Integrated Strategic Heating and Cooling Planning on Regional Level for the case of Brasov

Richard Büchele[a1], Lukas Kranzl[a], Marcus Hummel[b]
[a] TU Wien, Institute of Energy Systems and Electrical Drives – Energy Economics Group, Gusshausstr. 25-29/370-3, 1040 Wien, Austria
[b] e-think energy research, Argentinierstrasse 18/10, 1040 Wien, Austria

Abstract

In this work a method for integrated strategic heating and cooling planning applicable for any city or region is presented and applied for the case study city of Brasov. The overall methodology comprises the calculation of the cost-optimal combination of heat savings with either district heating or individual supply technologies for different building groups located in different areas according to the availability of a current district heating network. This optimal combination is calculated for different scenarios and framework conditions, and different indicators like total system costs, total CO_2 emissions, share of renewables etc. are calculated and compared to analyse the economic efficiency as well as the CO_2 reduction potentials of various options to save heat and supply heat in the buildings. The results of the assessment show that in the assessed case study city heat savings of 58-78% are cheaper than all assessed heat supply options for the different building groups but that renewable supply options are not the most economical alternatives per se under stated conditions. The presented integrated planning process reveals that long term planning is essential to reach decarbonisation goals and that current framework conditions should be adapted to generate more favourable conditions for renewable heating systems.

Keywords

District heating; Heat savings and supply; Heating and cooling planning; Regional level

1 Introduction, motivation and definition

To reach the climate goals agreed on at the 2015 United Nations Climate Change Conference held in Paris (COP21) it is essential to also decarbonise the heating sector. In urban and densely populated areas district heating is seen as an important decarbonisation option, where it is often the only possible option to integrate large shares of renewable and / or excess heat into the heating sector: For example Werner [1] already found in his early works that district heating and cooling is a highly underestimated energy efficiency and decarbonisation method that could increase both energy efficiency and decarbonisation in the global energy system if concentrated heat and cold demands are supplied via district heating by local fuel or heat resources that would otherwise be wasted. During the Heat Roadmap Europe Project Connolly et al. [2] showed that a heating and cooling strategy based on district heating in densely populated areas could reduce heating and cooling costs by approximately 15%. And in one of his most recent works Werner [3] found that although the situation has improved at least in Europe and a commitment to the fundamental idea of district heating and a higher awareness of its benefits can be seen, still more efforts are required for identification, assessment, and implementation of these potentials in order to harvest the benefits of district heating and cooling. But because heating and cooling cannot be transported over too long distances its issues mainly appear on local and regional level and are very different depending on the local settings and therefore these assessments need to be done on the local or regional level. In former times there was no planning effort given to heating supply and the sector developed according to pure economics, availability and historic technology preferences without taking into account climate targets and long-term issues. But to exploit the decarbonisation potential of the heating and

[1] Corresponding Author: Email: buechele@eeg.tuwien.ac.at

cooling sector, integrated methods are needed on how to perform strategic heating and cooling planning on local and regional level. Only since the last few decades more and more research is done on respective planning processes however usually referring to the power sector or the overall energy sector. For example, the concept of integrated energy planning was proposed in the 1970's by the International Energy Agency, followed by different planning methodologies mostly applied on national level like Integrated Resource Planning, Least-Cost Planning etc. [4]. In the 2000's the European Commission recognized the importance of integrated approaches for planning of urban areas [5] and several studies elaborated on this: For example Ravetz et. al [6] looked on how to appraise the sustainability of a city, a region, a policy, or programme and outlined a conceptual framework and a practical tool based on a holistic or integrated assessment approach. However his Integrated Sustainable Cities Assessment Method, a scenario accounting system for the total environmental metabolism of a city or region did not mention heating or heat savings at all. Nilsson et. al [7] examined how municipalities address the supply, distribution, and use of energy to promote oil reduction, efficient energy use, and the use of renewable energy by a study of 12 municipal energy-plans in Sweden where national law has required them to develop an energy plan for more than 40 years and found that the plans varied in planning processes, contents, and level of ambition and that the role of energy-planning in the municipalities' comprehensive planning-processes has not been a prioritized subject. Also Bhatt [8] found that many cities tend to regard comprehensive long-term planning as secondary, although it would bring multiple benefits to the community and showcased an energy and environment systems model to provide a quantitative vision of technology and management strategy options for effectively deploying energy efficiency and renewable energy for reducing the carbon footprint. Sperling [9] examined to what extent municipal energy planning matches national 100% renewable energy strategies based on a review of 11 municipal energy plans in Denmark and suggested that the role of municipalities as energy planning authorities needs to be outlined more clearly in, e.g., strategic energy planning which integrates savings, efficiency and renewable energy in all sectors and requires the state to provide municipalities with the necessary planning instruments and establish a corresponding planning framework. All these works made their point for an integrated strategic heating and cooling planning process and in the recent years several studies tried to tackle some of the issues: For example Nielsen [10], Fallahnejad [11], Chicherin [12] and others, all focussed on finding expansion potentials for existing or new DH systems, assessing the costs of DH expansions, the costs of heat production, distribution, and transmission or even including scenarios of heat density development, expected market shares or the simultaneous improvement of both pipe routing and energy efficiency. However their models did not include other heating and cooling options nor the cost and potentials of heat savings. Others proposed different energy system models on local level: For example Lind and Espegren [13] developed a technology-rich optimisation model in order to analyse how various energy and climate measures can transform Oslo into a low-carbon city where the main focus of this work has been to find optimal ways of reducing the CO2 emissions, and secondly, the energy consumption. Also Simoes et. al [14] make a case for energy system modelling at city level and identified the optimum mix of measures for a sustainable energy future for four European cities in a holistic manner by combining quantitative modelling with Multi-Criteria Decision Analysis and found that urban level energy modelling should be more geographically explicit, and urban modelling results should expect scrutiny by local agents which makes transparency and effective communication with local decision-makers even more important than at national or transnational level. And only very few works like Pereverza et.al [15] deal with strategic heating planning for sustainable heating in cities where they developed a method for scenario development and selection based on the morphological approach and scenario criteria applied to participatory strategic planning for sustainable heating but they did not calculate any solution for saving or supplying heat. The importance of finding the balance between heat saving and supplying heat has been elaborated in [16] however not focussing on detailed regional level.

Summing up, strategic energy planning usually focusses on the power sector or the whole energy system but not on the heating and cooling sector. And in the case of demand and supply of the heating sector, only single aspects are tackled, but there is no scientific literature on an integrated strategic heating and cooling planning process finding least cost combination of heat savings and different heat supply options for different types of buildings situated in different proximities to existing district heating. In this paper we present the steps and method of our integrated strategic heating and cooling planning process performed for the case of Brasov where we develop an integrated framework finding least cost combination of heat savings and different heat supply options for different types of buildings situated in different proximities to existing district heating of a city with all steps integrated into a strategic planning process which can be applied to any other city or region. The discussion and implementation of the different scenarios and policies in line with the presented planning process are presented in [17] and the assessment of different policies and their impact on different renewable heating options in [18].

We define our integrated strategic heating and cooling planning in the manner that "Integrated" means on the one hand, that the connection of the heating and cooling sector with at least the power sector is included and on the other hand integrated means that the demand and supply are not seen as independent dimensions but that heat savings and the future development of heating and cooling demand influence the economic efficiency of different supply options and that they are interlinked and also linked to other sectors. With "Strategic" we mean that the whole planning process should be guided by the desired final state which always should be an efficient, renewable and affordable low carbon system. Therefore this aspect includes the future development and a long term vision and target of the demand and supply system. Additionally the strategic aspect includes the needed framework conditions to reach an efficient, renewable and affordable low carbon system. This means that policies and economic assumptions and their development over time play an important role in the strategic planning process and they are used as additional degrees of freedom to suggest framework conditions favourable to achieve the desired goals.Therefore the whole planning process should include long term targets and the assessment of different heat saving and heat supply options accompanied by intensive and target-group oriented information campaigns and involvement of all relevant stakeholders in order to ensure the achievement of the desired objectives. For example, district heating (DH) in general is seen as an important technology to decarbonise the heating sector especially in urban areas but especially this technology needs an integrated planning approach to include future development of heat demand into the assessment and to ensure a sufficient heat density with enough customers making DH an economic effective solution.

2 Method

The integrated strategic heating and cooling planning process presented in this paper was developed for different local case studies mainly within the Horizon 2020 project progRESsHEAT and then the methodology was adapted to the case study municipality of Brasov, located in the centre of Romania. The overall planning process included an empirical analysis of status quo, analysis of barriers and drivers based on interviews and surveys, a quantitative analysis of the heating related energy system and a policy assistance process. The latter, which is further described in [17], accompanied the whole quantitative analysis with intensive and target-group oriented information campaigns and involvement of all stakeholders in different types of workshops in order to ensure a broad consensus on the used input data, the methodology of the quantitative analysis and the used framework conditions and to guarantee acceptance of the results and the recommendations. In this paper we focus on the most important elements for the quantitative analysis in section 2.1 and on the modelling framework for the quantitative analysis itself, which is based on the calculation of the cost-optimal combination of heat savings with either district heating or individual supply technologies for different building groups located in different areas and included following steps which will be described in detail in section 2.2:

(1) Calculation of costs and potentials for heat savings for different building types with different construction periods with the Invert/EE-Lab model[2].
(2) Calculation of costs for heat supply with different individual heating technologies for the defined building types.
(3) Modelling of the existing district heating system and possible alternative supply portfolios for the future of the district heating system in energyPRO[3] to obtain the district heating generation costs and the sensitivity of the costs to disconnection or to additional customers.
(4) GIS based analysis to divide the municipality into different types of areas according to the availability of a current district heating network or the feasibility and costs of expanding the network into adjacent areas.
(5) For all building types and all areas within the municipality the cheapest combination of heat saving level and the supply with district heating or individual technologies is calculated.

All these steps are performed for a reference scenario and for a technical alternative scenario depicting a desirable future regarding the heat supply portfolio of the district heating system. Indicators like total system costs, total CO_2 emissions, share of renewables etc. are calculated both for the reference and for the alternative scenario to analyse the economic efficiency as well as the CO_2 reduction potentials of various options to save heat and supply heat in the buildings.

2.1 The planning process

In this chapter the most important accompanying elements for the quantitative analysis of the integrated strategic heating and cooling planning process are described. The first step of this process always includes a detailed analysis of the current situation, the needs and targets and available options and potentials. These results then are used to define the method and the framework for quantitative analysis. During the whole quantitative analysis several iterations were performed in different forms of meeting events in which local stakeholder were invited to discuss key factors affecting the results of the integrated strategic heating and cooling planning process and where the framework conditions for the analysis are constantly discussed.

2.1.1 Status quo of heating and cooling demand and supply

The calculation of the current heating and cooling demand is done bottom up via the Invert/EE-Lab model which uses detailed information on the building stock regarding building category, gross floor area, construction period and location. The building stock is categorized into ten different building categories, namely single-family houses, single-family row houses, small and big multi-family houses, private offices, public offices, schools, wholesale and retail buildings, hotel and restaurants and health buildings and into ten construction periods (1800-1910, 1910-1929, 1930-1944, 1945-1960, 1961-1970, 1971-1980, 1981-1989, 1990-1994, 1995-1999, after 2000). Each of the building categories with its construction period and with typical parameters for building size, building volume, size of windows, typical transmission values of the different parts of the building envelope etc. represents a building class for which the Invert/EE-Lab model than calculates the annual heating and cooling demand based on a standard static monthly balance approach, taking into account regional climate data and user behaviour to include rebound effects [19].

[2] Invert/EE-Lab is a dynamic bottom-up techno-socio-economic simulation tool that evaluates the effects of different policy packages on different indicators and was used to simulate the scenarios of development of the building stock and its energy demand in the EU-28 up to 2030/2050/2080 for various scenario assumptions and was applied in more than 35 projects. For more information see: http://www.invert.at

[3] energyPRO is a modelling software for combined techno-economic optimization and analysis of a variety of heat, CHP, process and cooling related energy projects developed by EMD International A/S. For more information see: http://www.emd.dk/energypro

The current heat supply in Brasov mainly relies on individual natural gas boiler with more than 95% of the current heat demand in buildings supplied by this technology, less than 5% supplied by the district heating system and far below 1% supplied by individual biomass boiler. The district heating network is split into three district heating networks and several so called district thermal units which are located in different areas and each unit supplies a couple of buildings. The current district heating network was mainly installed during the communist era and remained without major investments since then. Although the district heating network supplied more than 15% of the cities' heat demand in 2008 it now only supplies less than 5%. Only within the last decade reinvestments into the network started together with the replacement of the former coal fired heating plants by high-efficient natural gas fired combined heat and power engines. But the failing network lead to disconnection of many consumers and further increased the inefficiencies and lowered the security of supply. Therefore the current network infrastructure is overdimensioned and has losses of more than 50% making the operation economically unviable.

2.1.2 Scenarios and potentials

Within the planning process two different technical scenarios for the future of the district heating network were developed in close cooperation with the local energy authority and during various stakeholder integration meetings where first modelling results already have been taking into account. The developed technical reference scenario describes a reference future where the current district heating supply situation is kept. In this scenario heat is mainly purchased from an external company producing heat in natural gas fired high-efficient cogeneration engines at a certain price and investments will only be made to renew 50% of the old parts of the existing district heating network infrastructure to reduce the losses. It is assumed that by renewing 50% of the not yet renewed parts of the transport and distribution network the losses can be decreased to 20%. This replacement requires 9 Mio EUR to renew the remaining 23 km (800 EUR/m) of old transport network and 19 Mio EUR to renew the remaining 54 km (700 EUR/m) of old distribution network. The alternative scenario assumes that additionally to the investments into the network infrastructure, renewable supply technologies will be installed in different parts of the network to supply district heat. Further assumptions for both scenarios are:

- Heat can be purchased from the external heat producer at costs of 48.8 EUR/MWh (resulting from the current (2014) charged heat price of 35 EUR/MWh and an assumed price increase of 2% p.a. until 2030)
- Fixed operation expenditures of 2 EUR/MWh for heat purchased from the external heat producer
- Heat alternatively can be produced by the municipality owned natural gas heat only boilers or in the alternative scenario also by the installed renewable supply technologies
- Fixed operation expenditures of 5 EUR/MWh for heat produced by own production units
- CO_2 Certificates are needed for the heat produced in the natural gas heat only boilers
- Electricity for the plants and pumps has to be purchased from the grid

The two technical scenarios for the district heating system are implemented in energyPRO and for both scenarios the levelized costs of district heat (LCODH) are calculated, representing the necessary heat price that has to be charged to end-consumers to cover all expenses further explained in section 2.5.

Starting from the current number of customers with a supplied heat demand of 66.9 GWh the LCODH for both future scenarios are calculated for heat demand variations from -70% to +100% of the current heat demand to calculate the sensitivity of the LCODH to implementation of heat savings or connection or disconnection of consumers. Figure 1 shows the components and the parameters for each of the four different energyPRO district heating network models used for the reference and the alternative scenario. In the reference scenario in all DH areas heat is purchased from the external heat producer except for the "DH Cvartal" area with local heat production units owned by the municipal heat supplier. In the alternative scenario the additional renewable supply technologies installed in the different DH areas can be seen with their respective capacities. The cost assumptions are stated in the Appendix.

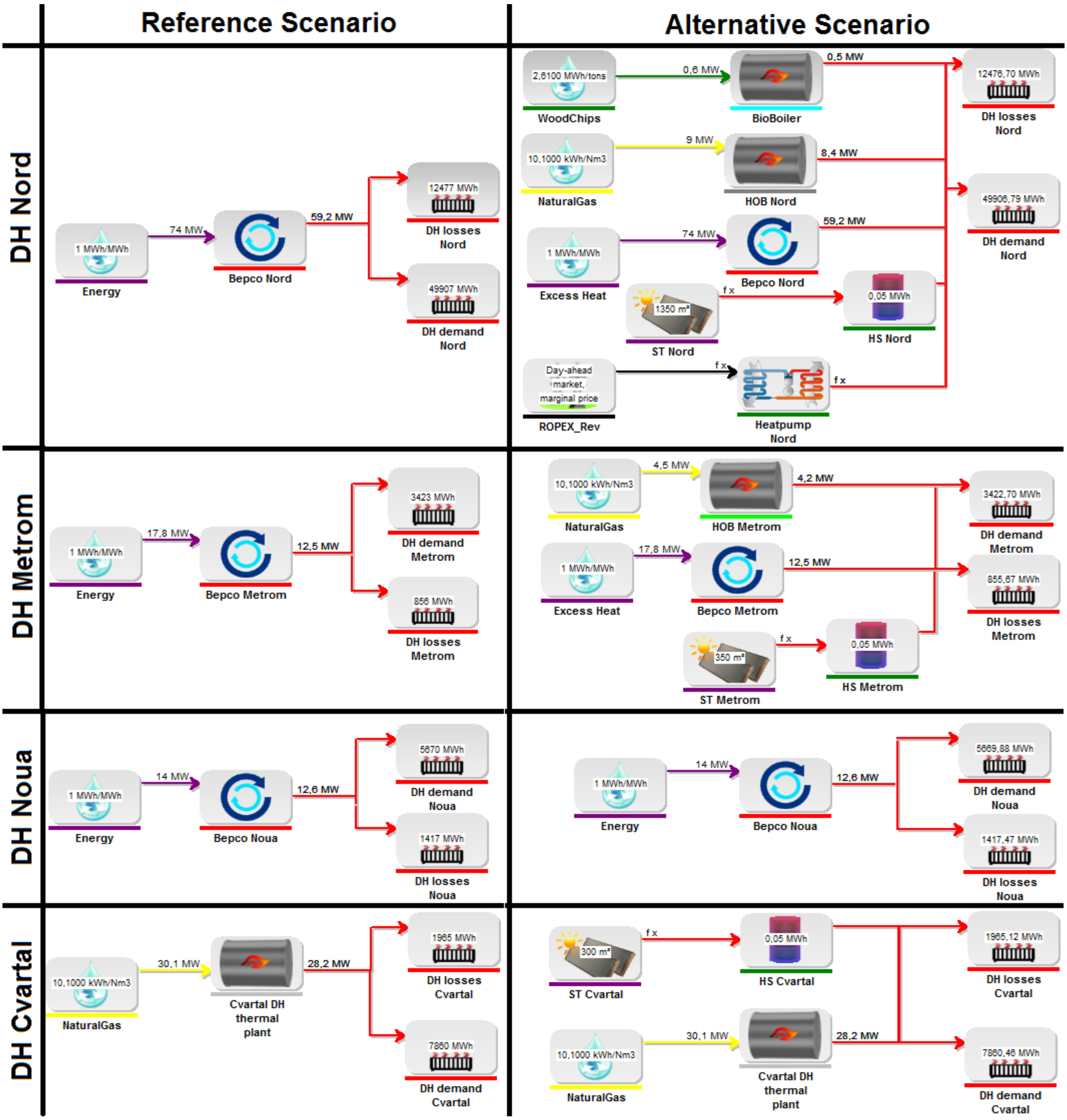

Figure 1: EnergyPRO models for the reference and the alternative scenario for the different district heating networks in Brasov

2.2 Quantitative analysis

In this chapter the different steps of the quantitative analysis are described in detail.

2.2.1 Costs and potentials for heat savings

To calculate the costs and potentials for heat savings, in a first step, the minimal investment costs into the different elements of the building envelope (building base, exterior wall, flat or steep roof and windows) to achieve a certain level of heat saving is calculated for the building classes described in section 2.1.1. This is done by using an optimisation model developed by Steinbach [20] and adapted by the author for the here presented work. For each building the model minimises the investment costs into the different building components IC_{bc} with their respective area A_{bc}.

$$\min \sum_{bc}(IC_{bc} * A_{bc}) \quad \text{(eq. 1)}$$

Depending on the buildings dimension and the quality of the different elements of the buildings envelope each building class achieves a certain current overall transmittance value. The optimisation constraint requires that after implementation of heat savings the new transmittance value has to fall below the reference transmittance value ht_{ref} resulting from the national building codes[4]:

$$\sum_{bc}(U_{bc} * A_{bc}) \leq ht_{ref} * A_b * f \quad \text{(eq. 2)}$$

The overall transmittance value resulting from the sum of the transmittance values U_{bc} [W/m²K] and the thickness of all building components with their respective surface A_{bc} [m²] has to be lower or equal to the reference transmittance value ht_{ref} [W/m²K] resulting from the national building codes with the respective surface A_b [m²] of the building and a factor f [-] defining the heat saving level that has to be achieved. Based on the current existing national building codes nine different levels of heat savings are defined. The levels were set to 1.9, 1.75, 1.6, 1.45, 1.3, 1.15, 1, 0.85 and 0.7 times the transmission coefficient resulting from the current building codes. This means that the worst renovation level achieves a transmission coefficient of 1.9 times the coefficient resulting from the current building codes and the best renovation achieves a 30% lower transmission coefficient then foreseen in the building codes. Therefore six renovation levels achieve transmission coefficients below the current building codes and three levels are equal or better than the current building codes in Romania. Additionally the costs of maintenance work without improvement of the thermal quality were calculated and used as a reference and also the costs for a possibly needed scaffold are added for the respective renovation options. Table 1 shows the cost of the different renovation actions for the different building components which are used to calculate the cost optimal renovation to achieve certain transmittance values. The cost data was taken from [21] for Germany and was transformed into costs for Romania using the European construction cost index as stated in [22].

Table 1: Cost of maintenance and refurbishment of different building components used for the calculation of heat saving costs (Source: Cost data for Germany from [21] transformed into costs for Romania using the European construction cost index as stated in [22])

Building component	Cost of maintenance [EUR/m²]	Cost of refurbishment [EUR/m²]								
		Insulation thickness of the different components [mm]							U-Value of window [W/m²K]	
		5	10	15	20	25	30	35	1.3	0.95
Steep roof	62.8	70.9	76.0	81.1	86.3	91.4	96.6	101.7	-	-
Flat roof	54.6	61.5	62.7	64.0	65.2	66.4	67.6	68.8	-	-
Exterior wall	17.1	37.8	42.5	47.1	51.7	56.3	61.0	65.6	-	-
Building base	-	12.1	14.0	16.0	18.0	20.0	22.0	23.9	-	-
Scaffold	4.18									
Big window	-	-	-	-	-	-	-	-	131.2	148.0
Small window	-	-	-	-	-	-	-	-	106.9	127.0

The cost data for refurbishing the different components of the buildings envelope with different thickness or transmittance values are used in a second step to calculate the minimal refurbishment costs to reach the nine

[4] The national building codes for Romania used for the calculation require U-values of 0.2 for the roof, 0.56 for exterior walls, 0.22 for the building base and 1.3 for windows

proposed transmission coefficient levels. The investment costs for a certain heat saving level IC_{HSL} [EUR] minus the investment costs for maintenance IC_{maint} [EUR] are divided by the heat demand of the respective heat saving level HD_{HSL} [kWh] minus the heat demand when performing maintenance work only HD_{maint} [kWh] to calculate heat saving costs in terms of levelized costs (of investments) per saved unit of energy $LCOHS_{HSL}$ [EUR/kWh].

$$LCOHS_{HSL} = \frac{IC_{HSL} - IC_{maint}}{HD_{maint} - HD_{HSL}} \quad \text{(eq. 3)}$$

In the calculation of the heat demand the Invert/EE-Lab model takes into account the rebound effect of renovation measures. For the calculation of the levelized costs of heat savings it is assumed that all buildings will be refurbished once within the considered period and therefore the costs are calculated as additional costs to an anyway performed maintenance. For the time horizon until 2030 the share of renovated buildings is limited to the share of renovated buildings per building class that undergo a renovation calculated by the Invert/EE-Lab model. This share ranges from 6% for newer residential buildings that will undergo a renovation and up to 31% for older residential buildings that will be renovated until 2030 according to the model calculation.

2.2.2 Geographical zoning of the municipality (GIS Analysis)

To differentiate the costs of district heating within the municipality it is divided into different zones based on a performed GIS analysis: District heating areas are defined as the area 50 m around existing distribution network. For the buildings located in district heating but currently not supplied by district heating it is necessary to invest only in connecting pipes and heat exchangers to be able to connect to district heating. Next-to-district heating areas are sharing a border with existing district heating areas and are defined as the area 1 km around existing transport network but excluding the district heating area. For the buildings located in Next-to-DH areas, it is necessary to invest in distribution pipes, connecting pipes and heat exchangers to be able to connect to district heating. Buildings in this area whose 10 nearest neighbours are altogether farer away than 1 km (mean distance of more than 100 m between the 10 nearest neighbours) will not be connected in case of an expansion. They are classified into the group of individual buildings. The individual area is defined as the area outside the next-to-DH areas. The individual area is not supplied by district heating and is not sharing a border with existing district heating area. For the buildings located in Individual areas, it is necessary to invest in transmission pipes, distribution pipes, connecting pipes and heat exchangers to be able to connect to district heating. Scattered buildings represent buildings across the municipality which are not close enough to other buildings. All buildings in the next-to-DH area and in the individual area which have less than 10 buildings within a range of 1 km are classified as individual buildings. The expansion of district heating to these buildings is not considered to be an alternative. Figure 2 shows a map of the municipality of Brasov with the four areas defined as district heating areas and the residential buildings that are located within each area. The four different areas are called “Nord”, “Metrom”, “Noua” and “ThermalUnits”. They are not connected to each other but each areas is supplied by own units. The yellow dots represent buildings currently connected to the respective DH-System. It can be seen that many buildings lie within the four district heating areas defined as the area within a distance of 50 m to existing distribution network but only few of the buildings are currently connected to district heating. This shows the former expansion of the network and the disconnection that took place leading to a now overdimensioned network with high losses.

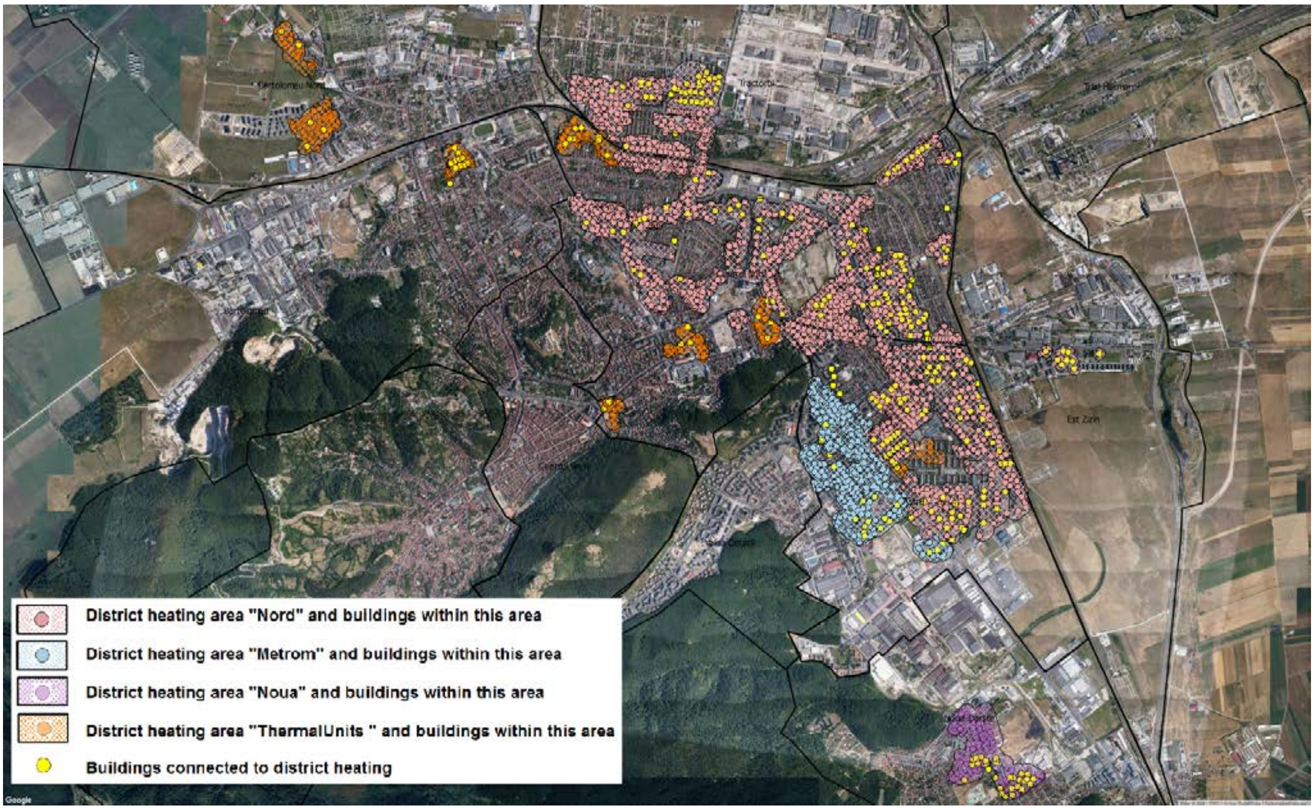

Figure 2: Different district heating areas and buildings in Brasov according to the GIS analysis

2.2.3 Heat supply costs for individual heating technologies

The considered individual heating technologies include oil boiler, natural gas boiler, biomass boiler, ground-source heat pumps and air-source heat pumps. The levelized costs of heat for these supply technologies are calculated for the different building classes according to the common calculation method:

$$LCOH_{indiv} = \frac{IC * cap * CRF + c_{O\&M}}{HD} + \frac{costs_{fuel}}{\eta} \quad \text{(eq. 4)}$$

Where IC are the specific investment costs [EUR/kW], cap is the installed power capacity [kW], CRF is the capital recovery factor [-], HD is the annual heat demand [kWh], $c_{O\&M}$ are the annual operation and maintenance costs [EUR/kW], c_{fuel} are the costs of the used fuel [EUR/kWh] and η is the efficiency of the heating technology. The annual heat demand for each building class is calculated with the Invert/EE-Lab model and the needed capacity of the heating system that has to be installed is calculated according to the month with the highest heating degree days, and an overcapacity-factor of two is used to cover the demand of the coldest day of the coldest month.

2.2.4 Heat Supply costs for district heating

The levelized costs of heat supplied by district heating (LCODH) are calculated using the energyPRO modelling tool. EnergyPRO conducts a techno-economic analytical operation optimization, accounting for weather, technical properties of units, maintenance costs, fuel prices, taxes and subsidies, losses etc. The tool contains time series for weather like air temperature, solar radiation, wind speed etc., which are accessed through links to online databases (NCAR, CFSR, CFSR2). Energy demands, electricity prices and results are also expressed in the form of time series. A set of power curves like fuel consumption, electricity and/or heat and/or cooling production etc. describes each production unit. The operation optimisation can be made with exchange to the electricity market against fixed tariffs for electricity or variable spot market prices. The operation strategy for the optimisation follows the minimisation of the net production cost. The used calculation step is 1 hour for an optimization period of 1 year. The calculated LCODH in the district heating area $LCODH_{DH}$ [EUR/kWh] include all investments into the old parts of the network IC_{oldnet} [EUR], into the additional supply units IC_{supply} [EUR] and the fuel costs c_{fuel} as well as costs for operation and maintenance $c_{O\&M}$ as a sum for all supply units coming from the optimization model. The $LCODH_{DH}$ are calculated as one single price for the overall district heating system that hast to be charged to consumer within the district heating area to cover all costs and investments of the scenarios based on the sold district heat demand HD_{DH} $[kWh]$.

$$LCODH_{DH} = \frac{\min(\sum_{supplyunits}(c_{fuel} + c_{O\&M})) + IC_{oldnet} * CRF_{oldnet} + IC_{supply} * CRF_{supply}}{HD_{DH}} \quad \text{(eq. 5)}$$

For customers in the next-to-district heating area additional costs for the expansion of the distribution network are included.

$$LCODH_{n2DH} = LCODH_{DH} + \frac{IC_{dnet} * CRF}{lhd_{dist}} \quad \text{(eq. 6)}$$

Where IC_{dnet} are the specific investment costs into the distribution network [EUR/m], CRF is the capital recovery factor [-] and lhd_{dist} is the linear heat density of the current distribution network [kWh/m]. The linear heat density of the current distribution network gives the district heat sold per length of distribution network. This approach assumes that within the expanded area the same amount of heat can be sold per meter of network than within the current network and therefore assumes the same heat density and connection rate in the expansion area.

For customers in the individual area additional costs also for the expansion of the transmission network are included with the same approach

$$LCODH_{indiv} = LCODH_{n2DH} + \frac{IC_{tnet} * CRF}{lhd_{trans}} \quad \text{(eq. 7)}$$

Where IC_{tnet} are the specific investment costs of the transportation network [EUR/m], CRF is the capital recovery factor [-] and lhd_{trans} is the linear heat density of the current transportation network [kWh/m].

2.2.5 Least cost combination of heat saving and heat supply

To find the least cost combination of heat savings and heat supply an iterative calculation procedure is applied. According to the building stock data each of the defined building types has a certain current heat demand and therefore different costs of heat supply based on the required capacity, investment costs of the supply technology and fuel costs.

1. For each building type in each area the initial costs of district heat, individual heat supply and heat savings are compared
2. The heat saving level which is cheapest in combination with the cheapest supply technology is chosen and implemented in the building:

   $$min(HS * LCOHS + (HD - HS) * \min(LCOH, LCODH)) \quad \text{(eq. 8)}$$

   Where HS is the heat saving [kWh] $LCOHS$ are the levelized costs of heat saving, HD is the heat demand of the building, $LCOH$ are the levelized costs of individual heating technologies and $LCODH$ the levelized costs of district heating
3. Required capacities of the heat supply technologies are recalculated according to the heat demand after implementation of the heat savings
   a. LCOH for individual supply are recalculated according to heat demand after implementation of heat savings

b. LCODH are recalculated according to the amount of sold district heat after implementation of heat savings in all buildings of this type

4. For each building type in each area the cheapest supply technology after implementation of the heat savings and recalculation of the costs of heat is chosen
   a. LCODH are recalculated again according to sold district heat after connection or disconnection of additional buildings
5. For each building in each area the cheapest supply technology after connection or disconnection of additional buildings to district heating is chosen

3 Results

3.1 Cost and potentials for heat savings

Figure 3 shows the additional costs of thermal renovations per m² of floor area compared to performing maintenance work only. In the presented results we focus on the different classes of residential buildings because they are the most important category covering 77% of the gross floor area and 73% of the energy demand for space heating and hot water in Brasov. The construction periods are grouped according to periods with changes in heating demand due to historic reasons. The construction period "very old" considers buildings built before the Second World War and comprise constructions before 1945. The construction period "old" comprises buildings built between 1945 to 1994 and considers buildings built during the communist era, which were mainly very large buildings with bad insulation quality. And the construction period "New" comprises buildings built after 1994, which were smaller and with better insulation quality. With more than 8500 residential buildings (55% of all residential buildings) most buildings are "old" buildings built in the period after the Second World War, and because also most large multi-family buildings where built in this period "old" buildings account for 72% of the gross floor area in Brasov with 59% of the total gross floor area being large multi-family houses. On the left picture the additional costs per m² are shown for the different relative saving levels and on the right picture for different absolute savings per gross floor area. The presented savings are effective savings taking into account the rebound effect. Both pictures show the relation that higher savings (both, relative and per saved energy per floor area) need higher additional investments per m² of floor area and that smaller buildings (e.g. single family houses) tend to have higher additional costs per m² than bigger buildings (e.g. multi-family houses).

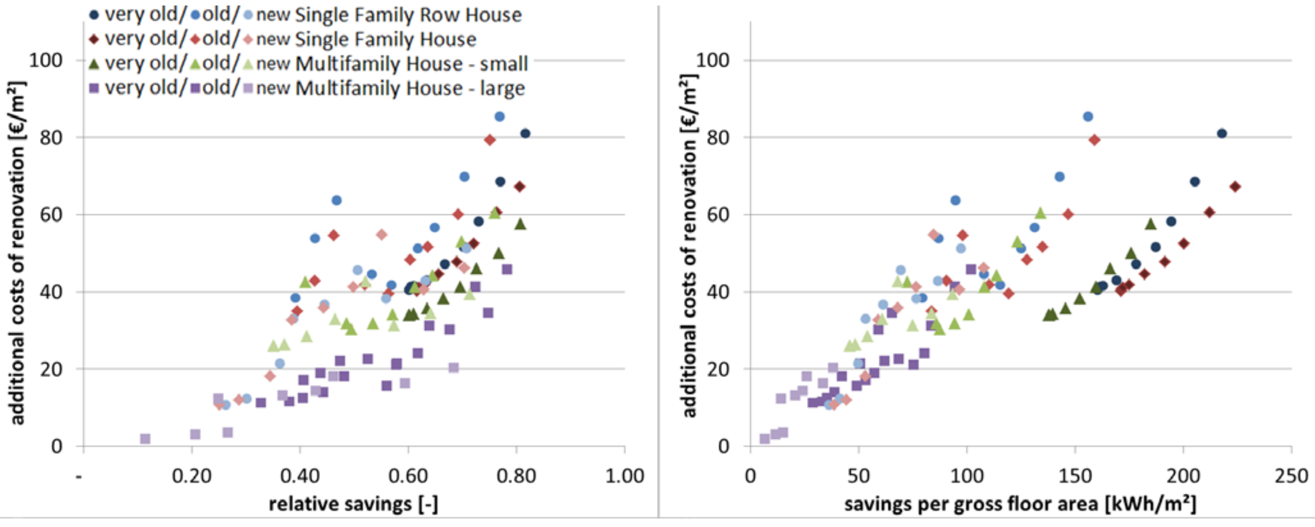

Figure 3: Additional cost of renovation to achieve different energy saving levels for space heating in different residential buildings in Brasov

Figure 4 shows the additional costs of thermal renovations per kWh of saved energy compared to performing maintenance work only. These heat saving costs [€/kWh] are directly used to compare them against heat supply costs. The figures show that the costs per saved kWh do not necessarily increase with higher relative savings or with higher absolute savings per m². The figures rather shows that the highest savings can be achieved most economically in buildings with currently high energy demand but that also reasonable savings that can be achieved at low costs in newer buildings.

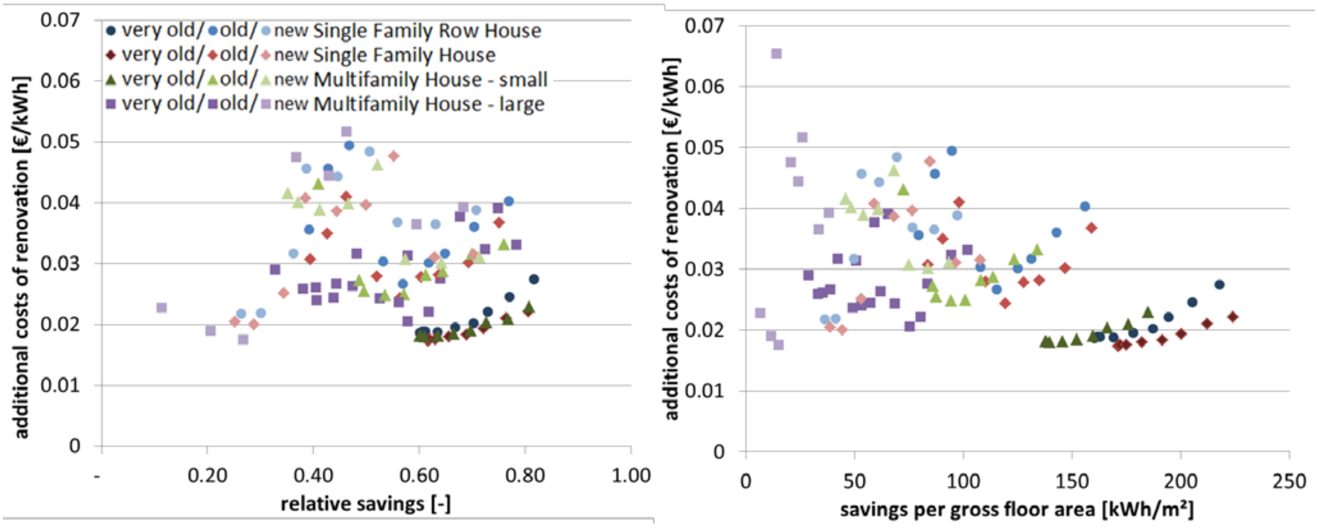

Figure 4: Additional cost of renovation for different savings per gross floor area in different categories of very old buildings in Brasov

3.2 Heat supply costs

Figure 5 shows the results of the energyPRO calculation for the levelized cost of district heat (LCODH) in the district heating areas for the reference and the alternative scenario in 2030. Starting from the current amount of sold heat of around 67 GWh per year the variation of the LCODH with up to 100% additional sold heat due to further customers and down to 70% less sold heat due to disconnection or implementation of heat savings is shown. The given LCODH are applicable within all four district heating areas where distribution pipelines already exist within 50 m of distance and only the investment into the connection of the building to the network has to be made. In both scenarios calculated LCODH include the assumed investments of 28 Mio EUR to renew the old network infrastructure and depreciate it over the next 25 years. The alternative scenario additionally includes investments of almost 8 Mio EUR for the different renewable heat supply technologies shown in Figure 1 and depreciated over the next 15 years. The investments and the assumed increase of the heat purchased from the external company until 2030 lead to LCODH in the reference scenario of 108 EUR/MWh assuming constant amount of sold heat. For the alternative scenario LCODH of 90 EUR/MWh can be achieved and even could be reduced to 80 EUR/MWh when 50% additional heat could be sold. On the other hand this would also reduce the share of renewables in district heating and increase the specific emissions to the same level as the reference scenario. This is because the additional renewable capacities in the alternative scenario are not enough to supply additional customers and increasing district heat demand would be supplied by peak load natural gas boiler. In the figure also the range of costs of the cheapest individual heating supply technologies for the different building types is shown schematically. For the current heat demand there is for all building types at least one individual heating system that is cheaper than the cost of district heating in both scenarios. A heat demand reduction due to renovation measures only slightly increases the levelized costs of individual supply technologies due to higher specific investment costs but lower installed capacities. This means that under both scenario assumptions and after implementation of heat savings but without connection of additional clients to the district heating system the district heating system is not competitive and further clients would disconnect.

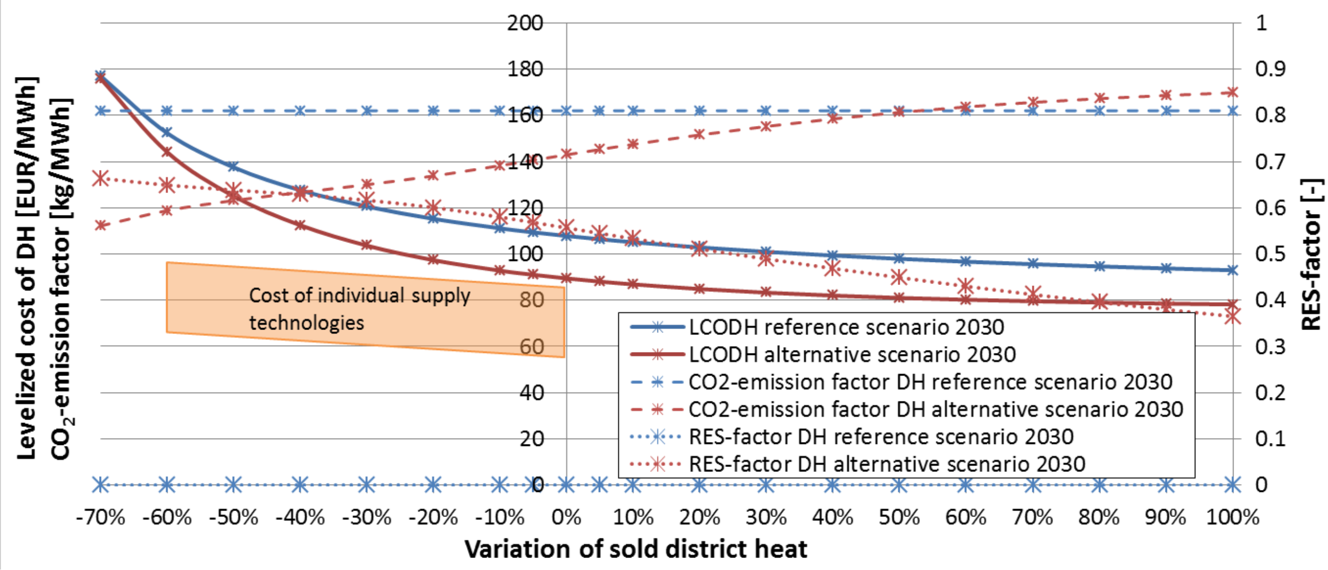

Figure 5: Variation of levelized cost of district heat according to sold district heat

3.2.1 Least cost combination of heat savings and heat supply

Figure 6 shows the results of the least cost combination of heat savings and heat supply for both technical scenarios for all areas and the whole building stock in Brasov until 2030 and 2050 compared to the status quo. The energy demand supplied by the different technologies, the resulting share of renewables and district heating and the costs and CO_2 emissions relative to the current situation are shown.

By implementing the most cost effective combination of heat savings and supply a demand reduction of 17% can be achieved until 2030 which is limited by the renovation rate until 2030. There is no difference in achieved heat savings and respective supply system between the two scenarios because district heating is not economically viable in none of the buildings as it was seen in the previous section. Therefore further buildings would disconnect and change to individual natural gas boiler resulting in a remaining share of DH of only 1.5% of the annual heat demand. Hence the lower CO_2 emissions and the higher share of renewables in the alternative scenario for the district heating system do not have a visible effect.

Until 2050 the whole heat saving potential can be implemented leading to a heat demand reduction of 64% for the overall building stock. For the 2050 scenario heat pumps are the most economic combination with heat savings for some building classes and all other buildings would keep individual natural gas boiler. This would result in a renewable share of around 20% and a CO_2 reduction of 75%.

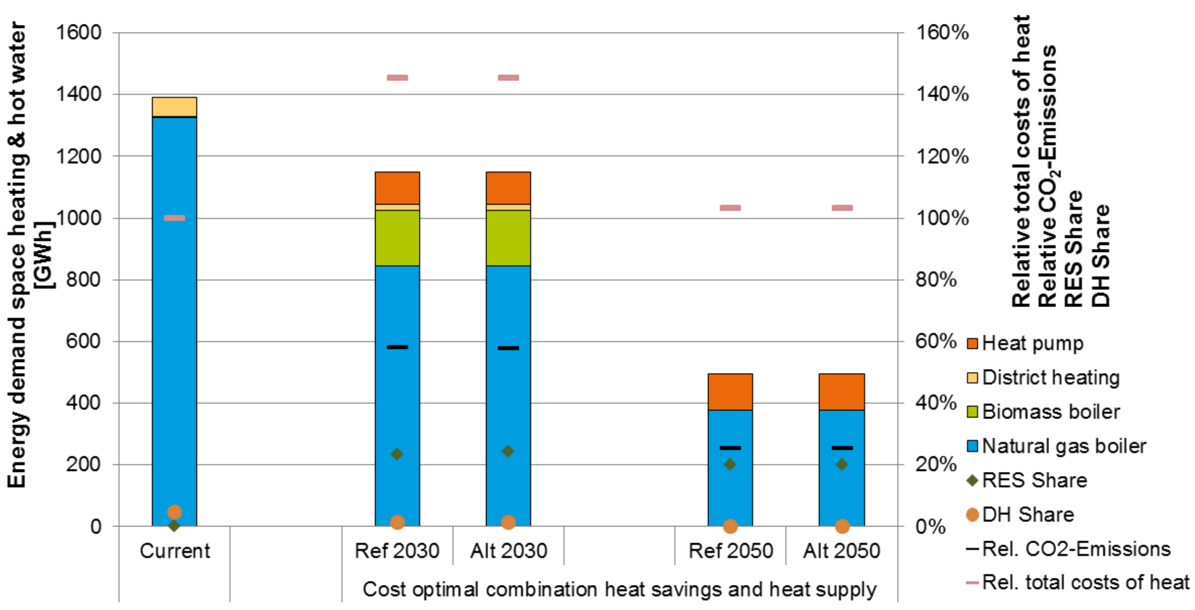

Figure 6: Results of the least cost combination of heat savings and heat supply for the different technical scenarios for the whole building stock in Brasov for 2030 and 2050

Figure 7 shows the results of the least cost combination of heat savings and heat supply for the different residential building classes until 2030 and 2050. The results show that at least a certain amount of heat savings, if performed when maintenance work is needed anyhow, is cheaper than all assessed heat supply options for all building categories. This applies especially for the old building stock but also for the newer buildings with construction period between 1995 and 2008. Until 2030 only a limited heat saving potential can be achieved due to limitations in the number of buildings that undergo a renovation and also the heating system exchange rate is limited. In 2050 the full heat saving potential is applied and all heating systems get changed assuming that the whole building stock will undergo a renovation until then. It can be seen that until 2050 all residential buildings apply heat saving levels at or higher than the national building codes (0.7 to 1.0) resulting in a relative demand reduction between 58% and 78% for the different buildings. Most of the residential buildings apply the highest of the calculated heat saving level (0.7) which means a 30% more ambitious reduction then foreseen in the building codes. For non-residential buildings the most economic heat saving is in the range of 0.85 to 1.15 times the building codes and therefore a little lower than for residential buildings. Between different scenarios there is almost no variation in the cost-optimal heat saving level. This is due to three main reasons: First, the heat saving costs in the Romanian building stock are relatively low due to low average thermal quality of the current building stock and high achievable savings at moderate costs of working force. As a result the deep renovation levels are cost effective leading to a low difference in heat demand of renovated buildings. Second, in all scenarios the cost optimal combination of heat saving level with the cheapest heating system is chosen. As a result when the heat supply costs of a certain heating system increases the next-best heat supply system is chosen resulting in the same heat saving level. Here the third reason takes effect, which is, that most heating systems have levelized heat supply costs close to each other.

Therefore the heat supply options chosen in combination with the most economic heat saving level vary for the different buildings: Biomass boilers are the cheapest supply option in combination with heat savings for all single family row houses until 2030. For single family houses and small multi-family houses ground source heat pumps are the most economic combination and for big multi-family houses it’s the natural gas boiler. In 2050 heat pumps will be the most economic combination with heat savings for old and very old row houses, for newer single family houses and for all types of multi-family houses. In all other buildings again the natural gas boiler is the most economic combination under the stated conditions.

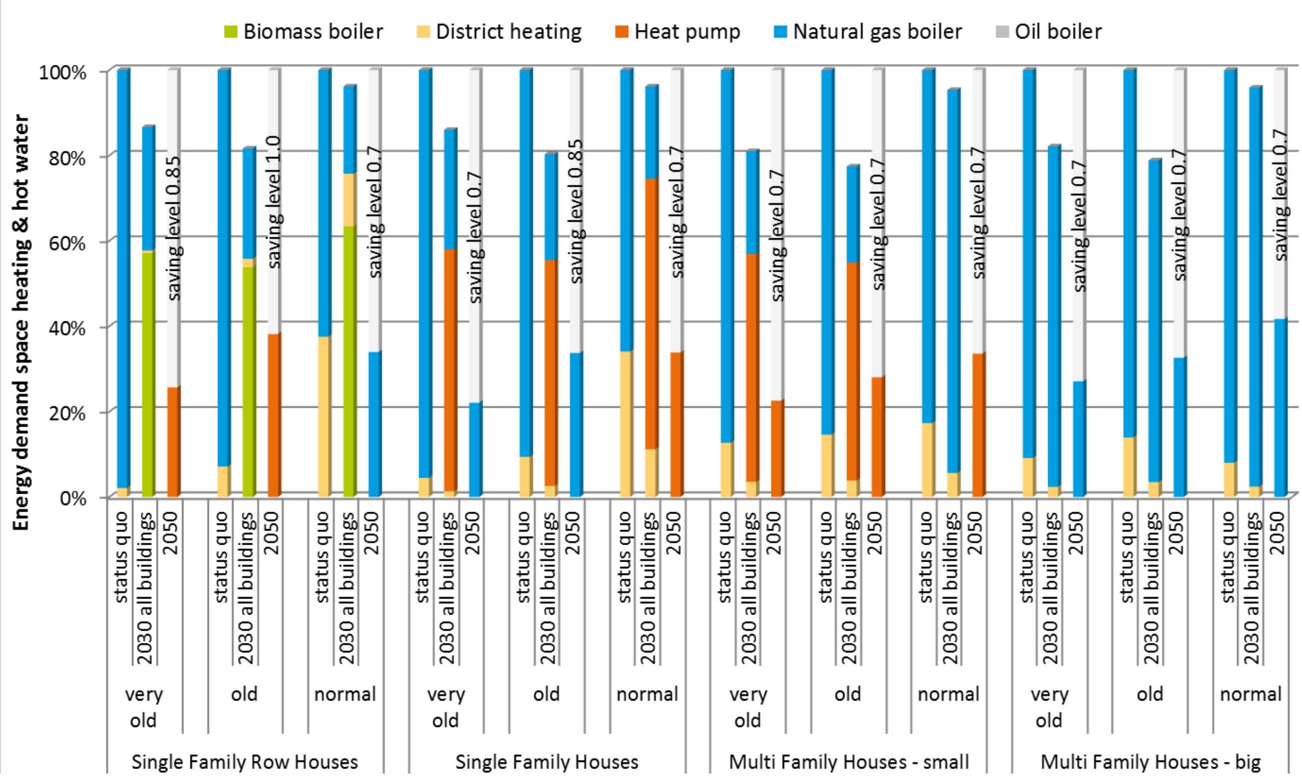

Figure 7: Results of the least cost combination of heat savings and heat supply for the different residential building classes until 2030 and 2050. The results for 2030 show the relative shares of savings and supply for all buildings of the respective category whereas the results for 2050 are the same for each building and the sum of all buildings (because all buildings are assumed to undergo a renovation until 2050 and all chose the most economic combination)

4 Discussion

For the first time an integrated planning approach trying to find the cost optimal combination of heat savings in combination with different heat supply options taking into account the local and regional framework condition and also trying to integrate different stakeholder interests is described in detail. The presented integrated strategic heating and cooling planning process can be seen as guidance on how heating and cooling planning could be performed and although it was developed and applied for a specific case study the process itself can be applied to any other city or region. The used approach, however, lacks the level of detail needed to perform detailed investment or expansion planning of district heating network or to obtain the necessary information on the optimal solution at the individual buildings level. For example, the performed simple GIS analysis to define district heating and other areas is not detailed enough to reflect the real cost of connection for all buildings. Also, the categorisation into different types of buildings with different characteristics allows estimating the heat saving potential and potentially feasible supply options for a building stock consisting of different building groups but not a detailed answer on the exact renovation measures that should be performed for an actual building. Additionally, our approach of finding the least cost combination of heat savings and heat supply options may reflect the general aim of investors to invest into cost-effective solutions, but in reality investment decisions depend on many other factors not reflected in our model. This means, that actually applied measures usually do not represent a cost optimal solution and due to uncertainties it is hard to find economic optimal combinations between heat savings and heat supply options in reality, in contrast to our model results resulting from several simplifications. However, the presented method has shown that an integrated strategic heating and cooling planning process has to consider the interaction between cost-effective heat saving levels in the long term and the resulting economics of the supply systems. Heat demand and supply cannot be seen as independent dimensions and the future development of the heat demand influences the economic efficiency of different supply options. We have also seen that all assessed supply technologies have heat generation costs close to each other and their economic feasibility depends on assumed taxes, lifetimes and other framework conditions. Especially the economic efficiency of district heating highly depends on the achieved number of connected customers within the network area. These findings show that a strategic heating and cooling planning process should always also consider the local conditions and should be flexible enough to adapt to them.

For the assessed case study we have seen that in the long term cost effective levels of heat saving are between 58% and 78% for the different buildings. These heat savings reflect buildings with heat demands at or below currently implemented building codes. Increasing the cost of just one energy carrier does not remarkably influence the cost-optimal level of heat saving. This is the case when we assume that investors choose the most economic combination of savings and supply and therefore switch to the next supply option which in the end does almost not affect the heat saving level. However, assuming higher overall energy prices would make higher saving levels more economic. But the results also show that the cost-optimal combination of heat savings and heat supply in the case of Brasov is not necessarily the most ecological or desired solution and may result in missing important climate protection targets. This is because investors often decide on current investment costs and energy prices not taking into account long term targets or sustainability. This shows the importance of integrated strategic heating and cooling planning to evaluate the needed framework conditions facilitating the implementation of cost optimal combination of heat savings with renewable and low carbon heating technologies. In strategic heating and cooling planning importance should be given to defining policies as well as assumptions on economic framework conditions and their development over time. These can be used as additional degrees of freedom to suggest framework conditions favourable to achieve an efficient, renewable and affordable low carbon system.

5 Conclusions

This paper has presented a method and framework for integrated strategic heating and cooling planning on regional level which in general can be applied to any city or region. The approach is based on identifying the least cost combination of heat savings and various heat supply options for different buildings situated in different areas relative to an existing district heating network. The results for the assessed case of Brasov reveal cost optimal levels of heat savings between 58% and 78% for the different buildings in the city. These cost optimal levels of heat savings are reached when also choosing the cheapest supply option for the different buildings in the long term for the assessed case study. However, the assessed supply technologies have heat generation costs close to each other and the chosen cheapest supply option may not be the most ecological option which may result in not achieving CO_2 reduction targets. It can be said that an integrated strategic planning process is needed and long term planning is essential to reach decarbonisation goals and that current framework conditions may need to be adapted to generate more favourable conditions for renewable heating systems. The presented integrated strategic heating and cooling planning approach can help to assess different framework conditions that may be needed to achieve an efficient, renewable and affordable low carbon system in the long term.

Acknowledgement

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Appendix 1: Cost assumptions

Cost parameter for DH utility	2014	2030	2050
Natural gas price	30.8 EUR/MWh	45.3 EUR/MWh	52.6 EUR/MWh
Biomass price (wood chips)	14.0 EUR/MWh	18.0 EUR/MWh	19.5 EUR/MWh
CO_2 emission costs	7.5 EUR/tCO2	31.5 EUR/tCO2	87.0 EUR/tCO2
Electricity price (plants and pumps)	80.7 EUR/MWh	81.5 EUR/MWh	70.8 EUR/MWh
Heat purchased from external producer	35.5 EUR/MWh	48.8 EUR/MWh	72.0 EUR/MWh

Cost parameter for private households	2014	2030	2050
Natural gas price	38.2 EUR/MWh	77.7 EUR/MWh	90.2 EUR/MWh
Biomass price (wood pellets)	28.4 EUR/MWh	36.5 EUR/MWh	39.6 EUR/MWh
Oil price	144 EUR/MWh	264 EUR/MWh	305 EUR/MWh
Electricity price	150 EUR/MWh	150 EUR/MWh	134 EUR/MWh

Investment assumptions	Interest rate	Lifetime [Years]	Specific Investment	Capacity
Transport network	6%	25	800 EUR/m	11 500 m
Distribution network	6%	25	700 EUR/m	27 000 m
Natural gas heat only boiler	6%	15	100 EUR/kW	12 600 kW
Biomass boiler	6%	15	400 EUR/kW	500 kW
Heat pump	6%	15	1 500 EUR/kW_{el}	3 000 kW_{el}
Solar thermal collectors	6%	15	524 EUR/m²	2 000 m²