CO_2 mitigation in the Hungarian domestic sector: opportunities and associated costs

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Abstract

Residential sector is the key target for climate mitigation policy in Hungary. In 2004, this sector was responsible for 30% of total national carbon dioxide (CO_2) emissions, the largest share among all energy end-use sectors in Hungary. At the same time, buildings house the largest potential for CO_2 emission reductions worldwide as demonstrated by the recent IPCC report. However, estimates for the size and associated costs of GHG mitigation or energy-efficiency opportunities in the Hungarian domestic sector have not been assessed for the last decade. Such knowledge is essential for designing evidence-based climate policies and for understanding of the business opportunities on the markets of abatement technologies.

The paper aims to address this gap in knowledge and summarizes the results of research quantifying CO_2 mitigation potential in the Hungarian residential sector by 2025 via bottom-up model. The paper concludes that a wide range of opportunities for cost-effective CO_2 mitigation is available in all studied types of residential buildings. Efficient lighting, heating and water flow controls were identified as the most cost-effective measures. Fuel switch to low carbon heating solutions and improvement of the thermal envelope in old buildings provide the largest potential. The application of cost-effective measures will result in a reduction of app. 29% of the total sector baseline CO_2 emissions in 2025 (5.1 Mt CO_2). Realization of the cost-effective potential requires an investments of 9.6 billion EUR over 2008 – 2025, but will result in energy cost savings of 17.1 billon EUR. The total maximum potential achievable due to implementation of all investigated measures is app. 50% of baseline CO_2 emissions in 2025 (8.7 Mt CO_2). Implementation of the suggested abatement measures will help reduce energy poverty, improve social welfare and relieve social tensions related to the recent energy price increase.

Introduction

The application of energy efficiency and low and zero carbon technologies is one of the main step to sustainable energy development and the key to limiting the effect of climate change. In this regard buildings-related technologies play an increasingly important role. Research (Ürge-Vorsatz and Novikova, 2008) implemented for the IV Assessment Report of the Intergovernmental Panel on Climate Change (Levine et al., 2007) identified 29% of the global business-as-usual carbon dioxide (CO_2) emissions in 2020 available for cost-effective reduction in the buildings sector; more than half of this potential is locked in residential buildings.

Nevertheless, many opportunities for energy efficiency improvement in the buildings sector are not covered well by existing policies and this is especially true for transition economies. Many policy designers simply do not have good enough information to develop a comprehensive strategy for this sector. More specifically, there is the lack of knowledge of how large the potential for greenhouse mitigation is in this sector; what energy end-uses and technologies secure this mitigation; whether or not it is economically feasible; and which options should be promoted to easily. According to the best knowledge of the authors, as of March 2008 there were only four case studies covering the buildings sector of countries of Central and Eastern Europe (CEE) and the Former Soviet Union (FSU) within the last ten years (Petersdorff et al., 2005; Lechtenböhmer et al., 2005; Kallaste et al., 1999; Szlavik et al., 1999).

The aim, the objectives and the task of the research

The paper presents the selected results of the research of the PhD dissertation of one of the authors (Novikova, 2008) and of the report to the Hungarian Ministry of Environment and Water (Novikova and Ürge-Vorsatz, 2007) which address the gap in knowledge placing a special focus on the residential buildings of Hungary. This sector has been consistently the largest final energy consumer in the country since 1991 and due to this fact and the high carbon intensity of fuels used, it emits the largest share of total national CO_2 emissions, 30% (ODYSSEE NMC, 2007).

The overall **research aim** was to assist the evidence-based design of the new policies targeted at CO_2 emission reductions in the Hungarian residential buildings sector with the necessary information. More specifically, the **research goal** was to estimate and to analyze CO_2 mitigation potential in the Hungarian residential sector and the associated costs resulting from the application of energy efficient technologies and practices as well as the use of fuel switch options at the point of energy demand. Hence, the **research objectives** were: a) to estimate the baseline CO_2 emissions of the Hungarian residential sector in the future; b) to identify the key mitigation technologies applicable in the residential sector of the country; c) to estimate the CO_2 emission mitigation potential existing in the Hungarian residential sector from the application of identified individual options and associated mitigation costs; d) to estimate the total CO_2 mitigation potential of the Hungarian residential sector as a function of the costs of CO_2 mitigation technologies. To achieve these objectives, the **research task** was to develop a bottom-up model[1] which allows estimation and analysis of CO_2 mitigation potential in the Hungarian residential sector and associated costs based on presently available data.

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[1] Bottom-up model is a method of system analysis through combining estimates of its components.

Research design and methodology

Overall research design and procedures

Figure 1 presents the overall process of the research. A spreadsheet-based analysis was applied as the most appropriate tool which allows variation of modeling methods dependant on the available data. Due to space limit, the present paper does not go into the details of calculation procedures; they are extensively discussed in (Novikova 2008; Novikova and Ürge-Vorsatz 2007).

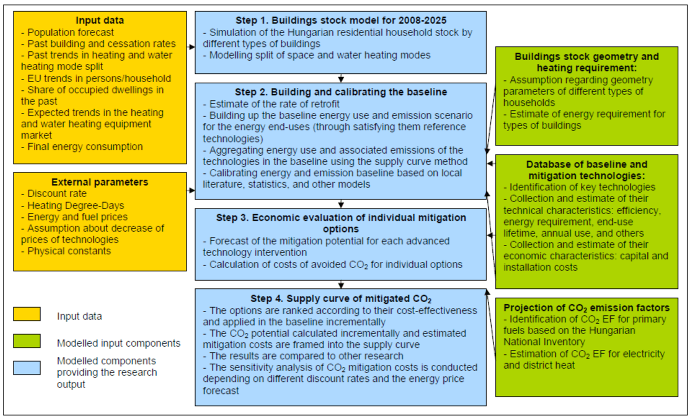

Figure 1 Research design

Method used: a supply curve of CO_2 mitigation

The principal output of the research is a supply curve of CO_2 mitigation. The curve characterizes the potential CO_2 reductions from a sequence of mitigation technological options as a function of marginal costs per unit of mitigated CO_2. The main advantage of the supply curve analysis is that it provides comprehensive, easy-to-read information on suggested efficiency technologies, their costs, their potential energy (CO_2) saving and the best schedule for their implementation (Laitner, 2003). Another advantage is that estimates of the potential for CO_2 emission reduction are already adjusted for the effects of overlapping options that are targeted at the same energy end-uses.

The marginal costs of CO_2 mitigated in year i of a technology were estimated as the annualized investment costs of the technological intervention deducting the sum of saved costs in year i per unit of CO_2 mitigation in year i. Investment costs take into account only additional costs associated with advanced options, i.e. they exclude costs associated with the reference case. Investment costs required for the technological intervention in year i consist of capital costs of the technology and associated installation costs. Saved costs in year i due to the technological intervention imply only saved energy costs.

The limitations of the supply curve method include the necessity to collect a significant amount of input data which are often uncertain, the strict linkage of the identified list of measures to a specified point of time, disregard of the economic feedback to sectoral advances, capture of only sequential and marginal technological opportunities, missing the systematic and integrated opportunities, and presentation of only one of mutually exclusive options.

Limitations of the developed model

Besides the limitations of the research inherited from the modelling method and described above, there are other opportunities to improve the research results. This is for instance, consideration of benefits beyond the value of saved energy and the costs associated with overcoming barriers for efficiency penetration and fuel switch. Assessment of the rebound effect was limited to the consideration of the energy consumption growth due to installation of advanced heating solutions which cover a larger heating area (from premise to central dwelling heating). Furthermore, while the authors tried to cover as many mitigation options as possible, their number was limited to only those which provide undoubtedly the largest potential for CO_2 mitigation. Due to a lack of data, options related to cooking, motors (lifts), and air-conditioning were not studied. Finally, non-technological options for CO_2 mitigation were either not included.

Projections of baseline energy consumption and associated CO_2 emissions

For the purposes of the research **a reference scenario** as close as possible close to the business-as-usual case is considered. The section describes the main assumptions applied to develop reference energy consumption and associated CO_2 emissions.

The buildings stock model

The building stock model represents a separate complex element of the research. The Hungarian housing stock was split into five buildings types, which possess different architectural and/or thermal characteristics: a) multi-residential traditional buildings constructed at the end of the 19th century and during the inter-war years; b) multi-residential buildings constructed using industrialized technology (including panel, block, and cast buildings) built after the 2nd World War until 1992; c) single-family houses in suburban and semi-urban areas constructed until 1992; d) multi-residential buildings and single-family houses constructed during 1993 – 2007; e) multi-residential buildings and single-family houses which will be constructed after 2008 until the end of the projection period, i.e. 2025. Due to space limitations, the paper does not detail the assumptions behind the projection of the household stock by types of buildings and the projections of the split of space and water heating technologies. The detailed description is provided in (Novikova 2008; Novikova and Ürge-Vorsatz 2007).

Assumptions on the reference case retrofit

Modeling the reference scenario for the building shell, space and water heating technologies assumes that their technical and financial characteristics in the future will stay approximately the same as they are today. The retrofit of the thermal envelope is undertaken for multi-residential traditional buildings, multi-residential buildings constructed using industrialized technology, and old single-family houses (constructed before 1992). The reference rate of insulation of roofs, basements, and external walls, window exchange and weather stripping is assumed to be constant and on the level of that in 2003 – 2004, i.e. c. 1% of the household stock/yr. (based on KSH 2005). The exchange of space heating solutions occurs due to their expired lifetimes. The reference scenario assumes zero penetration rates for heating controls and individual heat meters in relatively old buildings, i.e. traditional and industrialized buildings as well as single-family houses constructed before the 1990s. The water heating technologies are exchanged if their lifetime expires. With regards to water saving fixtures, it is assumed that they are not installed in the reference case.

The reference scenario models the turnover of main electrical appliances such as refrigerators, freezers, clothes washing machines. The efficiency of electrical appliances driven by the EU labelling and standardization programs was changing during the modelling period. With regards to the financial characteristics, it was assumed that the costs in real terms of the reference and the best available appliances do not change over time. In other words, the presently efficient appliances are becoming cheaper in the future and the newer, more efficient appliances are taking over their price. The reference scenario also models the exchange of lights due to their retirement. Reference energy consumption other than that for space and water heating, refrigeration, freezing, clothes washing, and lighting was modelled in aggregate terms due to the limited background data.

Calibration of the base year balance

Once the methodology, calculation procedures, and assumptions were defined and documented, the input parameters were inserted into the spreadsheets to calculate the final energy consumption and associated CO_2 emissions, first in the start (base) years 2004 - 2008 and then to 2025. The base year balance was calibrated to the national statistics and the PRIMES model (ODYSSEE NMS, 2005; Capros et al., 2007).

Forecast of the baseline sectoral energy consumption and associated CO_2 emissions

Figure 2 presents the results of modeling the sectoral energy consumption and associated CO_2 emissions. The Figure illustrates that the final energy consumption for space and water heating barely changes from 2008 to 2025. This is because the efficiency improvement of thermal energy use is closely negated by the growing number of households. The final energy consumption of appliances and lights is growing over the projection period boosted by the growing number of miscellaneous electrical appliances. The overall result of the energy baseline forecast is that the final energy consumption of the residential sector is expected to grow from 81.9 TWh in 2008 to 84.2 TWh in 2025. Figure 2 demonstrates that the sectoral CO_2 emissions are expected to decline until 2015 (mainly due to decreasing emission factors of electricity and district heat) but then they are likely to rise again, reaching the 2008 level by the year 2025. The CO_2 emission growth is caused by the increasing demand for electricity multiplied by its growing CO_2 emission factor (from 2015) due to the installation of new lignite power plants.

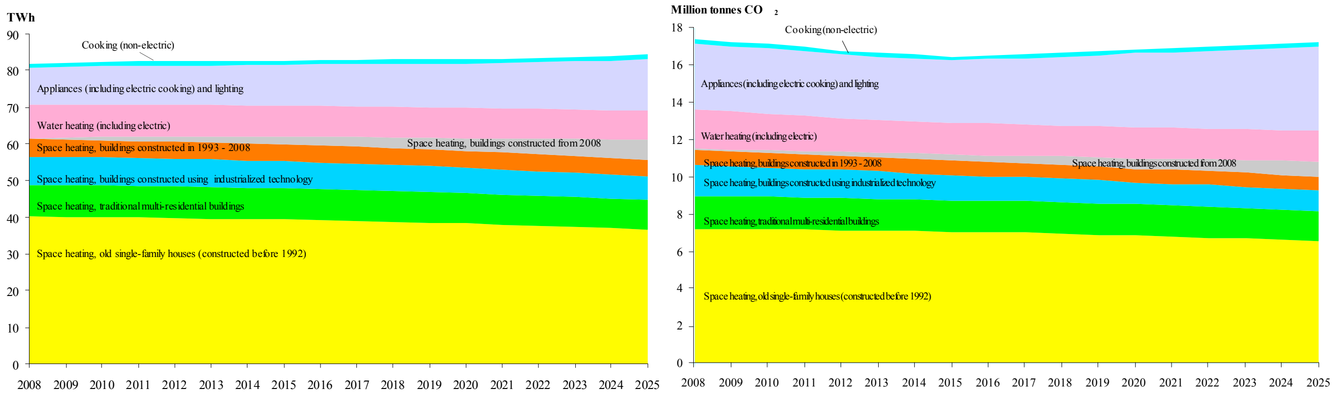

Figure 2 Energy consumption and CO_2 emissions projected in the reference case, 2008 – 2025

Economic evaluation of mitigation options and their aggregation to the supply curve

Summary of mitigation technological options

Table 1 lists the key energy efficiency and fuel switch technologies applicable in the residential sector of Hungary which were identified in the research. This list is the subject to limitation described in the methodological section.

Table 1 Efficiency and fuel switch options investigated in the dissertation research

Mitigation options	**Households in**				
	Multi-residential traditional buildings	**Multi-residential industrialized buildings**	**Old single-family houses (constructed before 1992)**	**Buildings constructed from 1993 to 2007**	**Buildings constructed from 2008**
Thermal envelope					
Insulation of walls, roofs, and cellars		X	X		
Exchange of windows	X	X	X		
Weather stripping of windows			X		
Application of the passive energy design					X
Heating efficiency and fuel switch					
Exchange of central building standard gas systems with central building condensing gas systems	X	X			
Exchange of premise and central dwelling gas systems and premise and central dwelling coal systems with central dwelling condensing gas systems	X		X		
Exchange of premise and central dwelling gas systems and premise and central dwelling coal systems with space and water heating pumps			X		
Exchange of premise and central dwelling gas systems and premise and central dwelling coal systems with pellet space and water heating systems			X		
Exchange of premise and central dwelling gas systems and premise and central dwelling coal systems with solar thermal space and water heating systems backed-up with pellets			X		
Heating controls					
Installation of thermostatic radiator valves (for district and centrally heated households only)	X	X			
Installation of programmable thermostats (except households with district and central heating and those having coal and biomass heating systems)	X		X		
Installation of individual heat metering (for district, central heated households only)	X	X			
Water heating					
Efficiency improvement of combined space and water heating systems	X	X	X		
Exchange of dedicated water heating appliances with more efficient appliances of the same class (electric storage, gas storage, gas instantaneous water heaters)	X	X	X	X	X
Installation of water saving fixtures (showerheads and sink faucets)	X	X	X	X	X
Electrical appliances and lights					
Higher efficiency refrigerators and freezers	X	X	X	X	X
Higher efficiency clothes washing machines	X	X	X	X	X
Reduction of electricity consumption of TV- and PC- related appliances in low power mode	X	X	X	X	X
Exchange of incandescent lamps with CFLs	X	X	X	X	X

Assumptions of economic analysis

The economic evaluation of applying the mitigation options was conducted based on calculative procedures described in the methodology. Analysis of the methodology shows that the CO_2 mitigation costs are the most sensitive to the discount rate chosen and the cost of energy and fuels projected over the modelling period. The discount rates were estimated at the level of 6%. Energy and fuel prices in Hungary were collected on the date of the research running, i.e. as of December 2007. They are presented in Table 2 . In agreement with other pieces of research, which focused on the CEE region (Petersdorff et al.; 2005; Waide 2006), energy prices are assumed to grow by 1.5%/yr. in real terms.

Table 2 Energy and fuel prices for the residential end-users of Hungary, December 2007

Fuels	**Energy price, EUR/kWh**	**References**
Natural gas	0.044	Estimate based on Hungarian Energy Office (2007)
Agripellet	0.030	Estimate based on DBO (2007)
Brown coal	0.024	Estimate based on Hungarian Energy Office (2007)
Firewood	0.012	Estimate based on DBO (2007)
District Heat	0.041	Estimate based on FŐTÁV (2007)
Electric energy	0.155	Estimate based on Hungarian Energy Office (2007)

Assumptions on the retrofit in the mitigation scenario

The scenario which implies the realization of all mitigation options is referred to **the mitigation scenario**. In this scenario, the advanced technologies replace the reference technologies exchanged due to their stock turnover. They also replace some of the technologies currently installed and which will remain until 2025. The technical and financial characteristics of the thermal efficiency technologies do not change over time except the additional construction costs of passive energy buildings (with space heating requirement of 15 kWh/m^2) decrease to half, the investment costs into the renewable energy solutions (pellet burners and solar thermal) go down to their 70%, and investment costs into heating pumps low down to their 80% by 2025.

First, it is assumed that the thermal envelope of all household stock, which is not retrofitted in the reference scenario and which remains at least until 2025, is retrofitted from 2008 to 2025. The stock is retrofitted by the same number of households per annum, i.e. the number of retrofitted households per year is the total stock divided by seventeen years. The technological options aimed to improve the thermal envelope retrofit of the existing buildings are the same as in the reference case. As regarding to the households which will be constructed from 2008, it was assumed that their whole stock would be constructed following the passive energy design.

As regarding the space heating solutions, it is assumed that households the old single-family houses (constructed until 1992), traditional and industrialized buildings install advanced space heating solutions, namely condensing gas boilers, or pellet boilers, or solar thermal systems backed-up with pellet boilers, or heat pumps for space and water heating instead of the reference technologies. As with the thermal envelope improvement, the stock is retrofitted by the same number of households per annum. The only exception is made for the premise gas heating. This is one of the most economical and efficient space heating systems in Hungary and it is likely that a share of households would prefer to leave this system in place. It is also important to mention that due to infrastructural and spatial barriers only half of single-family houses can switch from the reference technologies to pellets or solar heating backed-up with pellet boilers, similarly only half of single-family houses can switch to ground-source heating pumps.

One of the easiest and most beneficial technological options is installation of space heating and water demand controls. It was assumed that households with district or central building heating are retrofitted with thermostatic radiator valves (TRVs) and all other households except those fuelled with coal and traditional biomass are retrofitted with programmable thermostats. Also, installation of individual heat exchanges and heat meters was applied to households with district or central building heating. All water heating system and appliances are retrofitted with low-flow fixtures. All water heating systems and appliances are retrofitted with low-flow fixtures. The number of households retrofitted with space heating per annum until 2025 is the same as the number in which the thermal envelope is retrofitted. The installation of water saving fixtures is a very simple option and it is assumed that it is possible to apply this option to the whole stock within five years.

For the electrical appliances modelled, the penetration rates in the mitigation case are the same as in the reference case. For the mitigation case, the purchased appliances are the best (presently known and estimated) available on the market for the projected year. It is assumed that the costs in real terms of the reference and the best available appliances do not change over time i.e. the current appliances become cheaper and the newer appliances become more expensive. The mitigation case focuses on the exchange of only these six lamps. The exchange of lights is a very simple option and therefore is carried out on the whole stock in the first year of the modelling period.

Research results: evaluation of the key individual CO_2 mitigation options

This section describes the results of the bottom-up assessment applied to mitigation options independently from each other. This information is useful for the design of policy tools in targeting a particular option and for the households which prefer to and are able to exchange a particular technology. The economic evaluation of the mitigation options is subject to limitations described in the methodology. Figure 3 (left) illustrates the potential CO_2 savings and costs which result from the installation of individual mitigation options.

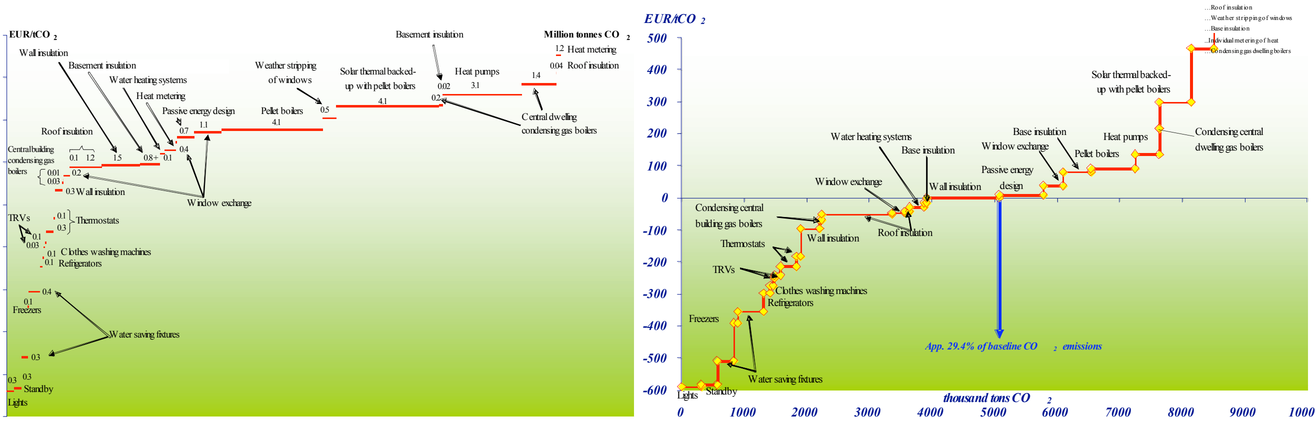

Figure 3 Potential and costs of individual options for CO_2 mitigation in 2025 (left) and the supply curve of CO_2 mitigation for the residential sector of Hungary in 2025 (right)

Notes: 1) Some thermal technological options are applied to different types of buildings and they are referred to several times in the figure. 2) On the left figure, the potentials from individual options cannot be simply added together because of possible double-counting if the options are targeted to the same baseline technologies and energy end-uses.

Figure 3 (left) shows that technological options supplying the potential for CO2 mitigation at negative costs are available for each building type and each energy end-use. The top negative-cost measure in terms of cost-effectiveness is the exchange of incandescent lamps with CFLs. It is followed by the reduction of electrical consumption of TV- and PC- related appliances in the low power mode and efficient appliances such as freezers, refrigerators, and clothes washing machines, the application of which is justified by the high price of electricity in Hungary. Installation of heat and hot water demand controls such as low-flow fixtures, TRVs and programmable thermostats ranks the third. Many options aimed at insulation of building components (walls, basements, and roofs) and weather stripping or exchange of windows are characterized with negative mitigation costs as do actions towards installation of condensing central building gas boilers. Installation of improved water heating systems and individual central and district heat meters in traditional buildings are the last in the list of measures with negative costs of CO_2 mitigation. The application of passive energy design to buildings constructed from 2008 is also attractive with the mitigation costs below 20 EUR/tCO_2. The rest of the options are above 20 EUR/tCO_2. In terms of the quantity of CO_2 reductions, the improvement of the thermal envelope, fuel switch and efficiency improvement of heating systems in old single-family houses (constructed before 1992) are able to supply the largest potential in the residential sector. The application of passive energy design to buildings constructed from 2008 and improved water heating systems and installation of water saving fixtures also can cut a significant amount of CO_2 emissions.

Countrywide potential for CO_2 mitigation and its supply curve

Figure 3 (right) illustrates the results of the bottom-up mitigation assessment of the mitigation options conducted with the supply curve method. As described in the methodology, the advantage of the supply curve method is that it allows an estimation of the total potential to be made without double-counting the mitigation potential supplied by individual options targeted at the same baseline technologies and energy end-uses (for instance, insulation improvement reduces the need for space heating and, thus, also reduces the energy saving potential from installation of more efficient heating systems). Therefore, the potential estimates described in this section can be added together.

Figure 3 (right) demonstrates a wide range of opportunities for negative- and low- cost CO_2 mitigation in all studied types of residential buildings. In general, the thermal options supply the most significant savings in both terms of absolute values as well as the share of their baseline emissions compared to the electrical efficiency options. Figure 3 (right) shows that there is a potential for CO_2 mitigation at negative costs in 2025 with various technological options, such as efficient appliances and lighting technologies, space heating and water flow controls, TV- and PC- related equipment with reduced electrical consumption in low power mode, construction according to the passive energy design principles and many insulation options. If all these options were implemented, they would cumulatively reduce CO_2 mitigation by 5.1 million tonnes in 2025. This is about 29% of total CO_2 emissions emitted by the residential sector of Hungary in 2025. Implementation of the mitigation options at negative cost of CO_2 would result in energy savings of 22.1 TWh/yr., which is about 26% of the total final energy consumption of the residential sector in 2025. Realisation of this potential would require total investment over the period 2008 – 2025 of about 9.6 billion EUR but would save 17.1 billion EUR in energy costs.

The CO2 mitigation potential in cost categories, the associated energy savings, the required investment costs and the associated saved energy costs are presented in Table 3 . The technical potential achieved due to the implementation of all investigated measures is estimated to be as high as c. 50.5% and 42% of the sectoral baseline CO_2 emissions and final energy consumption in 2025. In absolute terms, these savings represent about 8.7 million tonnes of CO_2 and 35.3 TWh/yr. The total investments over 2008 – 2025 needed to realize the maximum potential are about 29.0 billion EUR and they return 25.7 billion EUR in terms of saved energy costs.

Table 3 CO_2 mitigation potential in cost categories, associated energy savings, investments and saved energy costs

Cost categories of CO_2 mitigation costs, EUR/tCO_2	Cumulative CO_2 mitigation potential		CO_2 mitigation potential by cost category		Cumulative energy savings		Energy savings by cost category		Investments over 2008-2025, billion EUR		Saved energy costs 2008 – 2025, billion EUR	
	BL share	Million tCO_2/yr.	BL share	Million tCO_2/yr.	BL share	TWh/ yr.	BL share	TWh/ yr.	Total	By cost category	Total	By cost category
< 0	29.4%	5.1	29.4%	5.1	26.3%	22.1	26.3%	22.1	9.6	9.6	17.1	17.1
0 – 20	33.4%	5.8	4.0%	0.7	31.8%	26.8	5.5%	4.7	13.6	3.9	19.0	1.8
20-50	35.3%	6.1	1.9%	0.3	33.7%	28.4	1.9%	1.6	15.0	1.4	19.8	0.8
20 – 100	41.6%	7.2	6.3%	1.1	36.2%	30.5	2.5%	2.1	18.1	3.1	21.9	2.1
>100	50.5%	8.7	8.9%	1.5	42.0%	35.3	5.7%	4.8	29.0	10.9	25.7	3.8

Conclusion

For designing effective policies against the climate change challenge, evidence-based knowledge of the potential for energy efficiency and low carbon opportunities is necessary. This research addresses this need and supplies the information on the potential for cost-effective reduction of CO_2 emissions in the residential buildings of Hungary.

To address the questions stated, the authors constructed a bottom-up, technology-rich model. The authors developed a forecast of the reference final energy consumption and associated CO_2 emissions of the sector from 2008 to 2025, identified and economically evaluated the key CO_2 mitigation opportunities in the sector, if they were installed individually and in sequence. The principal outcome of the research is a supply curve of mitigated CO2.

The paper concludes that the final energy consumption of the residential sector is expected to grow to 84.2 TWh in 2025, whereas the sectoral CO_2 emissions decline until 2015 but then they rise again to reach c. 17.3 million tonnes CO_2 in 2025. Nineteen technological options to reduce the reference energy consumption and associated CO_2 emissions applied to different building types were considered.

The analysis of options installed individually concludes that the potential for CO_2 mitigation at negative costs is abundant for all building types and all energy end-uses. The paper shows that there are thirteen top priority options which are able to mitigate more than 1% of reference sectoral CO_2 emissions at negative cost. These are the exchange of incandescent lamps with CFLs, the reduction of electricity consumption of TV- and PC- related equipment in low power mode, the installation of water flow controls, the installation of programmable thermostats in single-family houses (constructed before 1992), the improvement of water heating systems, a few insulation options (for walls, basements, and roofs) and the exchange of windows in different types of buildings.

The research concluded with the potential for CO_2 mitigation as a function of costs for the investigated technological mitigation options. The advantage of the supply curve method is that it allows the estimation of the total potential while avoiding double-counting of the mitigation potential supplied by individual options targeted to the same baseline technologies and energy end-uses. The *supply curve analysis* concludes that if negative cost options are implemented, they can reduce CO_2 by 5.1 million tonnes in 2025; this is approximately 29% of the reference CO2 emissions of the Hungarian residential sector. The total technical potential that would result from the implementation of all investigated measures is estimated as c. 50% of the sectoral reference CO_2 emissions in 2025 or 8.7 million tonnes of CO_2/yr.

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