public and residential, still remains the core issue in the heating sector, which hinders improvements in energy efficiency, reduction in heat production as well as fuel dependency. Moreover, it is argued that poor condition of buildings constructions sometimes even threatens inhabitants' safety. (LEI, 2014a)

Apart from the DH sector, individual heating is equally important. Analysing final fuel consumption in the household and service sectors, which are mainly subject to heating, it is concluded that the main fuel type for individual heating is biomass. In 2010, biomass accounted for 61% of final fuel consumption in the households and service sectors, leaving 23% for natural gas, 11% for peat and 5% for oil. (LEI, 2011)

It is worth mentioning that the share of biomass in the final country's fuel balance reached 21.6% in 2012 and if the existing biomass potential is used rationally, Lithuania can exceed the national renewable energy target of 23%, under the EU Renewable Energy Directive 2009/28/EC (LEI, 2014a). However, dependency on Russian natural gas remains the biggest issue at the moment to deal with. Therefore, in the future prospect, wider utilisation of local biomass resources is the key factor to be achieved, which is described in Subsection 4.2.2.

3.2 Building Stock and Heating Characteristics

The Lithuania's building stock comprises of around 500 thousand residential buildings and almost 60 thousand non-residential buildings excluding auxiliary buildings, agriculture houses and summerhouses. As illustrated in Figure 1, heat consumption issue is more crucial in residential buildings, while non-residential buildings might show sufficient energy efficiency, and therefore, heat saving analysis is based on the residential building sector.

Residential buildings can be divided into two main groups:

- One- and two-dwelling buildings (assumed to be individual houses);
- Three- and more dwelling buildings (multi-apartment buildings including residential buildings for social groups).

Information about their amounts and areas in 2011 is given in Table 5. It can be concluded that the total residential area in the country is distributed equally between individual houses and multi-apartment buildings, each of them accounting for around 50% of total area.

Table 5: Lithuanian building sector in 2011

Group of buildings	Number	Total area, [thousand m^2]	Average area per building, [m^2]
Residential, total	**478,898**	**109,038**	
One- and two-dwelling	439,767 (92%)	53,482 (49%)	122
Three- and more dwelling	39,131 (8%)	55,556 (51%)	1,420
Non-residential, total	**57,970**	**36,038**	**622**

Source: (Centre of Registers, 2012)

As far as multi-apartment buildings are concerned, 15% of total area belongs to 1-2 floor multi-apartment buildings, 65% of the area – 3-5 floor buildings with the rest belonging to buildings with more than 5 floors (Gudzinskas, et al., 2011). An average area per dwelling in multi-apartment buildings is around 63 m^2 (OSP, 2015), whereas for individual houses typical area is around 122 m^2 (Table 5). Table 5 also suggests that non-residential buildings (administrative, medical, recreational buildings, etc.) are likely to be multi-storey buildings, due to higher average area per building.

It seems logical that heat consumption in the building sector is closely related to buildings age. However, as discussed in (Ropaitė & Savickas, 2014), it is not a rule that the older the building is, the more heat for space heating it consumes. Distribution of total buildings area by the intervals of building year can be seen in Figure 4. It can be concluded that around 80% of both residential and non-residential buildings were built before 1990 in accordance with the former building code, which was in force until 1993. The majority of them were built in the period of 1961-1990, when Lithuania was a part of Soviet Union. One of the main features of that period is massive low quality constructions of brick-built and concrete-block multi-apartment buildings, which are characterised as being energy inefficient and tend to have low energy performance category, due to low thermal resistance of envelopes, outdated inefficient one-pipe heating systems and lack of proper ventilation. In these buildings, annual heat consumption is twice as high as in multi-apartment buildings built after 1993 (LRP, 2011), making the former uneconomical. This can be explained by the fact that until 1994 heat transfer coefficients fluctuated around the values given in Table 6, which could not ensure energy efficiency. Only after 1992, when Lithuania restored independence, intensive energy saving policy started and resulted in significantly improved building codes (Juodis, et al., 2009).

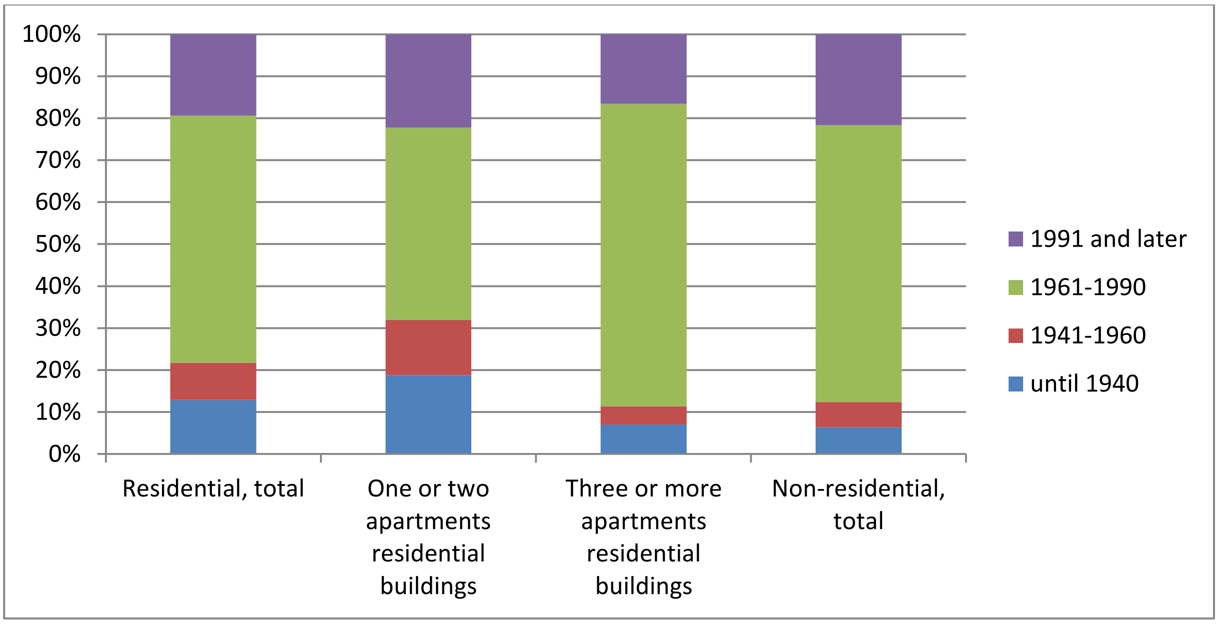

Figure 4: Distribution of total buildings area by building year

Source: (Centre of Registers, 2012)

Table 6: Heat transfer coefficient values according to building codes in force

Years	Heat transfer coefficient values, [W/m²·K]			
	Wall	**Windows**	**Roof**	**Floor**
Until 1994	1.0	2.5	0.83	0.83
1994-1998	0.28	2.0	0.22	0.4
1998-2005	0.26	1.43	0.18	0.26
After 2006	0.2	1.6	0.16	0.25

Sources: (Juodis, et al., 2009), (LRP, 2005a)

Another relevant aspect to discuss is heating type of buildings. Focusing primarily on the residential building stock, there is a clear difference in the heating type between individual houses and multi-apartment buildings, as represented in Figure 5. The information is based on the *Results of the 2011 Population and Housing Census of the Republic of Lithuania* (Statistics Lithuania, 2013).

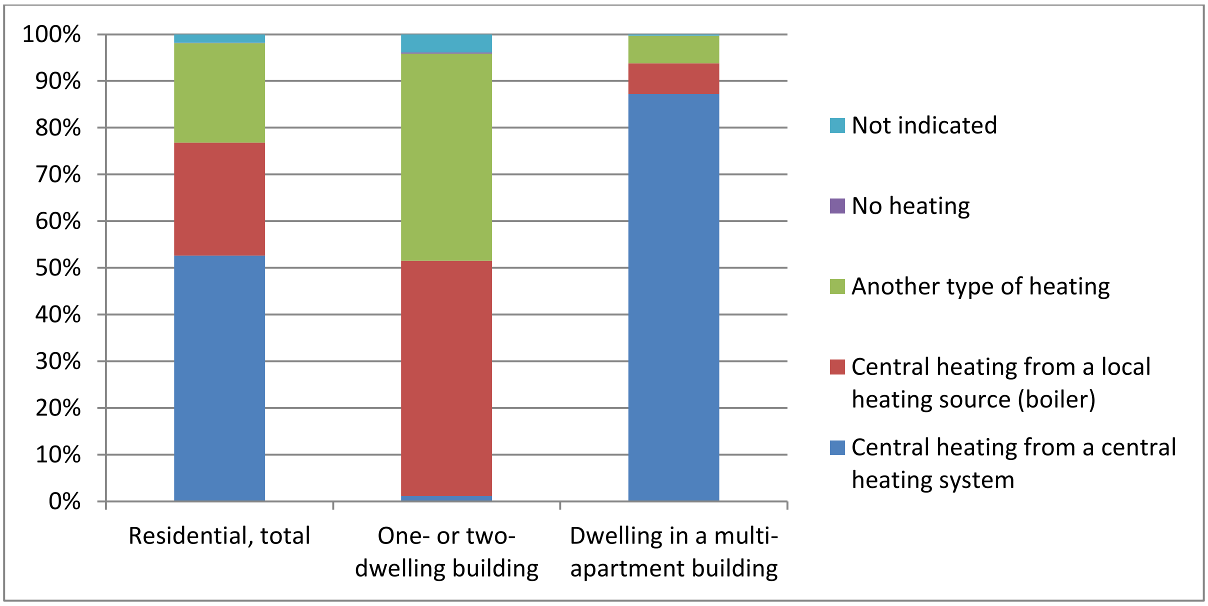

Figure 5: Distribution of total buildings amount by heating type

Source: (Statistics Lithuania, 2013)

To start with, 52.6% of the whole residential building stock in Lithuania is supplied by DH (75.6% in urban areas and 6.8% in rural areas), with the rest covered by local heating sources, equipped in the building (individual boilers) or another type of heating (stove, fireplace, etc.). In more details, the majority of multi-apartment buildings (87,2%) are served by district heating (92.4% in urban areas and 37.6% in rural areas), whereas one- or two-dwelling buildings are mainly (94.7%) supplied with individual heating solutions. (Statistics Lithuania, 2013)

Based on the above, multi-apartment buildings served with district heating and individual houses equipped with individual heating solutions are analysed in the study as being typical combinations in Lithuania. In this relation, it is relevant to further analyse the heating characteristics and heating consumption trends in these two types of buildings.

3.2.1 Multi-Apartment Buildings

Heating season in DH systems (and thus multi-apartment buildings) starts when the average ambient temperature of three days in a row is below 10°C and ends when it is above 10°C (Gudzinskas, et al., 2011). Usually, heating season continues for around 220 days (LR, 1995), which is around seven months (October-April).

Lithuanian District Heating Association (LDHA) divides the entire stock of multi-apartment buildings into four categories depending on the amount of heat consumed, as shown in Table 7.

Table 7: Categories of multi-apartment buildings and their heat consumption

Category of multi-apartment buildings, rated by heat consumption	Average monthly heat consumption (for space heating)*	Heating bill of typical 60 m^2 dwelling**	Share of all multi-apartment buildings
I: Least (new and of high quality)	~10 kWh/m^2	~600 kWh/60 m^2 (~39 EUR)	4%
II: Low and moderate (new and with implemented heat saving measures)	~15 kWh/m^2	~900 kWh/60 m^2 (~65 EUR)	16%
III: Substantial (old and renovated)	~25 kWh/m^2	~1500 kWh/60 m^2 (~91 EUR)	60%
IV: Highest (old and non-renovated)	~35 kWh/m^2	~2100 kWh/60 m^2 (~151 EUR)	20%

* Average heat consumption during heating season (October-April)

** Average heat price of 0.072 EUR/kWh during 2014/2015 heating season is used (LDHA, 2015)

Source: (LDHA, 2011)

These are the actual heat consumptions in multi-apartment buildings. There is a possibility though that normative heat demand, ensuring adequate indoor climate conditions in these buildings, might be different. To explain, there are likely to be cases that residents in multi-apartment buildings with still manually controlled DH substations reduce heat flow from the DH system, in order to save energy, which results in reduced and usually inadequate indoor temperature (Staskevičius, 2015).

Heat consumption within multi-apartment buildings constitutes (1) space heating (SH) and (2) domestic hot water (DHW) including hot water recirculation. It is assessed by LDHA that heat demand for DHW including hot water recirculation hardly varies between the multi-apartment buildings (see Figure A-1 in 0 Appendix), whereas heat demand for SH recognisably depends on the buildings' categories, which are listed in terms of heat consumption in Table 7 (see Figure A-2).

Based on Figure A-1 for DHW and Table 7 for SH, the specific annual heating demand is calculated and presented in Table 8 respectively. Heat demand for SH is calculated assuming that heating season lasts for seven full months. It is concluded that the share of SH is higher in case of old and inefficient buildings (up to 82%) and lower in case of new buildings, where it can reach only 60% of total annual heat demand, with the rest covered by the DHW component. Based on Table 8, in further calculations for multi-apartment buildings it is assumed that approximately 72% of the total end-use heat demand is used for SH and 28% for DHW. Also, an average specific heating demand for SH in multi-apartment buildings is 174 kWh/m^2.

Table 8: Annual heat demand for DHW and SH in multi-apartment buildings

Multi-apartment buildings, rated by heat consumption	Share of buildings	DHW, [kWh/m^2/year]	SH, [kWh/m^2/year]	Total, [kWh/m^2/year]
I: Least	4%	52	**70**	122
II: Low & Moderate	16%	56	**105**	161
III: Substantial	60%	55	**175**	230
IV: Highest	20%	53	**245**	298
Average		**55**	**174**	**228**

Source: (LEI, 2014b), (LDHA, 2011)

After the analysis of heat consumption in multi-apartment buildings, it is briefly discussed why the DHW component has such a significant share of the total end-use heat demand. However, it is not of high importance to go into details, since it is decided that the analysis focuses only on reductions in heat demand for space heating.

As mentioned, a part of the DHW component is related to hot water recirculation. Hot water recirculation is a required component when planning and installing DHW systems in order to maintain standard hot water temperature (around 55°C) that is instantly available at any point within the end-users' hot water system. In addition, from economic point of view, more cold water would be used without recirculation loop as waiting for hot water of the right temperature coming. (Gudzinskas, et al., 2011) Heat consumption of hot water recirculation system depends on which type of system is installed. These are summarised in Table 9.

Table 9: Average heat consumption for hot water recirculation in multi-apartment buildings

Type of hot water supply system	Per dwelling per month, [kWh]	For typical 60 m^2 dwelling per month, [kWh/m^2]
Supply and circulation pipes are mounted in kitchen and utility room and water passes through coil-pipes in bathroom	240	4
Supply and circulation pipes are mounted in utility room and water passes through coil-pipes in bathroom	160	2.7
Supply and circulation pipes are mounted in utility room and there is no coil-pipes	80	1.3
Hot water recirculating system is in only in basement	10	0.17

Source: (NCC, 2003)

It is worth to mention that the majority of old multi-apartment buildings do have coil-pipes in bathrooms and thus consume 2.7-4 kWh/m^2 of heat per month for hot water recirculation. In these buildings, hot water recirculation loop is passing through coil-pipes located in bathrooms, thereby serving as a heater and/or towel dryer. Even though it serves as space heating, it is a part of the DHW component and is present throughout a whole year. As a result, a DHW share of total annual heat demand in Lithuanian multi-apartment buildings is rather large compared to, for instance, Denmark, where it accounts only for 15% (Lund, et al., 2014).

To sum up the situation, it seems that there is a potential of heat savings related to hot water recirculation, yet in this study it is not analysed. However, future studies could include considerations whether energy savings might be achieved by retrofitting/changing heat recirculation systems, as a separate component from DHW.

3.2.2 Individual Houses

The information about individual houses and their heating characteristics is rather scarce, compared to multi-apartment buildings. It seems logical though that specific heating demand (kWh/m^2) in individual houses should be higher than in multi-apartment buildings that have the same envelope composition, due to the higher ratio of outer walls, roof, floor or windows per unit of heated area.

To find the specific heating demand in individual houses, total individual heat demand of 8.08 TWh in 2010 (found in Subsection 4.1.1) is divided by the total area of individual houses from Table 5, resulting in 150 kWh/m^2 of heat consumed per year in one individual house on average, assuming that all the given area is heated. To validate the number, (Statistics Lithuania, 2011) is looked into, where the average heat consumption of individual house per year of 18,360 kWh is given. In case of the average area of 122 m^2 per individual house (see Table 5), the same 150 kWh/m^2 is concluded. However, the question is whether the statistics are close enough to reality with regard to final fuel consumption in individual houses, since it is likely that people can heat their houses by using firewood from their own and thus non-registered property, use additionally stoves, etc., which is difficult to estimate. Moreover, the heat demand in individual houses seems too low when comparing to multi-apartment buildings, which have an average heat demand of over 200 kWh/m^2, and which does not correspond to the assumption that specific heating consumption in individual houses is typically higher due to higher ratio of envelope.

Regardless of these considerations, it is assumed further that the average specific heating demand in individual houses is 150 kWh/m^2. In contrast to multi-apartment buildings, individual houses usually do not have hot water recirculation system, since the distance between heating source and hot water taps is short. Thus, it is assumed that DHW and SH components account for 17% (OSP, 2015) and 83% respectively, meaning that specific heating demands in individual houses is 25.5 kWh/m^2 and 124.5 kWh/m^2 for DHW and SH components respectively. However, generally there are houses with higher as well as with lower specific heating demands in the country.

It should be noted that for both multi-apartment buildings and individual houses, there is no available data on possible heat consumption based on electric heating and therefore, it is not taken into account in this study.

4 Future Energy System

To identify marginal heat production costs, the *EnergyPLAN* software is applied and a model of Lithuania's future energy system in 2030 is constructed. First, Section 4.1 presents the data of the reference year 2010, which is used for the modelling. Afterwards, future energy system is modelled by defining new energy demands, conversion units and fuel consumptions. Modelling is based on the pre-study for the upcoming National Energy Strategy that outlines future energy system projections, as described in Section 4.2. It is important that, when defining the overall energy system, much more attention is given and more detailed analysis is done for the heating sector. Finally, the results are presented as marginal heat production costs in Section 4.3.

4.1 Reference Data

Reference data of the Lithuania's energy system, mainly in 2010, is used to help constructing the *EnergyPLAN* model of the future energy system in 2030. The main input data needed for the modelling includes reference energy demands, used as a starting point to find the future demands, and typical hourly distribution profiles of district heat demand, electricity demand and renewable energy productions. Heat demand data is the most relevant for the analysis and therefore is analysed in more detail.

4.1.1 Energy Balances

Energy balances describing the energy system in 2010 are found in annual issue of statistical indicators *Energy in Lithuania 2010* (LEI, 2011), whereas more specific indicators can be also found in Official Statistics Portal of Lithuania (OSP, 2015). Energy balances for the year 2010 are presented in Table B-1 in B Appendix.

According to the statistics, in 2010 the total net heat demand in the household and service sectors was 16.60 TWh divided into 8.52 TWh of district heating and 8.08 TWh of individual heating. Here, individual heat demand in the building stock is defined by final fuel consumption in the household and service sectors, divided by assumed boilers efficiencies (Gudzinskas, et al., 2011), as presented in Table 10.

As a result, the share of the district heating is 51%. As far as DH production units are concerned, both heat boilers and CHP plants are relevant. According to (LEI, 2011), in 2010 the shares of heat production were 43% and 56% respectively.

Finally, as far as electricity demand is concerned, it accounted for 10.75 TWh in 2010.

Table 10: Individual heat demand by fuel type in 2010

Fuel type	Final fuel consumption in 2010, [TWh]	Boiler's efficiency, [%]	Heat demand in 2010, [TWh]
Coal/Peat	1.32	65	0.86
Oil	0.53	80	0.42
Natural gas	2.62	85	2.23
Biomass	7.03	65	4.57
Total	**11.5**		**8.08**

Source: (LEI, 2011)

As mentioned, the described demands in 2010 are used as a point of departure in Subsection 4.2.1 to calculate the demands in the future energy system.

4.1.2 District Heat Demand Profile

Distribution of DH production on hourly basis (8,784) is obtained from district heating company "Vilnius Energy" for the year 2014, as being a typical profile throughout the years. In *EnergyPLAN*, hourly heat production values are relative and relates to the specified annual value. Therefore, the curve can be applied for the whole energy system of the country. The profile is presented in Figure 6.

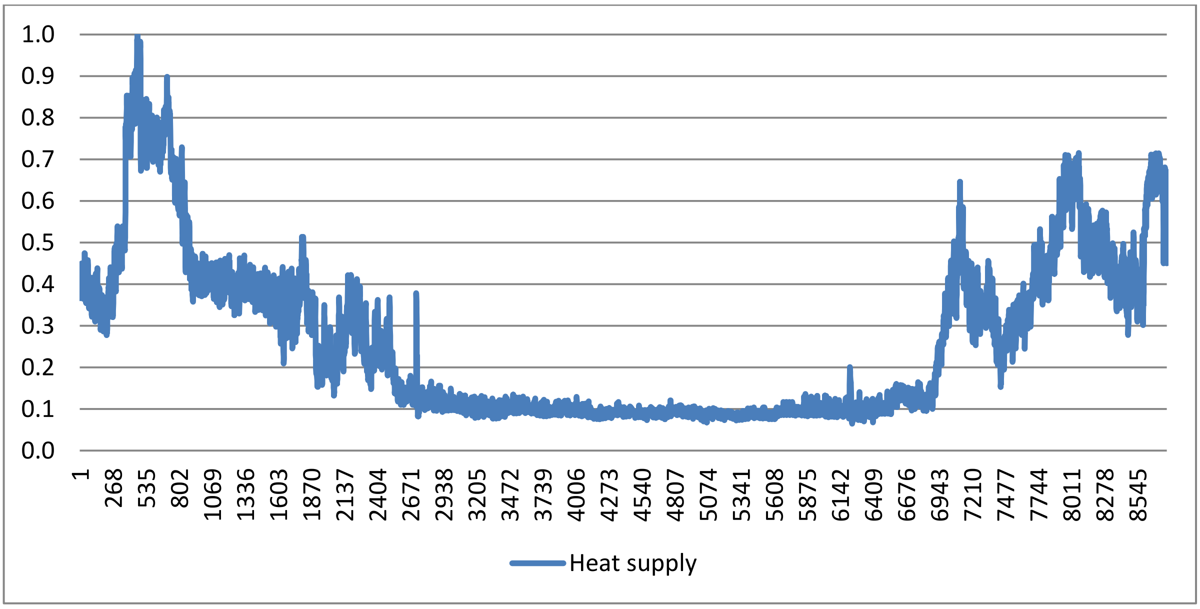

Figure 6: Hourly distribution of district heat production

Source: obtained from district heating company "Vilnius Energy"

The data represents heat supply for the city of Vilnius, meaning that it serves both residential and non-residential buildings, including heat for (1) space heating, (2) domestic hot water (including hot water recirculation) and (3) distribution losses. Since these components are not reported separately in production data, the share of each demand (SH and DHW) has to be found.

First of all, average heat losses in Lithuania's DH systems are equal to 15.7% (LDHA, 2011). According to (Frederiksen & Werner, 2013)[p.77], heat losses calculation is as follows:

$$Q_{hl} = K \cdot \pi dl \cdot (t - t_a) \quad (5)$$

Here: K – total heat transmission coefficient, [W/m^2·K];

d – pipe diameter, [m];

l – pipe length, [m];

t – temperature of supplied hot water, [K]; assumed to be equal over a year;

t_a – ambient (ground) temperature, [K]; assumed to be equal over a year.

Since the above mentioned factors are constants, heat losses are even throughout a year, i.e. absolute heat losses do not depend on the amount of supplied heat. District heat losses accounting for 15.7% of total heat supply are indicated in Figure 7.

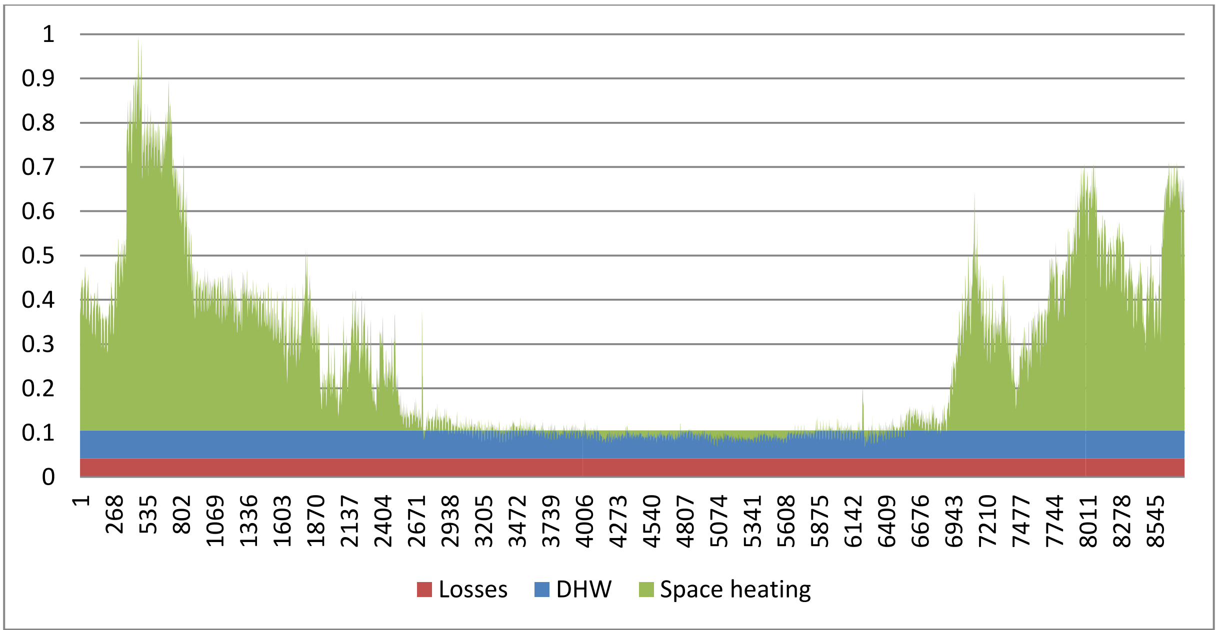

Figure 7: Hourly distribution of heat losses, heat demand for DHW and SH

It is assumed that heat demand for DHW does not depend on outdoor temperature and is thus constant throughout a year. Thereby, an average heat demand for DHW is identified as the average heat production during summer period after subtracting heat losses, knowing that there is no SH during summer season. The constant heat demand for DHW is then added on top of heat losses in Figure 7. The rest of area represents heat demand for SH, which is dependent on outdoor temperature and therefore is fluctuating throughout a year, as seen in the figure. As a result, annual heat demand for DHW (including recirculation) accounts for 28% of total heat end-use demand in buildings, hereby leaving 72% for SH, as already defined in Subsection 3.2.1.

Since individual heating is supplied with individual boilers and there is no relation to centralised heat supply systems, an hourly distribution curve is not created.

4.1.3 Electricity Demand Profile

Actual hourly electricity demand for the year 2010 is taken from European Network of Transmission System Operators for Electricity (ENTSOE) database (Entsoe, 2015).

4.1.4 Renewable Energy Production Profile

Actual hourly distribution of wind power generation is taken from Lithuanian Electricity Transmission System Operator (LITGRID) database (Litgrid, 2015).

Due to insignificant solar power generation in Lithuania's energy system, it is difficult to obtain PV output. Therefore, available Danish hourly solar distribution from 2001 is used instead, as Denmark's solar radiation is somewhat similar to solar radiation in Lithuania (Solargis, 2015).

4.2 Future Scenario

As mentioned, the least-cost heating strategy highly depends on the future energy system's context. The following subsections describe the future energy system projections for 2030 in terms of demand side and supply side, which are then used as an input data into the *EnergyPLAN* software.

4.2.1 Demand Side Projections

Over the last decade, Lithuania's residential building stock has been increasing 0.5% per year (Gudzinskas, et al., 2011). On this basis, it is assumed that the future scenario include an expansion of total heated area by the same 0.5% annual rate, meaning 10% increase from 2010 to 2030. It seems an appropriate assumption, as Eurostat projections identify that population in Lithuania is expected to decrease dramatically (Eurostat, 2015). However, predictable declining population can be offset by a continuous trend towards fewer people living per household (IEA, 2013) and increasing average area of dwellings over the years.

Following that, due to better thermal efficiency of new buildings, net heat demand is assumed to increase only by 5% from 2010 to 2030 in buildings both connected to DH system and with individual heating equipment. It also corresponds to the LEI projections for future DH demand where only a minor increase in space heating is projected in case there is no heat saving measures being implemented, as indicated by green line in Figure 8. Figure 8 also illustrates the expected 2 TWh heat savings from 2010 to 2030 due to reduced SH demand, which is a result of expected large-scale renovation carried out for the majority of multi-apartment buildings, as described in Chapter 2.

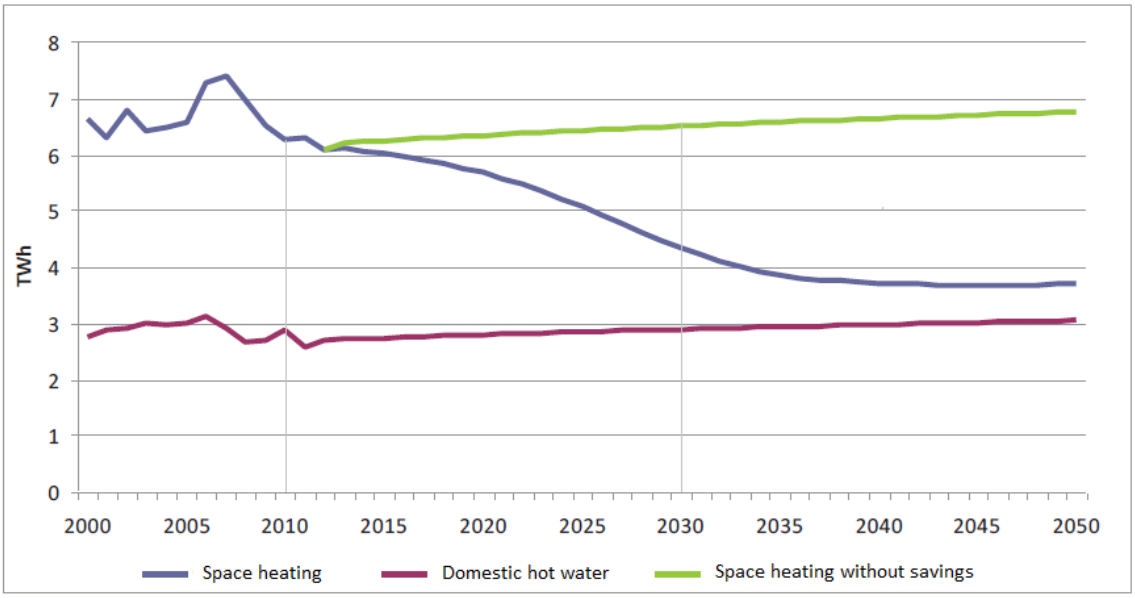

Figure 8: District heat demand projections by LEI

Source: (LEI, 2014b)

As found in the statistics, in 2010 the total net heat demand in the building sector was 16.60 TWh divided into 8.52 TWh of district heating and 8.08 TWh of individual heating (DH demand is slightly higher in Figure 8 since other sectors, such as construction or industry, are also included). With the assumed 5% increase in the heat demand by 2030, the total heat demand increases to 17.43 TWh/year, i.e. 8.95 TWh/year and 8.48 TWh/year for district and individual heating respectively.

It is though not taken into account that within a few decades, there is a possibility that people will migrate from rural areas, where individual houses with individual heating solutions are common, to the cities, where the majority of buildings are multi-apartment buildings connected to DH systems, thereby changing the shares of district and individual heating demands.

Even though the population is expected to decrease and/or more efficient hot water systems might be present in the future, in the analysis it is assumed that people will use more hot water (for bathing, kitchen purposes, etc.) due to the increasing economy and comfort level. Therefore, the DHW component is assumed to remain constant, around 28% of total end-use heat demand in multi-apartment buildings and 17% in individual houses, as described previously. Meanwhile, the space heating component changes along with the implemented heat saving measures.

Table 11 represents a matrix, which is constructed for the analysis consisting of four different levels of reduced heat demand for space heating in buildings, i.e. 100%, 75%, 50% and 25% of initial SH demand in 2030, for both district and individual heating. Heat demands are also divided into demand for space heating (SH) and domestic hot water (DHW). The latter remains constant.

Table 11: Matrix of net heat demand in 2030 divided into district and individual heating

% (of space heating)	District, [TWh/year]			Individual, [TWh/year]		
	Total	DHW	SH	Total	DHW	SH
100%	**8.95**	**2.50**	**6.44**	**8.48**	**1.44**	**7.04**
75%	7.34	2.50	4.83	6.72	1.44	5.28
50%	5.73	2.50	3.22	4.96	1.44	3.52
25%	4.12	2.50	1.61	3.20	1.44	1.76

In each case of reduced heat demand for SH, hourly heat demand curve of DH is adjusted so that the share of DHW remains the same and only the share of SH is reduced. It is done within the software as illustrated in Figure C-1 in C Appendix, where an example of 50% cut in SH demand is given. As a result, reductions in heat demand for SH reduce peak load capacities needed to cover higher heat demands during winter period.

Finally, electricity demand in Lithuania had grown the most among all energy types, by 3.1% per year between 2000 and 2012. Until 2030, final electricity consumption (excluding needs in energy sector) is expected to increase further by 2.2% per year, due to increasing economy and thus increasing comfort level. As a result, total electricity consumption (including needs in energy sector) is expected to increase from 10.75 TWh in 2010 to around 15.89 TWh in 2030. (LEI, 2014b)

4.2.2 Energy System Projections

To model the Lithuania’s future energy system, firstly it is due to look into the national energy strategy. The existing National Energy Independence Strategy published in 2012 (Ministry of Energy,

2012) needs to be revised due to the changed situation in the energy sector and already implemented the most significant projects, such as installing LNG terminal as a potential substitute for natural gas imports. Therefore, a new strategy is expected to come into force in autumn of 2015. For that reason, the largest energy research institution Lithuanian Energy Institute (LEI) has prepared and published a consultative study for the upcoming national energy strategy, where comprehensive and detailed analyses of prospective energy system development scenarios are presented, taking into account economic and social factors and the impact of regulation measures (LEI, 2014a). The latter is used to construct a model of Lithuania's energy system in 2030, as described further.

It is difficult to foresee how the future energy system exactly looks in 2030 due to many uncertainties, such as security of natural gas supply or debate about the project of building new nuclear power station, and since the new national strategy has not been agreed on yet, a number of scenarios are discussed in the above mentioned study.

It is though emphasised that a focus in the DH sector should be given to CHP plants, which have technological advantages as well as strengthen the security of power supply, which is today largely imported. Furthermore, in all scenarios the priority in the DH sector is given to local biomass resources and municipal waste, accounting for up to 70% of total fuel consumption. Natural gas is the second important fuel in the DH system, which together with a small share of peat accounts for up to 30%. (LEI, 2014b) Biomass potential has been investigated by Lithuanian Energy Consultants Association in (LEKA, 2013) and proved to be sufficient enough to cover the mentioned forecasts.

Deployment of CHP plants is also in line with the recently published National Heat Sector Development Programme for 2015-2021 (LRV, 2015), which underlines the need to change the current tendency of relying on biomass boilers to meet heat demand in district heating systems, giving a priority to CHP plants where technically possible, with biomass boilers covering higher heat demands during heating season and fossil fuel boilers covering peak demands.

Based on above, to determine marginal costs of district heat production, the following path for the future energy system in 2030 is assumed and modelled as the main scenario:

- Up to 70% of district heating is produced in CHP plants.
- Biomass (including municipal waste) is the major fuel in DH systems, accounting for up to 70% of final fuel consumption. The rest is covered by natural gas (20%) and peat (10%). In CHP plants biomass account for around 85% of fuel consumed for heat production.
- Apart from domestic electricity production in CHP plants, wind and hydro power plants as well as pump storage power plant, the rest is imported, based on the assumption that new connection lines with Sweden and Poland will create favourable conditions for the imports.

- CHP electric and thermal efficiencies are set as 32% and 59% respectively in 2030 scenario, which are the values of existing Vilnius CHP plant (LEI, 2014b). Efficiency of boilers is 84%.

There are no projections for the individual heat production though. Thus, in the main scenario shares of individual boilers in terms of fuel type are assumed to be the same as in 2010 (see Table 10).

Modelling and calculation in *EnergyPLAN* is done separately for district heating and individual heating, since they typically serve different types of buildings. Between the scenarios of different levels of reduced heat demand for SH, the following is changed each time:

- DH demands and DH distribution curve;
- The installed capacity of CHP plants;
- The capacity of DH boilers, calculated as the maximum demand in the system plus 10%, meaning that the higher the DH demand is, the higher investment in boilers is needed;
- For individual heating, only individual heat demands.

Once technical indicators of the system are defined and set up, the economic evaluation is done, as described in the following section.

4.3 Marginal Heat Production Cost

After constructing future energy system model and including heat demands with different levels of reduced space heating (100%, 75%, etc.), costs described in Section 2.1 are incorporated in the software. In the main scenario, fuel prices of temperate price growth scenario for 2030 are applied.

Total annual costs of each energy system configuration are extracted from the results and converted to marginal heat production costs, which is found as the change in total cost related to a change in heat demand. The outcome of *EnergyPLAN* contains a summary of the main technical and economic indicators. In order to get an insight into the results, a few summaries of the DH calculation are given in C Appendix, while the rest can be found in the attached CD.

The results are presented for district heating and individual heating separately in Figure 9 and Figure 10. The bold line presents the main scenario, described previously, where the prices of temperate fuel price growth scenario and interest rate of 3% are considered.

Afterwards, a few other scenarios are tested. First, the high fuel price scenario is applied. Second, in order to see how the energy system cost changes in relation to changes in biomass share in the final fuel consumption, the following models are tested:

- For district heating, biomass share in the final fuel consumption is reduced from 70% to 45%, replacing it with natural gas (changes are done for CHP plants).

- For individual heating, share of biomass boilers is increased, replacing 100% of oil boilers and 50% of peat boilers.

The main scenario curves are also tested for sensitivity to interest rate (1% and 5%), which can be found in D Appendix, Figure D-3 and Figure D-4.

In the figures, the horizontal axis is created under the assumption that, in case of district heating, initial level (100% of current space heating demand) represents the average heat demand for space heating equal to 174 kWh/m^2, while in case of individual heating, 100% represents the average heat demand for space heating equal to 124.5 kWh/m^2, as found in Section 3.2.

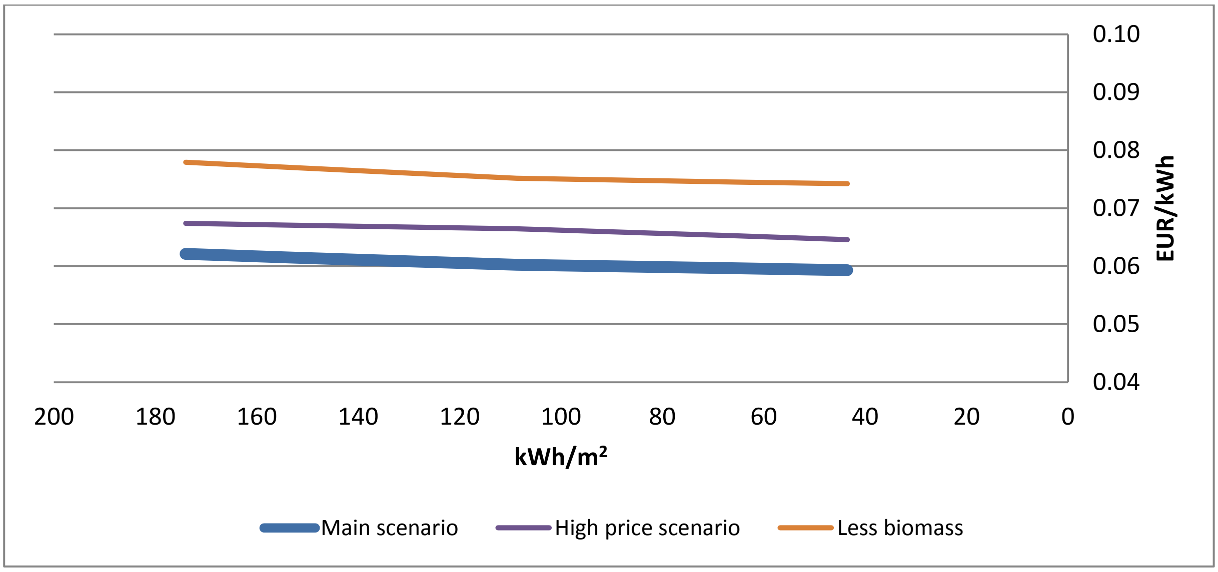

Figure 9: **Marginal district heat production cost in relation with heat demand for space heating**

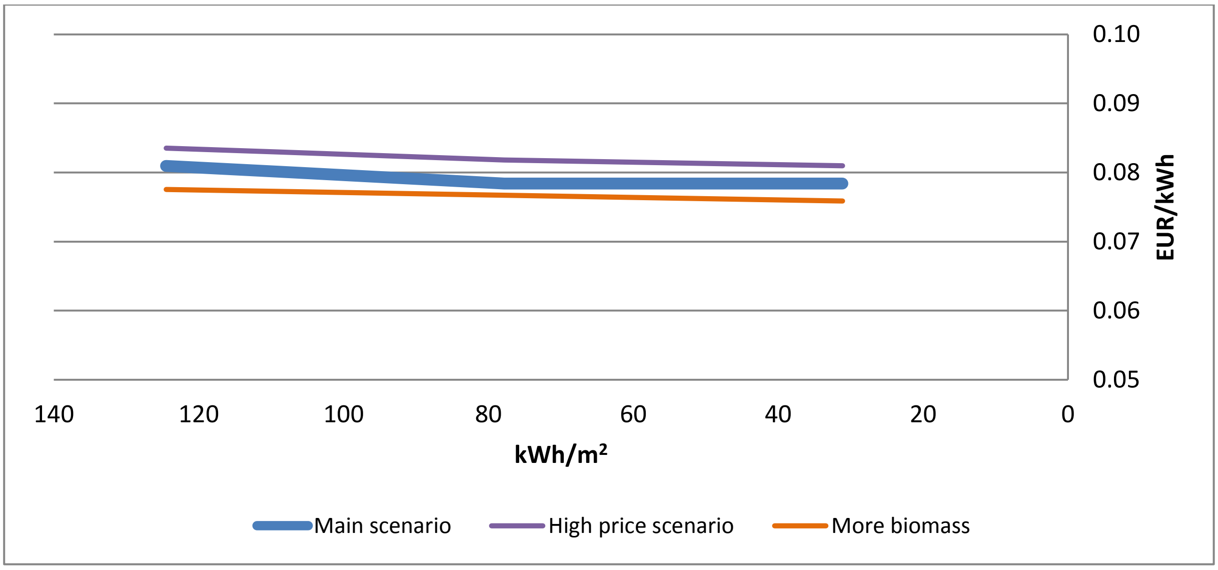

Figure 10: Marginal individual heat production cost in relation with heat demand for space heating

Several conclusions can be made:

- Basically, the achieved end-use heat savings reduce the total cost of the energy supply system. When it comes to marginal heat production cost, it slightly decreases along with heat demand reductions and is around 0.06 EUR/kWh for DH and around 0.08 EUR/kWh for individual heating. Such a slight reduction has to do with the prospected energy system, which is less diverse in terms of production units and less flexible comparing to e.g. Danish energy system, analysed in (Lund, et al., 2014). The latter is referred as smart energy system, based on a wide use of different heat sources and where firstly cheaper heat sources are utilised, such as waste-to-energy or industrial surplus heat, and only then further heat production is required from boilers along with additional investments in production capacity. In analysed case for Lithuania, the shares of heat production in DH boilers and CHP plants are kept the same along with heat demand reductions and so are fuel shares, so the reduction basically has to do with the lower needed installed capacity of heat production units.
- In general, individual heat production cost is higher than district heat production cost, due to a combination of factors, such as lower efficiencies and shorter lifetime of heat production units, higher fuel handling costs, etc.
- Giving a priority to biomass instead of natural gas in the future energy system results in the reduced heat production costs and vice versa, due to the higher price of natural gas. It proves the need to utilise local biomass resources as well as municipal waste energy potential, in order to reduce heat production costs as well as dependency on natural gas. Moreover, deployment of local biomass resources results in money staying in the country, rather than leaving the country, as it is in the case of imported natural gas. At the same time it creates job opportunities and added value for Lithuania.
- Final consideration is that along with a higher level of end-use heat saving measures in the buildings, which are served by district heating, the DH systems need to be adjusted to lower heat load in the grid and eventually turned into low-temperature networks, in order to interact with energy-efficient buildings. When temperatures in the DH systems are reduced, it results in lower grid losses, according to Equation 5, which means saved energy. This should be taken into account when dealing with large-scale heat conservation.

After identification of marginal heat production costs, the following chapter is dedicated for the analysis of marginal end-use heat saving costs.

5 Heat Savings in Future Building Stock

To identify marginal heat saving costs for the year 2030, an analysis is carried out for both existing and new buildings, in Section 5.1 and Section 5.2 respectively, as well as for multi-apartment buildings and individual houses separately. The chosen heat saving measures and calculations used to evaluate reductions in heat demand are in accordance with the methodology described previously in Section 2.2. Finally, the results are summarised and discussed in Section 5.3.

5.1 Marginal Heat Saving Cost in Existing Buildings

In the following subsections, the existing buildings are analysed from the two aspects: first, buildings that are going to be renovated anyways (marginal costs) and second, buildings which are not being renovated (total costs). The main difference is that for the buildings which are going to be renovated anyways, only the costs of material and marginal labour force are included as an addition to the renovation, whereas for the buildings which are being renovated solely for the heat conservation purpose, total costs are taken into account, including initialising and closure of renovation. It should be noted that the analysis is restricted by the data availability. Marginal heat saving cost curves for the existing buildings represent the investments in an increasing number of buildings.

5.1.1 Multi-Apartment buildings

For the analysis of heat savings in multi-apartment buildings, different heat transfer coefficients are chosen to model IV, III and II categories, described in Table 7. The first (I) category buildings has high-efficiency and is therefore not analysed. The coefficients are chosen as following.

Category IV coefficients are taken from national norms (LRP, 2005c), which represent buildings built before 1992. For category III and category II, 30% and 75% better *U* values for wall, roof and floor are used respectively compared to category IV and new windows are assumed to be already in place. To calculate heat losses due to natural ventilation, air change *n* value of 0.67 h^{-1} is kept constant. After insulating envelope components, new heat transfer coefficients are found according to Equation 4. Coefficients are summarised in Table 12 along with the specific heating demands before and after the renovation.

It is worth noticing that heat transfer coefficients and annual heat demands presented in Table 12 (as well as in further calculations) are found by theoretical calculations. In reality, they are likely to differ from these estimations due to a number of different factors, such as construction quality, difference in climate severity throughout the years, behaviour of inhabitants, etc.

Table 12: Heat transfer coefficients *U* before and after renovation of multi-apartment buildings

Heat transfer coefficients	Before renovation			After renovation		
	IV	III	II	IV	III	II
Wall *U*, [W/m^2·K]	1.27	0.89	0.32	0.17	0.16	0.12
Roof *U*, [W/m^2·K]	0.85	0.60	0.21	0.19	0.18	0.11
Floor *U*, [W/m^2·K]	0.71	0.50	0.18	0.34	0.28	same
Windows *U*, [W/m^2·K]	2.5	1.2	1.2	1.2	same	same
Annual heat demand, [kWh/m^2]	**226**	**162**	**97**	**79**	**77**	**68**

For each category different improvements, discussed in Subsection 2.2.1, are made. The main heat saving measures are thermal improvements of wall, roof, floor, windows as well as renovation of heating system. As a result, the renovation brings the building from the current heat consumption level to the level after the whole package of measures is implemented. This is based on the assumption that a full-scale renovation is the most likely choice comparing to a partial renovation, due to potential synergies of works and reduced disturbance.

Table 13 represents marginal heat saving costs for both cases: buildings which are being renovated anyways and include only the costs of material and marginal labour force, and buildings which are being renovated solely for the heat conservation purpose and include total costs. Marginal heat saving costs of all categories are then laid down on vertical axis in Figure 11, with a corresponding x coordinate representing a middle point between heat consumption for space heating before and after implementing a whole package of measures, in ascending order. In the figure, DH production cost curve of the main scenario from Figure 9 is also included.

Table 13: Marginal heat saving cost in renovated multi-apartment buildings

Category	Heat demand for SH, [kwh/m^2]	Material and marginal labour cost, [EUR/kWh]	Total cost, [EUR/kWh]
IV	152	0.014	0.031
II	120	0.024	0.041
II	83	0.068	0.115

Cost calculations are based on *Sistela* pricing. Source: (Sistela, 2014)

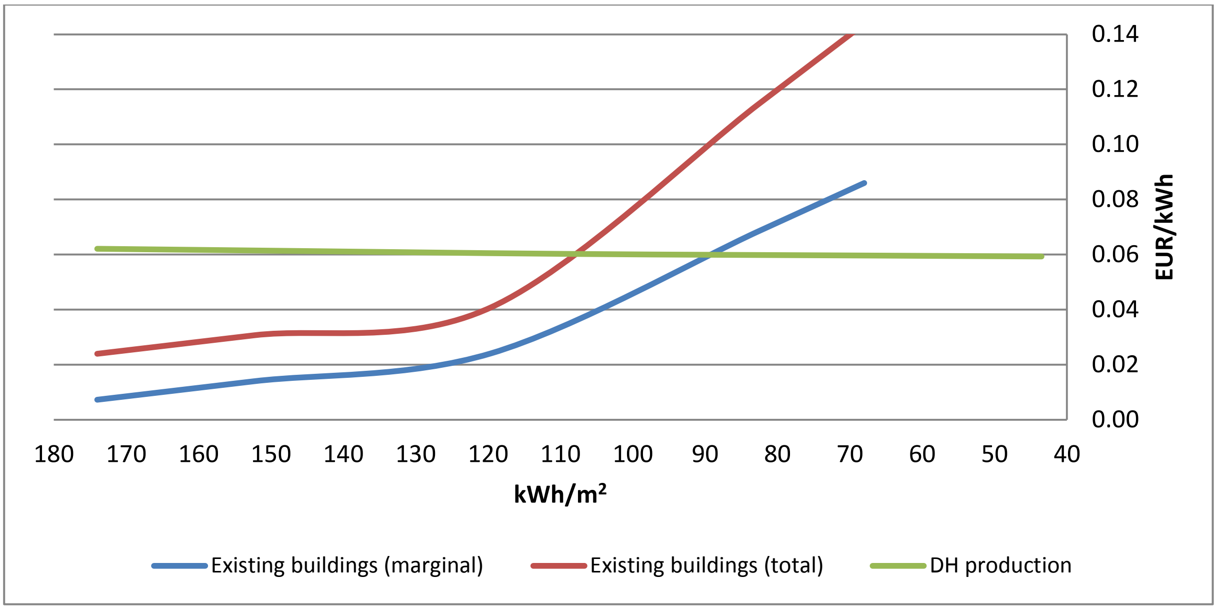

Figure 11: Marginal heat saving cost in renovated multi-apartment buildings

Marginal stands for material (insulation) cost and marginal labour cost, which is used to calculate marginal heat saving cost in buildings being renovated anyways. *Total* stands for total renovation cost (including supplementary costs, such as decoration layers, building lot expenses, etc.) for the buildings which are not being renovated. The same naming is also used in the following graphs.

The results are rather rough, due to small amount of different categories to analyse, yet presents the main recognised multi-apartment building types in the country. It is not necessary to analyse I category buildings though, since the curve already crosses the curve of marginal DH production cost.

To conclude, Figure 11 suggests that it is more economically feasible to implement heat savings in the existing buildings which are going to be renovated anyways. In this case, heat consumption for space heating in multi-apartment buildings should be reduced down to 89 kWh/m^2, where it reaches the marginal DH production cost curve. After this point, the cost of district heat supply is cheaper than implementing further heat saving measures. For buildings which are not going to be renovated, the least-cost heating strategy is to reduce heat demand for space heating down to 108 kWh/m^2, which is due to the fact that total costs of renovation are taken into account, while for the former, only costs related to additional energy efficiency improvements are considered. As a result, multi-apartment buildings falling under categories IV and III and constituting around 80% of total multi-apartment buildings are feasible to renovate without doubt and should be of the highest priority.

5.1.2 Individual Houses

For individual houses, there is no available information about their heating characteristics, as mentioned before. Therefore, different *U* values are chosen to create a list of houses with decreasing specific heating demand for space heating before renovation, starting from very inefficient houses. Both old and new *U* values (before and after heat saving measures) are presented in Table 14.

Table 14: Heat transfer coefficients *U* before and after renovation of individual houses

Heat transfer coefficients	Before renovation					After renovation				
	V	IV	III	II	I	V	IV	III	II	I
Wall U, [W/m^2·K]	1.0	0.7	0.5	0.3	0.25	0.17	0.16	0.14	0.12	0.11
Roof U, [W/m^2·K]	0.85	0.6	0.43	0.26	0.26	0.19	0.18	0.16	0.13	0.13
Floor U, [W/m^2·K]	0.71	0.5	0.36	0.21	0.21	0.34	0.28	0.23	same	same
Windows U, [W/m^2·K]	2.0	2.0	1.2	1.2	1.2	1.2	1.2	same	same	same
Annual heat demand, [kWh/m^2]	**281**	**221**	**167**	**127**	**121**	**112**	**107**	**103**	**97**	**96**

To find marginal heat saving costs, the renovation again brings the building from the current heat consumption level to the level of implemented package of measures. Marginal costs for each category are presented in Table 15 and illustrated by Figure 12 for both, buildings that are being renovated anyways (material and marginal labour cost) and buildings that are being renovated solely for the heat conservation purpose (total cost), in the same way as it is done previously. Marginal individual heat production cost curve from Figure 10 is also included to identify intersection.

Table 15: Marginal heat saving cost in renovated individual houses

Category	Heat demand for SH, [kwh/m^2]	Material and marginal labour cost, [EUR/kWh]	Total cost, [EUR/kWh]
V	196	0.017	0.037
IV	164	0.025	0.055
III	135	0.044	0.082
II	112	0.086	0.161
I	109	0.104	0.194

Cost calculations are based on *Sistela* pricing. Source: (Sistela, 2014)

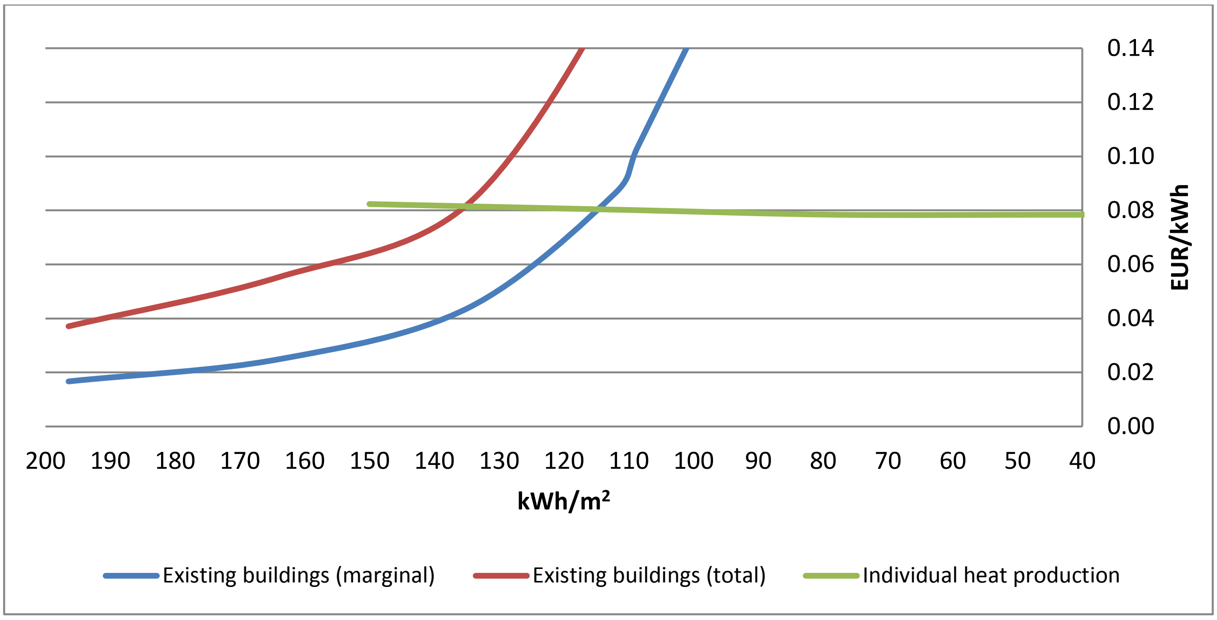

Figure 12: Marginal heat saving cost in renovated individual houses

Figure 12 suggests that the least-cost heating strategy for individual houses which are going to be renovated anyways is reduction in heat demand for space heating down to 115 kWh/m^2. In case total renovation costs are taken into consideration, optimum point of heat demand for space heating demand is 135 kWh/m^2.

It is though likely that there are individual houses which are very old and represents significant amount of heat consumption (higher than showed in Figure 12). However, based on the fact that heat loss reduction is easy to achieve with low thermal resistance, it is assumed that heat savings in these buildings are cheap to implement. However, there might be a situation where it is not feasible to renovate these buildings at all due to too poor conditions, as pointed out in (Ministry of Energy, 2015). As mentioned, in practice each case of renovation needs to be analysed separately in detail.

5.2 Marginal Heat Saving Cost in New Buildings

When new buildings are constructed, there is a possibility to choose the level of insulation and types of elements such as more efficient windows. Therefore, marginal cost curve of heat savings in new buildings are identified using step-by-step approach, by looking at the impact of choosing a higher level of insulation or better efficiency windows. In this case, marginal costs are identified as an increasing investment in all new buildings.

As a starting point, normative heat transfer coefficients of A class are chosen for the new buildings, both multi-apartment and individual houses (LRP, 2005c). After that, more energy-efficient elements are chosen to develop an increasing curve.

For multi-apartment buildings, the implemented step-by-step measures and marginal heat saving costs are presented in Table 16 and illustrated in Figure 13. The same measures are applied for individual houses and the results are shown in Figure 14. Marginal heat production cost curves are also included in the graphs, where horizontal axis represents the specific heat demand for space heating.

Table 16: Marginal heat saving cost in new multi-apartment buildings

Measure	Heat demand for SH, [kWh/m^2]	Heat saving cost, [EUR/kWh]
No	89.3	
Windows 0.95 W/m^2·K	85.3	0.025
Wall 100 mm	82.1	0.039
Floor 100 mm	81.1	0.041
Windows 0.74 W/m^2·K	76.8	0.047
Wall 150 mm	75.7	0.059
Roof 100 mm	75.0	0.071
Wall 200 mm	74.1	0.074
Roof 150 mm	73.9	0.101
Roof 200 mm	73.7	0.123

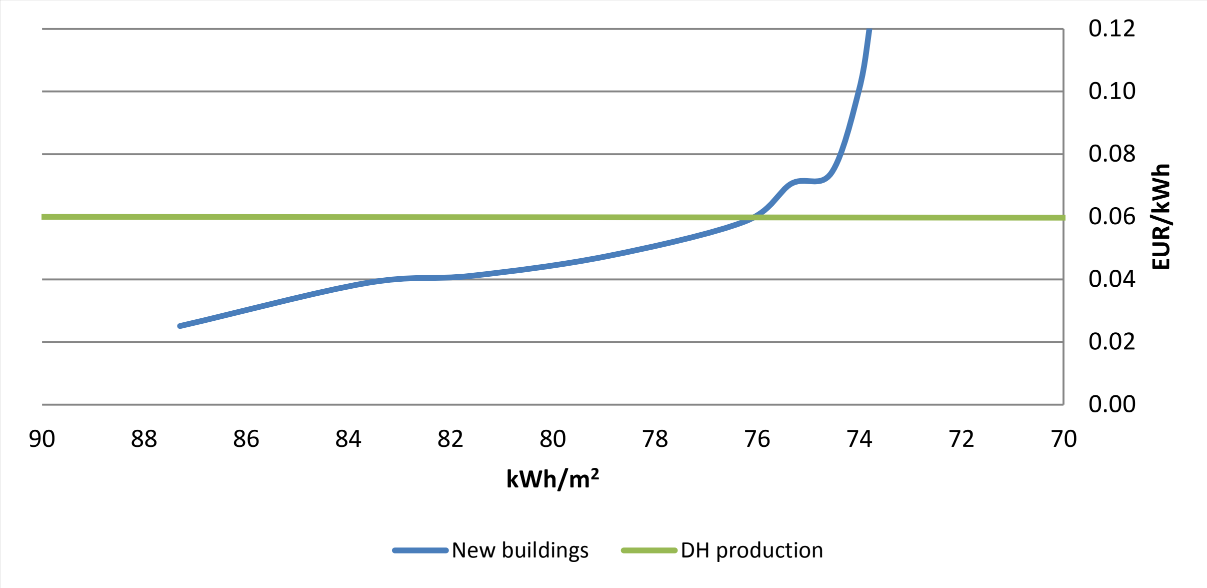

Figure 13: Marginal heat saving cost in new multi-apartment buildings

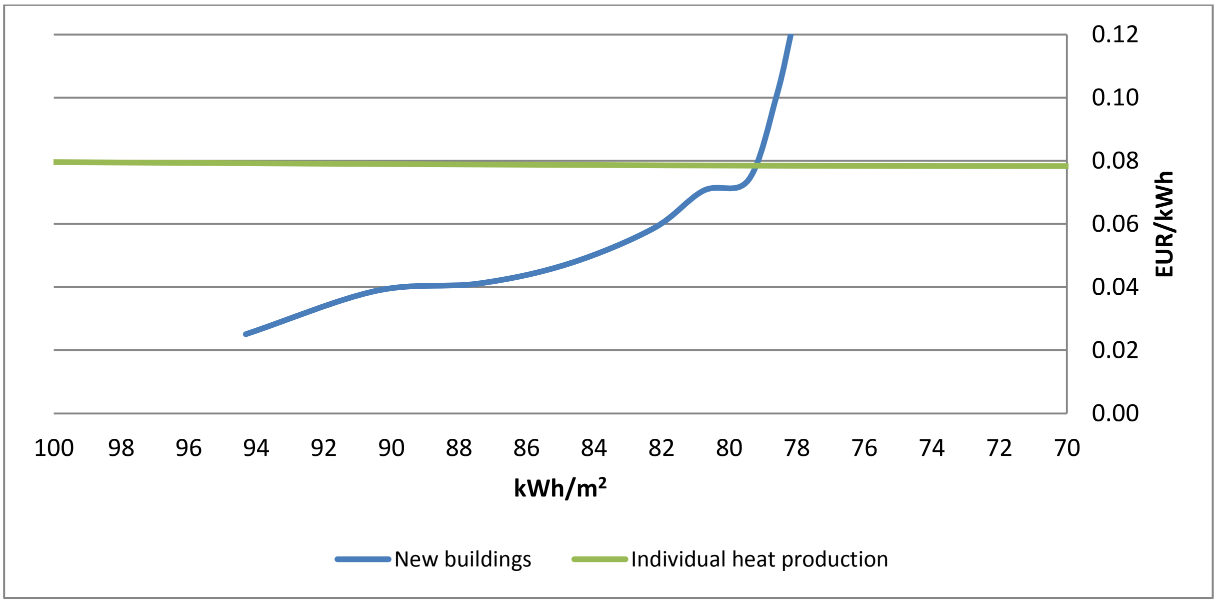

Figure 14: Marginal heat saving cost in new individual houses

As a result, in new multi-apartment buildings the optimum point is to implement measures which reduce heat demand for space heating down to 76 kWh/m^2, whereas for individual houses level of 79 kWh/m^2 seems feasible to reach. After this point, the marginal heat supply cost is lower.

5.3 Results and Discussion

Figure 15 presents the combination of the previous analyses for multi-apartment buildings, where marginal cost of DH production in the overall energy system in 2030 is compared to marginal cost of improving the energy efficiency in both existing and new buildings. The same combination for individual houses with individual heating is shown in Figure 16.

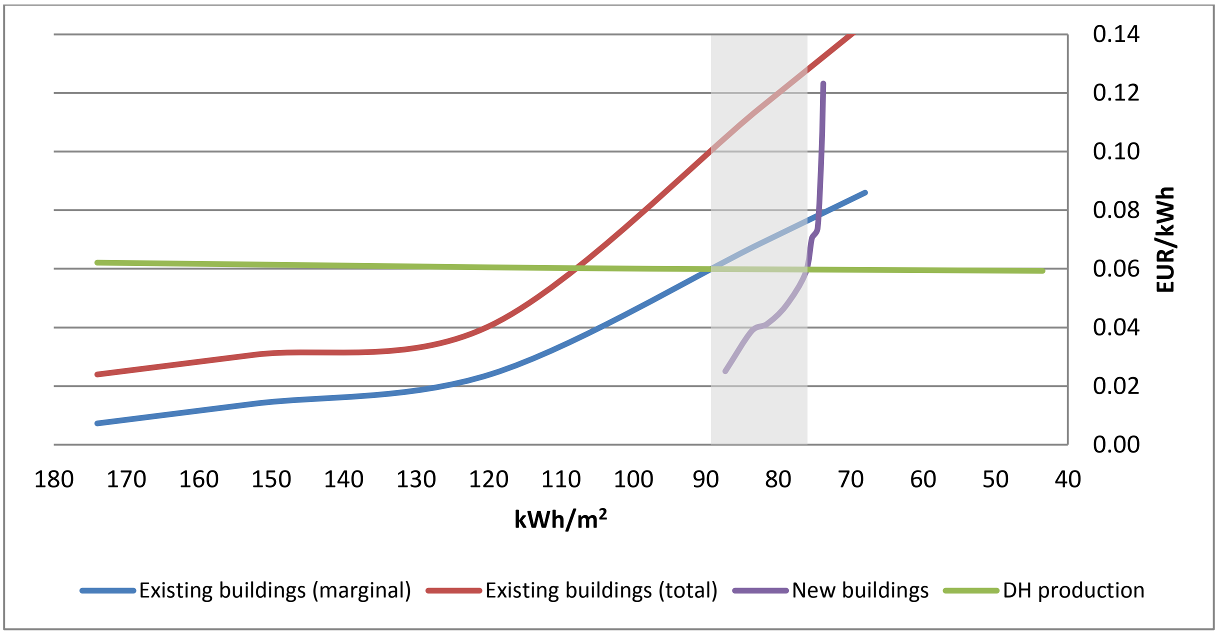

Figure 15: Marginal cost of district heat production compared to marginal cost of heat saving measures in multi-apartment buildings: existing (total), existing being renovated anyways (marginal) and new

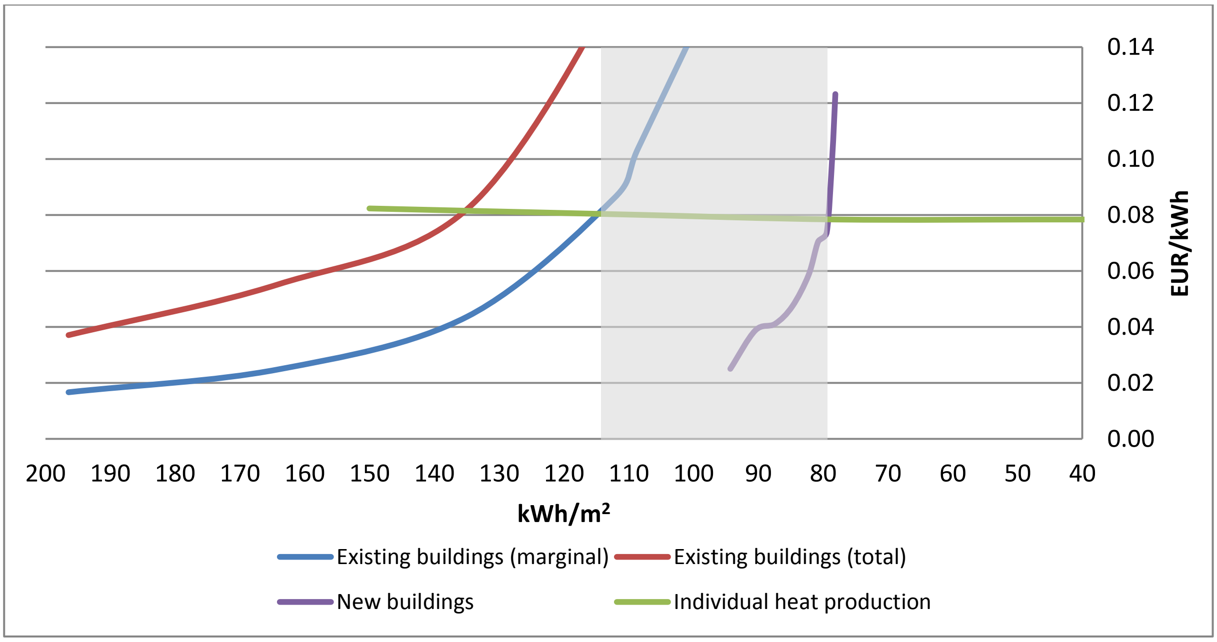

Figure 16: Marginal cost of individual heat production compared to marginal cost of heat saving measures in individual houses: existing (total), existing being renovated anyways (marginal) and new

The following can be concluded from the above:

- For the existing building stock, heat saving measures should be primarily implemented in the buildings which are being renovated anyways, since it is cheaper to invest in additional insulation than to pay for the total investments in renovation that is carried out solely for the heat conservation purpose. At the intersection with the heat supply curve, buildings being renovated anyways involve 26-27 kWh/m^2 higher heat savings related to space heating.
- Thereby, the least-cost heating solution for the energy system in 2030 seems to be reducing average heat demand for space heating from 174 kWh/m^2 to 76-89 kWh/m^2 for multi-apartment buildings (down to 44-51% of current level) and from 124.5 kWh/m^2 to 79-115 kWh/m^2 for individual houses (down to 63-92% of current level). The optimum range is shaded in the figures. However, the analysis is carried out only for residential buildings and therefore, for the whole building stock heat savings are expected to be higher, since it is likely that in non-residential buildings it is easier to achieve heat savings.
- When looking at the figures above, Figure 16 seems questionable. An optimum point of heat demand reduction in existing individual houses results in considerably higher specific heating demand (kWh/m^2) compared to multi-apartment buildings, even though marginal individual heat production cost curve is higher than the one for DH production. It could be argued that it has to do with a higher ratio of building's envelope per unit of heated area in individual houses, which causes higher specific heating demand. Thereby, much more effort and higher investments in thermal improvement to reduce heat losses further might be required. A conclusion could be that, in contrast to what has been done in this analysis, where the same measures have been applied for both multi-apartment buildings and individual houses in accordance with (Sistela, 2014), higher level of thermal improvement and its cost-effectiveness could have been tested for individual houses, in order to achieve higher heat savings.

  On the other hand, another consideration whether the average specific heating demand for space heating of 124.5 kWh/m^2 represents the real situation of individual houses in Lithuania could be questioned. One of the hypotheses could be that the statistics are not comprehensive enough and there are houses, where heating is based on private or other non-regulated firewood sources, or which have additional heating units, such as stoves, next to e.g. natural gas boilers, which is difficult to estimate and reflect in the statistics.
- As mentioned, the marginal cost curves of heat savings in existing buildings represent investments in an increasing number of buildings. As a result, in those which have lower energy efficiency, higher heat savings can be achieved by implementing less expensive

measures, compared to the buildings which are more energy-efficient. Therefore, when it comes to the prioritisation of which part of the building stock has to be renovated first, a priority should be given to the least energy-efficient buildings, as they are the most feasible to renovate. Following that, another consideration is that the buildings of higher energy efficiency today, are likely to deteriorate over the years and thereby, be more feasible to implement heat saving measures at the time it is being renovated. This should be considered when it comes to the national goal to give a priority of renovation for buildings, which can significantly contribute to heat savings in the least-cost way (Ministry of Energy, 2015).

- Finally, Figure 15 shows that the marginal heat saving cost of new multi-apartment buildings ends up being higher than that of existing buildings. This phenomenon could be explained by the fact that for the new buildings, the curve indicates increasing investments in all new buildings (more expensive measures by each step), while for the existing ones, the curve represents investments in an increasing number of buildings, where full renovation packages are implemented, including a mix of both “cheap” and “expensive” heat saving measures. Thus, the tail of the existing buildings curve also includes a portion of “cheaper” measures, making it possible to be less expensive than the new buildings.
  On the other hand, it could be argued that a cheaper solution can be identified by analysing each measure of renovation packages in different building categories separately and arranging them in ascending order, from the cheapest to the most expensive. However, it hardly matches the reality, where full-scale renovations are more common.

Further, a sensitivity analysis is carried out and the main findings are as follows:

- Figure D-1 in D Appendix for multi-apartment buildings shows that the more the future energy system is dependent on natural gas, the higher costs of heat production are and the more heat saving measures need to be implemented in order to achieve the least-cost point. For instance, in the scenario of less biomass in DH systems, the least-cost solution would be to reduce specific heating demand down to 74-78 kWh/m^2. Higher heat savings are also involved in case of higher fuel prices. The same tendency applies for individual houses as well, yet the influence is significantly lower due to the steep rise in marginal heat saving cost curve (see Figure D-2).
- The main calculations above are carried out with 3% interest rate. Therefore, sensitivity analysis of 1% and 5% interest rates is also carried out (see Figure D-3 – Figure D-6) and shows that heat saving costs are particularly sensitive to interest rate, since they involve significant investments.

- Apart from that, the results might be sensitive not only to interest rate, but also to material and labour force cost. It is a question though, whether the prices will go down in the period until 2030. Even if material cost might be reduced, it is realistic that labour force cost might grow up further, as it has been growing constantly until now (Trading Economics, 2015a). Moreover, the calculation in the analysis has been carried out with the basic renovation materials, e.g. expanded polystyrene, and one could expect that more sophisticated and thereby more expensive materials, e.g. mineral wool, might be used in the future. However, if this is a case and material and labour force costs are reduced, higher heat savings could be expected being involved in the heat saving strategy. However, where the rise in marginal heat saving costs is rather steep (for instance, for new buildings), the reduced investment costs would probably have a minor influence to the results.

In the calculations it has been assumed that mechanical ventilation is not considered as a heat saving measure due to a bulge which is expected to be created by required investment, as explained in Section 2.2. However, according to the figures above, the curve of marginal heat saving cost already crosses the curve of heat production marginal cost, suggesting that mechanical ventilation would not be feasible to install anyways with the expected considerably higher marginal cost, as heat production cost is already lower than investment in further heat saving measures. However, in order to see what improvement mechanical ventilation might bring, potentially achieved heat savings are calculated. Decentralised mechanical ventilation systems are taken into account with heat recovery of around 80%, since these systems can be seen case-by-case in some multi-apartment buildings in Lithuania (Staskevičius, 2015). In this case, additional heat savings of 37.4 kWh/m^2 can be achieved[3]. Thereby, if mechanical ventilation along with its investment was attributed as an indoor climate improvement rather than a heat saving measure, the least-cost heating strategy would involve a significantly higher level of heat savings.

It should be noted that the calculations of heat saving measures carried out in this chapter are rather rough and should be seen as a guide. The results of the analysis are valid under the assumptions made when modelling the buildings and choosing heat transfer coefficients as well as different renovation measures. As it is found, different levels of thermal improvement could have been tested for individual houses. Furthermore, as already mentioned calculations are purely theoretical and based on the normative methodology, which usually differs from the reality. In reality actual space heat consumption in buildings barely matches with its calculated demand value, even after factors

[3] According to Equation 3, approximate annual heat losses per 1 m^2 due to natural ventilation are calculated as follows: $0.67 \cdot (1 \cdot 2.7) \cdot 0.279 \cdot 1.2 \cdot 18 \cdot 220 \cdot 24 \cdot 10^{-3} \cdot 0.8 = 46.8$ kWh. By coefficient 0.8, it is assumed that not all the areas are ventilated. Thereby, heat recovery with 80% efficiency results in 37.4 kWh/m^2 savings.

such as thermal properties, dimensions, indoor processes and climate severity are taken into account. The main reason is a difficulty to determine variation in actual thermal conditions, quality of construction works, building maintenance level and behaviour of residents, which are not reflected in heat loss calculation norms (described by Equation 2 and Equation 3) and not considered at the building design phase. (Juodis, et al., 2009)

Moreover, apart from that, it is also worth to mention that calculations carried out in this study do not consider the fact that, after the renovation heating period might become shorter than is assumed, i.e. 220 days. Hereby the annual heat demand for space heating might be lower, resulting in more buildings being feasible to renovate compared to what is shown in Figure 15 and Figure 16.

Finally, it is interesting to compare the results with the similar study carried out for Denmark in (Lund, et al., 2014). First of all, it should be noted that much more detailed and accurate data was available for the Danish case, especially for individual houses which have been divided into 27 different categories, representing different specific heating demands, whereas in this study a number of assumptions are made and different building categories are created due to lack of data. Also, the results show that in Denmark higher heat savings can be achieved, i.e. reduction down to 58-80 kWh/m^2 (including domestic hot water needs) for individual houses, while in this paper it seems difficult to reduce heat demand for individual houses. Higher heat savings in Danish case might be caused by a number of factors. First, mechanical ventilation is assumed to be implemented independently from heat saving measures and thereby additional considerable amount of heat is saved. Second, higher level of insulation is used in Danish buildings. And third, one can expect somewhat colder climate in Lithuania, which results in different parameters used in heat loss calculations: average ambient temperature during the heating season, heating period throughout the year, indoor temperature, etc. Finally, the difference between buildings being renovated anyways and buildings not being renovated is less significant in Lithuanian case, whereas in Danish case, for the buildings not being renovated, implementation of heat saving measures is not feasible at all.

6 Household Expenditure

In order to achieve the least cost heating strategy in the year 2030, a huge step further in buildings renovation has to be done, since it is found in Section 5.3 that it is more feasible to carry out energy improvements in buildings which are going to be renovated anyways. However, dwelling owners are the final decision makers who choose whether to implement heat saving measures or not. It is clear that such renovation involves significant investment, which might create a financial burden for dwelling owners and become one of the barriers towards successful large-scale renovation. Therefore, it is important to understand the impact of carrying out renovation to private finances. However, in this chapter an analysis of household's expenditure related to renovation is done only for multi-apartment buildings, due to the time restrictions. Yet it does not mean that individual houses are less important, and they should have been investigated as well, if given more time.

Sample calculations are carried out for III category multi-apartment building, since it represents the majority of multi-apartment buildings in Lithuania (see Table 7). To simply understand the extent of investment, an analysis for one dwelling (around 55 m^2) is done. In Lithuania, each dwelling normally is owned by natural person (96.6% (Statistics Lithuania, 2013)), except from residential buildings such as those for social groups, which are owned by the state. It is assumed that the investment is made in the beginning of 2016 and the first heat savings are achieved in the beginning of 2017.

To start with, renovation measures for the analysed building are summarised in Subsection 5.1.1, which result in annual heat savings of 85 kWh/m^2 (from 162 to 77 kWh/m^2), i.e. 4,680 kWh/year per dwelling. To convert it to monetary value, heating price is introduced. As a point of departure, an average district heating price of 0.072 EUR/kWh including VAT during the 2014/2015 heating season in Lithuania is used (LDHA, 2015). To calculate heating price for further years, an inflation rate of 1.2% is applied, which represents the mean value of inflation rate over the past three years in Lithuania (Trading Economics, 2015b). For instance, the heating price in the investment year 2016 is $0.072 \cdot (1+0.012)^1 = 0.073$ EUR/kWh, while in the year 2017 when the first heat savings are achieved the price is equal to $0.072 \cdot (1+0.012)^2 = 0.074$ EUR/kWh.

As far as investment is concerned, the calculated total cost of construction works (wall, roof, floor, heating system) including VAT (21%) is equal to 103.0 EUR/m^2 of heated area or 5,652 EUR per dwelling (the number comes from calculations carried out to find marginal heat saving costs). However, not only construction work, but also project preparation (energy performance certification, investment plan, etc.), construction quality control and administration costs have to be taken into account, since these procedures are required for multi-apartment buildings. Recommendable costs for calculations are as follows: project preparation – 7% of construction work cost, quality control –

2% of construction work cost, administration – 0.121 EUR/m^2 of heated area per month (usually two year period is used) (BETA, 2015a). The costs are summarised in Table 17.

Table 17: Investment costs related to renovation of multi-apartment buildings (III category)

Investment	EUR/m^2	EUR/dwelling (55 m^2)
Construction work	103.0	5,652
Project preparation (7% of construction work cost)	7.2	396
Quality control (2% of construction work cost)	2.1	113
Administration (0.121 EUR/m^2 per month)	2.9	161
Total	**115.2**	**6,322**

According to the Ministry of Environment, renovation cost for 1 m^2 of heated area in multi-apartment buildings is 145 EUR on average (Ministry of Environment, 2014), which validates the calculated total investment cost of 115.2 EUR/m^2.

The costs in Table 17 represent the situation of renovation without any support and therefore, currently existing governmental support scheme, which is described later in Subsection 7.1.2, needs to be included and shortly presented. Financial support for renovation of multi-apartment buildings covers the following (support rates change over the time and the rates below are applicable for renovation carried out after 1st October 2015):

- 50% of project preparation, quality control and administration costs;
- 15% of energy improvement measures (construction work) related costs if heat savings reach 20%. Additional 20% support is given if heat savings of 40% are achieved (35% in total).
- Preferential credit with fixed interest rate of 3% for the period of maximum 20 years.
- All the costs (including loan and interest) are covered for deprived people.

The above described support scheme creates one scenario for the analysis. However, it is interesting to assess what the difference in private finances is, if the support rates are lower or if there is no governmental support at all. Based on this, the following scenarios are constructed:

A. 50% support for project preparation, quality control and administration costs and 35% support for construction work costs (if heat consumption after renovation is reduced by no less than 40%, according to current rules).

B. 50% support for project preparation, quality control and administration costs and 15% support for construction work costs.

C. No support.

Preferential credit is taken into account in each scenario. However, in the last scenario it is also tested how household expenditure changes, if there is no preferential loan and residents have to take a loan with higher interest rate (as an example, 8% is used). In calculations, the loan is paid as annuity payments and the loan period of 20 years is used.

In each scenario, annual net payments are calculated, which represent a sum of cash outflows (loan payment) and cash inflows (annual monetary heat saving). The results are given in Table 18. Detailed calculation of several examples can be found in E Appendix.

Table 18: Results of household expenditure analysis

Scenario	Loan	Investment (2016), [EUR]	Annual loan payment, [EUR]	Sum of loan payments (20 years), [EUR]	Sum of savings (20 years), [EUR]	Accumulated net payments (20 years), [EUR]	Result
A.	No loan	4,008.6	-	-	7,748	3,379	Payback time: 10 y 11 m
A.	20 years, 3% interest	4,008.6	269.4	5,389	7,748	2,359	Annual savings are higher than loan payment
B.	20 years, 3% interest	5,138.9	345.4	6,908	7,748	839	Annual savings are higher than loan payment
C.	20 years, 3% interest	6,321.7	424.9	8,498	7,748	-751	Payback time: 21 y 8 m
C.	20 years, 8% interest	6,321.7	643.9	12,878	7,748	-5,130	Payback time: 31 y

From Table 18 it can be seen that currently existing support scheme (scenario A) is greatly favourable for dwelling owners, as the difference between annual heat savings and annual loan payment is positive from the first year and increasing over the time due to increasing heating prices. It means that without any initial investments, residents overall pay less after the renovation than before renovation. The different situation is though when dwelling owners have money at the beginning and do not take a loan. In this case, the payback time of around 11 years is expected.

In case of lower support (15% for construction works in scenario B), annual loan payment is similar to annual heat saving during the first year and is lower during the rest of the loan payment period, meaning positive annual net payments.

If the whole monetary support is removed and the only incentive left is preferential credit, annual net payments during the period of loan payment (20 years) are negative. Accumulated annual net payments turn into positive after almost 22 years (2 years after the loan is paid off). In case preferential credit is also eliminated and people can borrow money from banks with 8% interest rate (which is quite optimistic), payback time is 31 years.

The calculations above are carried out with the average district heating price of 2014/2015 heating season in Lithuania. However, heating prices in different cities can vary almost twice between each other, e.g. 0.05 EUR/kWh in Utena and 0.093 EUR/kWh in Prienai (data from 10th April 2015) (NCC, 2015), which has an influence to the attractiveness of investments. In more detail, investments in renovation are more cost-effective in cities with higher heating prices, which cause higher monetary savings and thus bring the benefit to dwelling owners earlier. In contrast, in cities where heating prices are lower, lower heat savings and longer payback time of investment in renovation should be expected. Therefore, it might be easier to induce people to renovate in cities where heating prices are higher and thus the benefit of renovation is more tangible.

To conclude, investments in renovation might impose negative accumulated cash flows for several decades and become one of the main barriers, in case there is no financial support. However, as proved in the calculations above, the current governmental support for multi-apartment buildings eliminates financial burden of renovation investments for dwelling owners and thus, is a great incentive to increase the interest in renovation. It should be noted though that for individual houses there is no such monetary support and this might become an obstacle. Apart from that, other potential barriers towards successful renovations are looked into in the following chapter.

7 Barriers Identification

After indicating the least-cost heating strategy, it is necessary to look into the potential barriers which might hinder its implementation. Here again, only multi-apartment buildings renovation is looked into due to restricted time of the study. However, individual houses are equally important and, if given more time, could have been investigated.

Comparing to individual houses, the renovation process of multi-apartment buildings has a wider extent, since it includes a number of public procedures, such as preparing investment plans, procurement documents, etc. Therefore, a longer chain of process and a higher number of actors involved might create more potential barriers for multi-apartment buildings. Moreover, comparing to individual houses, multi-apartment buildings are likely to encounter more difficulties, when making decisions related to the procedures for the whole building, which is a result of many different dwelling owners with their different circumstances and opinions.

As Found in Chapter 6, financial impact to household's expenditure in multi-apartment building does not seem to be a barrier under the existing governmental support scheme. To find other potential barriers, it is important to identify the roles of different actors involved in the whole process. Based on this, a short stakeholders' analysis is carried out first in relation to renovation of multi-apartment buildings in Section 7.1. Afterwards, findings from the interviews carried out with recognised important stakeholders are described in Section 7.2, which leads to the conclusion on the main barriers and recommendations in Section 7.3.

7.1 Stakeholders' Analysis

In the whole process of reducing heat consumption in the Lithuanian building sector, a number of stakeholders are recognised. In this section, stakeholders related to successful process of multi-apartment buildings renovation are briefly described pointing out their main roles in the process as well as potential interest and influence.

7.1.1 European Union

The EU strongly supports Union's decarbonisation and reduction in dependency on fossil fuels, where a special focus is given to the building sector and its extensive energy consumption, in particular heat, as mentioned in Section 1.2. Thereby, the EU is a leading actor in Lithuania's energy efficiency improvement and heat savings implementation, by setting up targets, such as "20-20-20" in the Climate and Energy Package, which have to be attained. More detailed guidelines are expressed in various directives, such as the Energy Performance of Buildings Directive 2010/31/EU or the Energy Efficiency Directive 2012/27/EU, and have to be followed by Lithuanian legislation.

Apart from being the main legislative institution, the EU also plays a financial supporter's and thereby facilitator's role in Lithuania's attempt to reduce heat consumption in the building stock. The EU has helped to develop statutory and financial instruments, necessary to frame an approach of the multi-apartment buildings renovation programme. Currently, the existing support scheme includes 20% of heat saving measures covered by EU funds, which is coordinated by European Investment Bank (EIB). (LRP, 2011)

7.1.2 Lithuanian Government

Lithuanian government is the main and most powerful national actor, which defines the goals in order to increase the national economy and create better living conditions for citizens. As far as energy policies are concerned, the government defines related goals and how to implement these, which are then expressed in national energy strategies and laws. To make the implementation of new heat saving solutions easier and more efficient, continual revision and amending of current policies as well as setting up new mechanisms are crucial.

With this regard, due to the deteriorating situation of the Lithuanian building sector and its extensive consumption of heat, in 2004 the Lithuanian government has decided to set the housing renovation programme to stimulate heat savings in country's multi-apartment buildings built before 1993, both legally and financially. Since then, the programme has improved, i.e. the policies have been amended, the rules have been renewed and new measures have been included. Moreover, collaboration with the EU has been established in 2009.

The main support coming from the governmental renovation programme is as follows:

- 100% compensation of project preparation, supervision and administration works, if energy consumption in the building after renovation is reduced by more than 20%. The support is reduced to 50% after 1st October 2015.
- 35% compensation of heat saving measures implementation (15% from the State and 20% from the EU funds), if energy consumption in the building after renovation is reduced by more than 40%. The support is reduced to 30% (15% from the State and 15% from the EU funds) if renovation is implemented after 31st December 2017.
- Preferential loan with fixed 3% interest rate for the period of maximum 20 years.
- 100% coverage for low-income families and deprived persons, who have a right to social security and heating compensation. (LRP, 2014)

The support is given only for heat saving measures described in the approved exhaustive list (LRP, 2011). The programme of multi-apartment buildings renovation is under supervision of the Ministry of Environment.

7.1.3 Municipalities

Municipalities are interested in job creation, industry development and overall economic growth in the region as well as welfare of inhabitants. Municipality can participate in the governmental renovation programme, yet to limited extent, i.e. it can initiate the renovation of multi-apartment buildings (which otherwise is done by dwelling owners) by selecting buildings which need to be renovated the most. The choice and prioritisation of buildings is done by observing heat consumption data from DH companies and identifying the worst cases. Once the project is approved, municipality's function is to appoint an investment plan maker and administrator (building manager) for the renovation process. Apart from that, there is no other direct contribution to the process.

However, as the main authority in municipality, it can promote renovation and stimulate people by carrying out campaigns and thereby raising their awareness. There are great examples of several municipalities in Lithuania, where due to active mayors, renovation rates have grown significantly, e.g. municipality of Ignalina (Gėgžnas, 2015).

7.1.4 Investment Plan Makers

Investment plan (IP) makers are people from private companies and therefore, apart from their interest in their specific work field, the main concern is to increase their income. Therefore, increasing rates of renovation, which create additional job opportunities, might be of interest for IP makers.

As far as their influence is concerned, IP makers are crucial actors involved in the process from the first steps. They are responsible for evaluation of initial buildings physical conditions and heating characteristics, preparation of building's energy efficiency certificates, continual collaboration with building manager as well as dwelling owners, in order to structure the final desirable package of heat saving measures, which can then be finally turned into an investment plan[4] (Staskevičius, 2015).

IP makers have to follow the guidelines of how these plans are prepared and to meet the requirements set in laws (Staskevičius, 2015). Since IP is the first and the main document determining further procedures of renovation, it is crucial that calculations are carried out correctly by competent specialists.

[4]Investment plan includes identified necessary renovation measures, their contribution to energy efficiency improvement, investments, their payback time as well as sponsorship plan.

7.1.5 Technical Project Makers

Similarly to investment plan makers, the main interest of technical project makers is more job opportunities and increase in their income. Meanwhile, from the process point of view, they have a significant influence to the quality of the procedures carried out.

Technical project of buildings renovation is prepared based on the approved IP and in accordance with national Technical Construction Regulations. The document elaborates on specifications of solutions and measures, used to improve the performance of the building's construction as well as engineering systems, supported with calculations and schemes. The document is used to understand the extent of work, to estimate the costs and to find the contractor. Therefore, experience and qualified work of technical project makers are crucial in order to avoid mistakes in the next implementation stages.

7.1.6 Responsible Consultancy

Housing Energy Efficiency Agency (BETA) is the public company established in 2013 and the main coordinator as far as multi-apartment buildings renovation programme is concerned. Their main interest and responsibility is to ensure smooth, efficient and high-quality process, by meeting legal requirements of the procedures and bridging missing links between different stakeholders. (BETA, 2015b)

Firstly, the agency provides consultancy and assistance for dwelling owners regarding technical, administrative and legal issues related to renovation of multi-apartment buildings. Also, the agency carries out campaigns to encourage residents to renovate their buildings, raises their awareness and disseminates the information. Furthermore, the institution is responsible for evaluation and approval of submitted investment plans and procurement documents, cooperation with municipalities, administrators, engineering companies, etc. and therefore can be seen as a bridge to well-functioning system, ensuring proper management and implementation of renovation projects. (BETA, 2015b)

7.1.7 Contractors and Craftsmen

Contractors are the companies committed to carry out construction works (including engineering systems) according to customer's requirements. These companies are private and therefore, their main interest is better-paid job opportunities and making profit.

From the process point of view, they are the key actors in the implementation stage, as they are responsible for works being done. Professional and experienced craftsmen determine the effectiveness and quality of implemented solutions. Therefore, growing demand of renovation requires first of all, properly educated and knowledgeable craftsmen and secondly, sufficient amount of companies which can deal with renovation rates.

7.1.8 Quality Controller

Technical supervisors and construction inspectors form another actor directly related to the implementation stage, who has to ensure that the company responsible for carrying out the renovation performs their work properly and avoids any possible mistakes. This is of particular importance in order to achieve the quality and planned heat savings.

The main difference between the technical supervisors and construction inspectors is that the former usually comes from a private company whereas the latter is governmental institution, which has a greater degree of interest in the process transparency. Furthermore, quality control can be also done by the Housing Energy Efficiency Agency, described previously.

7.1.9 District Heating Companies

District heating companies are not involved in the renovation process directly as an active and influential institution. However, they provide necessary information for the project preparation about technical issues, such as heating specifications, and financial issues, such as existing debtors.

Nevertheless, DH companies contribute to national heat conservation in other ways. There is an EU requirement to set up national energy efficiency obligation schemes which ensure that energy companies each year achieve energy savings of 1.5% of the annual energy sales (EC, 2012). This is done by reducing heat losses in distribution network, replacing old and inefficient heat production units with more efficient ones, installing economisers, etc. One of the other means to attain the target could be a provision of financial support for heat conservation measures in the form of, for instance, subsidies for renovation.

7.1.10 Dwelling Owners

Dwelling owners are the final decision makers, whether to renovate their buildings or not, and thus have the highest influence to the process. They can stand as initiators of renovation or as a contradictory group who are against renovation. As a rule, the decision is made when the majority agrees, i.e. more than 50% of dwellings in a multi-apartment building; unless there is a created community, where different rules can be established. In both cases though, each dwelling has its owner, who has responsibilities and rights towards that dwelling, and represents a part of the whole multi-apartment building.

Dwelling owners is the most diverse actor in the process, due to different attitudes, knowledge or financial status. The main interest area of dwelling owners is a quality of life and better financial situation. The latter is of particular importance in the analysed process due to high investments required to carry out renovation. People also tend to lack understanding of what benefits, both financial and related to living comfort, are brought by investing in heat saving measures. For that reason, the government, municipalities, building manager and other relevant actors should raise people's awareness by providing necessary, easy understandable and transparent information.

Despite the fact that people are more and more interested in renovation process (Staskevičius, 2015), there are a lot of social factors though, which might hinder the process. Distrust, feeling of insecurity and opinion instability are worth mentioning. These are recognised in Section 7.2, where the interviews with relevant stakeholders are analysed. Therefore, motivation and raising awareness of dwelling owners are seen as crucial factors towards successful process and have to be ensured. In other words, if the majority of people resists, the process will never start.

7.1.11 Building Managers

Building manager in the renovation process can be either a chairman of the community, if there is any, or a representative from the caretaking company (each multi-apartment building has the appointed caretaking company). Building manager is the official body acting on behalf of and representing multi-apartment building residents.

Building manager organises the meetings of dwelling owners, explains the existing situation of building's physical condition, elaborates on heat saving measures, which are crucial in order to improve building's performance, disseminates and provides all the essential information related to the renovation process. Apart from dealing with dwelling owners, building manager also takes care of documentation and its delivery to right institution (BETA agency, banks, etc.). The person is involved throughout the whole renovation process, from the beginning until the end, and therefore his dedication, sincere and hard work can influence the process smoothness and efficiency.

Regarding differences between chairman of the community and a representative from the caretaking company, it is likely that the chairman might be more dedicated and motivated to contribute to the community's welfare since he is a part of that community. Meanwhile, a supervisor from the private caretaking company is likely to be less interested in social issues and more focused on legal things being done right and on time as well as making profit.

7.1.12 Banks

Generally, banks are the major financial source next to people's private funds, which can normally act as a driver or as a barrier towards implementation of heat saving measures, depending on whether they can offer favourable conditions for dwelling owners to borrow money.

At the moment, renovation of multi-apartment buildings in Lithuania is supported with encouraging financial model launched by the Lithuanian government (described previously) and three banks are in charge to execute it, allowing people to take a preferential loan of 3% interest rate for the period of maximum 20 years. As calculations in Chapter 6 show, this is a great incentive for people to implement heat saving measures, as it releases a financial burden.

Their influence is valid as long as the borrower complies with the requirements of the governmental support scheme. However, every commercial bank has its own policy and for security reasons, it is common though today that banks request to have at least 60% level of residents' acceptance when voting for the renovation process (Petrauskas, 2015), instead of standard 50%.

7.1.13 Research Institutions

There are a number of active research institutions in Lithuania, of which Lithuanian Energy Institution (LEI) or technical universities are worth mentioning. Their main mission is to carry out research and therefore profit making is not their main focus.

Research institutions are not directly involved in the renovation process, but they can provide a solid basis for further development of multi-apartment buildings renovation solutions, relevant technologies as well as provide consultancy, if necessary.

7.1.14 Media

Media is a very important actor in people's every-day life. The main role of media is to inform citizens on the latest news, developments and achievements and thereby to raise their awareness. Media can also influence and manipulate the public opinion, either negatively by disseminating unsuccessful experiences and thereby creating distrust, or positively by describing success stories and creating public acceptance. However, apart from information-sharing function, the main interest of media is usually making a profit.

More stakeholders who are to some extent engaged to the multi-apartment buildings renovation process could be found. However, the above described seem to be the most relevant. After the descriptions of each stakeholder, they are analysed in terms of their influence and interest towards successful implementation of renovation and placed in the interest/influence diagram, presented in F Appendix. The diagram is used as a supporting tool for better own understanding of actors' positions.

7.2 Findings from Interviews

Based on the previous section, the main actors with different functions and backgrounds have been identified and contacted in order to understand what the real situation of the current renovation programme is and what main obstacles still exist. The contacted persons are: 1) IP maker, 2) head of division of project implementation quality supervision in responsible consultancy BETA, 3) chairman of community of multi-apartment building, where renovation process is in progress, and 4) the president of Lithuanian Building Association (LBA).

During the interviews with the mentioned stakeholders, a number of obstacles are identified. These are divided by types (technical, organisational, etc.) and described in Table 19.

Apart from these issues, a lot of positive feedback is received during the interviews. Among others, the following should be mentioned:

- The interest in renovation of multi-apartment buildings is increasing steadily. This is likely due to the favourable financial support scheme launched by the government, which is a huge driver. (Staskevičius, 2015) None of the interviewees pointed out financial problems from residents' point of view as a barrier.
- More and more people are choosing more expensive solutions rather than the cheapest packages of heat saving measures. Furthermore, unlike some years ago, people start considering mechanical ventilation and an installation of decentralised systems is becoming present. (Staskevičius, 2015)
- As far as media is concerned, publications of success stories accelerate and replace unsuccessful experiences, which used to be present some time ago (Staskevičius, 2015).
- According to the responsible consultancy BETA, the quality of investment plans and technical projects is improving. Moreover, a significant attention is given to quality control of contractors and construction works. (Petrauskas, 2015)

Table 19: Main issues found during interviews

Type	Description	Noted by
Information	- People lack all kind of information, regarding both technical issues and the existing renovation programme.	IP, BETA, chairman
Motivation	- The main social problems are: changing people's opinion, lack of voluntary involvement, uncertainty, distrust and apathy. Older people are unwilling and do not see a point in changing their way of living.	IP, chairman
	- There is a lack of sincere contribution and hard work of buildings managers.	IP
Technical	- There is a shortcoming of energy efficiency certification, which excludes consumers' behaviour and takes into account only building's characteristics. Consequently, the basis, which is used to compare the results after the renovation, is not always correct. For instance, if people used to regulate heat flow at the building's DH substation manually and keep lower temperature than normative in order to save money, after the renovation where automatic regulation is installed, a higher normative indoor temperature is maintained and therefore actual heat savings are lower than expected.	IP
	- Based on the interviewee's experience, there was a case when DH company regulated heat flow for the building improperly and after an independent regulator took over the responsibility, building's heat consumption was reduced by 23%. This is most likely not a problem today, since around 80% of DH substations are automated, yet it might indicate a barrier of people's distrust towards DH companies.	Chairman
Labour	- There is a potential lack of qualified construction labour force to cover the increased renovation demand. One of the reasons is emigration.	IP, BETA, chairman, LBA
Organisational	- Municipality as an initiator selects buildings for renovation superficially, according to actual heat consumption data, meaning that the real situation and residents' opinion are not considered at this stage. As a result, it creates people's distrust that someone on the outside intrudes into their every-day life and property.	IP
	- Sometimes construction works are done by the companies which are not competitive and have neither financial, nor material resources.	IP, LBA, chairman
	- Procurements through Central Procurement Organisation system are based on the lowest price principle and are not flexible, i.e. there is no possibility for contractors to offer a higher price. As a result, it reduces	LBA

	the interest and thus the number of participating construction companies.	
	- Only minority of residents of multi-apartment buildings collect money regularly for the purposes of renovation, maintenance or accidents related to the building. This is though solved by the recently released law on mandatory fund-raising.	IP
Financing	- There is a sponsorship problem: funds coming from European Investment Bank to the commercial banks in Lithuania are not coordinated well and get stuck.	Chairman
Legal	- The Ministry of Environment lacked better and more detailed preparation for the leap of renovation rates and could not control it properly and competently, including the demand for craftsmen, the financial support scheme, regulations and rules. The latter are changing very often and this is an obstacle for the procedure carriers, who have to follow and learn the newest methodologies.	IP, LBA
	- Also, the conditions of governmental support are changing and have an impact to procurements. For instance, before the expiry of higher rate of support, the number of procurements increases twice or threefold, whereas afterwards, even though customers continue publishing tenders, there are no contractors who could take it.	BETA
	- There is a mismatch between investment plan and technical project, because they are prepared by different specialists from different companies, even though their content is similar. As a result, in case there is a problem with technical project, people have to come back to IP maker to do corrections. This requires a lot of extra time and the procedures are delayed.	Chairman
	- IP makers do not take any responsibility, which does not promote the highest quality of prepared investment plans.	Chairman, LBA
	- There is no mandatory inspection for investment plans and technical projects, which results in substantial mistakes made in these documents.	LBA
Market	- Due to the growing costs of works, older investment plans, prepared some time ago, do not correspond to the current prices and therefore cannot find contractors to implement them.	BETA, chairman, LBA

The above suggests that the renovation programme has a success, yet the existing obstacles found during the interviews still have to be dealt with. This is discussed in the following section.

7.3 Results and Discussion

Based on the stakeholders' analysis presented in Section 7.1 and barrier analysis presented in Section 7.2, the main conclusion and recommendations of how these barriers can be overcome are as follows:

- It seems that there are no crucial stakeholders, i.e. important stakeholders that have either no interest but a high influence or vice versa. An exception could be dwelling owners who have no motivation and interest in renovation.
- Dwelling owners are key players and have the highest influence in the process, since they are the final decision makers. Even though people's interest in renovation process has been recently growing, there is still place for improvement. As found during the interviews, uncertainty, distrust and lack of awareness still exist and therefore residents should be treated carefully and engaged in all procedures to the highest level, showing that their opinion and participation in the process is important and appreciable. In this way, their interest and acceptance might be increased. Furthermore, information about the renovation programme and technical heat saving measures should be provided to people. Elaboration on benefits brought by renovation as well as engagement can increase their motivation. Otherwise, if there is no interest from dwelling owners' point of view, it might become the main barrier towards successful renovation rates.
- The second recognised problem in Lithuania is a lack of craftsmen, who would be able to meet the increasing renovation demand and who are crucial to the renovation process, both in terms of labour force availability and its quality. It is hard to predict though whether it is possible to increase the amount of qualified craftsmen. Currently, an unemployment rate in Lithuania is 9.5% (March 2015) (Eurostat, 2015), meaning that there might be a potential of labour force, which could be realised by creating new education programs and attracting people, especially young. However, as noted by LBA (Gedvilas, 2015), one of the reasons of lack of craftsmen is emigration of qualified people. During the period of 2011-2013, the annual percentage of emigrants was 1.3-1.8% (Eurostat, 2015), half of which though was covered by immigrants. People most likely emigrate due to higher salaries offered abroad and it might be hard to attract people to Lithuania without raising wages. The latter however might impose another issue: increased labour force cost would make renovation process more expensive and thus less attractive for dwelling owners. The Lithuanian government needs to find a way to break this vicious circle and create favourable conditions for craftsmen, which in return would benefit the whole country by increased employment rate, taxes and thereby added-value. Also, the problem solving could be eased, if the

statistics on Lithuanian labour market were collected, allowing to assess the number of available craftsmen, predict the shortage for the increasing renovation demand and according to that, create educational programmes (Gedvilas, 2015). Following that, educational programmes are also necessary in order to improve the qualification and competence of craftsmen, so that the mistakes would be avoided and the highest effect of renovation would be achieved.

- The following barrier which should be solved is related to building managers, who are also identified as being key actors due to their high influence in coordination of the procedures. The issue recognised by the interviewee (Staskevičius, 2015) is that building managers lack sincere work and contribution, which might be particularly absent in case of representative from caretaking company. Therefore, a suggestion could be to assign administration functions for more concerned persons, who could exploit their influence usefully as well as encourage dwelling owners. The interviewed chairman of community is a good example showing that an active, interested and related to the process person (one of dwelling owners) can achieve higher quality results with fewer difficulties during the process.

  Following the previous consideration, municipalities should also establish a closer and stronger link with dwelling owners. Before taking any measures, municipalities should inform residents about their building's conditions and hear their opinion in order to avoid resistance. As mentioned, municipalities could carry out campaigns in order to raise the awareness about possible heat saving measures, as it is in their power. This also directly linked to the increase in people's motivation. In return, municipalities would benefit from new potential job opportunities for local craftsmen and thus taxes staying in the region. Furthermore, the place would become more attractive for inhabitants, which is also in favour of municipality.
- As far as governing institutions are concerned, i.e. the EU, the Lithuanian government, municipalities as well as dedicated consultancy BETA, they have both interest and influence in implementation of renovations as well as smooth and transparent process. However, there are still some legal issues, recognised by the interviewees, which should be solved by the Lithuanian government, as one of the most influential actor:
  - Better prepared and considered decisions and amendments in legislation could avoid difficulties in execution and prolonged procedures. Also, by unifying investment plan and technical project preparation and appointing these tasks to the same entity, more realistic and concerted results as well as time-efficient process could be achieved, which is also a facilitation for building managers.

    - The rules of public procurements through Central Procurement Organisation should be changed, in order to enable contractors to offer higher price than a bid and thereby attract more participants, as today it is hindered by the lowest price principle. It would be fare that dwelling owners of multi-apartment buildings can evaluate the offered prices and renovation packages, even if it is more expensive than initial one. This also has something to do with the fact that the lowest price usually contravenes the quality of energy efficiency improvements. (Gedvilas, 2015)
    - Government should also solve the financing problem to ensure funding coming from European Investment Bank on time. If this cannot be done, a possibility of temporary funds to cover the ongoing projects can be considered, in order to avoid stopped renovation processes.
- In general, contractors, investment plan and technical project makers have crucial influence to the quality of renovation process, yet lower interest in heat saving achievements and rather high interest in making profit. It is important therefore to engage them into the process and control in order to ensure that procedures are carried out properly. For instance, to date IP makers do not carry any responsibility, as found during the interviews. If it is legally changed and IP makers have a penalty for wrongly prepared IPs, higher quality of work can be expected. Mistakes in investment plans as well as technical projects could be also avoided by introducing mandatory quality inspection. Furthermore, the minimum requirements for qualification of contractors should be reviewed and tightened in order to avoid incompetent companies' participation in procurements and thereby low-quality construction works.

There are also several identified issues which are not directly related to the stakeholders' involvement in renovation process. Firstly, growing labour costs distort the already prepared investment plans; the growth in costs depends on economic level in the country and cannot be avoided though. The solution could be to take into account the price growth rates, either by investment plan makers at the preparation of investment plan stage or by Central Procurement Organisation by carrying out revisions. Elimination of the lowest price principle in the procurement process would also help here. The system should be flexible to market changes. In general, the problem could be eased if the time period between the IP making and procurement is kept as short as possible.

Finally, as far as energy efficiency certification and its shortcomings are concerned, until the certification system is improved, the problems, such as lower achieved heat savings after the renovation than it was expected, might be solved by explicit explanation to people, who are the most concerned group. This is a part of engagement and raising people's awareness.

To conclude, the overall renovation system seems to have a success. There are still a few missing links towards a well-functioning system, but most importantly, social problems are not as high as expected, meaning that there is no high resistance from decision making point of view. However, raising people's awareness and stimulating their motivation should be still of high importance. Apart from that, lack of craftsmen turned out to be the essential barrier, which might impede the growing rates of renovation in the country, if no solutions are found.

Since individual houses are not looked into due to time limitation, a few considerations should be mentioned. The value chain of the renovation of individual houses is likely to be shorter and thereby the process is likely to be less complicated. The main reason is that there is usually only one owner of individual house and thus one decision maker. The only important thing is to find how to motivate the owners to carry out renovation. In addition, the renovation process is simpler, since there is no need for a number of procedures, such as investment plan or technical project making, public procurements, etc. However, to date, there is no support programme for individual houses and therefore, financial burden of investments might become an issue.

8 Conclusion

Recently, an increasing focus has been given to the heat conservation in the building stock, which is the largest final energy consumer in the Union, significantly contributing to environmental pollution. However, heat saving measures are very investment-intensive and therefore, the question is to which extent such investments should be involved in the future least-cost heating strategies. In this connection, this paper attempts to analyse to which extent heat should be saved within the building stock rather than supplied in the future energy system of Lithuania.

Currently, a significant amount of buildings in Lithuania are old and energy-inefficient, thereby creating a burden for the energy system and resulting in money wasted on heating. Due to over-used heat energy and thus an imposed high dependence on imported natural gas, first, a significant amount of money is leaving the country and second, energy system is threatened with insecurity of supply, which calls for the solution. Multi-apartment buildings and individual houses in Lithuania are typically related to different heating solutions, i.e. district and individual heating respectively, and therefore are analysed separately. It should be noted though that data restriction has been faced during the study, especially when it comes to individual houses and their heating characteristics.

The methodology used in the report is based on comparing the marginal heat production cost with the marginal heat saving cost. Firstly, it is highlighted that the marginal heat production cost and thus the least-cost heating strategy strongly depends on which future energy system pathway is addressed. Secondly, as far as heat savings are concerned, even though the essential issue in the future energy system is the existing building stock, which is expected to constitute the major part of the heat demand, new buildings are also taken into account. With regard to this, the important point emphasised in the study is that the investment cost strongly depends on whether it is heat conservation in existing buildings or an additional investment in new buildings. Also, for the existing buildings, it is essential whether an investment is made solely for the heat conservation purpose or as a part of renovation, which will take place anyways.

The calculations are carried out in the way that for the buildings being renovated anyways, only costs of material and marginal labour force are taken into account, thereby making it cheaper than paying for the whole investments in the buildings, which are not being renovated. Meanwhile, for the new buildings, marginal heat saving cost is calculated as additional investments in energy efficiency improvements. Also, for the existing buildings marginal heat saving cost curve represents the investments in an increasing number of buildings, while for the new ones, the curve shows an increasing investments in all new buildings.

In the analysis, the future energy system for 2030 is modelled first, in accordance with the Lithuanian Energy Institute prospects, where the increased share of heat production in CHP plants as well as transition from natural gas to local biomass resources in final fuel consumption in the heating sector are emphasised as being crucial. The *EnergyPLAN* software is used and marginal heat production costs are found separately for district and individual heating. Second, marginal heat saving costs are identified for both multi-apartment buildings and individual houses separately, applying the most common heat saving measures in accordance with recommendations of a leading construction pricing company in Lithuania.

By comparing marginal heat production cost with marginal heat saving cost for one additional unit of saved heat energy, it is concluded that the least-cost heating solution for the Lithuania's future energy system in 2030 includes a reduction in space heating demand down to 44-51% of current level for multi apartment buildings. For individual houses, space heating demand of 63% of current level is feasible to reach for new houses, while for the existing ones more effort and higher investments seems to be necessary in order to reduce heat demand from the current level. However, the more in-depth analysis needs to be carried out for individual houses to clarify the results. Also, it is found that within the period until 2030, investments should be primarily made for new buildings and buildings being renovated anyways, while renovation solely for the heat conservation purpose is less feasible. In addition, a priority for renovation should be given to the existing buildings, which are the least-efficient and thereby are the most cost-effective to invest. Finally, it is indicated that the more the future energy system is dependent on natural gas, as it is now, the higher costs of heat production are and the more heat saving measures need to be implemented to achieve the least-cost solution, pointing out that deployment of local biomass resources is crucial in the future Lithuania's energy system.

After the socio-economic evaluation is done, the analysis looks into private expenditure, related to buildings renovation that normally involves significant investments. The analysis focuses solely on multi-apartment buildings due to the time restriction. It is concluded that renovation might impose a significant financial burden for dwelling owners, who are the final decision makers, resulting in a payback time of over 20 years, if there is no financial support, which might become one of the main barriers. Monetary support though, such as the current multi-apartment buildings renovation programme carried out by the Lithuanian government, is proved to be a great way to remove financial barriers and incentivise people to renovate.

Apart from finances, other obstacles related to buildings renovation are looked into, yet again only for multi-apartment buildings. The stakeholders' analysis is carried out based on the literature study, and interviews are conducted with identified stakeholders, who are of high importance and have different insights in the renovation process. First, it is found that even though the interest in renovation has been gradually increasing, uncertainty, distrust and lack of information are still present among dwelling owners. Therefore, the important point to emphasise is that engagement, motivation and raising awareness of dwelling owners is a crucial factor towards successful renovation, since they are the most influential actors in the process and decision makers. The second significant barrier turns out to be a lack of craftsmen who would be able to meet the renovation demand in the country, both in terms of quantity and quality of works. Finally, apart from these, a number of other barriers are identified in the study, such as legal shortcomings of the renovation programme as well as issues during its organisation, which need to be overcome in order to implement identified heating solution within the period in question, and which could be solved by the presented recommendations.

To conclude, the methodology carried out in this study should be considered by the Lithuanian government, when planning future heat energy savings within the building stock and prioritising which buildings need to be renovated first and to which extent. The least-cost heating strategy offers not only an increase in energy efficiency, but also a reduction in overall money spent on heating, primary energy use and hereby dependency on imported fuel, not mentioning mitigation of climate issues. Moreover, it should be highlighted that heat conservation can bring a number of benefits to the society, such as lower heating bills, better living conditions and thus standard of living as well as higher value of the real-estate. However, the still existing barriers need to be removed to accelerate successful renovation rates, giving an equal focus to individual houses, which are currently to some extent overlooked. This and other drawbacks are discussed in the following chapter, where recommendations of how the study could be improved further are given.

9 Perspective Analysis

After the conclusion on the study, a few recommendations and ideas for future investigations are presented in this chapter. Furthermore, some of the weaknesses of the study are brought up.

9.1 Data Availability

As mentioned, in the study investment prices and operation and maintenance costs of large plants are taken from Danish catalogues. Carrying out much more detailed investigation, based on the methodology presented in this study, more in-depth analysis of prices relevant to the country should be done, which then could be used in calculations.

Furthermore, in the Lithuanian heating sector, a big focus is given to multi-apartment buildings and collection of their heating characteristics. However, it is difficult to find such data for individual houses. Presumably, the heat consumption in individual houses for space heating might be significant, and even twice as high as in multi-apartment buildings in terms of kWh/m^2, as found in a report of Lithuanian District Heating Association (Gudzinskas, et al., 2011). Therefore, an investigation of Lithuanian individual houses, their state of structural elements, deterioration level and heat losses is crucial to discover a magnitude of issue. Furthermore, data collection on fuel consumption for the heating of individual houses should be looked into carefully, especially when it comes to firewood, since its regulated metering seems to be a shortcoming so far.

9.2 Heat Supply

One of the limitations made in this study is district heating infrastructure expansion. In future studies, it could be assessed to which extent district heating systems rather than individual heating should be used in order to find the least-cost heating strategy, since it is proved that district heating production cost is lower than individual heat production cost. However, in the case of DH system expansion, investment costs into the infrastructure needs to be considered. As another consideration, it is likely that people will migrate from rural areas to urban areas in the upcoming years, where district heating systems are present, and this connection of new buildings will bound to increase in district heat demand and infrastructure expansion.

As far as individual heating is concerned, introduction of e.g. heat-pumps in decentralised areas could be looked into, as one of possible heat production units in the future energy system.

In general, a lot of uncertainties exist when forecasting the future energy system in Lithuania and as mentioned, the results of the analysis largely depends on the future energy system vision as well as fuel prices. The main scenario analysed in this study is just a possible pathway, recognised in the consultative report published by Lithuanian Energy Institute. When the new national energy strategy is formulated, it could be looked into and the results could be tested according to the new prospects.

9.3 Heat Saving Measures

The costs of material and marginal labour force for the buildings being renovated anyways are found as an approximation. Thus, more accurate costs could be looked into by, e.g. consulting with construction companies or contacting *Sistela* for more detailed information.

For the existing individual houses, a further step to improve the investigation and clarify the results could be to carry out the more in-depth analysis of possibilities, on how the specific heating demand for space heating could be reduced further from the current level in cost-effective way.

As found during the analysis, domestic hot water amounts for a considerable part of total end-use heat consumption in multi-apartment buildings and can reach 28%. The reason of such a high share is found to be heat consumption for hot water recirculation system, which is included in the DHW component. Therefore, possible heat saving measures in recirculation systems could be looked into and potential heat demand reductions in multi-apartment buildings could be assessed along with its economic feasibility. For the purpose of understanding and inspiration, one could look into hot water recirculation system solutions in other countries, where it takes a lower share in the total heat demand, e.g. Denmark.

9.4 Barrier Identification

In the analysis, the higher focus has been given to multi-apartment buildings due to the time limitation. Therefore, an investigation of household expenditure as well as potential barriers related to renovation of individual houses is necessary to carry out.

Following the above, it has been recognised during the literature study as well as conducting interviews that the current renovation programme for multi-apartment buildings is quite successful and attracts dwelling owners to renovate. Some obstacles are still present in the process though. However, it seems a good time to solve these problems and learn lessons and a good opportunity to test the potential capabilities from e.g. craftsmen point of view, before larger-scale renovation projects start. When this is done, similar and already tested mature programme could be created for individual houses, as they are equally important from socio-economic point of view, yet to date there has been only a minor attention given to these buildings.

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