A dissertation submitted to
in part fulfilment of the Degree of Doctor of Philosophy

Carbon dioxide mitigation potential in the Hungarian residential sector

Aleksandra Novikova

Supervisor: Prof. Dr. Diana Ürge-Vorsatz, CEU
External supervisor: Dr. Sebastianos Mirasgedis, National Observatory of Athens / Greece
Advisor: Prof. Dr. Jonathan G. Koomey, LBNL & Stanford University / USA

PhD Committee:

Chair: Prof. Dr. Thomas B. Johansson, University of Lund / Sweden
Prof. Dr. Ruben Mnatsakanian, CEU
Prof. Dr. Alan Watt, CEU
Opponent : Dr. Lászlo Várro, MOL Plc.
External reviewer: Prof. Dr. Tamas Csoknyai, Bp University of Technology & Economics

Outline

- Introduction
- Research aims, goals, objectives, and tasks
- Research methodology
  - The overall design
  - Key assumptions
  - Main limitations
- Research results
  - The forecast of the baseline energy consumption and CO_2 emissions
  - Key efficiency and low-carbon options, their individual potential for CO_2 mitigation and associated costs
  - Supply curve of CO_2 mitigation
- Theoretical and practical contribution
- Conclusion

Introduction

Looking to the safe and sustainable world tomorrow implies reforming our model of development today (Laponche et al. 1997)

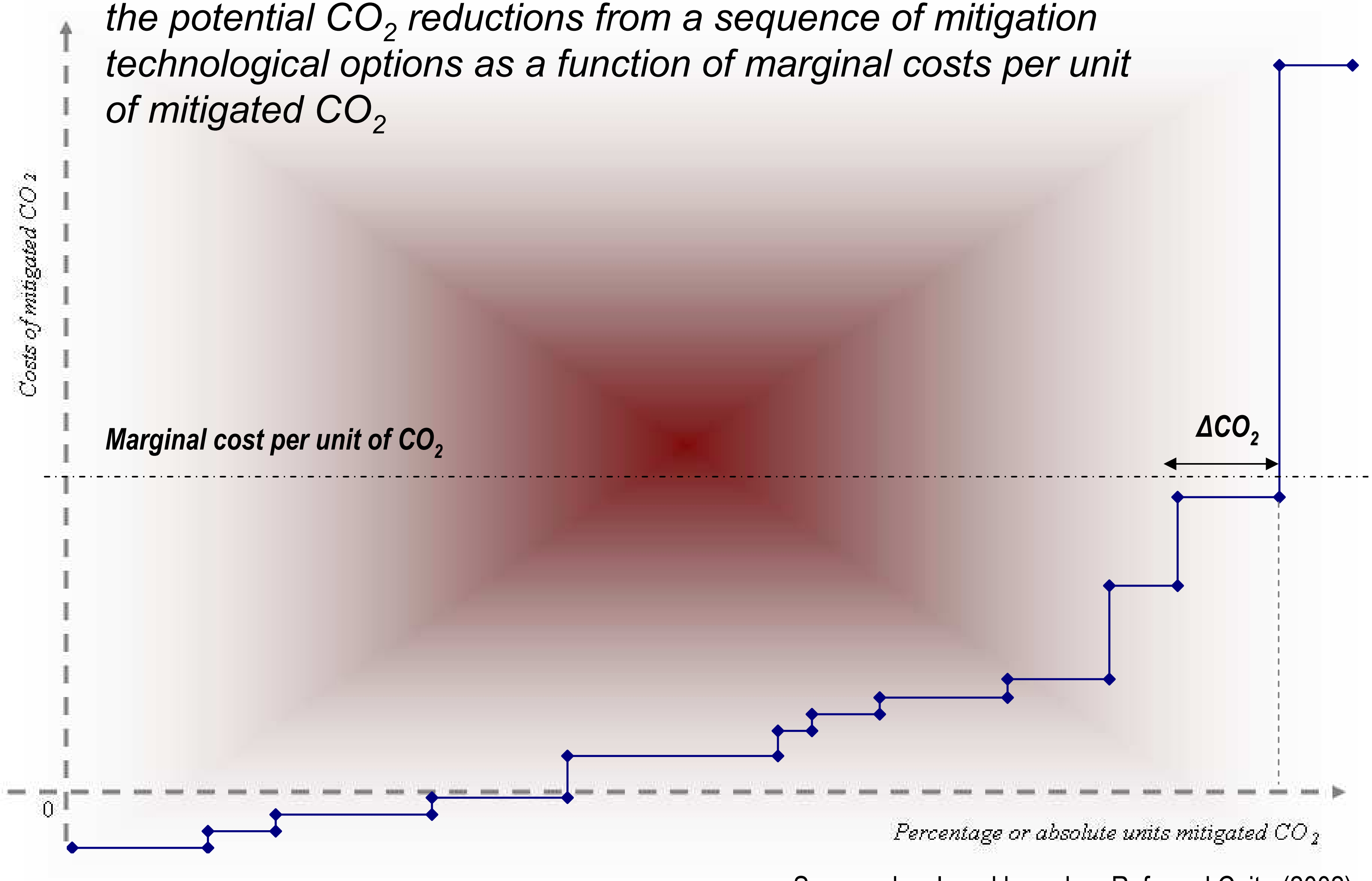
- Challenges
  - The unsustainable pattern of energy production and use
  - The climate change challenge
- Solutions
  - Desirable but unlikely: a reduction of demand for amenities
  - OR: revising the model of energy production and consumption
  - Energy efficiency can be considered as an energy source
- Priorities for efficiency and mitigation policies
  - The buildings sector
  - Residential buildings
  - Economies in transition?

Aim, goal, objectives, and task relative to the Hungarian residential sector

- The overall research aim is
  - To assist the evidence-based policy design
- The research goal is
  - To estimate the potential for CO_2 mitigation and associated costs
  - Options in focus: energy efficient technologies and practices + fuel switch options at the point of energy demand
- Research objectives are
  - The baseline CO_2 emissions of the Hungarian residential sector
  - Key energy-efficient and low-carbon technologies
  - CO_2 mitigation potential of individual options + their mitigation costs
  - Total CO_2 mitigation potential as a function of the cost of CO_2 mitigation technologies
- The task is
  - To develop a model which allows answering research questions based on the presently available data

Method used: a supply curve of CO_2 mitigation

Definition: the supply curve of CO_2 mitigation 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



Source: developed based on Rufo and Coito (2002)

Design of the dissertation research

Input data
- Population forecast
- Past building & cessation rates
- Past trends in heating and water heating mode split
- EU trends in persons/household
- Share of occupied dwellings in the past
- Expected trends in the heating and water heating equipment market
- Final energy consumption

External parameters
- Discount rate
- Heating Degree-Days
- Energy and fuel prices
- Assumption about decrease of prices of technologies
- Physical constants

Step 1. Buildings stock model for 2008-2025
- Simulation of the Hungarian residential household stock by different types of buildings
- Modelling split of space and water heating modes

Step 2. Building and calibrating the baseline
- Estimate of the rate of retrofit
-Building up the baseline energy use and emission scenario for the energy end-uses
- Aggregating energy use and associated emissions of the technologies in the baseline using the supply curve method
- Calibrating energy and emission baseline based on local literature, statistics, and other models

Step 3. Economic evaluation of individual mitigation options
- Forecast of the mitigation potential for each advanced technology intervention
- Calculation of costs of avoided CO_2 for individual options

Step 4. Supply curve of mitigated CO_2
- The options are ranked according to their cost-effectiveness and applied in the baseline incrementally
- The CO_2 potential calculated incrementally and estimated mitigation costs are framed into the supply curve
- The results are compared to other research
- The sensitivity analysis of CO_2 mitigation costs is conducted depending on different discount rates and the energy price forecasts

Buildings stock geometry and heating requirement:
- Assumption regarding geometry parameters of different types of households
- Estimate of energy requirement for types of buildings

Database of baseline and mitigation technologies:
- Identification of key technologies
- Collection and estimate of their technical characteristics: efficiency, energy requirement, end-use lifetime, annual use, and others
- Collection and estimate of their economic characteristics: capital and installation costs

Projection of CO_2 emission factors
- Identification of CO_2 EF for primary fuels based on the Hungarian National Inventory
- Estimation of CO_2 EF for electricity and district heat

Legend:
- Input data
- Modelled input components
- Modelled components providing the research output

Key assumptions and data sources

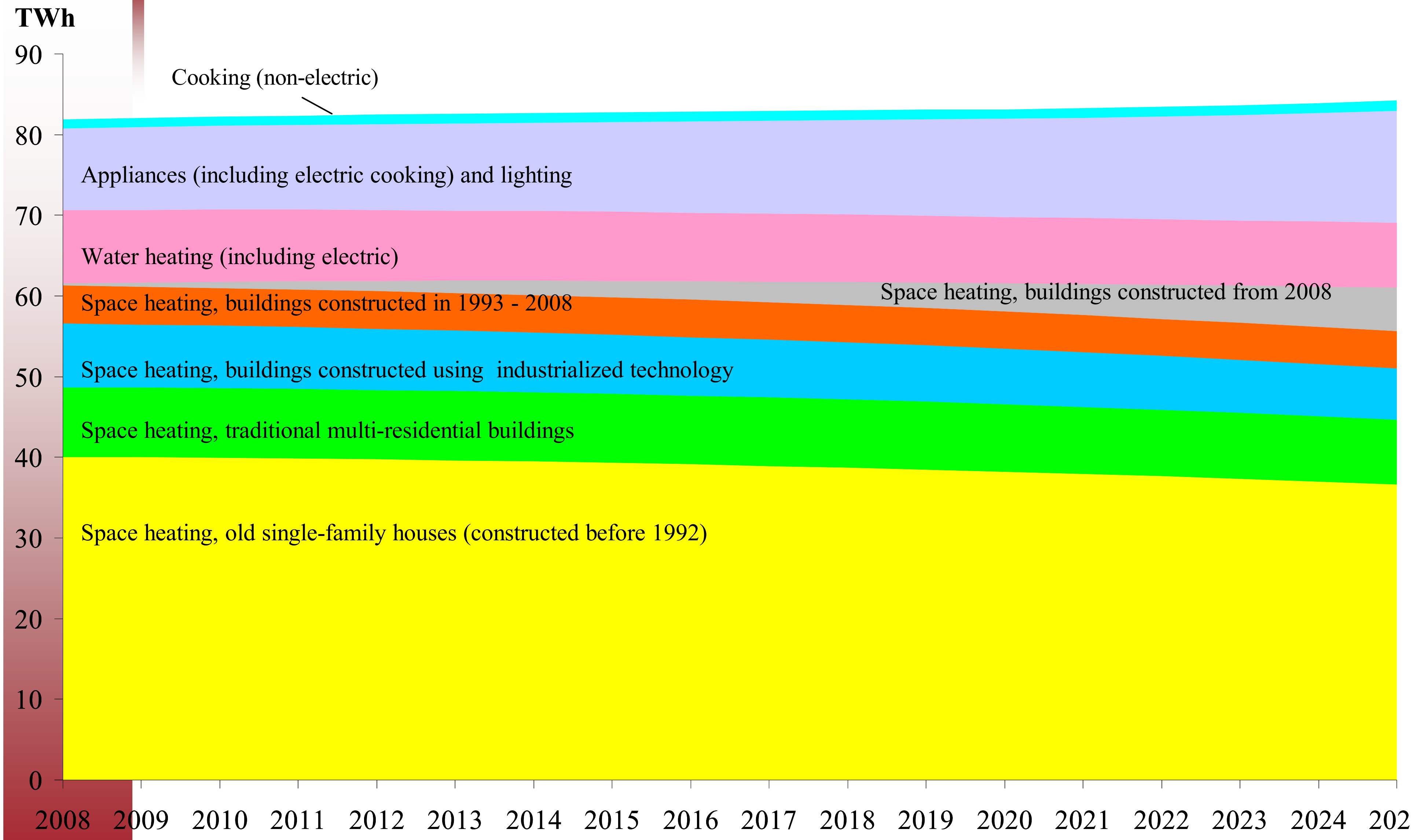
- Key assumptions
  - The modeling period is from 2008 to 2025
  - The reference case - as much as possible close to the business-as-usual
  - The mitigation case = the reference– the technical potential
  - Discount rate 6%
  - Fuel and energy prices grow by 1.5%/yr. in real terms
- Data sources: 161 references
  - ‘Encyclopaedias’
  - National and EU statistics and surveys
  - Interviews
  - Recent/on-going projects
  - Labelling and standardization programme reports
  - Reports, market reviews, and presentations of production associations and consultancies, equipment catalogues and pricelists
  - Other similar models

Research limitations

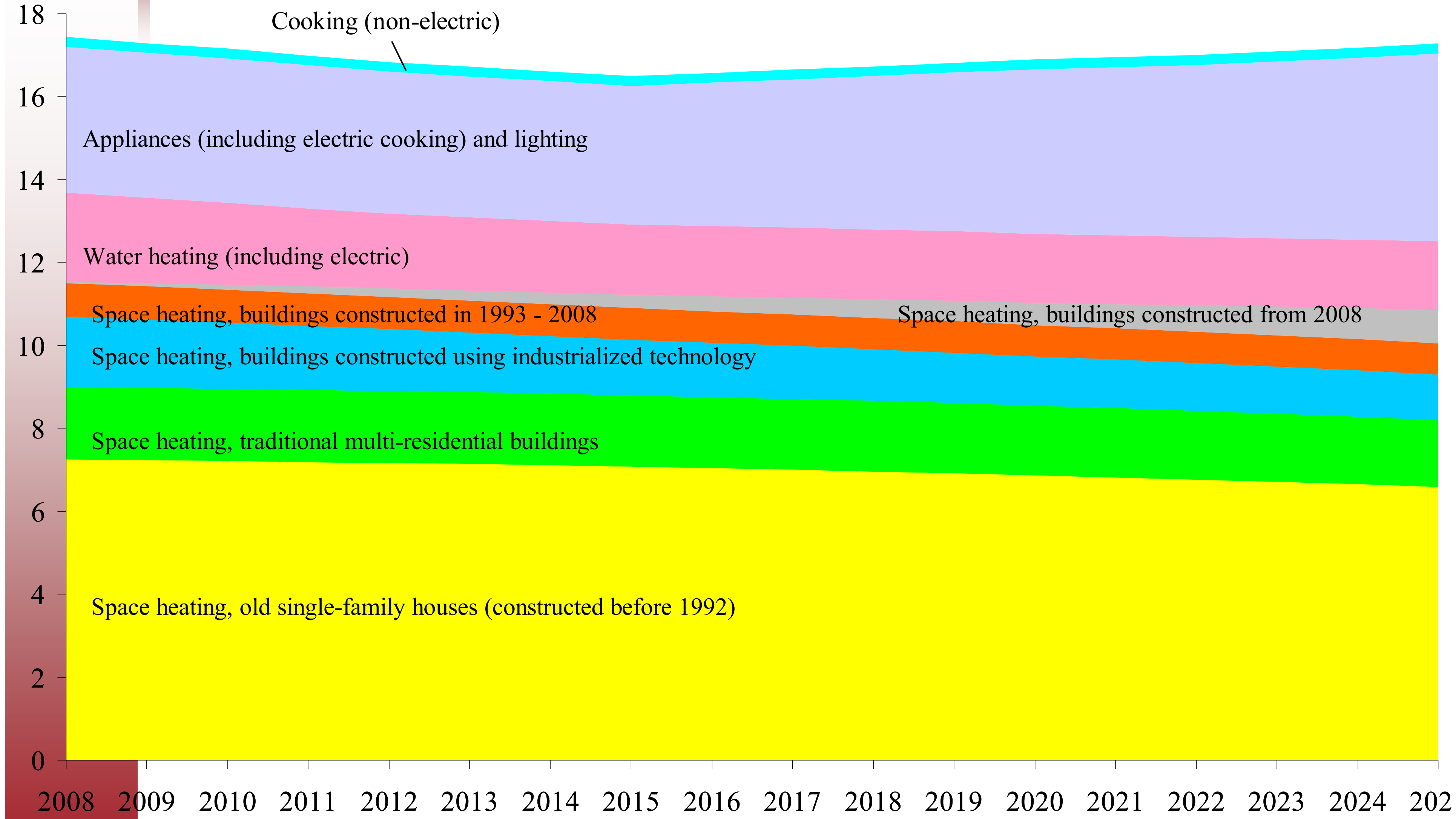
- Limitations associated with the selected modelling approach
  - Significant amount of input data
  - Potential is linked to the identified list of measures for a specified point of time
  - An understanding of the energy services does not change over time
  - Rely only on the rational decisions on the least-cost basis
- Disregard of the co-benefits and barriers of CO_2 mitigation
- Disregard of non-technological options
- Disregard of a few technological mitigation options
  - Electricity consumption of miscellaneous appliances
  - Options related to cooking and motors (lifts)
  - Air-conditioning
  - Some options aimed at retrofitting of the thermal envelope and heating systems
- Reduction of uncertainties and clarification of assumptions
  - Expected decrease of HDH and CDH
  - Heat released by domestic appliances and lights
  - Research on the energy price dynamics over 2008 – 2025
  - Investigation of the price dynamics of the reference and advanced technologies
  - CO_2 emission factors for electricity and consumed heat in households
  - Rebound effect

Research results

Sectoral final energy consumption projected in the reference case, 2008 - 2025



Sectoral CO_2 emissions projected in the reference case, 2008 - 2025

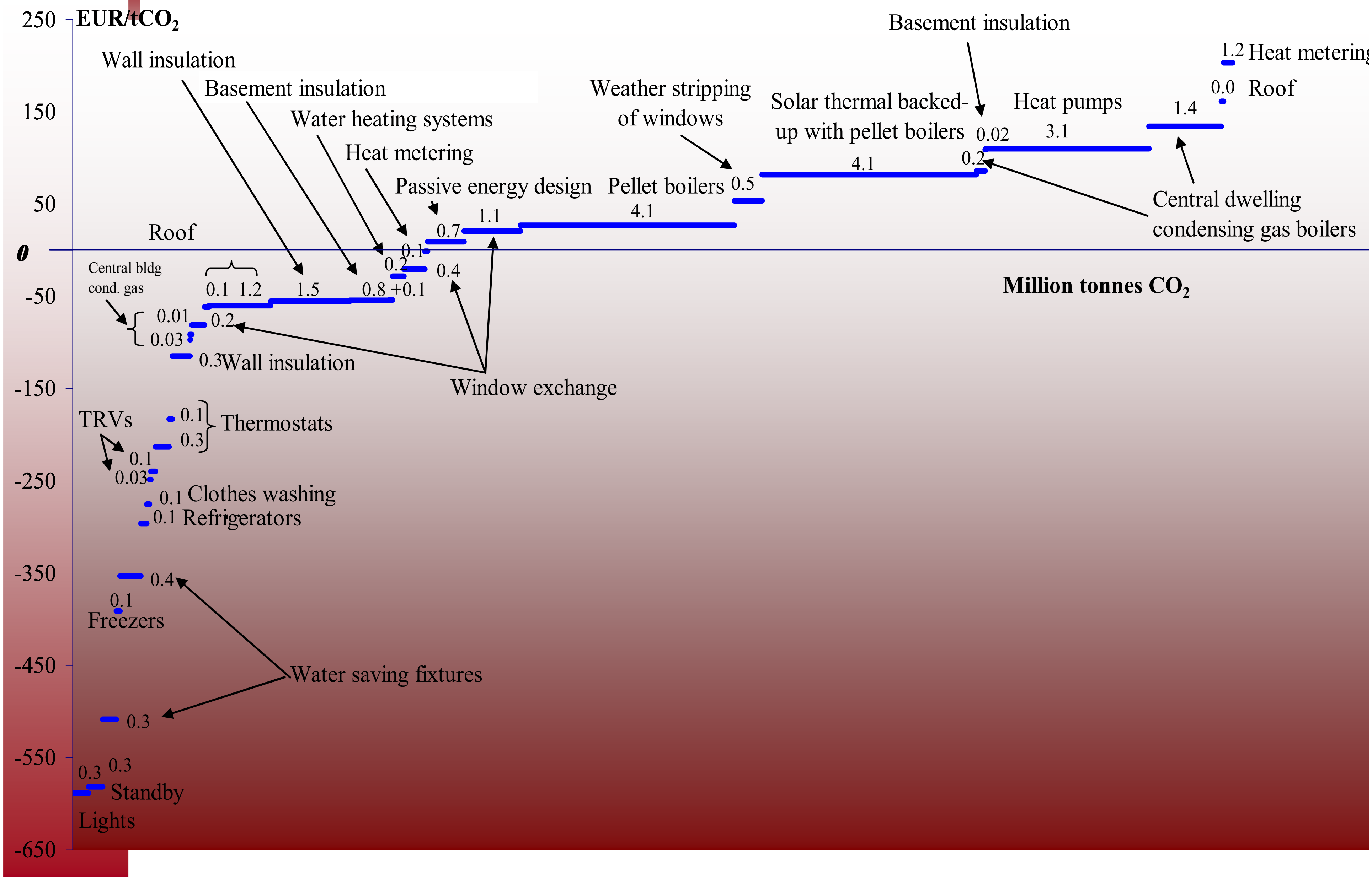


Efficiency and fuel switch options investigated in the dissertation research

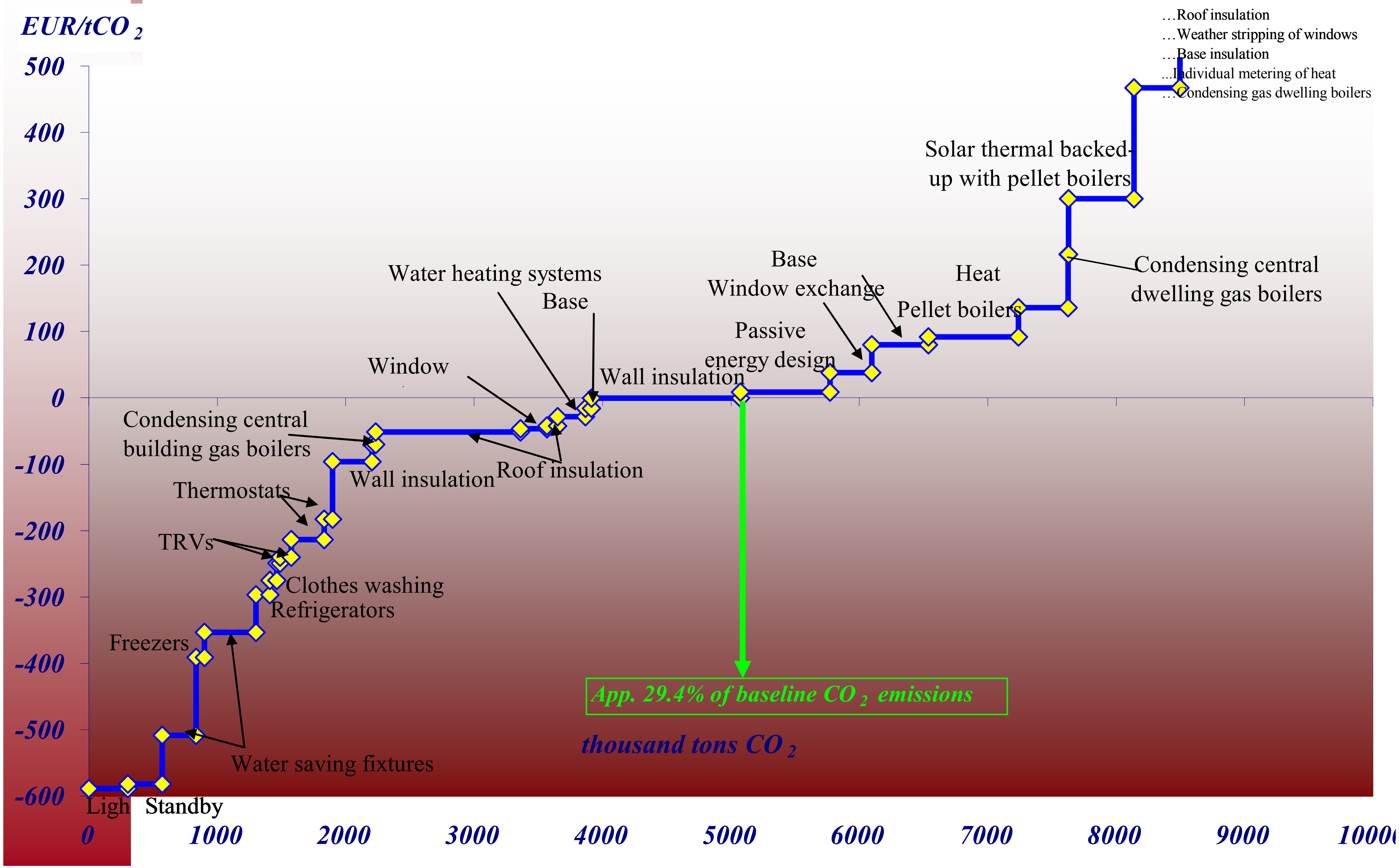
Mitigation options	Households in				
	Multi-residential traditional buildings	Multi-residential industrialized buildings	Single-family houses (constructed before 1992)	Buildings constructed from 1993 to 2007	Buildings construct ed from 2008
Thermal envelope					
Insulation of walls, roofs, and cellars		X	X		
Exchange of windows	X	X	X		
Weather stripping of windows			X		
The passive energy design					X
Heating efficiency and fuel switch					
Central building condensing gas systems	X	X			
Central dwelling condensing gas systems	X		X		
Space and water heating pumps			X		
Pellet space and water heating systems			X		
Solar thermal space and water heating systems backed-up with pellets			X		

Mitigation options	Households in				
	Multi-residential traditional buildings	Multi-residential industrialized buildings	Single-family houses (constructed before 1992)	Buildings constructed from 1993 to 2007	Buildings constructed from 2008
Heating controls					
TRVs (for DH and CH)	X	X			
Programmable thermostats (except DH and CH, coal and biomass systems)	X		X		
Individual heat metering (for DH and CH)	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	X	X	X	X	X
Water saving fixtures	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
Standby power reduction (TV and PC)	X	X	X	X	X
Exchange of incandescent lamps with CFLs	X	X	X	X	X

Potentials and costs of options installed separately, Hungary, the residential sector, 2025



Supply curve of CO_2 mitigation in the Hungarian residential sector, 2025

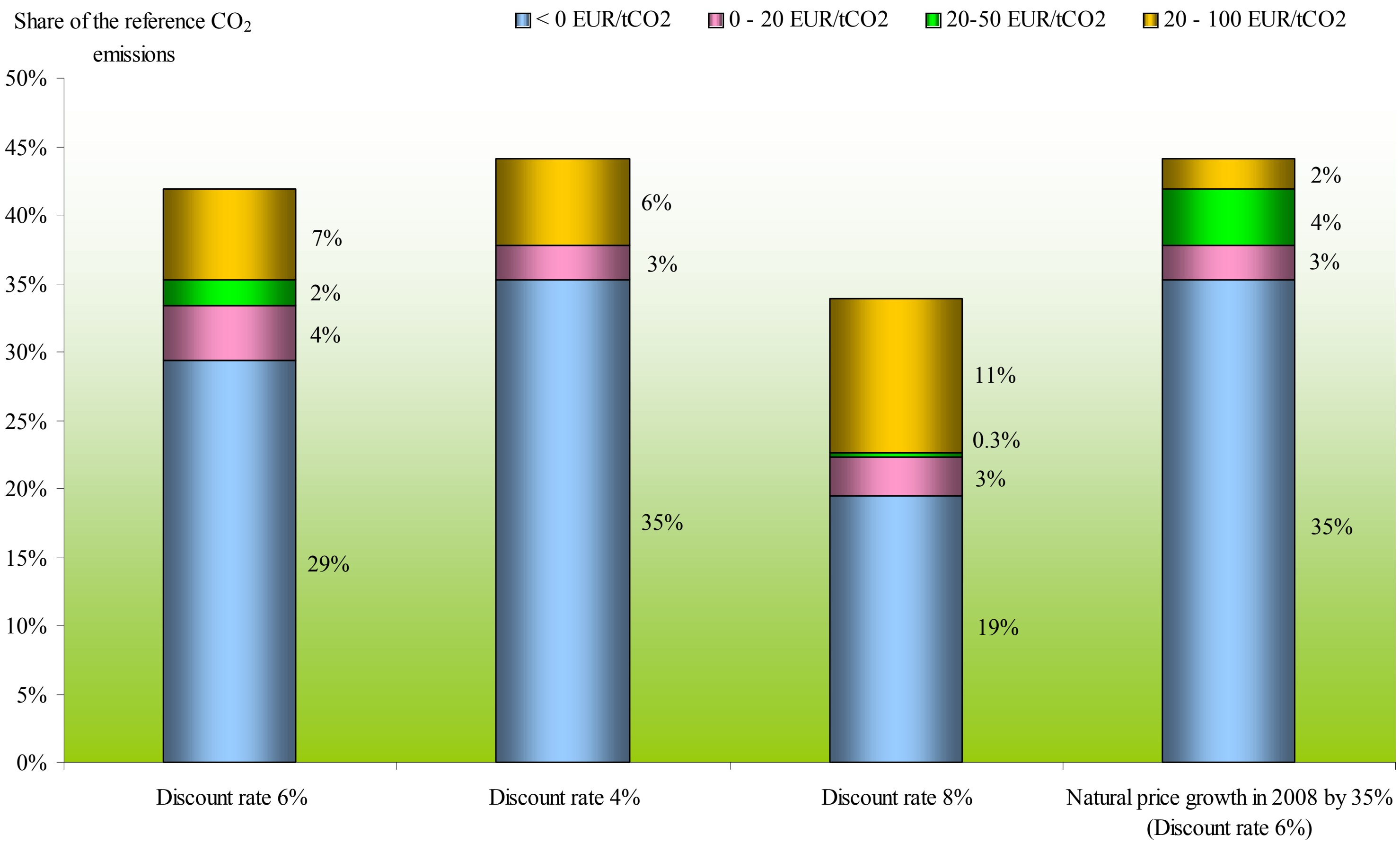


Investments versus Saved energy costs

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		Investments over 2008-2025, billion EUR		Saved energy costs 2008 – 2025, billion EUR	
	Baseline share	Million tCO_2/yr.	Baseline share	Million tCO_2/yr.	Baseline share	TWh/ yr.	Total	By cost category	Total	By cost category
< 0	29.4%	5.1	29.4%	5.1	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	13.6	3.9	19.0	1.8
20-50	35.3%	6.1	1.9%	0.3	33.7%	28.4	15.0	1.4	19.8	0.8
20 – 100	41.6%	7.2	6.3%	1.1	36.2%	30.5	18.1	3.1	21.9	2.1
>100	50.5%	8.7	8.9%	1.5	42.0%	35.3	29.0	10.9	25.7	3.8

Sensitivity analysis of mitigation costs

- Discount rates: 4% and 8%
- Energy price forecast
  - A 35% natural gas price increase by the end of 2008 -> other fuel and energy prices also change
  - After 2008, an increase of all fuel and energy prices by 1.5%/yr.



Research contribution: practical implications

- One of the keys for designing an influential policy tool
  - The solid background information
- The dissertation addresses this gap
- The research results have been used for:
  - The Hungarian Climate Strategy for 2008 – 2025 (KVVM 2008)
  - The design of the Green Investment Scheme in Hungary (BME ongoing)
- Potentially the research can assist with
  - Setting up the binding commitment for to the post-Kyoto
    - Ex., shown that the identified potential may offset c. 4.5% of the Kyoto Protocol base year (1985 – 1987) GHG emissions of Hungary
  - Good background for modeling various policy tools
    - Capital subsidies and grants, energy performance contracting, the Joint Implementation Mechanism of the Kyoto Protocol, an energy efficiency certificate scheme and others.

Research contribution: theoretical implications

- Limited research on mitigation opportunities in the CEE & FSU regions
- One of the key reasons
  - The difficulty to collect input data into the framework of highly detailed bottom-up technology-rich model
- The modelling framework and the technological database developed in the dissertation research can serve
  - As a basis for assessment of opportunities for CO_2 mitigation in the residential buildings sector other CEE and FSU countries having similar economic and climate conditions, in particular Slovakia, the Czech Republic, and Poland
  - Can be partially used for similar assessment of the commercial buildings sector of Hungary or other mentioned above countries of the region

Conclusion

- The cost-effective potential for CO_2 reduction from application of technological options
  - Is substantial in all studies types of buildings
  - Is significant in different scenarios of economic stability
  - C. 28% of the reference CO_2 emissions in 2025 (low estimate)
- The options with the lowest mitigation costs are relatively cheap and easy
  - Efficient lighting, heating and water flow controls
- Options which supply the largest potential are relatively more expensive
  - Fuel switch and improvement of the thermal envelope in old buildings
- The buildings stock turnover is extremely slow
  - A large share of CO_2 mitigation potential is locked in the existing buildings
  - Retrofitting of these buildings is one of the key priorities
- The results of the dissertation are comparable with those of other research
- The research has the number of theoretical and practical implications

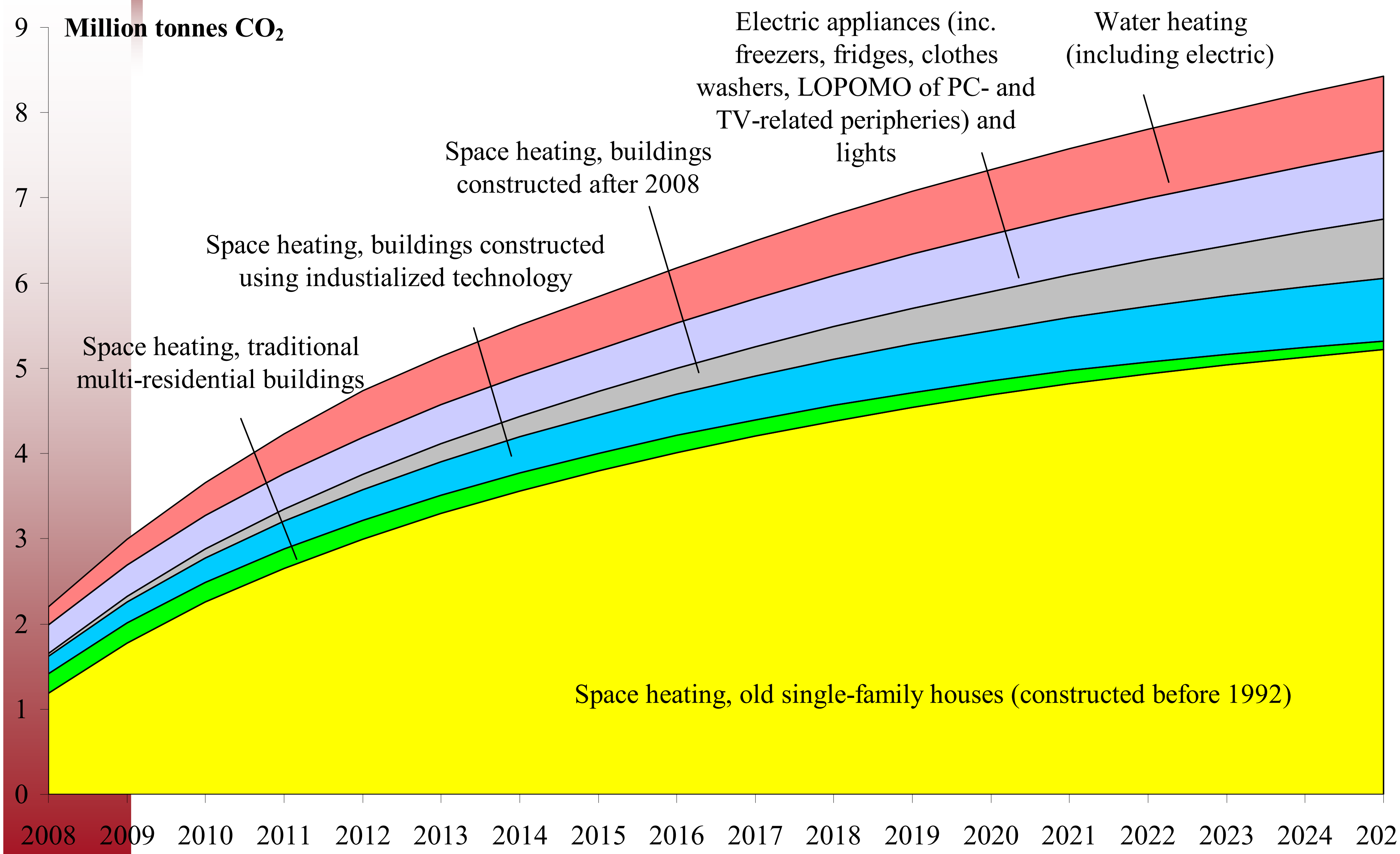
CEU

Thank you!

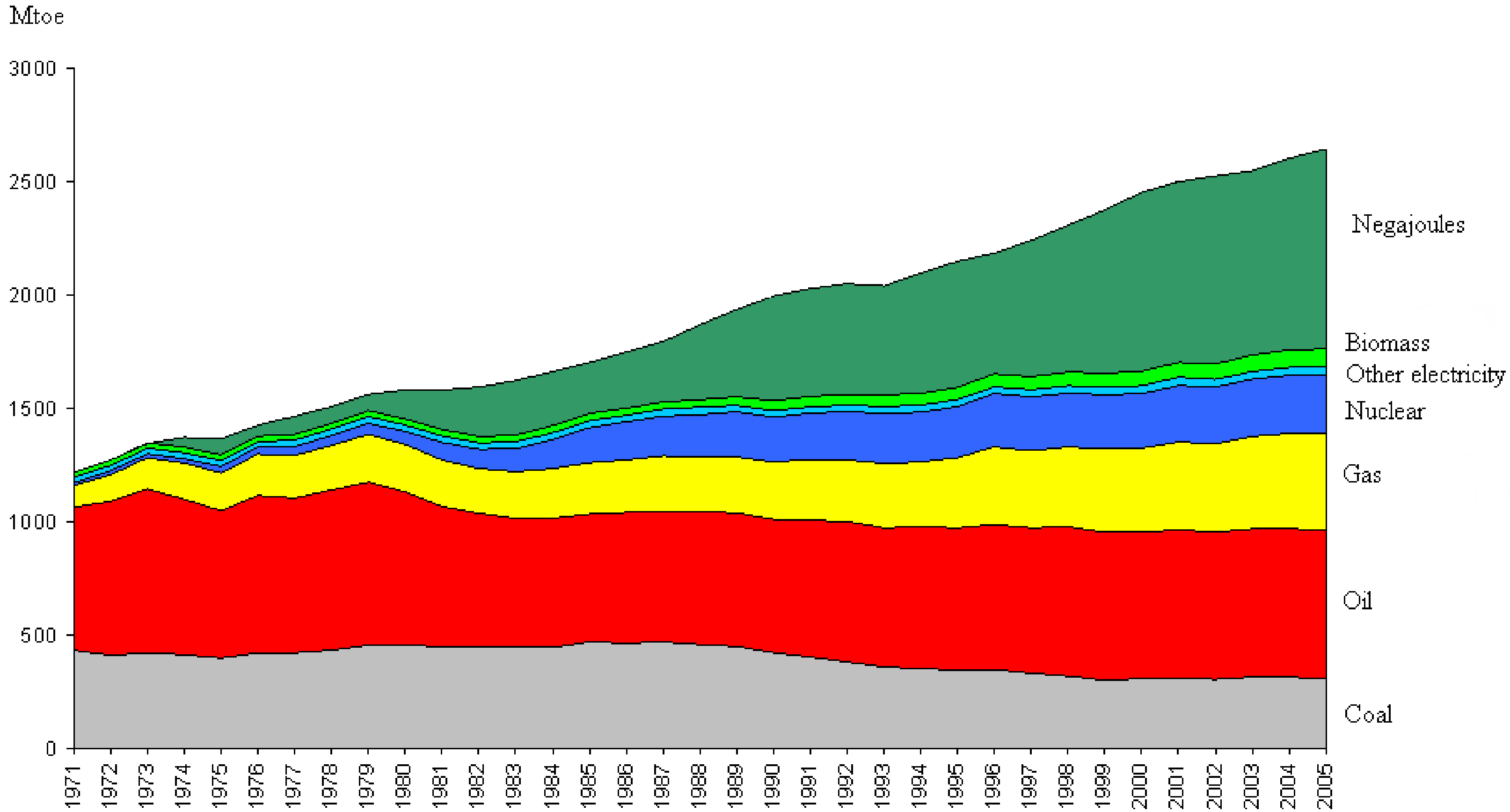
Additional slides

Introduction

Cumulative potential CO_2 emission reductions, 2008 - 2025



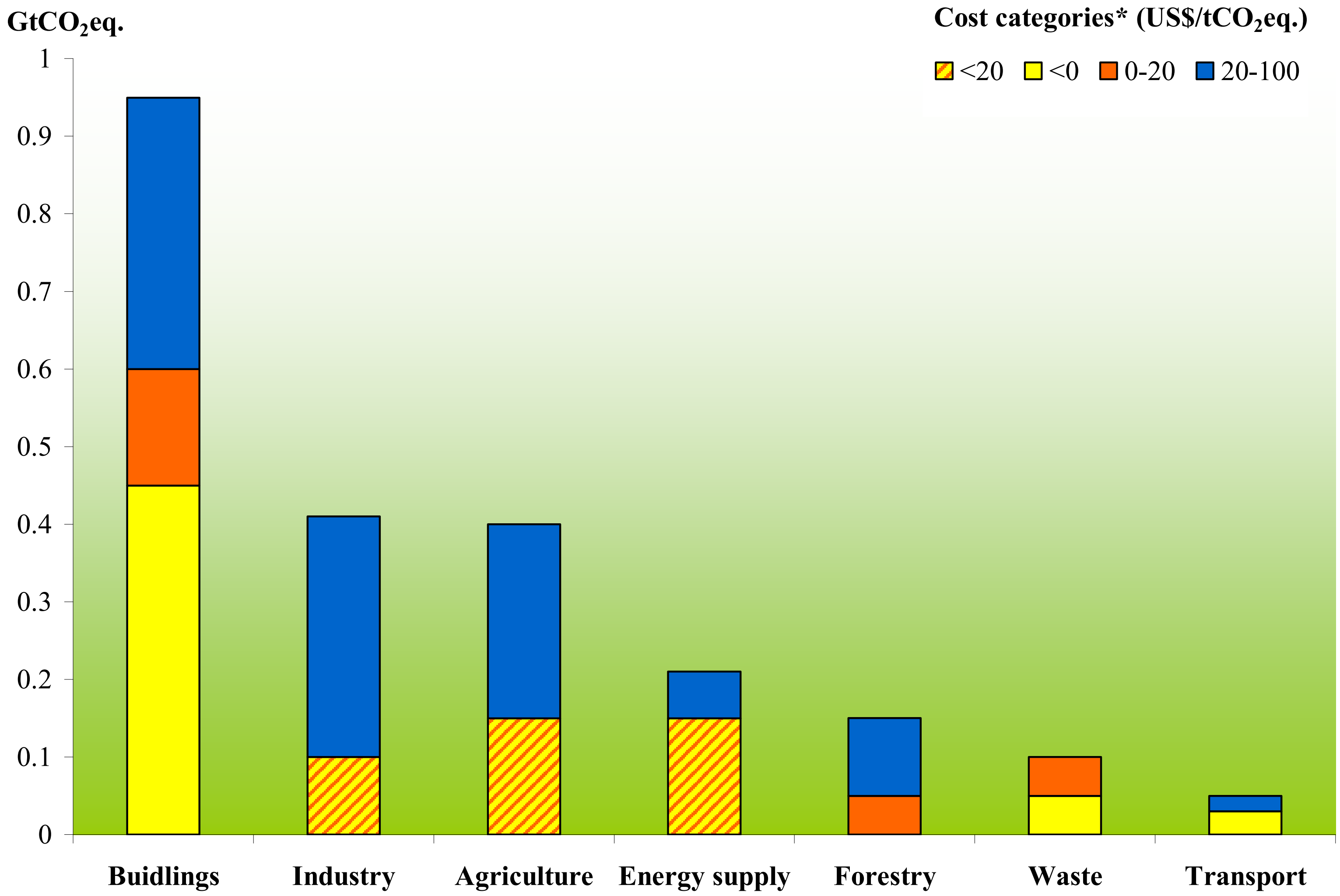
Dynamics of primary energy demand in the EU-25



Note: "Negajoules" refers to energy savings calculated on the basis of energy intensity in 1971.

Source: Commission of the European Communities 2006.

Potential for CO_2 mitigation in economies in transition at a sectoral level, 2030



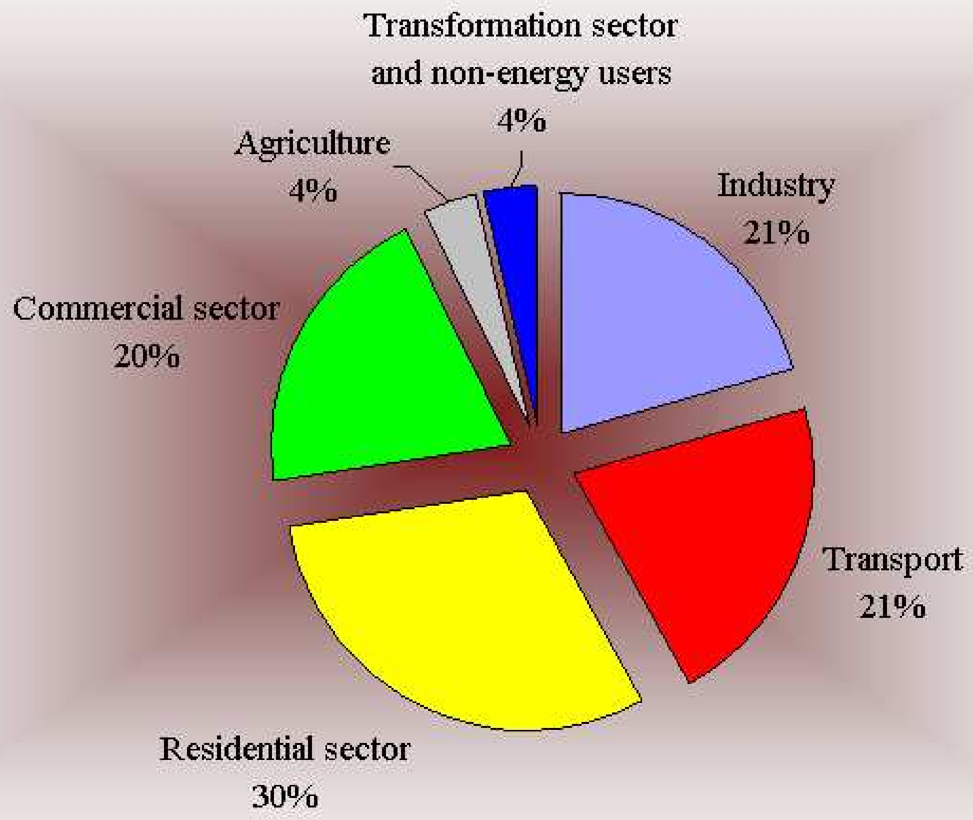
Note: For the buildings, forestry, waste and transport sectors, the potential is split into three cost categories: at net negative costs, at 0-20 US$/$tCO_2$, and 20-100 US$/tCO_2. For the industrial, forestry, and energy supply sectors, the potential is split into two categories: at costs below 20 US$/$tCO_2$ and at 20-100 US$/$tCO_2$.

Source: constructed based on Baker *et al*. (2007)

Additional slides

Sectoral review

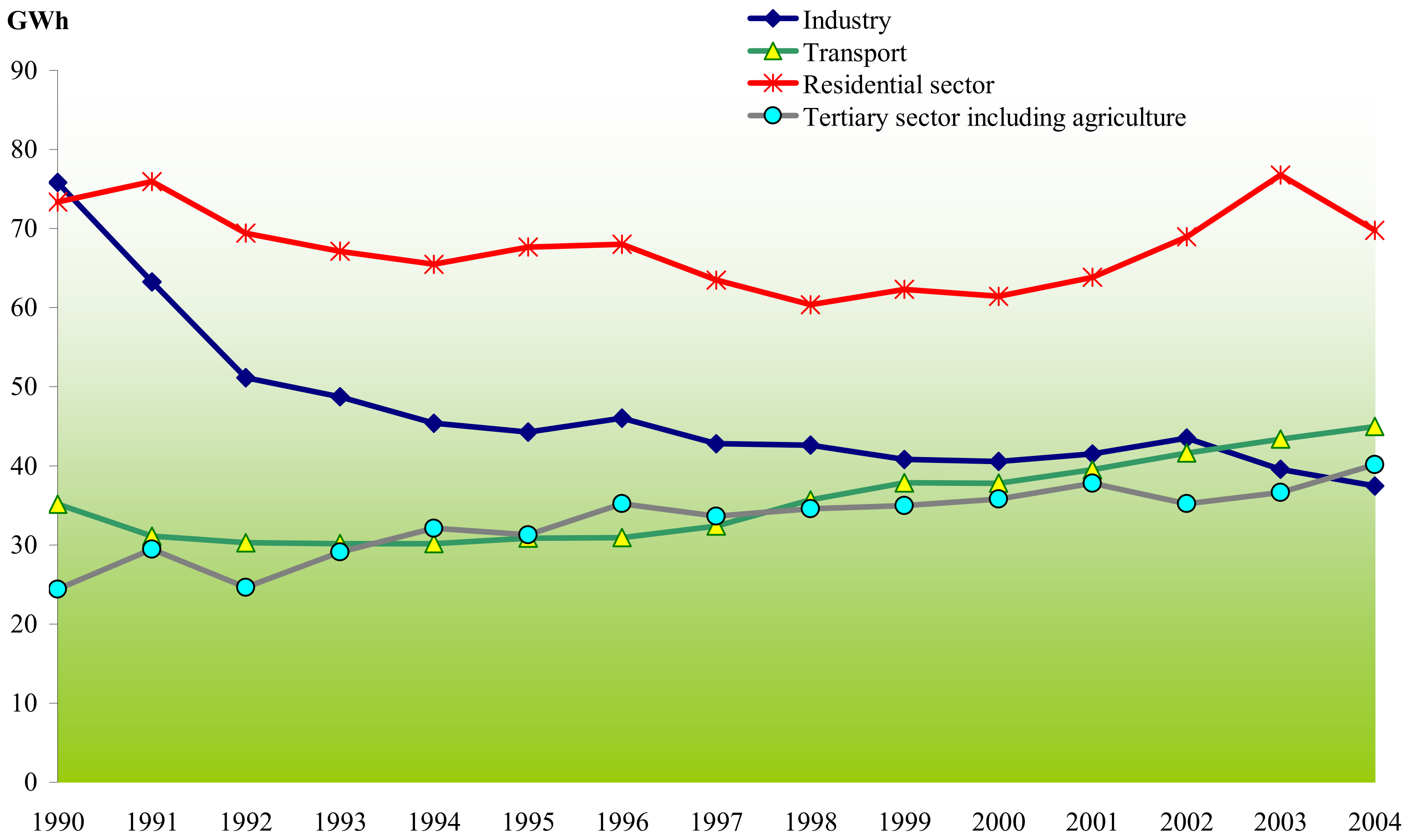
CO_2 emissions[*] by final energy end-users in Hungary, 2004



[*] Including emissions associated with electricity use consumed by the sectors.

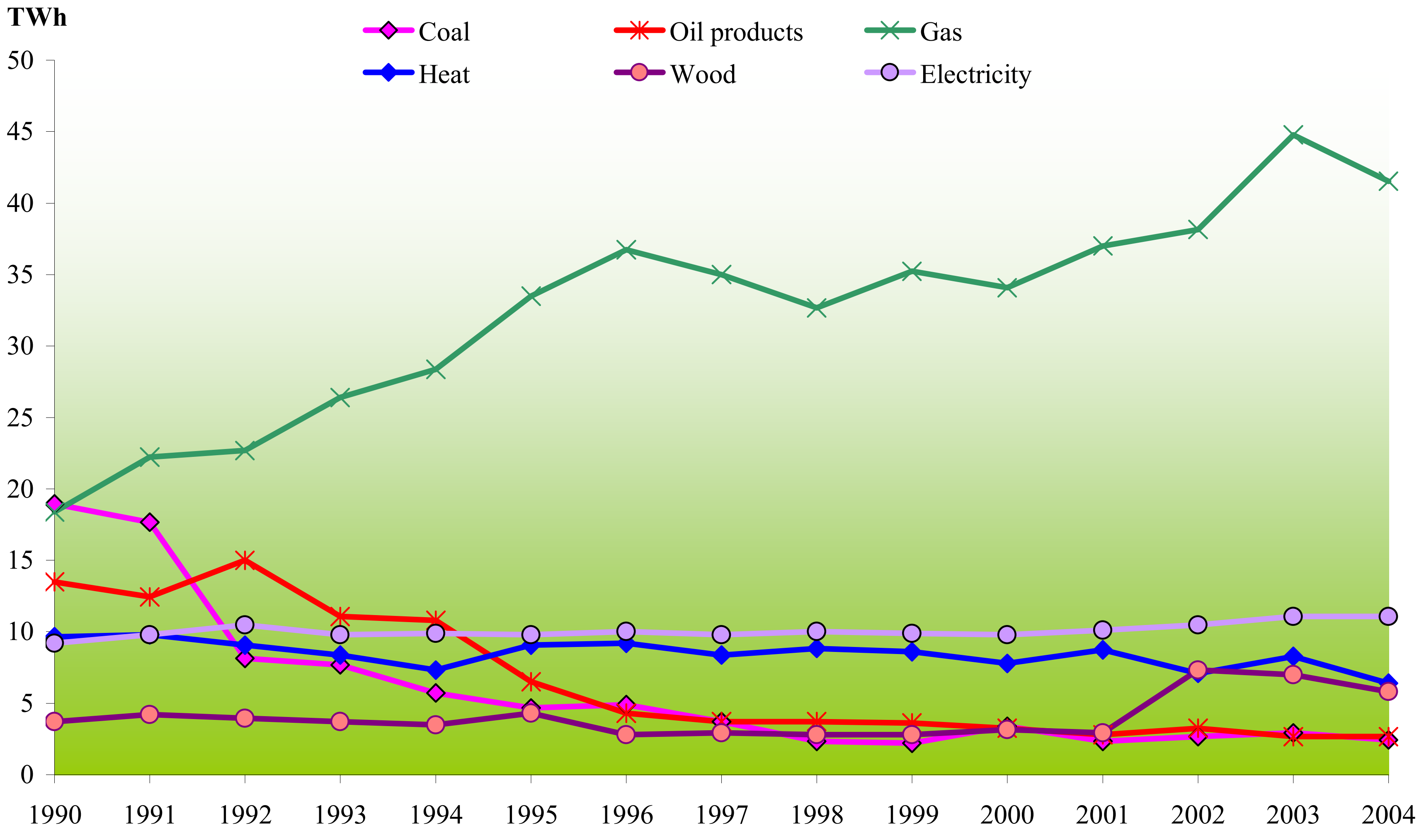
Source: constructed based on ODYSSEE NMS (2007)

Final energy consumption of energy end-use sectors in 1990 - 2004, Hungary



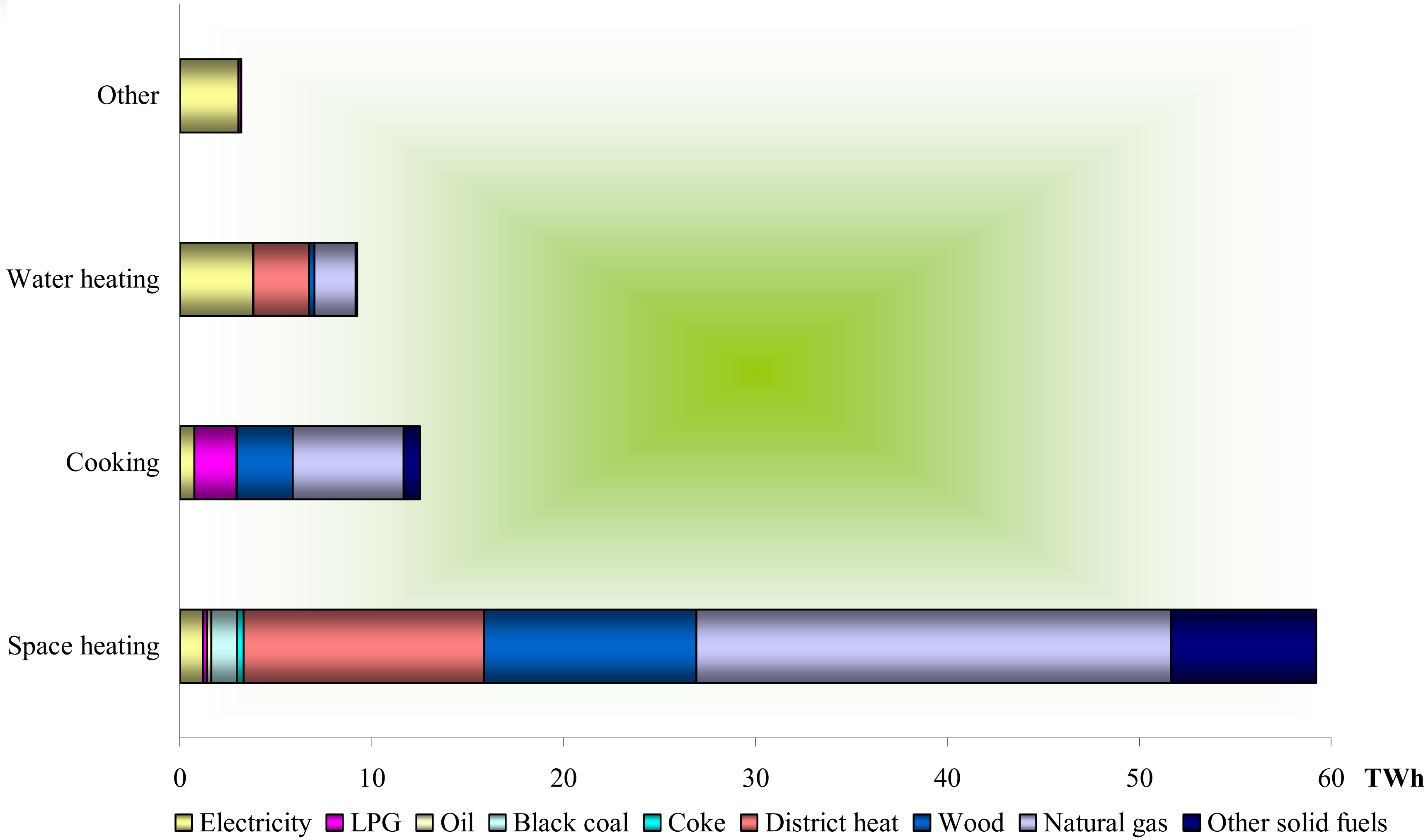
Source: constructed based on ODYSSEE NMS (2007)

Dynamics of final energy use in the residential sector of Hungary, 1990 - 2004



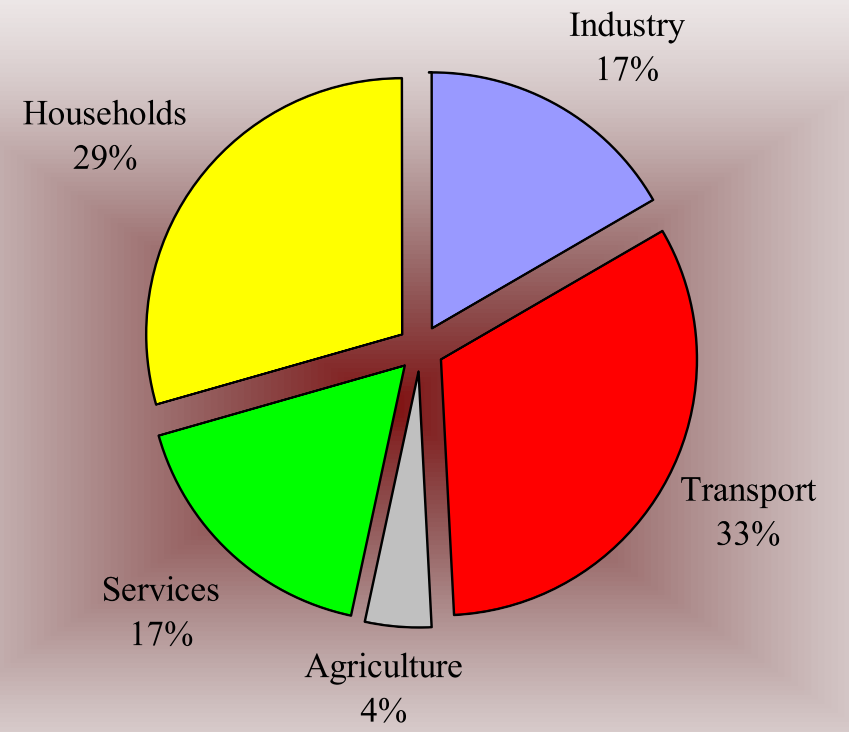
Source: constructed based on ODYSSEE NMS (2007)

Energy use breakdown of the Hungarian residential sector, 1996



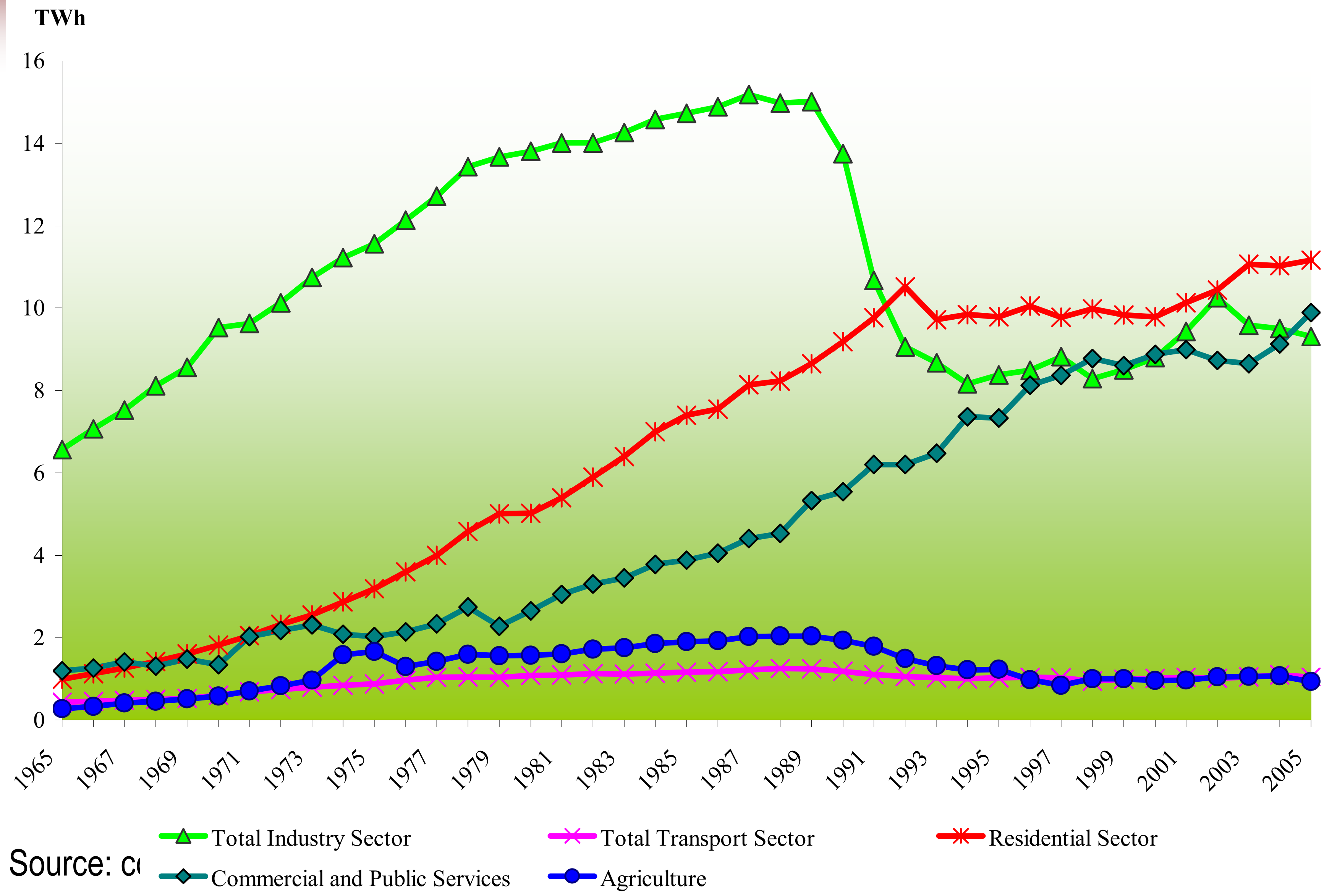
Source: constructed KSH 1998.

Breakdown of direct CO_2 emissions by final energy users in Hungary, 2004



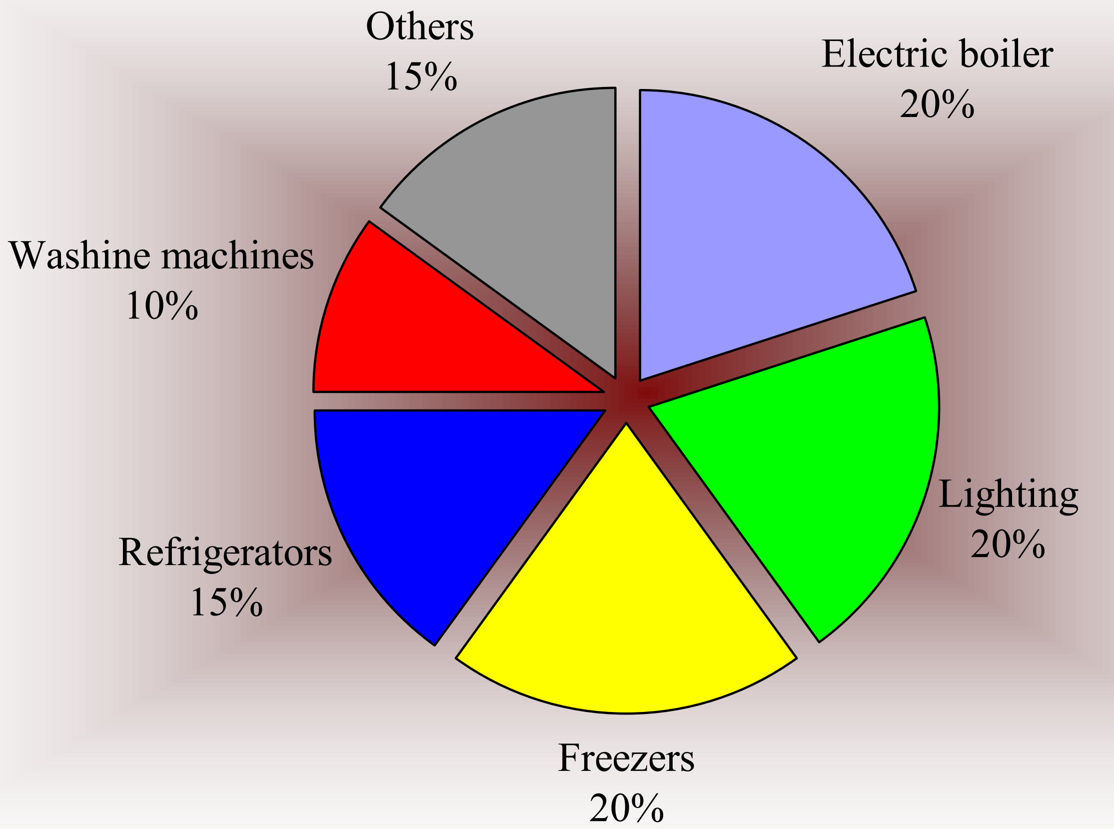
Source: constructed based on ODYSSEE NMS (2007)

Dynamics of electricity consumption of end-use sectors in Hungary, 1965-2005



Source: c

Breakdown of electricity consumption in the Hungarian residential sector, 2004



GFK, 2004

Best practices: SOLANOVA

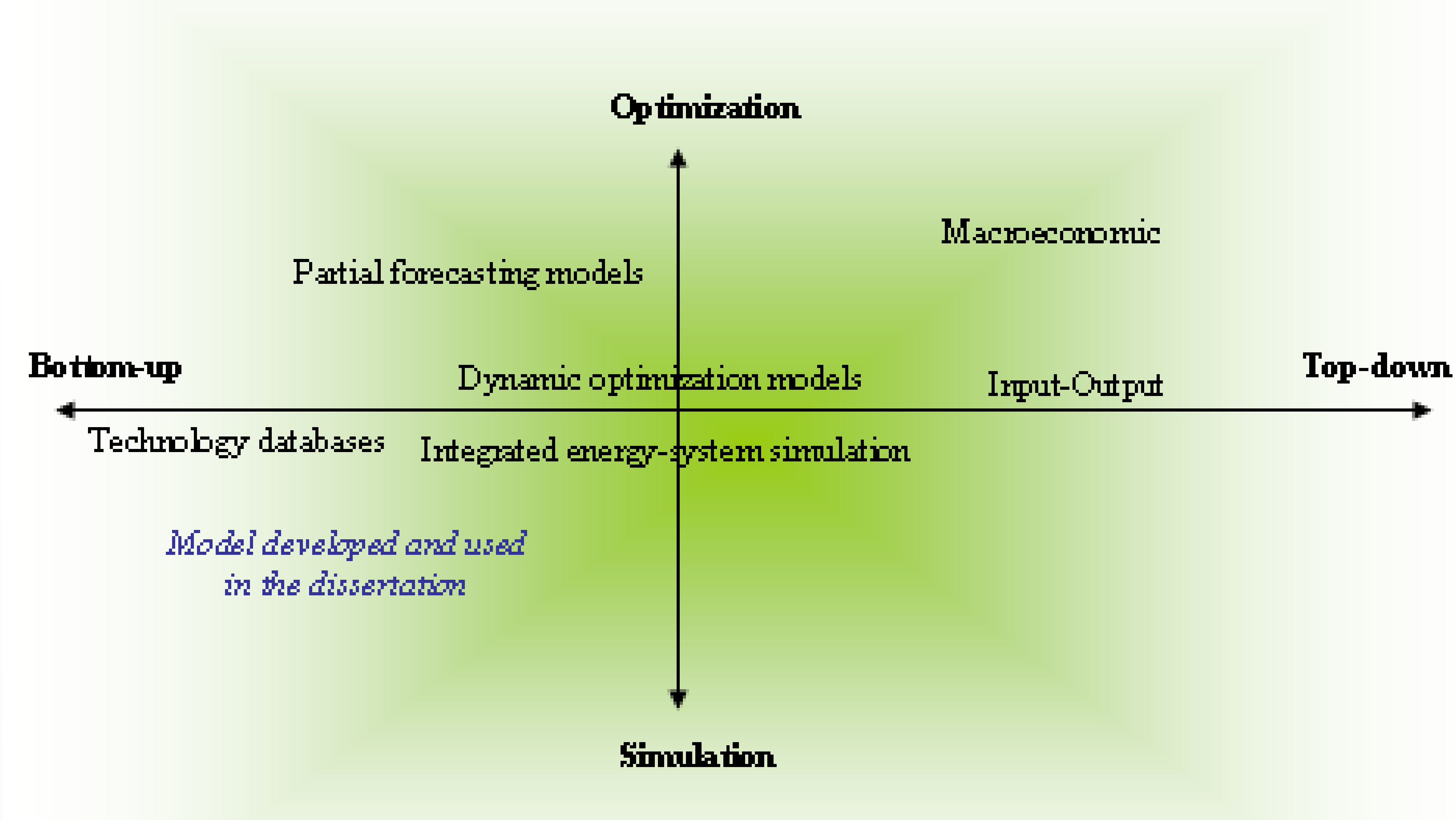
- Energy use for space and water heating
  - Before 220 kWh/m2-yr. for space heating
  - Reduction of space heating energy by 200 kWh/m2-yr. or app. **90%**
- Numerous co-benefits
  - Comfort
  - Very high saved energy costs
  - Real estate price increase by 18,900 EUR/flat (excl. of VAT)

Source: Hermelnik 2005

Additional slides

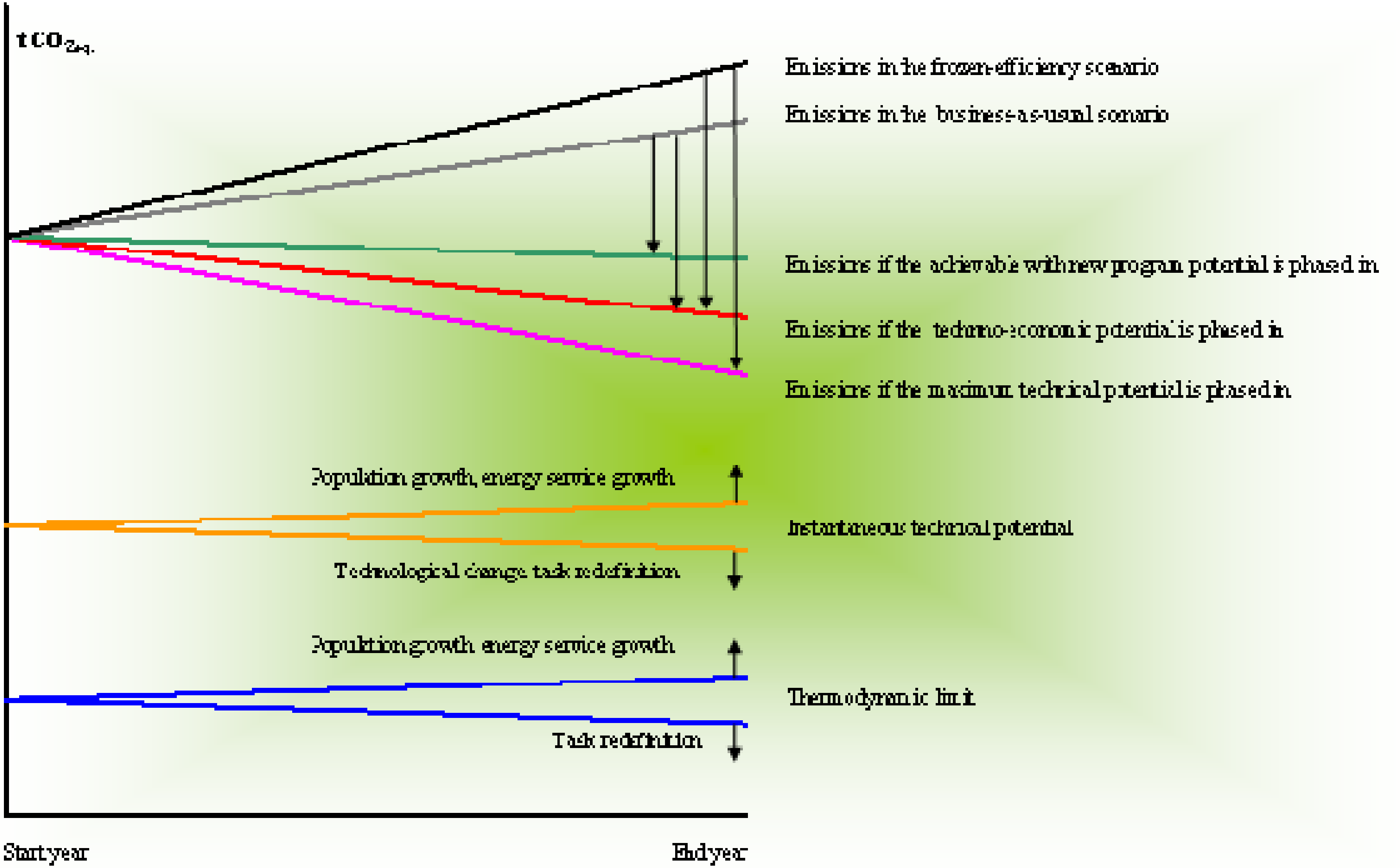
Review of methodologies from worldwide

Characterization of a few energy system assessment models



Source: adapted from van Vuuren (2008).

Alternative definitions of baselines and efficiency potentials



Source: adopted from Koomey et al. (1996) in Vorsatz (1996)

Comparison of top-down and bottom-up modelling approaches

Differences	Top-down models	Bottom-up models
Approach	- (Historic) behaviour - Aggregated data in the long term - Economic feedback is studied.	- Technologies at the energy end-use level - Economic feedback is not included
Subject of modelling	- Impacts of policy tools and measures on macro-economic indicators	- Energy savings available from application of specific technological options and associated costs
Technology understanding	- Efficiencies of technologies are modelled through coefficients of production factors - Elasticity of factors assume fuel switch	- A discrete shift from one technology to another assumes efficiency improvement - Price and factor elasticity are rarely studied
Equilibrium versus Optimum	- Models search for the state of equilibrium - The world without policy intervention was efficient	- Models search for optimization of energy systems in terms of allocation of the most cost-effective technological options
Projection period	- Applicable for the long-run assessment	- Short- and medium-term analyses

Source: Constructed on the basis of IPCC (2001), Sathaye and Mayers (1995), McFarland *et al*. (2002), Tol (2000), Krause (2000), Sathaye (2007), van Vuuren (2008).

Bottom – up models applied in selected country studies and their main assumptions. 1

Country/ region	Reference	Model type	Model-led unit	Baseline	Discount rate	Assumptions interesting from the point of view of dissertation research	Base/ Target years	Scenarios additionally to the baseline
EU-15	Joosen and Blok 2001	Bottom-Up, GENESIS	GHG	Frozen efficiency	4%	New and retrofit separately categorized	1990/ 2010	Mitigation scenario
Hungary	Szalvik et al. 1999	Bottom-Up, ENPEP[1]	Energy, CO_2	Business-as-usual	3% and 5%	New equipment and retrofitting. A wide range of supply side and demand side options.	2005/ 2030	Mitigation scenario
Hungary, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Poland, the Czech Republic	Petersdorff et al. 2005	Bottom-up and BEAM[2] model for the buildings stcck	Energy and CO_2	Frozen efficiency	6%	The buildings stock is modelled based on climate regions, building type, size, and age, energy carrier, insulation level, and emission factor.	2006/ 2015	Three scenarios with the EU EPBD[3], extended EPBD to buildings > 200m^2, extended EPBD to all buildings.
	Lechtenbohmer et al. 2005	Bottom-up	Energy and CO_2	Business-as-usual	3% and 5%	A moratorium on new nuclear power plants and compliance with ongoing nuclear phase-out.	2005/ 2020	The Policies and Measures scenario ('Target 2020')
Greece	Mirasgedis et al. 2004	Bottom-Up, ENPEP	CO_2	Frozen efficiency	6%	Climatic zones, age of buildings and their size result in 24 categories of buildings. Based on CBA analysis (NPV).	2000/ 2010	Three scenarios based on different definitions of incremental cost of CO_2 abatement.
Estonia	Kallaste et al. 1999	Bottom-Up, MARKAL[4]-MACRO	Energy, CO_2, NO_2	Scenario with modest economic growth	6%	No limit for fuel import and investment, electricity import is restricted. Buildings-related options are insulation mostly.	1995/ 2025	Low CO_2 tax, high CO_2 tax, all high taxes, expensive oil shale.
Switzerland	Siller et al. 2006	Bottom-up	Energy and GHG	Business-as-usual	N/a	Modelling of technologies is based on standards (present Vs future). Renovation and new constructions. Only space and water heating/	2005/ 2050	Final energy consumption reduced by a factor of 3; CO_2 emission reduced by a factor of 5 by 2050.

Bottom – up models applied in selected country studies and their main assumptions. 2

Country/ region	Reference	Model type	Model-led unit	Baseline	Discount rate	Assumptions interesting from the point of view of dissertation research	Base/ Target years	Scenarios additionally to the baseline
UK	Johnston et a. 2005	Bottom-up, Advanced BREHOMES[5]	Energy and CO_2	Reference and BAU	N/a	A "notional" dwelling type and efficiencies of its envelope and systems are modelled based on the present and expected standards.	1996/ 2050	'Demand side' scenario with the imposed target (60%)
UK	Boardman et al .2005	Bottom-Up, UKDCM[6]	CO_2eq.	Reference: 1997 carbon emissions	N/a??	Technologies are modelled in terms of fuel inputs, system efficiencies, and energy outputs assuming their take-over rates.	1996/ 2050	New scenario with 60% reduction of carbon emissions from 1997 levels by 2050('40% House')
Brazil	Almeida et al. 2001	Bottom-Up	Electricity, CO_2	No-conservation scenario	0%, 15%, 35%, 70%	Residences are split into 15 sub sectors in 5 geographical regions and 3 household income classes	2000/ 2020	Scenarios considered for different types of potential
USA	Koomey et al. 2001	Bottom-Up, CEF-NEMS	Energy, carbon	Business-as-usual	7%	New energy-efficient technologies and new policies	1997/ 2020	Moderate and advanced scenario.
South Africa	De Villiers 2000; De Villiers and Matibe 2000	Bottom-Up	CO_2	Frozen efficiency	6%	New equipment and retrofit with improved technologies are modelled (only known technologies).	1990/ 2030	Mitigation scenario
Ecuador	FEDEMA 1999	Bottom-Up, LEAP[7]	Energy, CO_2	Expected efficiency scenario	10%	Rural and urban areas. Reduction in specific E- needs and intensities, fuel switch.	1995/ 2030	Mitigation scenarios for each sector
India	ADB 1998	Bottom-Up, MARKAL and AHP[8] with imposed targets of GHG emission reductions by- 5,10,15,and 20%	Energy and GHG	Business-as-usual scenario and Baseline	6% and 12%	Business-as-usual is continuation of past trends whereas the Baseline is with the technologies likely to be used in the future	1990/ 2020	High efficiency scenario

Bottom – up models applied in selected country studies and their main assumptions. 3

Country/ region	Reference	Model type	Model-led unit	Baseline	Discount rate	Assumptions interesting from the point of view of dissertation research	Base/ Target years	Scenarios additionally to the baseline
Thailand	ADB 1998	Bottom-Up, EFOM-ENV[9]	Energy and GHG	Business-as-usual and baseline (see assumptions)	10%	The business-as-usual scenario is based on extension of present trends; the baseline is with policies but no special measures. Technological options are presented as programs targeted at efficiency improvement	1995/ 2020	1.Scenarios with CO_2 reduction by 10%, 20%, 25%, 30%, and 35% in 2020 as compared to Baseline 2.1st Scenario & 0.5% CO_2 reduction from 2010 compared to Baseline.
Viet Nam	ADB 1998	Bottom-Up, MEDEE/S-ENV[10] and EFOM-ENV	Energy and GHG	BAU as extension of past trends and the Baseline	10%	Two modelling approaches applied: the first one is that CO_2 evolution depends on set targets, and the second – on growth rates of CO_2.	1993-94/ 2020	1.Imposed targets for GHG reductions are 5%, 10% and 15%; 2. CO_2 emission growth rates are 0.5%, 1% and 1.1% /yr.

[1] Energy and Power Evaluation Program
[2] Building Environment Analysis Model
[3] The EU Directive on Energy Performance of Buildings.
[4] MARKet ALlocation model
[5] The Building Research Establishment's Housing Model for Energy Studies
[6] UK Domestic Carbon Model
[7] Long-range Energy Alternative Planning System
[8] Analytical Hierarchy Process
[9] Energy Flow Optimization Module-Environment
[10] Sectoral Energy Environmental Demand Analysis Model

Review of studies which assess mitigation potential in the CEE residential sector

Country/ region	Description of mitigation scenarios	Potential			Measures with lowest costs	Measures with highest potential	Notes
		Type	Million tCO_2	Base-line %			
Hungary (Szlavik et al. 1998)	Economic potential from 12 options and measures: building envelope, space heating, hot water supply, ventilation, awareness, lighting.	Technical	22	45%	1.Hot water metering; 2.Flow controllers; 3.Programmable thermostats for heating.	1.Post insulation; 2.Window retrofit; 3.Appliance procurement.	Discount rate is 3%-5%; The business-as-usual baseline; The projection period is 2000-2030; Potential estimates are for public and residential buildings; ranking of measures is for residences.
		Economic	15	31%			
Estonia (Kallaste et al. 1999)	Market potential from 4 insulation measures: 3d window glass, new insulation into houses, renovation of roofs, additional attic insulation.	Market	0.4%	3% of the whole economy emissions	1.New insulation into houses, 2.Additional attic insulation, 3.Third pane for windows.	1.New insulation into houses, 2.Third pane for windows, 3.Additional attic insulation.	Discount rate is 6%; The business-as-usual baseline; The projection period is 1995 – 2025; The whole buildings stock is modelled.
Member States accessed the EU in 2004 (Petersdorff et al. 2005)	Technical potential from measures in building envelope esp. insulation of walls, roofs, cellar/ground floor, windows with lower U-value; and renewal of energy supply.	Technical	62	-	1.Roof insulation; 2.Wall insulation; 3.Floor Insulation.	1.Windows replacement; 2.Wall insulation; 3.Roof insulation.	Discount rate is 6%; The baseline is frozen efficiency scenario; The projection period is 2006 – 2015; The whole buildings stock is modelled.
Member States accessed the EU in 2004 (Lechtenbohmer et al. 2005)	Improvement in space and water heating, appliances and lighting, cooling/freezing, air-conditioning, cooking, motors, process heat, renewable energies, reduced emissions from electricity generation.	Economic	41	30%	n.a. (Not listed in the study)	1.Insulation; 2.Heating systems, fuel switch, district heating and combined heat and power.	Discount rate is 3-5%; The projection period is 2005 – 2020. Data is for the residential sector.

Additional slides

Modeling methodology

Calculation procedures

$$FE_i = \sum_i FE_{SpaceHeating_{m,j,i}} + \sum_i FE_{WaterHeating_{j,i}} + \sum_i FE_{Appliances\&Lights_{j,i}} + \sum_i FE_{Cooking_{j,i}}$$

$$CO_{2_{s,i}} = FE_{s,i} \times EF_{s,i}$$

$$FE_{SpaceHeating_{m,j,i}} = \frac{UE_{SpaceHeating_{m,i}}}{\eta_{SpaceHeating_{j,i}}}$$

$$UE_{SpaceHeating_{m,i}} = EL_{Transmission_{m,i}} + EL_{Infiltration_{m,i}}$$

$$EL_{Transmission_{m,i}} = HDH_i \times \sum_l U_{l,m} \times A_{l,m}$$

$$EL_{Infiltration_{m,i}} = HDH_i \times ACH_m \times V_m \times \rho_{air} \times c_{air}$$

Calculation procedures

$$FE_{WaterHeating_{j,i}} = \frac{V_i \times UE_{WaterHeating}}{\eta_{WaterHeating_{j,i}}}$$

$$FE_{ColdAppliance_i} = UEC_{Reference} \times EEI_i$$

$$FE_{ClothesWashingMachine_i} = UEC_{Load_i} \times Load \times Time$$

$$FE_{Light_i} = Wattage_{Light_i} \times Time$$

Calculation procedures

$$MCCO_{2\,j,i} = \frac{\Delta AIC_{j,i} - EC_{j,i}}{\Delta CO_{2\,j,i}}$$

$$\Delta AIC_{j,i} = a_j \times AIC_{j,i} - a_{reference} \times AIC_{Reference,i}$$

$$a_j = \frac{(1+DR)^{n_j} \times DR}{(1+DR)^{n_j} - 1}$$

$$EC_{j,i} = \Delta FE_{j,i} \times \Pr ice_i$$

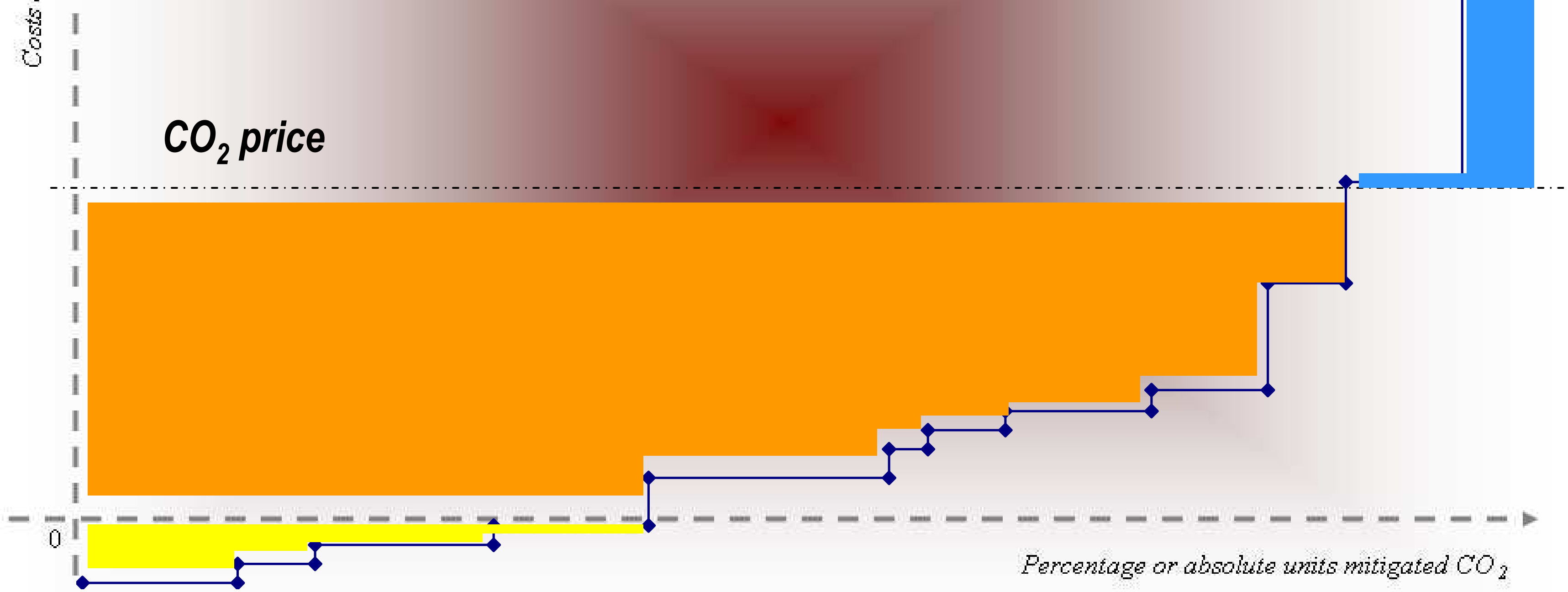
$$CCE_{j,i} = \frac{\Delta AIC_{j,i}}{\Delta FE_{j,i}}$$

Calculation procedures

$$MS_j = \frac{Q_j}{\sum_{j=1}^{k} Q_j} = \frac{\left(\frac{1}{PT_j}\right)^{\gamma}}{\sum_{j=1}^{k}\left(\frac{1}{PT_j}\right)^{\gamma}}$$

Messages of CO_2 mitigation curve

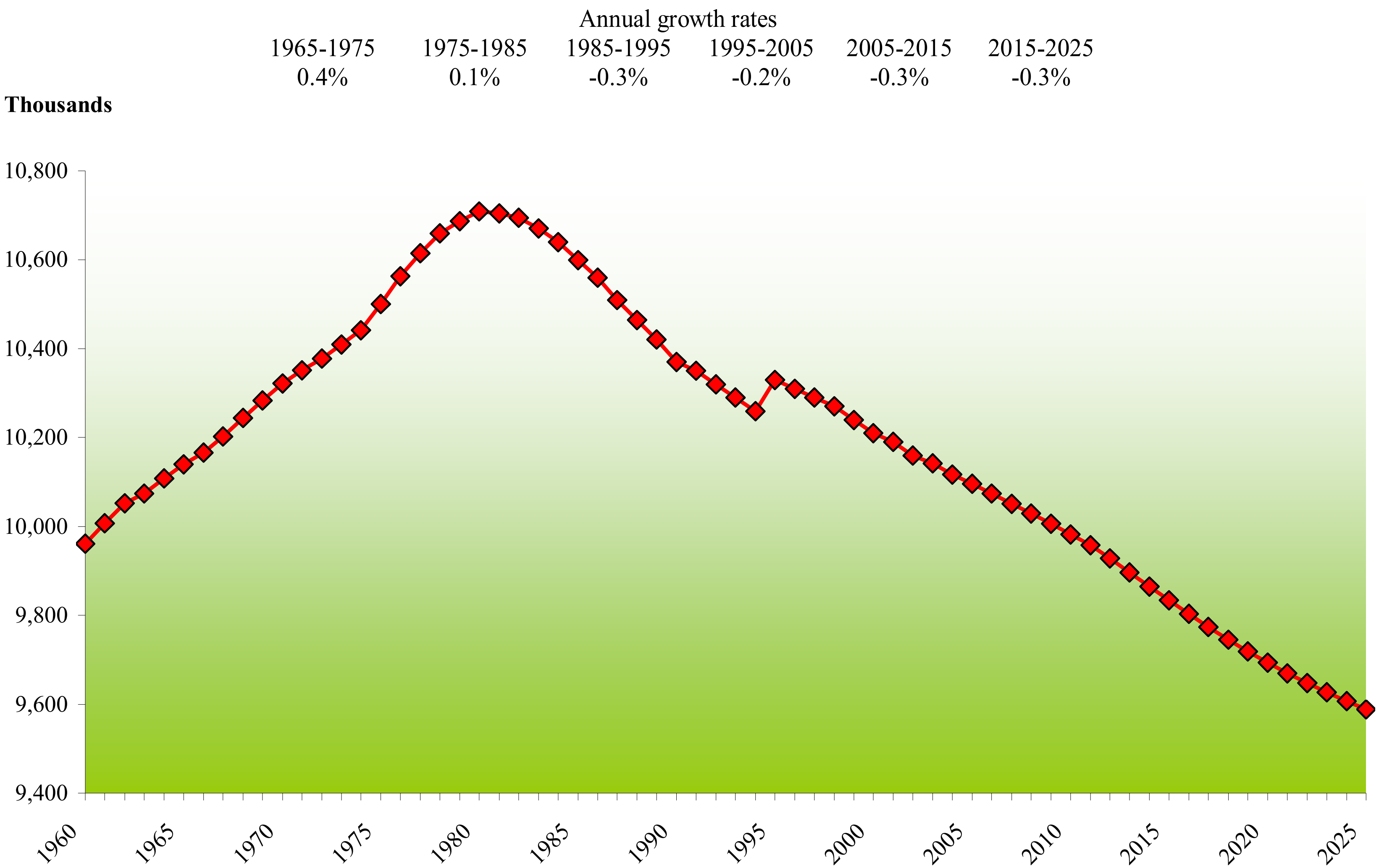
- Estimates of the potential are adjusted to double-counting
- Easy-to-read guidance: how CO_2 can be avoided
- Technological options are ranked
- Can be used to analyze future CO_2 emissions in a detailed breakdown
- The results can be often directly incorporated into follow-up research on modelling of mitigation policy tools
- Visualisation of benefits



Additional slides

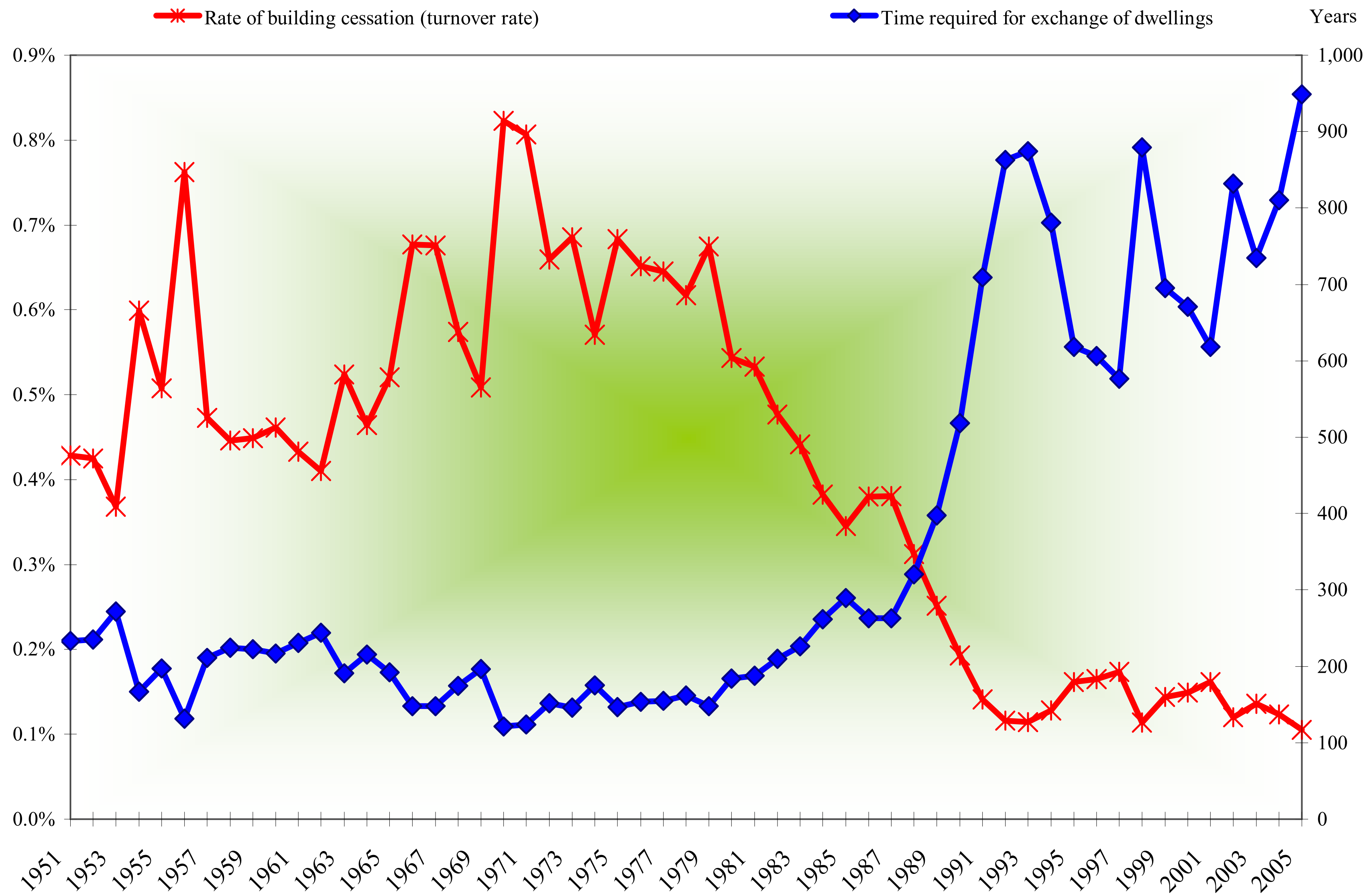
Buildings stock modeling

Population dynamics in Hungary, 1960 - 2025



Source: constructed based on KSH (2006a) and EUROSTAT (2007).

Rate of building cessation and time required for the buildings stock to exchange

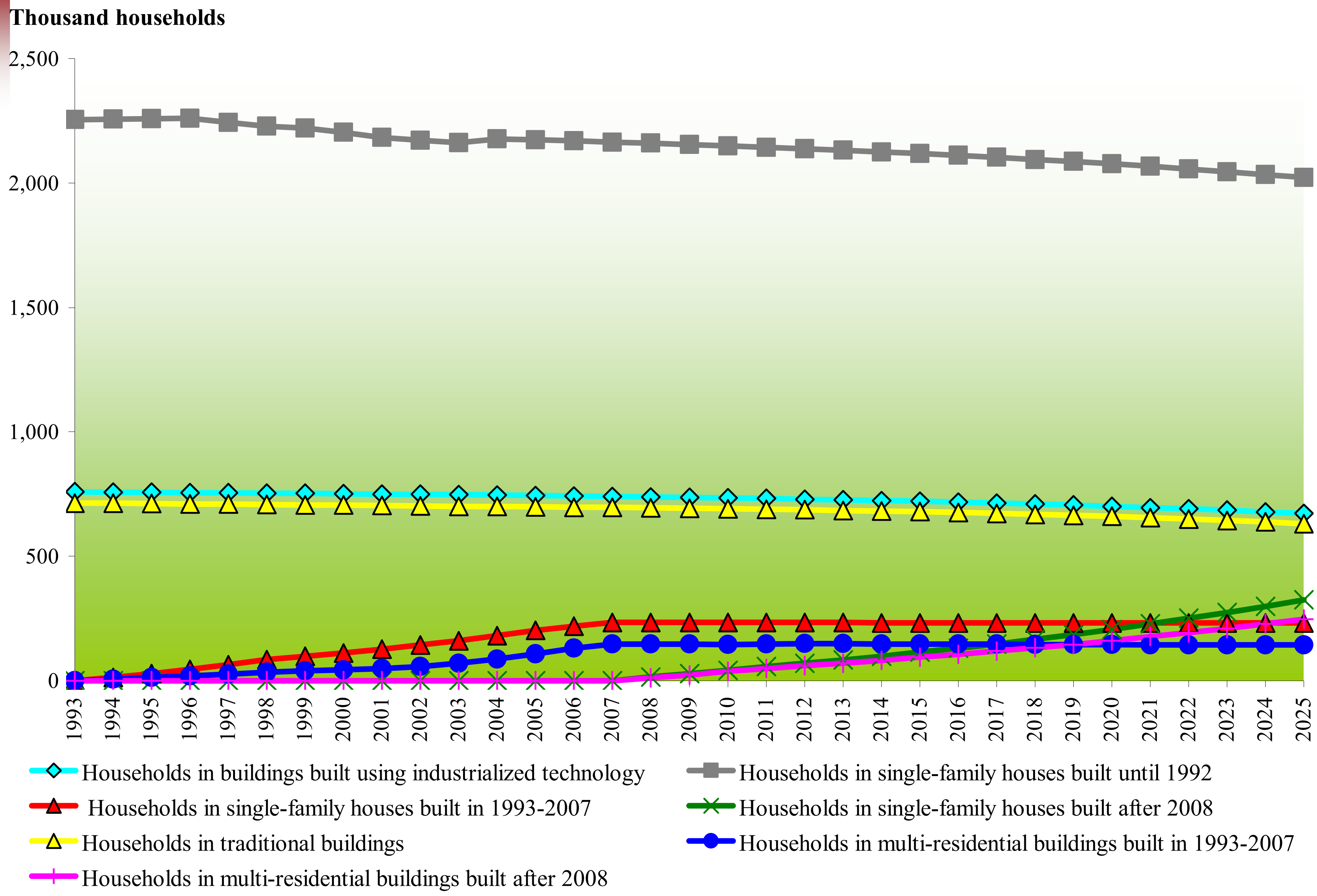


Source: Constructed based on KSH (2006b)

Modeling structure

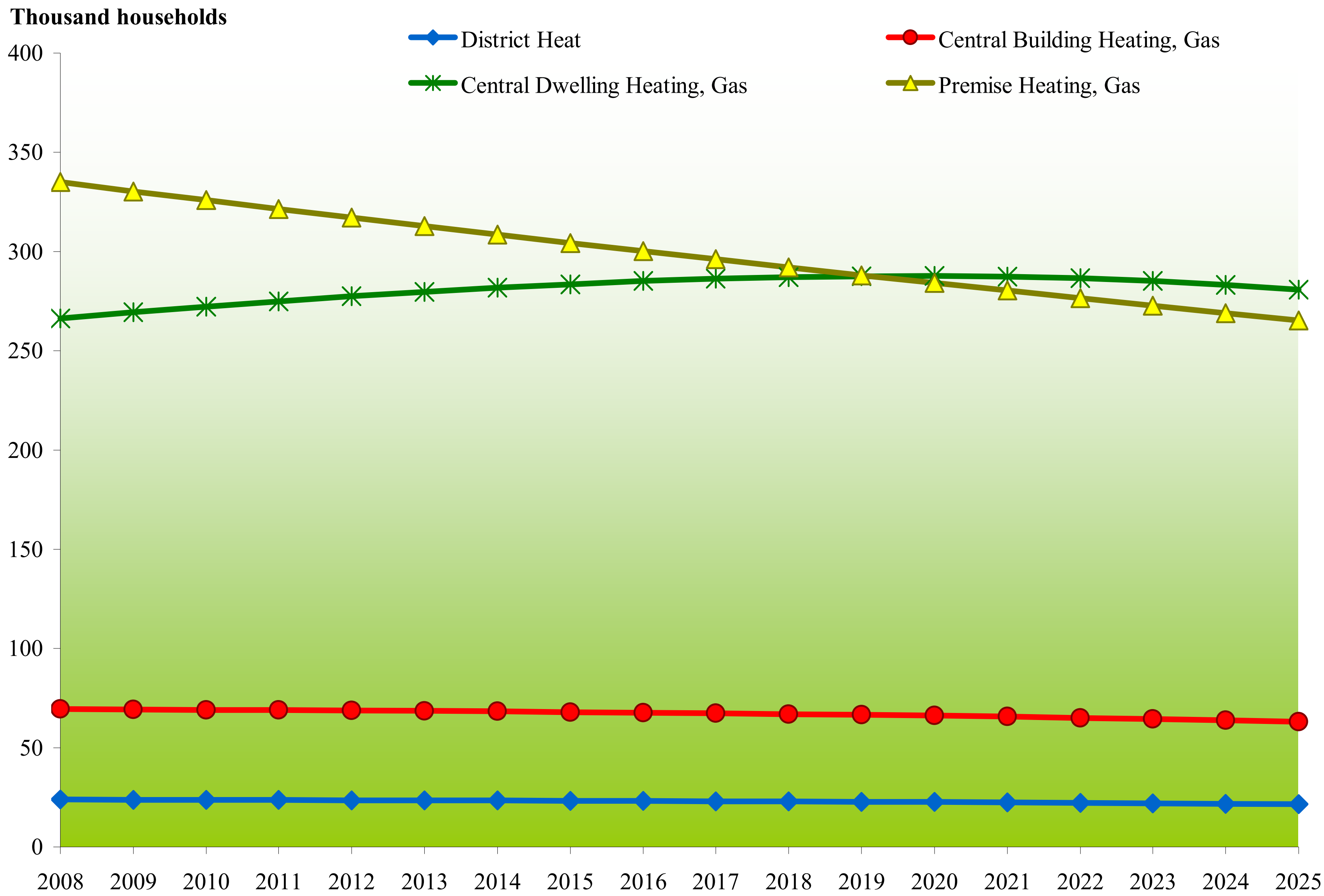
- Buildings are split into 5 categories
  - Architectural and thermal characteristics
- Main modeling steps
  - Buildings stock model for 2008 – 2025
  - Space heating split for 2008 – 2025
  - Water heating split for 2008 – 2025

The buildings stock model: projected household stock

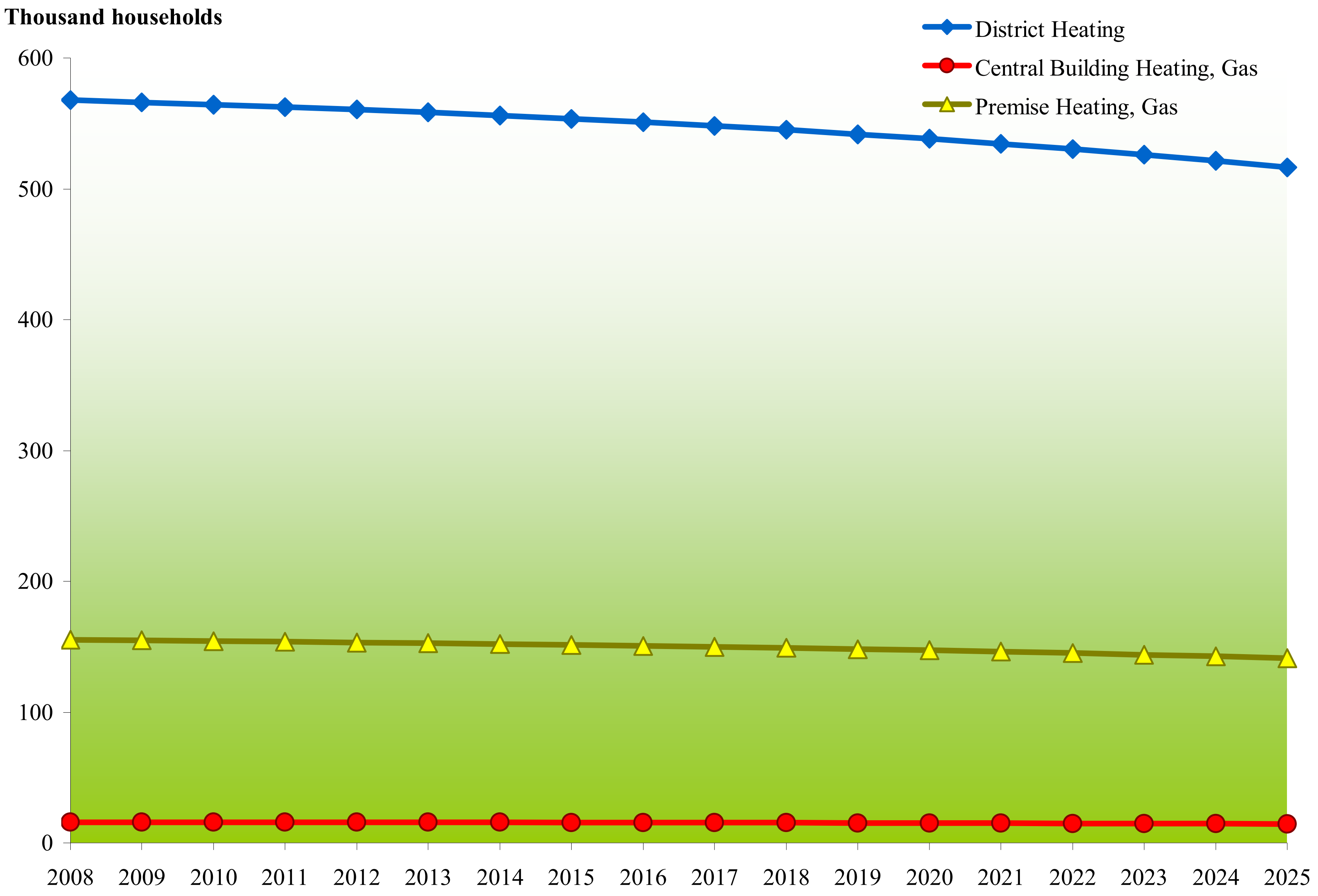


C E U

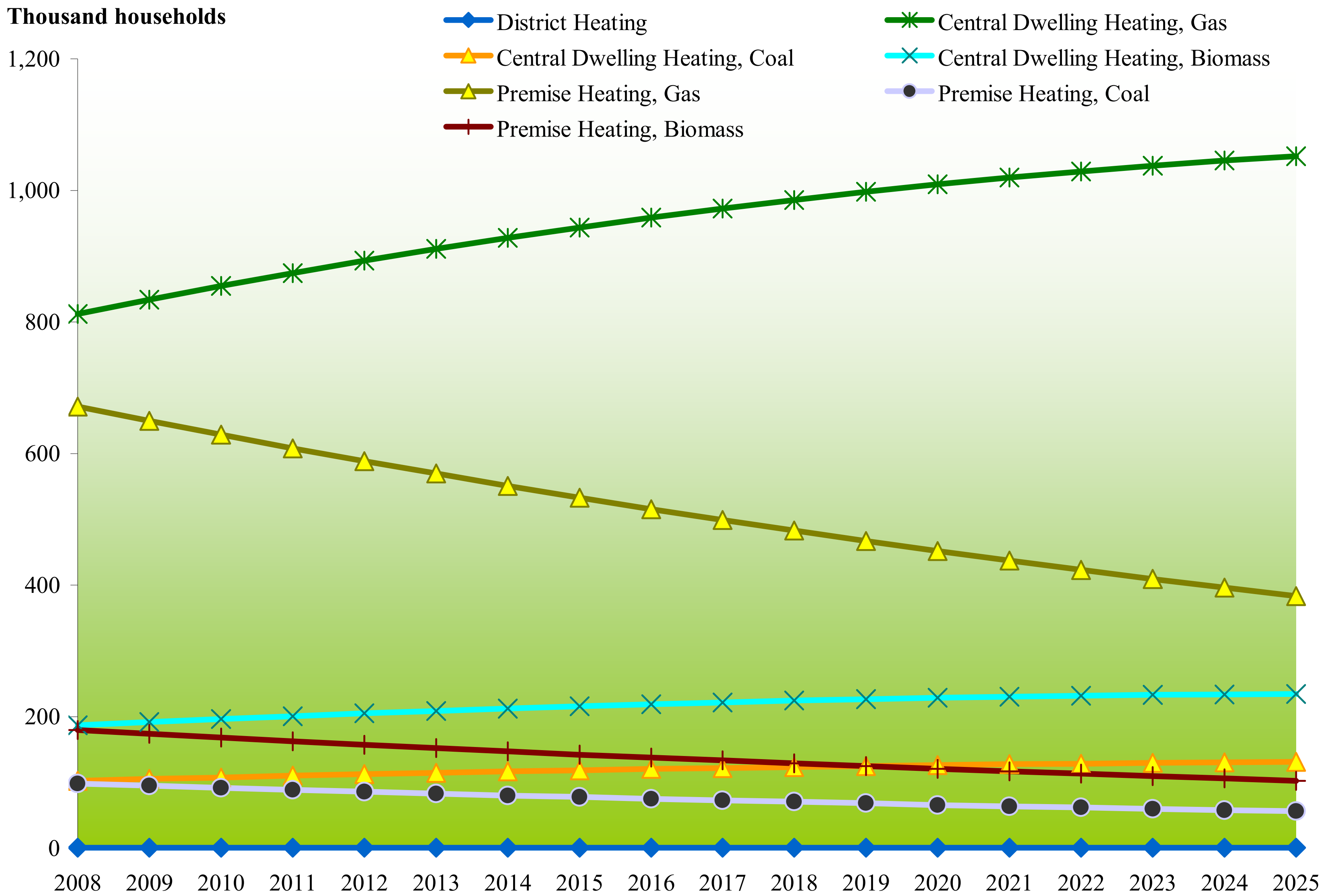
Space heating modes in households of the traditional buildings



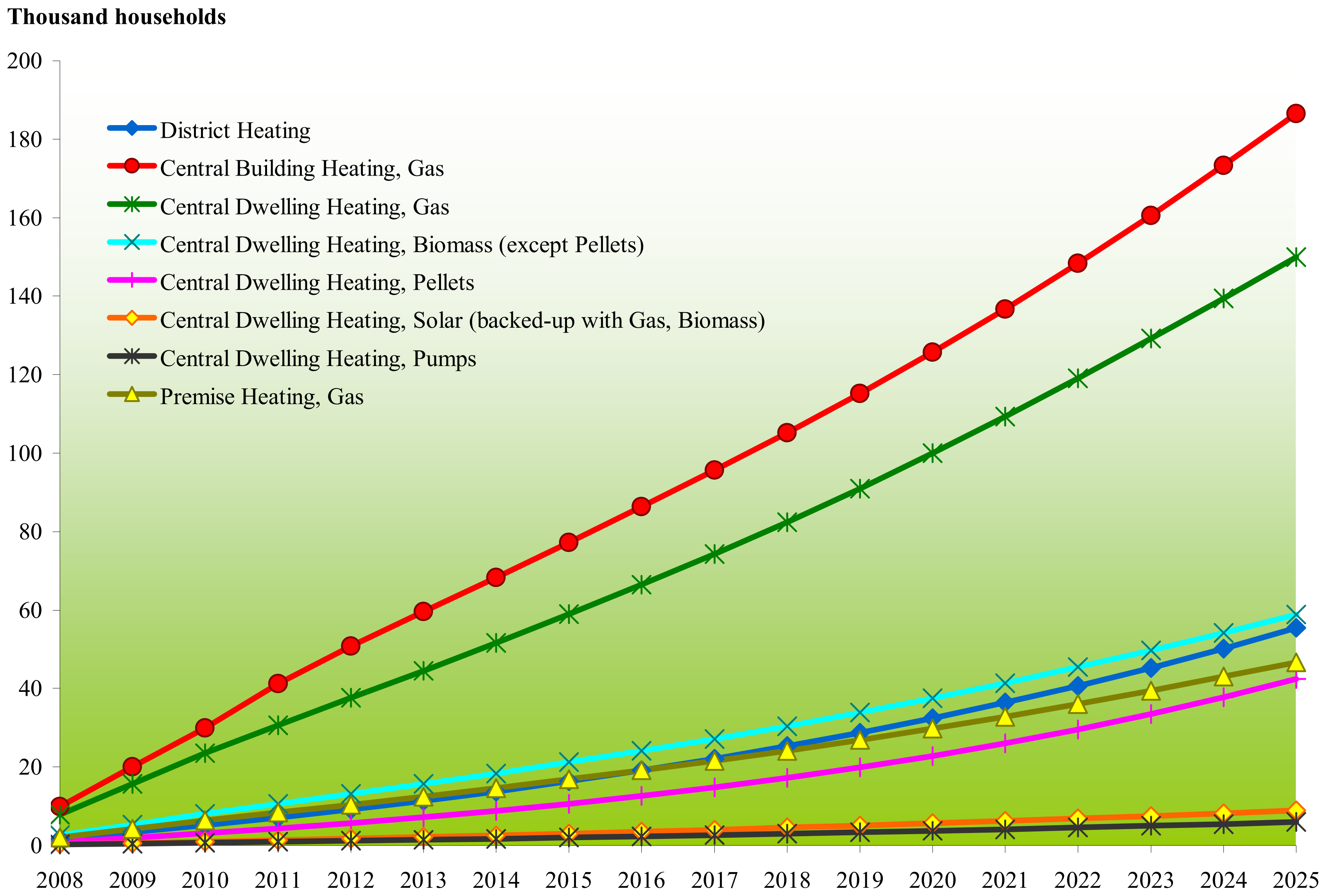
Space heating modes in households of the industrialized buildings



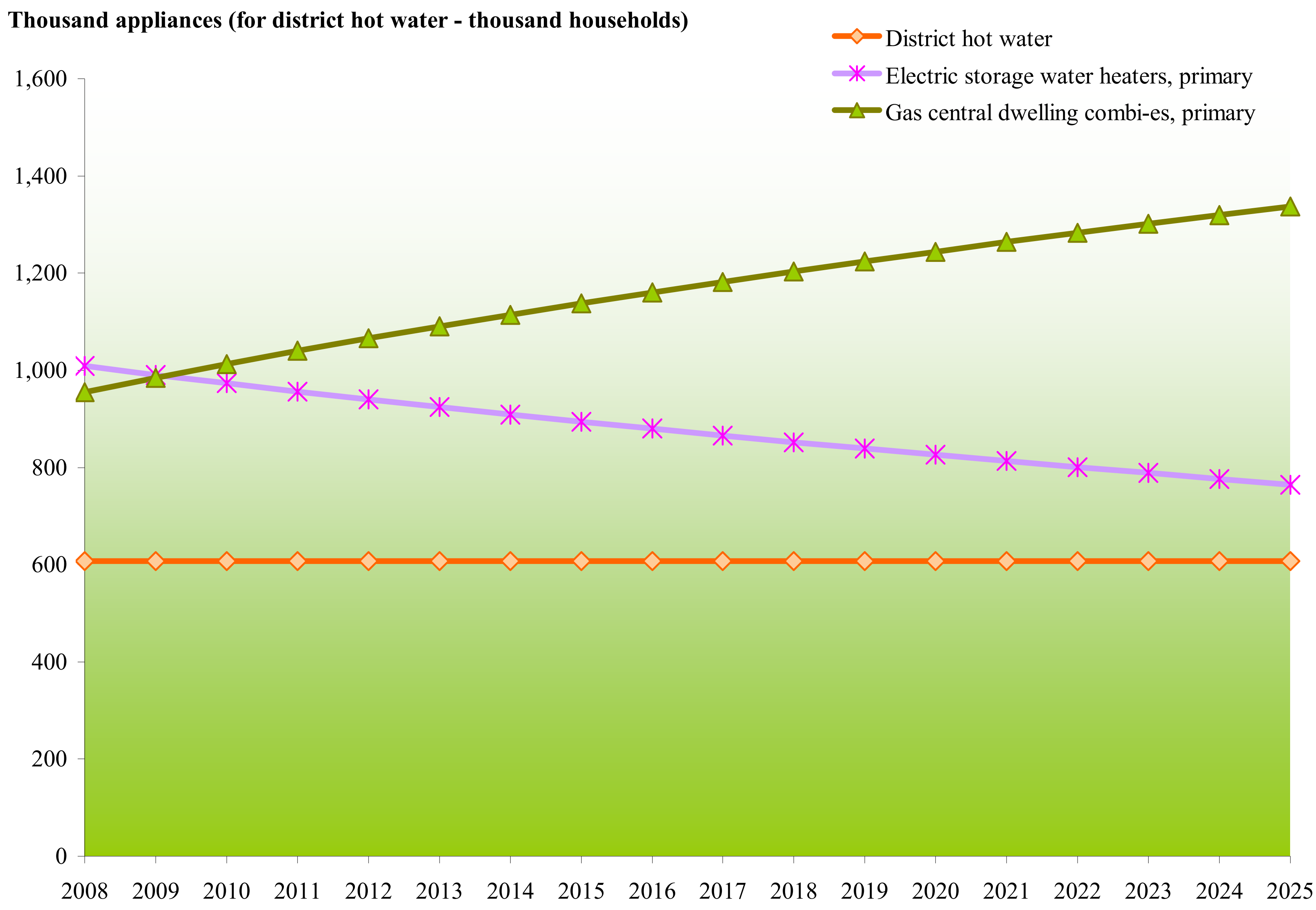
Space heating modes in old single-family houses



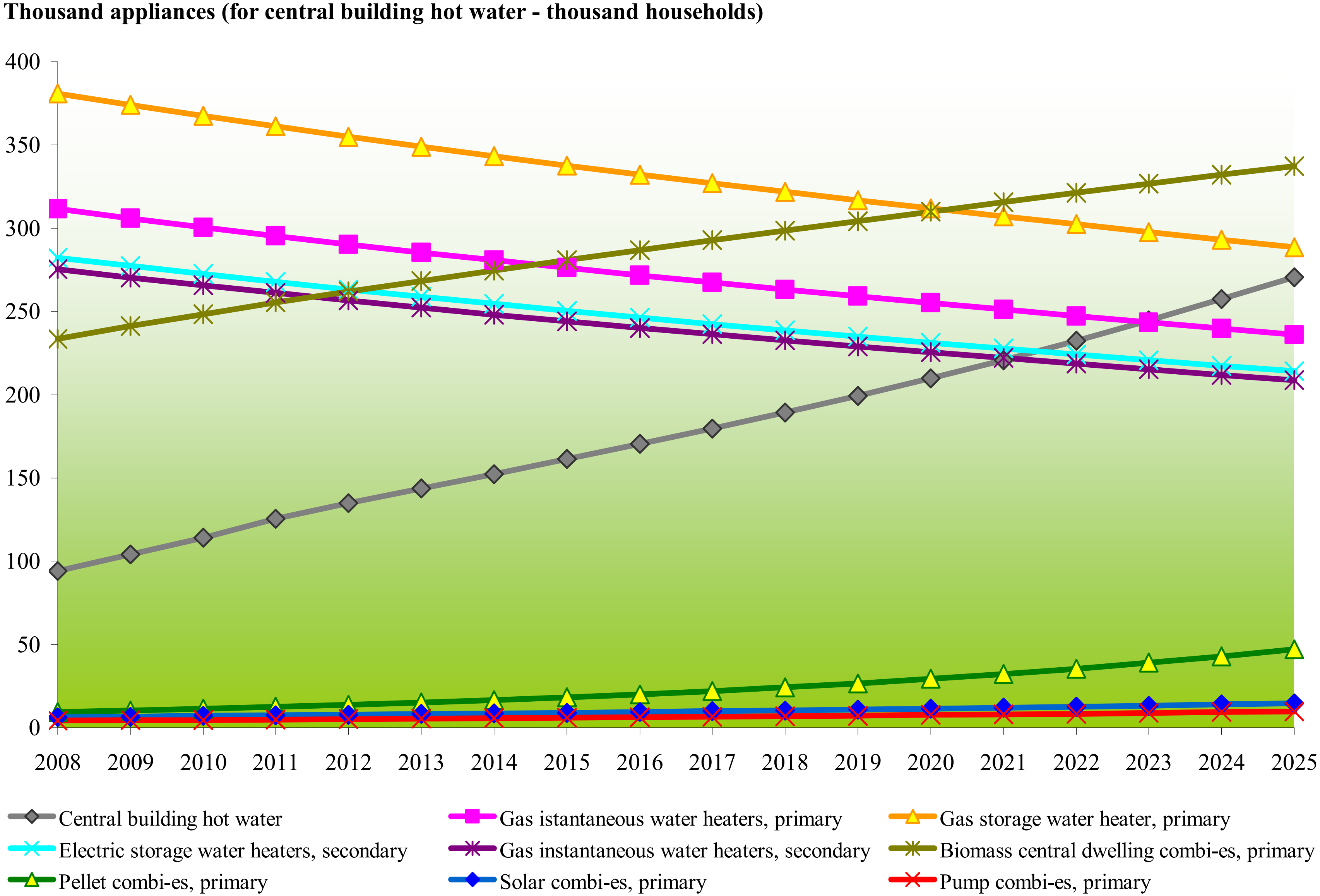
Space heating modes of households in new buildings



Water heating solutions – the number of systems, top three



Water heating solutions – the number of systems, excluding top three



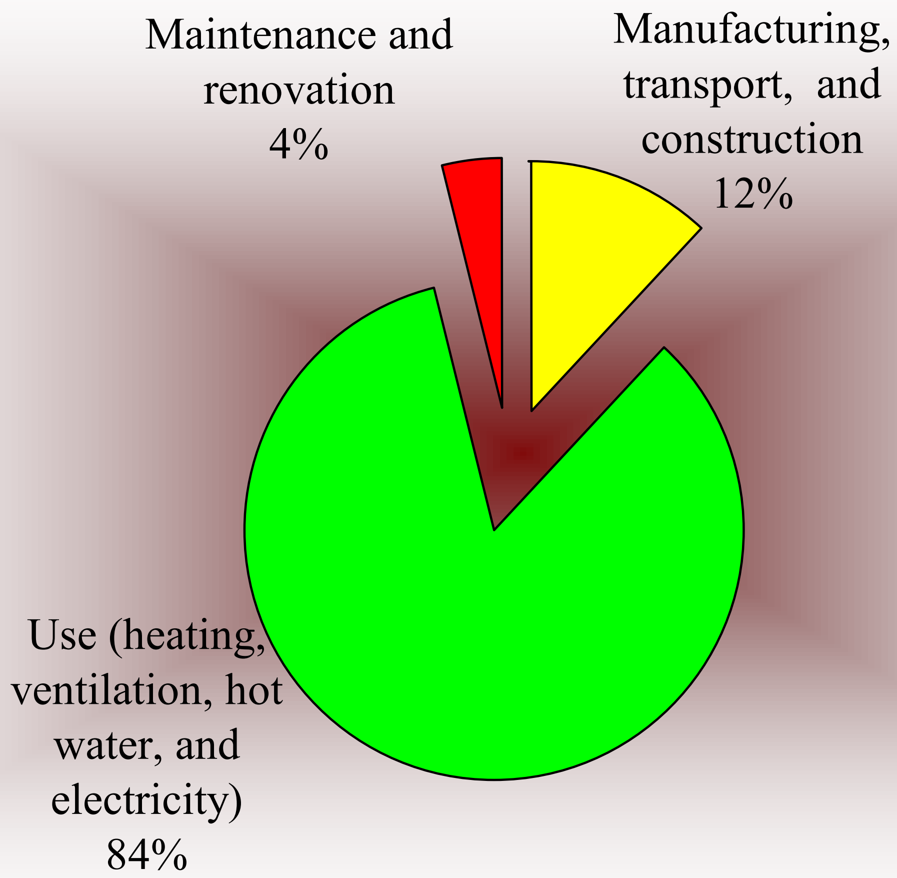
Additional slides

Baseline modeling

Estimated energy heating requirements of different types of buildings

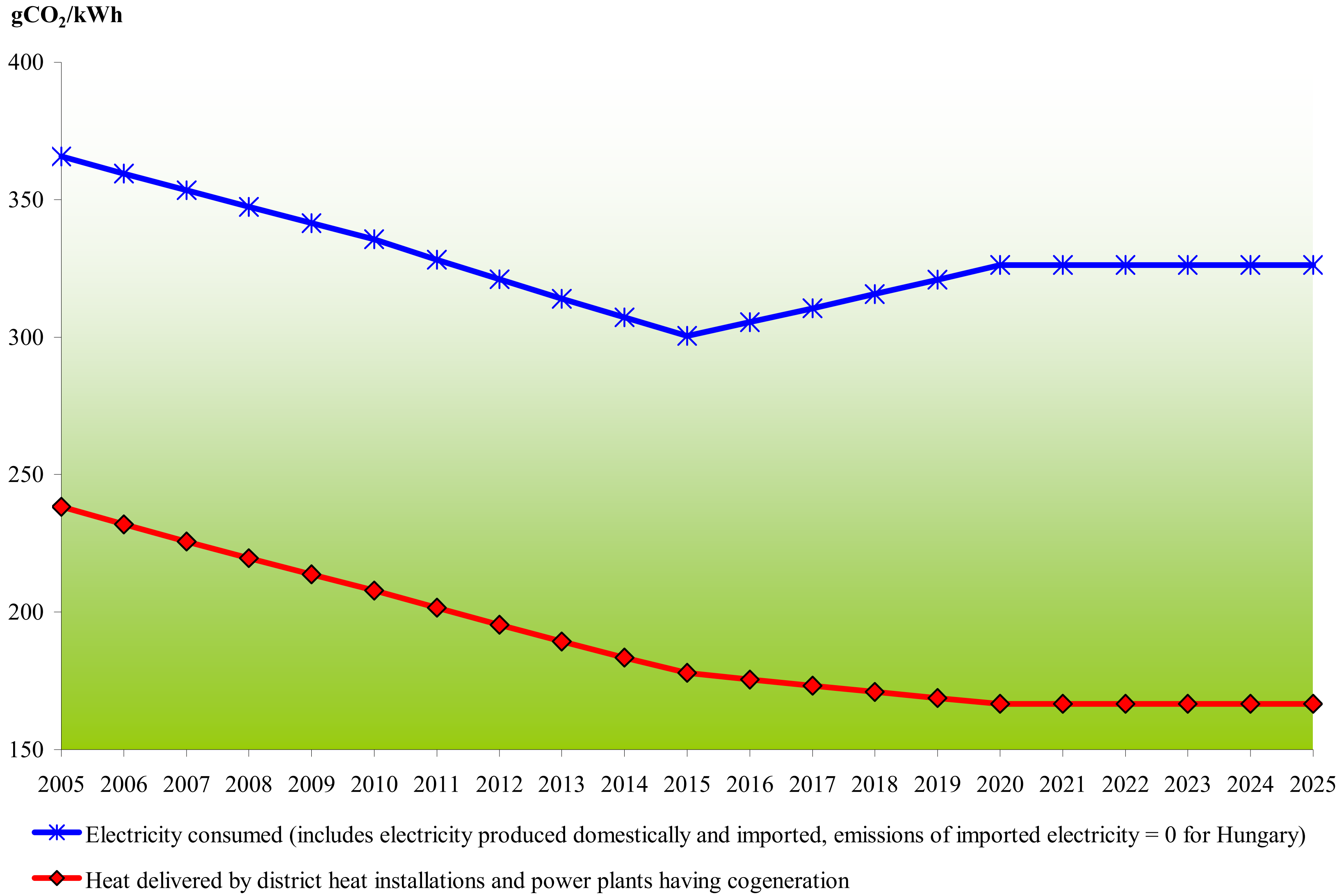
Types of buildings	Type of heating	Energy heating requirement, kWh/m²
Old single-family houses	Central dwelling	230
	Premise	299
Households in traditional buildings	Central dwelling	180
	Premise	234
Households in buildings built with the industrialized technology	Central dwelling	200
	Premise	260
Multi-residential buildings and family-houses built during the last fifteen years	Central dwelling	125
	Premise	163
New multi-residential buildings and family-houses	Central dwelling	105
	Premise	137

Life cycle energy use in buildings



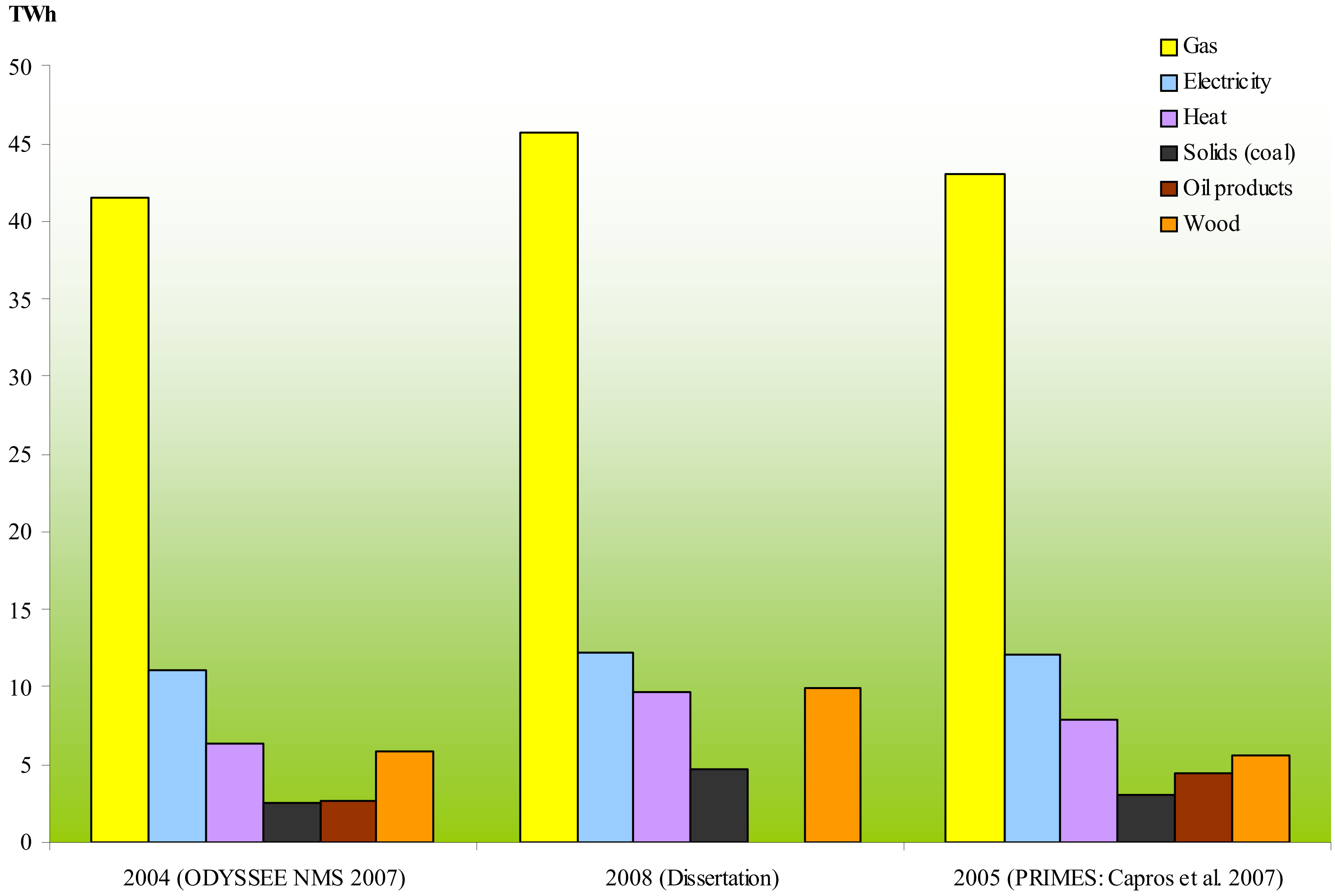
Source: Adalberth 1997 .

Projected emission factors of electricity and heat in Hungary, 2005 – 2025

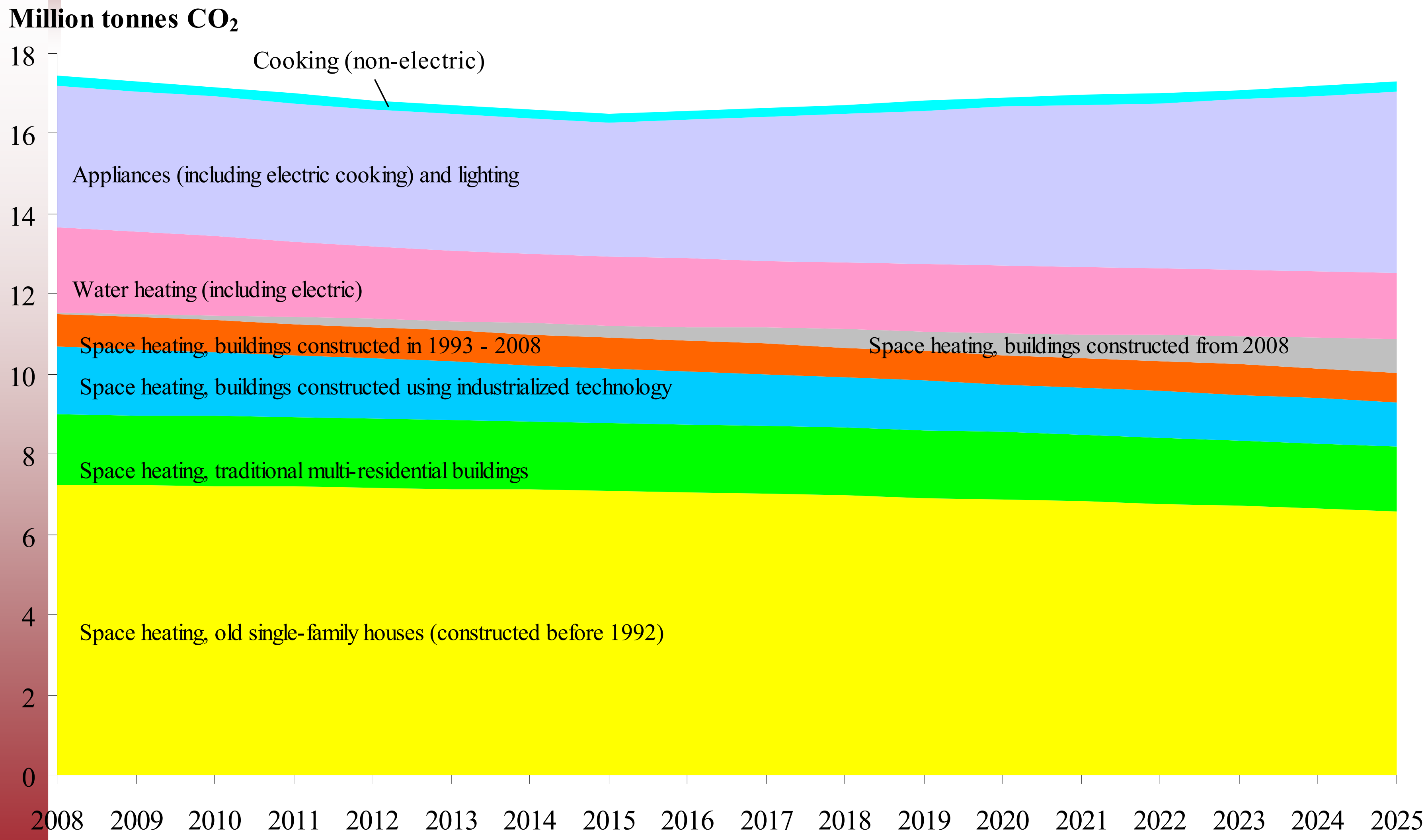


Source: research forecast based on GKM & KVVM (2007); MAVIR (2005); and Hungarian Ministry of Environment and Water (2007).

Comparison of the sectoral energy balance of the research model, national statistics, and the external model



Sectoral CO2 emissions projected in the reference case, 2008 - 2025



Energy consumption and associated CO2 emissions: the start year balance and the forecast for 2008 – 2025 according to different sources

	Units	2004	2005	2006	2008	2010	2015	2020	2025
The present dissertation									
Energy consumption	TWh	-	-	-	81.9	82.2	82.7	83.1	84.2
CO_2 emissions, total	1000 tCO_2	-	-	-	17.4	17.2	16.5	16.9	17.3
CO_2 emissions, direct					13.2	13.0	12.6	12.4	12.3
CO_2 emissions, indirect					4.2	4.1	3.9	4.5	5.0
PRIMES model (Capros et al. 2007)									
Energy consumption	TWh		76.3			85.3	93.6	98.5	101.5
CO_2 emissions, direct	1000 tCO_2		10.7			11.0	11.3	11.4	11.3
ODYSSEE NMS database (2007)									
Energy consumption	TWh	69.8	-	-	-	-	-	-	-
CO_2 emissions, total	1000 tCO_2	16.2	-	-	-	-	-	-	-
Energy Efficiency Action Plan of Hungary (GKM 2008)									
Energy consumption	TWh	-	-	75.7	-	-	-	-	-

Additional slides

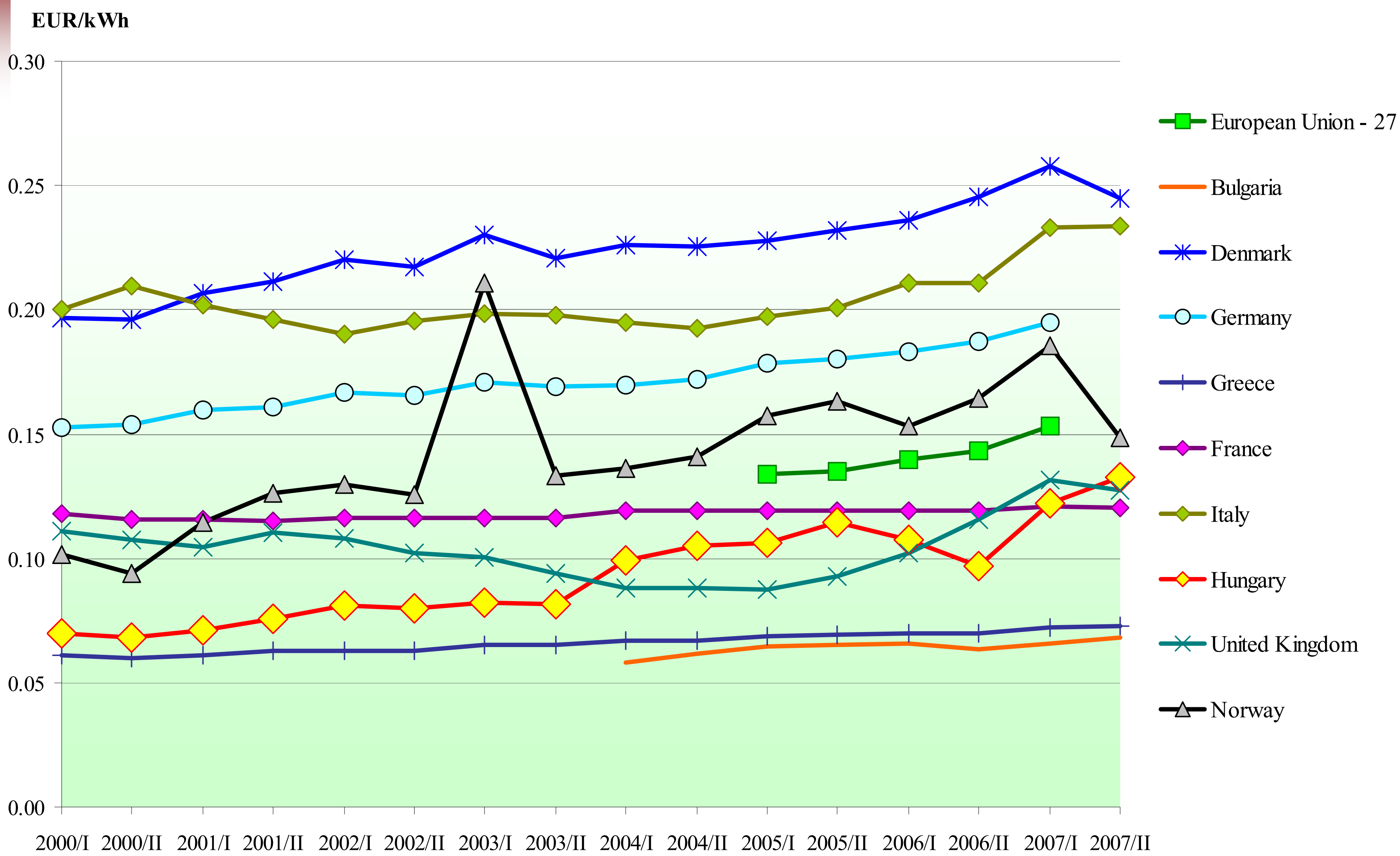
Economic evaluation

Energy prices for the residential end-users of Hungary, December 2007

Fuels	Energy price, EUR/kWh	References
Natural gas	0.044	Hungarian Energy Office 2007a
Agripellet	0.030	Estimate based on (DBO 2007)
Brown coal	0.024	Estimate based on (Hungarian Energy Office 2007b)
Firewood	0.012	Estimate based on (DBO 2007)
District Heat	0.041[1]	Call Centre (FŐTÁV 2007)
Electric energy	0.155	Hungarian Energy Office 2007c

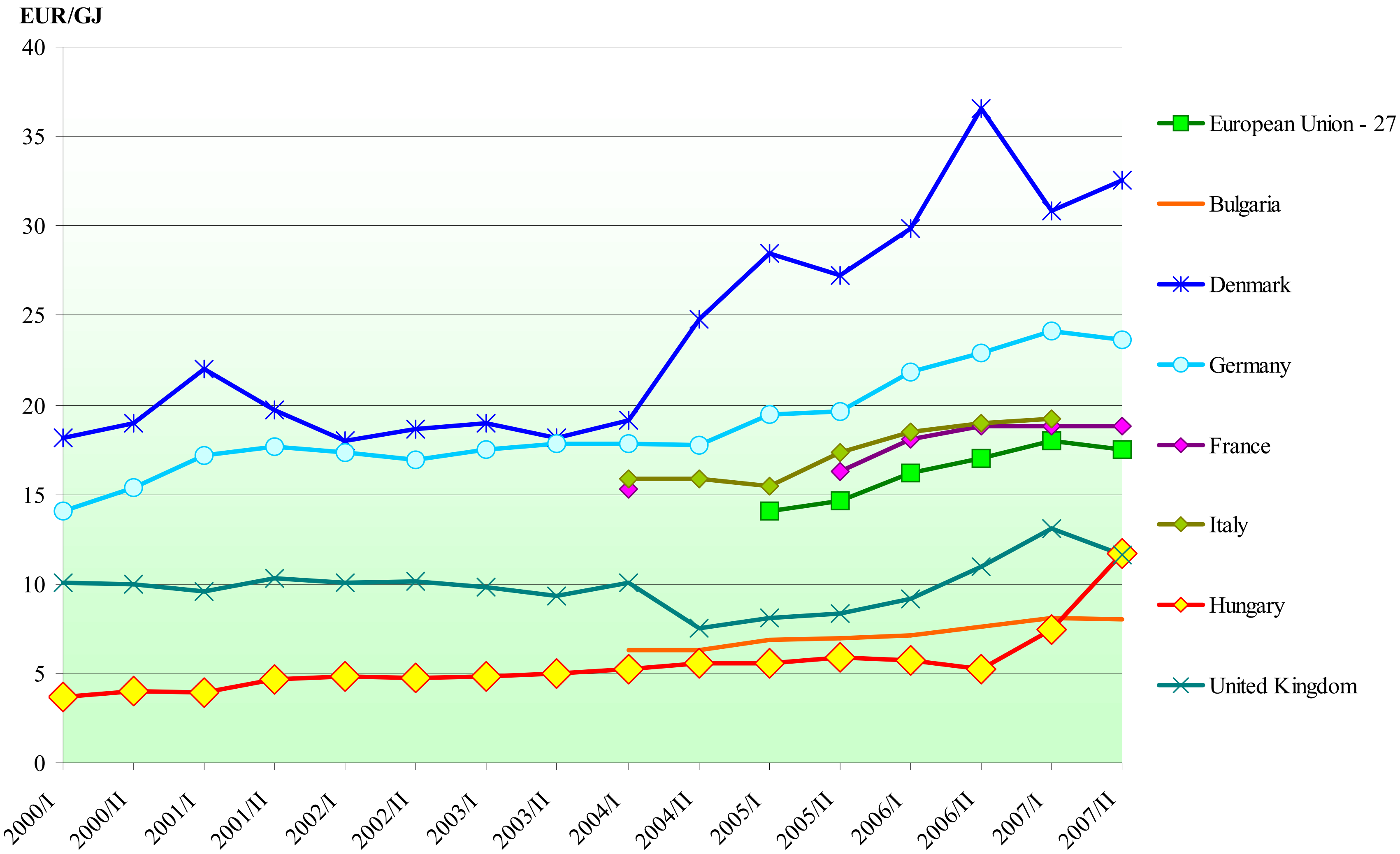
[1] To be consistent across the methodologies of estimation of energy saving costs of space heating options, it is considered that the district heat price is 100% flexible. In practice, only half of the district heat price is variable and it depends on heat consumption of a building distributed among heat payers. Another half of the price is not so called 'capacity cost' and is variable (Sigmond 2007).

Half-yearly price for domestic electrical consumers (including all taxes)



Source: EUROSTAT 2008.

Half-yearly natural gas price for domestic consumers (including all taxes)



Source: EUROSTAT 2008.

Potential available through application of options installed separately, 2025 *cont.*

Mitigation measure	CO_2 savings	Costs of mitigated CO_2	Energy savings	Costs of energy savings
	Thousands tonnes CO_2/yr.	EUR/tCO_2	GWh/yr.	EUR/kWh
Buildings constructed using industrialized technology				
Installation of thermostatic radiator valves	89	-240	529	0.01
Wall insulation	332	-115	1931	0.03
Installation of condensing gas central building boilers for space heating	6	-97	30	0.04
Window exchange	236	-81	1369	0.04
Basement insulation	19	109	110	0.07
Roof insulation	38	161	219	0.08
Individual metering of district and central heating	177	203	1057	0.09
Traditional buildings				
Installation of thermostatic radiator valves	26	-249	131	0.01
Installation of programmable thermostats	68	-183	335	0.02
Installation of condensing central building gas boilers for space heating	35	-91	171	0.04
Roof insulation	90	-61	449	0.04
Basement insulation	58	-54	290	0.05
Individual metering of consumed district and central heat	51	-1	263	0.06
Window exchange	399	-21	1987	0.05
Installation of condensing central gas dwelling boilers for space heating	169	86	837	0.07

Potential available through application of options installed separately, 2025

Mitigation measure	CO_2 savings	Costs of mitigated CO_2	Energy savings	Costs of energy savings
	Thousands tonnes CO_2/yr.	EUR/tCO_2	GWh/yr.	EUR/kWh
Old single-family houses (constructed before 1992)				
Installation of programmable thermostats	255	-213	1261	0.01
Roof insulation	1172	-60	5173	0.04
Wall insulation	1500	-56	6620	0.04
Basement insulation	757	-54	3340	0.04
Weather stripping of windows	4073	27	1447	0.30
Installation of pellets boilers for water and space central dwelling heating	1067	21	4709	0.06
Window exchange	528	54	1347	0.05
Installation of solar collectors for water heating backed up with pellet boilers for water and space central dwelling heating	4073	82	6348	0.13
Installation of condensing gas boiler for water and space central dwelling heating	1381	134	3206	0.08
Installation of pumps for water and space central dwelling heating	3093	110	14778	0.05
Buildings constructed after 2008				
Application of passive energy design	697	9	4651	0.05

Potential available through application of options installed separately, 2025 *cont.*

Mitigation measure	CO_2 savings	Costs of mitigated CO_2	Energy savings	Costs of energy savings
	Thousands tonnes CO_2/yr.	EUR/tCO_2	GWh/yr.	EUR/kWh
Appliances and lights				
Exchange of incandescent lamps with CFLs	305	-589	935	0.01
Reduction of electricity consumption by TV and PC-related equipment in low power and off - modes	266	-582	815	0.01
Efficient freezers	67	-391	206	0.07
Efficient refrigerators	107	-297	328	0.11
Efficient clothes washing machines	54	-275	167	0.11
Water heating				
Installation of water saving fixtures on dedicated water heating appliances and water heaters linked to boilers	263	-508	1231	0.00
Installation of water saving fixtures in households with central district hot water	400	-354	1942	0.00
Improved combi- space and water heating systems and dedicated water heating appliances	217	-28	420	0.14

Potential and costs of CO2 mitigation estimated with the supply curve method, 2025 *cont.*

Rank	Measure	CO_2 savings in 2025	Cost of mitigated CO_2	Energy savings in 2025	Investments 2008-2025	Saved energy costs
		1000t CO_2/yr.	EUR/tCO_2	GWh/yr.	Million EUR	Million EUR
1	Exchange of incandescent bulbs with CFLs	305	-589	935	73	551
2	Reduction of electricity consumption of TV and PC-related equipment in low power and off - modes	266	-582	815	20	391
3	Installation of water saving fixtures in households with district and central hot water	263	-508	1231	501	868
4	Efficient freezers	67	-391	206	239	245
5	Installation of water saving fixtures on dedicated water heating appliances and water heaters linked to boilers	400	-354	1942	78	1905
6	Efficient refrigerators	107	-297	328	103	1637
7	Efficient clothes washing machines	54	-275	167	126	2892
8	Installation of TRVs in households of traditional multi-residential buildings	26	-249	131	13	66
9	Installation of TRVs in households of buildings constructed using industrialized technology	89	-240	529	80	258
10	Installation of programmable thermostats old single-family houses (constructed before 1992)	255	-213	1261	204	654
11	Installation of programmable thermostats in households of traditional multi-residential buildings	68	-183	335	95	167

Potential and costs of CO2 mitigation estimated with the supply curve method, 2025 *cont.*

Rank	Measure	CO_2 savings in 2025	Cost of mitigated CO_2	Energy savings in 2025	Investments 2008-2025	Saved energy costs
		1000t CO_2/yr.	EUR/tCO_2	GWh/yr.	Million EUR	Million EUR
13	Installation of central building condensing gas boilers for space heating in households of traditional multi-residential buildings	31	-70	154	76	77
14	Roof insulation of old single-family houses (constructed before 1992)	1127	-51	4948	2858	2327
15	Window exchange in buildings constructed using industrialized technology	205	-47	1190	760	825
16	Roof insulation of traditional multi-residential buildings	83	-42	413	276	208
17	Improved combi- space and water heating systems and dedicated water heating appliances	217	-28	420	50	1536
18	Basement insulation of traditional multi-residential buildings	50	-16	248	166	125
19	Wall insulation of old single-family houses (constructed before 1992)	1160	-0.4	5092	3753	2394
20	Application of passive energy design to single-family and multi-residential buildings constructed from 2008	697	9	4651	3927	1841
21	Window exchange in traditional multi-residential buildings	326	38	1626	1448	818
22	Base insulation of old single-family houses (constructed before 1992)	439	80	1926	1905	905

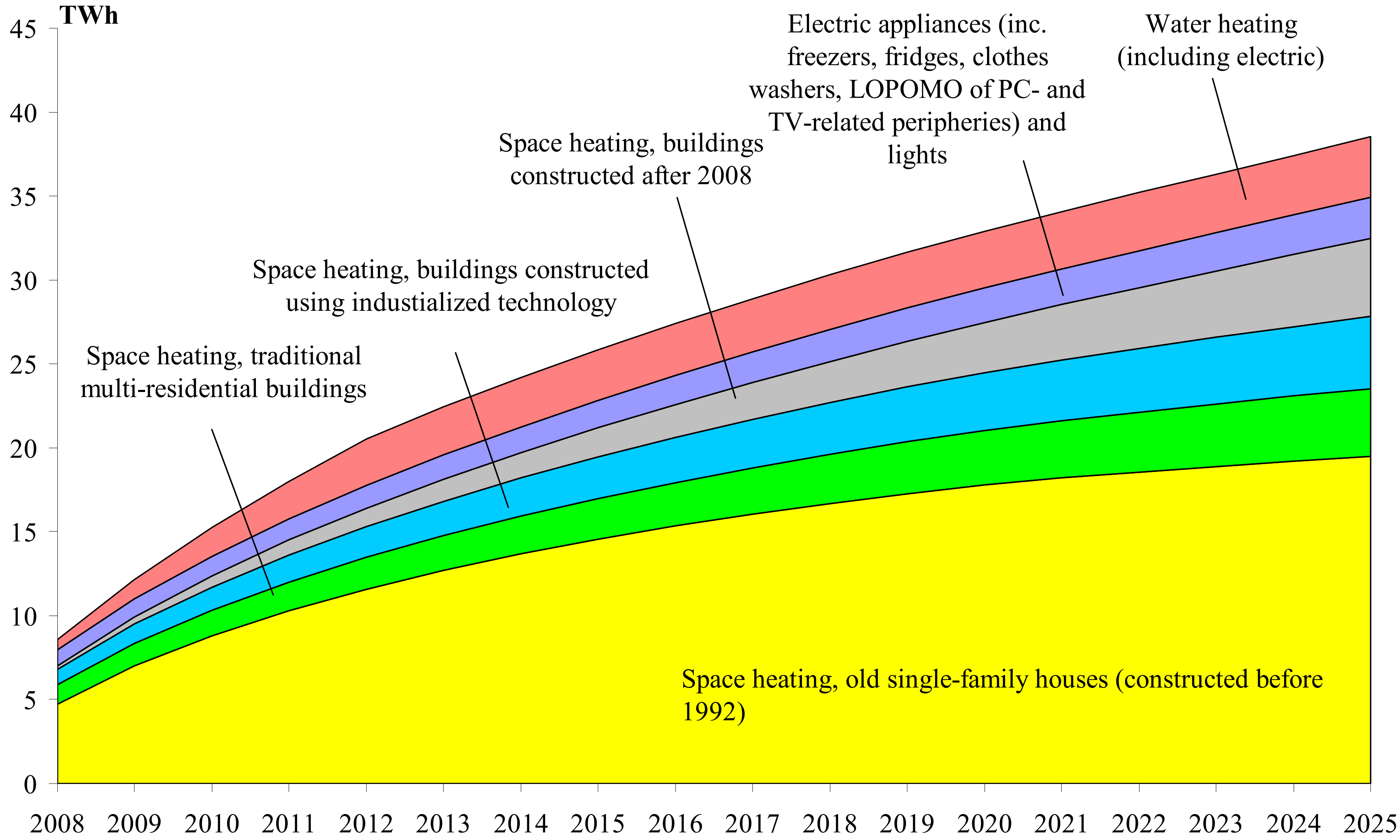
Potential and costs of CO2 mitigation estimated with the supply curve method, 2025 *cont.*

Rank	Measure	CO_2 savings in 2025	Cost of mitigated CO_2	Energy savings in 2025	Investments 2008-2025	Saved energy costs
		1000t CO_2/yr.	EUR/tCO_2	GWh/yr.	Million EUR	Million EUR
23	Installation of pellets boilers for central dwelling space heating and water heating in old single-family houses (constructed before 1992)	702	92	258	1336	574
24	Installation of pumps for central dwelling space heating and water heating in old single-family houses (constructed before 1992)	386	136	1877	1744	1531
25	Installation of central building condensing gas boilers for space heating of households in buildings constructed using industrialized technology	2	216	11	607	741
26	Installation of solar collectors backed-up with pellet boilers for central dwelling space heating and water heating in old single-family houses (constructed before 1992)	511	300	818	2488	600
27	Installation of condensing gas boilers for central dwelling space heating in old single-family houses (constructed before 1992)	359	467	773	2109	188
28	Individual metering of consumed district and central heat in households of traditional multi-residential buildings	17	558	90	169	59
29	Base insulation of buildings constructed using industrialized technology	8	743	43	131	20

Potential and costs of CO2 mitigation estimated with the supply curve method, 2025 *cont.*

Rank	Measure	CO_2 savings in 2025	Cost of mitigated CO_2	Energy savings in 2025	Investments 2008-2025	Saved energy costs
		1000t CO_2/yr.	EUR/tCO_2	GWh/yr.	Million EUR	Million EUR
30	Weather stripping of windows in old single-family houses (constructed before 1992)	64	746	419	1367	744
31	Installation of central dwelling condensing gas boilers for space heating in households of traditional multi-residential buildings	56	829	278	715	177
32	Roof insulation of buildings constructed using industrialized technology	15	897	85	340	40
33	Individual metering of district and central heat in households of buildings constructed using industrialized technology	65	1113	386	1062	284

Cumulative potential final energy savings, 2008 - 2025



Country/ region	Source	CO_2 mitigation potential as share of the baseline emission projections in cost categories (costs in USD/tCO_2)				Discount rate	Target year	Sectoral coverage
		<0	0-20	20-100	>100			
Hungary	Dissertation	29%	4%	8%	9%	6%	2025	Residential
		35%	3%	0.0%	6%	4%	2025	
		19%	3%	0.3%	11%	8%	2025	
Economies in transition	Levine et al. 2007	29%	12%	23%	n/a	Aggregated results of studies which used 3%-10%	2020	Residential & commercial
Developed countries		27%	3%	2%	n/a		2020	
Hungary	Szlavik *et al.* 1998	31%	9%	0%	5%	5%	2030	Residential & commercial
EU-15	Joosen and Blok 2001	11%	6%	2%	3%	4%	2010	Residential

References

Data sources

- Electric energy end-use
  - REMODECE 2007
  - The Status Report on Electricity Consumption and Efficiency Trends by Bertoldi and Atanasiu (2007)
  - The task reports of the Ecostandby project (Fraunhofer IZM 2007), and others.
- Thermal energy end-use
  - Numerous publications of the Hungarian Statistical Central Office
  - The task reports of the Ecohotwater project (Kemna et al. 2007), the EURIMA/ECOFYS report (Petersdorff et al. 2005)
  - Interviews with experts (Kovacsics pers.comm., Csoknyai pers. comm., and Sigmond pers. comm.), and other references.
- The database of efficiency and low carbon technologies is built based on:
  - Levine et al. (2007), Harvey (2006), IEA (2006);
  - Labelling and standardization programme reports (ADEME 2000; CECED 2001; SAVE 2001a, 2001b, 2002);
  - Equipment catalogues and pricelists (Danfoss 2007; Duplo-duplex 2007; Mega-öko Kazánfejlesztő-gyártó Kft. 2007; Megatherm 2007; ORIS Consulting 2007; Saunier Duval 2007; Szalontai and Sonnencraft 2007);
  - Reports, market reviews, and presentations of production associations and consultancies (Adam 2007; Trnka 2004; DBO 2007; EHPA 2007; Weiss et al. 2007);
  - Interviews (Kovacsics pers.comm; Csoknyai pers. comm.; Sigmond pers. comm.; Hermelink 2005; Kocsis and Beleczki email comm.).

References

- Adalberth, K. 1997. Energy use during the life cycle of single-unit dwellings: Examples. *Building and Environment* 32 (4): 321-329.
- Adam, B. 2007. The spreading of geothermal heat pump systems in Hungary. Presentation made at the EHPA (European Heat Pump Association) Heat Pump Conference, May 4, Paris, France.
- Accelerated Penetration of Small-Scale Biomass and Solar Technologies (ACCESS). 2007. Maps and databases on the biomass potential. Bulgaria, Czech Republic, Hungary, Romania, Slovakia, and Greece. URL: http://www.access-ret.net/info/deliverables.htm [Consulted 8 June 2008]
- ________. 2008. Report on the perspectives to the development of the biomass potential. Bulgaria, Czech Republic, Hungary, Romania, Slovakia. URL: http://www.access-ret.net/info/deliverables.htm [Consulted 8 June 2008].
- Agence de l'environnement et de la maîtrise de l'énergie (ADEME). 2000. *COLD II. The revision of energy labelling and minimum energy efficiency standards for domestic refrigeration appliances.* ADEME: France.
- Almeida, M. A., Schaeffer, R. and La Rovere E. L. 2001. The potential for electricity conservation and peak load reduction in the residential sector of Brazil. *Energy* 26 (4): 413–429.
- Asian Development Bank (ADB). 1998. Least-cost greenhouse gas abatement strategy. Series of country studies. Asian Development Bank: Manilla, Philippines
- Aunan, K. H., Asbjørn, A. and Seip, H., M. 2000. Reduced damage to health and environment from energy saving in Hungary. Assessing the ancillary benefits and costs of greenhouse gas mitigation strategies. Paper presented at the Workshop of the Intergovernmental Panel on Climate Change “Ancillary benefits and costs of greenhouse gas mitigation”, 27 – 29 March, OECD, Paris.

References

- Ball, M. 2005. *RICS (Royal Institution of Chartered Surveyors) European Housing Review 2005*. Turners: RICS Policy Unit.
- Barker, T., Bashmakov, I., Alharthi, A., Amann, M., Cifuentes, L., Drexhage, J., Duan, M., Edenhofer, O., Flannery, N., Grubb, M., Hoogwijk, M., Ibitoye, F.I., Jepma, C., J., Pizer, W. A., and Yamaji, K. 2007: Mitigation from a cross-sectoral perspective. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Ed. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Barta, J. 2006. Pasivní domy [Passive houses]. Presentation made at the Energy Efficiency Business Week, 7-11November, Prague, the Czech Republic.
- Baumann, M., Csoknyai, T., Kalmár, F. Magyar, Z., Majoros, A., Osztroluczky, M., Szalay, Zh., and Zöld, A. 2006. *Az új épületenergetikai szabályozás. Segédlet.* [The new regulation of energetics in buildings. Appendix]. Budapest: Budapest University of Technology and Economics.
- Bauland, 2007. Information from the URL: http://www.bauland.hu/ [Consulted 15 November 2007].
- Bertoldi, P. 2005. The latest energy efficiency policy developments in the European Union. Presentation made at the TAIEX – JRC workshop on Scientific Technical Reference System on Renewable Energy and Use Efficiency "Energy Efficiency potential in buildings, barriers and ways to finance projects in New Member States and Candidate Countries", July 6-8, Tallinn, Estonia.
- Bertoldi, P. and Atanasiu, B. 2007. *Electricity consumption and efficiency trends in the enlarged European Union. Status report 2006.* European Commission DG-JRC, Renewable Energies Unit.

References

- Bertoldi, P. and Atanasiu, B. 2006. Residential lighting consumption and saving potential in the enlarged EU. In *Proceedings of the International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL) 2006*. 21 - 23 June, London.
- Blesl, M., Das, A., Fahl, U. and Remme, U. 2007. Role of energy efficiency standards in reducing CO2 emissions in Germany: An assessment with TIMES. *Energy Policy* 35 (2): 772 - 785.
- Boardman, B., Darby, S., Killip, G., Hinnells, M., Jardine, Ch. N., Palmer, J. and Sinden, G. 2005. *40% house*. Oxford: Environmental Change Institute, University of Oxford.
- Boulanger, P-M. and Bréchet, T. 2005. Models for policy-making in sustainable development: The state of the art and perspectives for research. *Ecological Economics* 55 (3): 337-350.
- Butson, J. 1998. The potential for energy service companies in the European Union. Amsterdam. In Levine *et al*. 2007.
- Capgemini, 2006. Industry Insight: Europe 'faces clash of philosophies'. *Fuel for thought. A newsletter from Capgemini for the Utilities industry,* Fourth quarter. URL: http://capgemini.emailreaction.net/go.asp?/.newsletter.france.fuelext.2006q4.industry/bCGE001/uI5I95/x18ZM6 [Consulted 8 June 2008].
- Capros, P., Georgakopoulos, T., Filippoupolitis, A., Kotsomiti, S., and Atsaves G. 1997. *The GEM-E3 model: Reference Manual.* National Technical University of Athens.
- Capros, P., Kouvaritakis, N. and Mantzos, L. 2001. *Economic evaluation of sectoral emission reduction objectives for climate change. Top-down analysis of greenhouse gas emission reduction possibilities in the EU. Final Report*. National Technical University of Athens.
- Capros, P., Mantzos, L., Papandreou, V., and Tasios, N. 2007. *European energy and transport - trends to 2030. Update 2007.* European Commission, Directorate-General for Energy and Transport. Luxemburg: Office for Official Publications of the European Communities.

References

- Commission of the European Communities. 2006. *Communication from the European Commission. Action Plan for Energy Efficiency: Realising the Potential*. Brussels.
- Csoknyai, T. 2004. *Iparosított technológiával létesített lakóépületek energiatudatos felújítása.* [Energy conscious retrofit of residential buildings made with industrialised technology] PhD dissertation. Budapest University of Technology and Economics, Department of Building Energetics and Building Services, Budapest.
- Csoknyai, T. 2005. Fokozott hőszigetelésű épület fűtési kérdései [Heating questions of highly insulated buildings]. In *Proceedings of the 4th International Conference Climate Change - Energy Awareness - Energy Efficiency*. 8-10 June, Visegrád.
- Csoknyai, Tamás Dr. Associate Professor, Budapest University of Technology and Economics. Personal and email communications. Budapest, August 2007 - May 2008.
- Consultation Forum. 2008. Working document on possible ecodesign requirements for general lighting equipment. Annex 2. The 7th Meeting of the Forum, 27-29 May 2008. URL: http://ec.europa.eu/energy/demand/legislation/eco_design_en.htm [Consulted 5 June 2008].
- Danfoss, 2007. Catalogue of thermostat radiator valves. Phone communication. Budapest, 15 June 2007.
- De Villers, M. and Matibe, K. 2000. *Greenhouse gas baseline and mitigation options for the residential sector*. Cape Town: Energy and Development Research Centre, University of Cape Town.
- De Villiers, M. 2000. *Greenhouse gas baseline and mitigation options for the commercial sector*. *South African country study*. Pretoria: Department of Environmental Affairs and Tourism.
- Directorate-General for Research Energy, European Commission. 2003. *World energy, technology and climate policy outlook 2030*. Luxembourg: Office for Official Publications of the European Communities.

References

- DBO. 2007. New business opportunities for New Europe. Pellet burners market review. URL: http://www.dbo.hu/pellet_en.html [Consulted 9 June 2007].
- Duplo-duplex. 2007. Fűtési Energia Megtakarítás (Heating Energy Savings). URL: http://www.hohangszigeteles.hu/ [Consulted 15 June 2007].
- Ecuadorian Foundation for Energy and Environment (FEDEMA). 1999. *Economics of GHG limitations. Country study series. Ecuador.* Denmark, Riso: UNEP Collaborating Centre for Energy and Environment, Riso National Laboratory.
- European Heat Pump Association (EHPA). 2007. Heating costs - Heat pump beats oil and gas: URL: http://ehpa.fiz-karlsruhe.de/en/aktuell/kat1/akt239.html [Consulted 10 July 2007].
- EUROACE. 2005. *Energy efficiency in high-rise refurbishment. Case study series: Budapest, Hungary*. OECD/IEA, EuroACE.
- Union of the Electricity Industry (EURELECTRIC). 2004. *Electricity for more efficiency: electric technologies and their energy savings potential.* Brussels: EURELECTRIC.
- EURECO. 2002. *Demand-side management: end-use metering campaign in 400 households of the European Community –assessment of the potential electricity savings*. Project commissioned by the Commission of the European Communities.
- EUROSTAT. 2007. EUROSTAT population forecast. URL: http://epp.eurostat.ec.europa.eu/ [Consulted 20 January 2007].
- EUROSTAT. 2008. Electricity and natural gas price dynamics. URL: http://epp.eurostat.ec.europa.eu/ [Consulted 5 June 2008].
- European Committee of Domestic European Manufactures (CECED). 2001. Energy consumption of domestic appliances in European households. URL: www.ceced.org/ [Consulted 15 May 2007].

References

- European Central Bank. 2008. Online statistics. URL: www.ecb.int/ [Consulted 16 August 2007].
- European Commission. 2003. Proposal for a Directive of the European Parliament and of the Council on energy end-use efficiency and energy services. In Levine *et al*. 2007.
- European Commission. 2005. *Green paper on energy efficiency. Doing more with less.* Luxembourg: Office for Official Publications of the European Communities.
- Fraunhofer IZM. 2007. *Standby and Off-mode losses. Reports 1-6.* Berlin: Fraunhofer IZM . URL: http://www.ecostandby.org/ [Consulted 20 April 2007].
- FŐTÁV. 2007. Call centre FŐTÁV. Phone communication, Budapest, December 13, 2007.
- GFK. 2004. Report leaflet.
- Gazdasági és Közlekedési Minisztérium Magyarország Nemzeti (GKM). 2008. *Energiahatékonysági cselekvési terve (a kormány 2008 február 13-án elfogadta)* [Hungary's national energy efficiency action plan (approved by the Government on 13 February 2008)].
- Gazdasági és Közlekedési Minisztérium Magyarország Nemzeti, Környezetvédelmi és Vízügyi Minisztérium (GKM & KVVM). 2007. National Allocation Plan of the Republic of Hungary for the Period 2008 – 2012.
- Government of the Republic of Hungary. 2006. *Convergence Programme of Hungary 2006-2010*. Budapest.
- Gőrös, Z. 2005. Biomass utilization and potential in Hungary. Presentation made at the Conference "Biomass – Energy from Agriculture", Nyitra, Slovakia. In ACCESS 2007.
- Halsnaen, K., Callaway, L. and Meyers, H. J. 1999. *Economics of GHG limitations. Main Report. Methodological guidelines.* Risoe, Denmark: UNEP Collaborating Centre for Energy and Environment, Riso National Laboratory.

References

- Halsnæs, K., Shukla, P., Ahuja, D., Akumu, G., Beale, R., Edmonds, J., Gollier, C., Grübler, A., Ha Duong, M., Markandya, A., McFarland, M., Nikitina, E., Sugiyama, T., Villavicencio, A., and Zou, J. 2007: Framing issues. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Ed. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Harvey, L.D.D. 2006. *A Handbook on Low-Energy Buildings and District Energy Systems: Fundamentals, Techniques, and Examples*. London: James and James.
- Hermelink, A. 2005. Retrofit of residential panel buildings - the SOLANOVA adventure. In *Proceedings of Common Symposium of EU FP6 Eco-building Projects*. 22 – 23 November, Berlin.
- Hermelink, Andreas Dr. SOLANOVA project manager. Email correspondence, 1 June 2007.
- Hungarian Energy Office. 2007a. Authority controlled natural gas average prices in Hungary as of 22 Oct 2007. URL: http://www.eh.gov.hu/home/html/index.asp?msid=1&sid=0&lng=2&hkl=530 [Consulted 15 December 2007].
- Hungarian Energy Office. 2007b. Unit costs modified with heating technology efficiency as of August 2006. URL: http://www.eh.gov.hu/home/html/index.asp?msid=1&sid=0&lng=2&hkl=534 [Consulted 15 December 2007].
- Hungarian Energy Office. 2007c. Regulated wholesale and end-user tariffs for electricity in Hungary, as of 1st Feb 2007. URL: http://www.eh.gov.hu/home/html/index.asp?msid=1&sid=0&lng=2&hkl=217http://www.eh.gov.hu/ [Consulted 15 December 2007].
- Hungarian Central Bank. 2007. Statistical Time Series (as of August 2007). URL: http://english.mnb.hu/engine.aspx?page=mnben_statisztikai_idosorok [Consulted 16 August 2007].

References

- Hungarian Ministry of Environment and Water. 2007. Inventory 2005. Submission 2007 v1.1. Hungary. URL: http://www.unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php [Consulted 17 May 2007].
- International Energy Agency (IEA). 2004. *Electricity information*. CD-ROM. Paris: IEA.
- ________. 2006a. *Energy Balances of OECD countries*. Paris: IEA.
- ________. 2006b. *Light's labour costs. Policies for energy-efficient lighting. In support of the G-Plan of Action*. Paris: OECD/IEA.
- ________. 2006c. World Energy Outlook 2006. Paris: OECD/IEA.
- ________. 2007. *Energy Balances of OECD countries*. Paris: IEA.
- ________. 2007. *Energy Statistics of OECD countries*. Paris: IEA.
- ________. 2005. *Energy statistics manual*. Luxembourg: OECD/IEA.
- Jeeninga, H., Weber, C., Mäenpää, I., García, F.R., Wiltshire, V. and Wade, J. 1999. Employment impacts of energy conservation schemes in the residential sector. Calculation of direct and indirect employment effects using a dedicated input/output simulation approach. In Levine *et al*. 2007
- Joosen, S. and Blok, K. 2001. *Economic evaluation of sectoral emission reduction objectives for climate change. Economic evaluation of CO2 emission reduction in the household and services sectors in the EU. Bottom-up Analysis.* European Commissions by Ecofys.
- Johnston, D., Lowe, R. and Bell, M. 2005: An exploration of the technical feasibility of achieving CO2 emission reductions in excess of 60% within the UK housing stock by the year 2050. *Energy Policy* 33 (13): 1643 - 1659.
- Inter-departmental Analysts Group (IAG). 2002. Long-term Reduction in Greenhouse Gas Emissions in the UK. URL: www.berr.gov.uk/files/file38187.pdf [Consulted 15 February 2007].

References

- Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Kallaste, T., Pallo, T., Esop, M.-P., Liik, O., Valdma, M., Landsberg, M., Ots, A., Selg, A. Purin, A., Martins, A., Roos, I., Kull, A. and Rost, R. 1999. *Economics of greenhouse gas limitations. Country case study. Estonia*. Riso, Denmark: UNEP Collaborating Centre for Energy and Environment, Riso National Laboratory.
- Kemna, R., van Elburg, M., Li, W. and van Holsteijn, R. 2007. *Eco-design of water heaters. Draft reports of tasks 1-5.* VNK: Delft.
- Kocsis, Frigyes and Beleczki, Atilla. Bauland Kft. E-mail correspondence, 5 December 2007.
- Kovacsics, Istvan. Head of the Unit, EGI Contracting Engineering Co. Ltd. Personal communications on January 6, 2007 and July 26, 2007.
- Krause, F. 2000. The economics of cutting carbon emissions in the power sector: a review and methodological comparison of two European studies. Paper prepared for The IEA International Workshop on Technologies to Reduce Greenhouse Gas Emissions: Engineering-Economic Analysis of Conserved Energy and Carbon. 5-9 1999, Washington, D. C., USA. Revised version, January 2000.
- Koomey, Jonathan Dr. Consulting Professor, University of Stanford and Staff Scientist, Lawrence Berkeley National Laboratory. Personal and email communications. Berkeley, USA, April – July 2007.
- Koomey, J. Turning Numbers into Knowledge: Mastering the Art of Problem Solving. 2nd edition. Oakland, USA: Analytics Press.
- Koomey, J. G., Vorsatz, D., Brown, R. E. and Atkinson, C. S. 1996. *Update potential for electricity improvement in the U.S. residential sector*. Berkeley, CA: Lawrence Berkeley National Laboratory.

References

- Koomey, J.G., Webber, C.A., Atkinson, C.S. and Nicholls, A. 2001. Addressing energy-related challenges for the U.S. buildings sector: Results from the Clean Energy Futures Study. *Energy Policy* 29 (14): 1209 - 1222.
- Központi Statistikai Hivatal (KSH). 2004. *Household Statistics Yearbook 2004*. Budapest: KSH.
- ________. 2005. *Housing conditions at the turn of the century*. Budapest: KSH.
- ________. 2006a. *Statistical Yearbook of Hungary 2005*. Budapest: KSH
- ________. 2006b. *Yearbook of housing statistics 2005*. Budapest: KSH.
- ________. 2006c. *Electricity consumption of households*. Budapest: KSH.
- ________. 1998. Háztartások energiafogyasztása. [Household energy consumption]. Budapest: KSH.
- Környezetvédelmi és Vízügyi Minisztérium (KVVM). 2008. *A Nemzeti Éghajlatváltozási Stratégia 2008 – 2025* [National Climate Strategy for 2008 – 2025].
- Laitner, J.A., Worrel, E., Galitsky, C. and Hanson, D. A. 2003. Characterizing emerging industrial technologies in energy models. In *2003 ACEEE (American Council for an Energy Efficient Economy) Summer Study on Energy Efficiency in Industry.*
- Laponche, B., Jamet, B., Colombier, M. and S. Attali. 1997. *Energy efficiency for a sustainable world*. Paris : International Conseil Energie.
- Lechtenböhmer, S. and Thomas, S. 2003. Efficient appliances as keystone strategy in long-term energy policies – a policy oriented scenario approach system. *In Proceedings of the 3rd International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL)*, 1-3 October, Turin, Italy.
- Lechtenböhmer, S., Grimm, V., Mitze, D., Thomas, S. and Wissner, M. 2005. *Target 2020: Policies and measures to reduce greenhouse gas emissions in the EU*. Wuppertal: WWF European Policy Office.

References

- Lee, J.C., and Linky, E.J. 1999. MARKO_MARKAL – an integrated approach for evaluating clean development mechanism projects: the case of Taiwan. In *Proceedings of the IEA International Workshop on Technologies to Reduce GHG Emissions*, May 1999, Washington, D.C., USA.
- Levine, M., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G., Mongameli Mehlwana, A., Mirasgedis, S., Novikova, A., Rilling, J. and Yoshino, H. 2007. Residential and commercial buildings. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Ed. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Lovins, A. B., Lovins L. H., Krause F. and Bach, W. 1989. *Least-cost energy: solving the CO2 problem.* Andover, Mass.: Brick House.
- Matolcsy, K., Tiderenczl, G. and P. Matiasovsky, 2005. *NAS state of the art report on performance based building*. The Netherlands: CIB (PeBBu).
- MAVIR, 2005. *A villamosenergia-rendszer közép- és hosszú távú forrásoldali kapacitásterve* [Medium and long term capacity plan for the demand side of the electricity system].
- McFarland, J.R., Reilly, J., and Herzog, H.J. 2002. *Representing energy technologies in top-down economic models using bottom-up information.* MIT Joint Program on the Science and Policy of Global Change: MIT.
- Mega-öko Kazánfejlesztő-gyártó Kft. 2007. Production catalogue of central dwelling boilers. URL: http://www.tuzelestechnika.hu/megaoko/talalatangol.htm [Consulted 15 June 2007].
- Megatherm. 2007. Catalogues of thermostat radiator valves and communication by phone. URL: http://www.megatherm.hu/ [Consulted 15 June 2005].
- Meier, Alan Dr. Senior Scientist, Lawrence Berkeley National Laboratory. Personal communication. Berkeley, USA, March 2007.

References

- Meier, A., Wright, J. and Rosenfeld, A.H. 1983. *Supplying energy through greater efficiency. The potential for conservation in California's residential sector*. Berkeley, Los Angeles, London: University of California Press.
- Meli, L. 2004. Domestic appliances energy efficiency potential. Manufacturers' view. Presentation at the International Workshop "Electricity end-use efficiency in buildings and energy services in New Member States and Candidate Countries", 9-10 December, Brussels.
- MEEPH – Monitoring. 2007. An informative website on the Boiler Efficiency Directive 92/42/EEC [May 1992]. URL: http://www.boilerinfo.org/site.htm [Consulted 24 March 2007].
- Mirasgedis, S., Georgopoulou, E., Sarafidis, Y., Balaras, C., Gaglia, A., and Lalas, D.P. 2004. CO2 emission reduction policies in the Greek residential sector: a methodological framework for their economic evaluation. *Energy Conservation and Management* 45: 537-557.
- Mirasgedis, S., Makatsoris, J., Assimacopoulos, D. Papagiannakis, L. and Zervos, A. 1996. Energy conservation and CO2-emission abatement potential in the Greek residential services sector. *Energy* 21 (10): 871 – 878.
- Mirasgedis, Sebastianos Dr. Senior Researcher, the Institute for Environmental Research and Sustainable Development of the National Observatory of Athens. Personal and email communications and consultations. May 2006 – May 2007.
- Moezzi, M. and Diamond, R. 2005. Is efficiency enough? Towards a new framework for carbon savings in the California residential sector. Prepared for Public Interest Energy Research Program, California Energy Commission.
- Nagy, P. 2007. Building thermal modernization. Nyiregyhaza. URL: http://www.ruse-europe.org/IMG/pdf/Nyiregyhaza_Hungary_HU__en.pdf [Consulted 15 November 2007].
- NEMESIS. 2006. Online information about the project on NEMESIS model development. URL: http://www.nemesis-model.net/about/nemesis.stm [Consulted 15 November 2006].

References

- ODYSSEE NMC. 2007. Energy Efficiency Indicators In New EU Member countries. Database. Available on on the request from the Hungarian Ministry of Environment and Water.
- Öhliher, Ch. 2006. 50,000 Energy performance certificates for buildings. Presentation delivered at the European Energy Efficiency Conference, 1-3 March, Wels, Austria.
- ORIS Consulting, 2007. Online catalogue of low-flow fixtures. URL: http://cseppetsem.com/arak.htm [Consulted 14 June 2007].
- Reddy, B.S. and Balachandra, P. 2006. Dynamics of technology shift in the households sector - implications for clean development mechanism. *Energy Policy* 34 (16): 2586-2599.
- Petersdroff, C., T. Boermans, Joosen, S., Kolacz, I., Jakubowska, B., Scharte, M., Stobbe, O. amd Harnisch, J. 2005. *Cost effective Climate Protection in the Building Stock of the New EU Member States. Beyond the EU Energy performance of Buildings Directive.* Germany: ECOFYS.
- Price, L., De la Rue du Can, S., Sinton, J. and Worrell, E. 2006. *Sectoral Trends in Global Energy Use and GHG Emissions*. Berkeley, CA: Lawrence Berkeley National Laboratory.
- Ragwitz, M., Brakhage, A., Kranzl, L., Stadler, M., Huber, C., Haas, R., Tsioliaridou, E., Pett, J., Gürtler, P., Joergensen, K., Figorski, A., Gula, A., Gula, E., Sliz, B., and Wyrwa A. 2005. *Case studies. Final Report of Work Phase 6 of the project*. INVERT (Investing in renewable and energy rational technologies: Models for saving public money) research project within the Altener Program of the European Commission, DG TREN.
- Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE). 2007. Preliminary research results available from the Central European University.
- Rufo, M. 2003. *Attachment V – Developing Greenhouse Mitigation Supply Curves for In-State Sources, Climate Change Research Development and Demonstration Plan*. For the California Energy Commission, Public Interest Energy Research Program.

References

- Rufo, M. and F. Coito. 2002. *California's Secret Energy Surplus: The Potential For Energy Efficiency. Final Report.* Prepared for The Energy Foundation and The Hewlett Foundation. Prepared by XENERGY Inc. California: Energy Foundation.
- SAVE. 2001a. *Study on water heating - labelling / standards. The foundation for the policy to be followed in creating an energy use information system for domestic hot water appliances*. The Netherlands: NOVEM.
- SAVE. 2001b. *Revision of energy labeling and targets washing machines (clothes)*. The Netherlands: NOVEM.
- SAVE. 2002. SAVE II. *Labelling and other measures for heating systems in dwellings. Appendix 4 - Stock model of residential heating systems*. The Netherlands: VNK.
- Sathaye, J. and Meyers, S. 1995. *Greenhouse gas mitigation assessment: a guidebook.* The Netherlands: Kluwer Academic Publishers.
- Sathaye, J. 2007. Bottom-up modeling of energy and greenhouse gas emissions: approaches, results, and challenges to inclusion of end-use technologies. In *Human-Induced Climate Change* Ed. Schlesinger, M. E., Kheshgi, H. S., Smith, J., de la Chesnaye, F. C., Reilly, J. M., Wilson, T., and Kolstad, Ch. Cambridge University Press.
- Sanchez, M. C., Koomey, J. G., Moezzi, M. M., Meier, A. and Huber, W. Miscellaneous electricity in US homes: Historical decomposition and future trends. *Energy Policy* 26 (8): 585-593.
- Saunier Duval. 2007. Price list 2006/2.2. URL: www.aktivkft.hu/letoltesek/Arlistak/saunier_duwal_arlista_2006.pdf [Consulted 11 June 2007].
- Schild, R. 2006. Renewable energies in domestic heating and cooling systems. Presentation delivered at the Sustainable Energy Forum, 24 April, Amsterdam.

References

- 'Sigmond, György Dr. Board Member, COGEN Hungary Association and Chief Counsellor, Association of Hungarian District Heating Enterprises (MaTáSzSz). Personal interview, Budapest, 17 August 2007.
- Siller, T., Kost, M. and Imboden, D. 2007. Long-term energy savings and greenhouse gas emission reductions in the Swiss residential sector. *Energy Policy* 35 (1): 529-539.
- Slek, B. 2004. Energy efficient lighting potential in Central and Eastern Europe manufacturers' views. Presentation delivered at the International Workshop "Electricity end-use efficiency in buildings and energy services in New Member States and Candidate Countries", 9-10 December, Brussels.
- Szalontai and Sonnencraft. 2007. Price list of space and water systems. URL: http://www.szalontai.co.hu/ [Consulted 20 May 2007].
- Szalay, Zsuzsa Dr. Teaching Fellow, Budapest University of Technology and Economics. Personal and email communications. Budapest, February 2007 - March 2008.
- Szalay, Zh. *Life cycle environmental impacts of residential buildings*. PhD Dissertation. Budapest University of Technology and Economics, Department of Building Energetics and Building Services, Budapest.
- Szerdahelyi, György Dr. Ministry of Economy. Personal communication, Budapest, 2003. In: Ürge-Vorsatz *et al*. 2003.
- Szlavik, M., Palvolgyi, T., Ürge-Vorsatz, D. and Fule, M. 1999. *Economics of GHG Limitations. Country Case Study. Hungary*. Denmark, Riso: UNEP Collaborating Centre for Energy and Environment, Riso National Laboratory.
- SOLANOVA. 2007. Information about the project. URL: http://www.solanova.eu/ [Consulted 15 May 2007].
- Tol, R.S.J. 2000. Modelling the costs of emission reduction: different approaches. *Pacific and Asian Journal of Energy* 10 (1): 1-7.

References

- Trnka, L. 2004. *Pasivní dům - zkušenosti z Rakouska a české začátky* [Passive house – experience from Austria and Czech beginning]. Brno: Veronica.
- Thumann, A. and Mehta, P. D. 2001. *Handbook of energy engineering.* 5th ed. Lilburn: The Fairmont Press, Inc.
- Ürge-Vorsatz, D. and Novikova, A. 2008. Potentials and costs of carbon dioxide mitigation in the world's buildings. *Energy Policy* 36 (2): 642 - 661.
- Ürge-Vorsatz, D., Novikova, A. and Watt, A. 2007. Kyoto Flexibility Mechanisms in an enlarged EU: will they make a difference? *Climate Policy* 7: 179-196.
- Ürge-Vorsatz, D., Mez, L., Miladinova, G., Antypas, A., Bursik, M., Baniak, A., Janossy, J., Beranek, J., Nezamoutinova, D. and Drucker, G. 2003. The impact of structural changes in the energy sector of CEE countries on the creation of a sustainable energy path. Special focus on investment in environmentally friendly energy and the impact of such a sustainable energy path on employment and access conditions for low income consumers. Report commissioned by of the European Parliament. URL: http://web.ceu.hu/envsci/research/ep/index.htm [consulted 8 June 2008].
- Ürge-Vorsatz, Diana Dr. Professor and Director, Center for Sustainable Energy and Climate Mitigation Policy, Central European University. Personal and email communications and consultations, October 2006 – May 2008.
- UNEP Collaborating Centre on Energy and Environment (UNEP). 1998. *Mitigation and Adaptation Costs Assessment. Concepts, Methods and Appropriate Use*. Riso: UNEP Collaborating Centre on Energy and Environment.
- US Department of Energy (US DOE). 1996. *Polish Country Study to Address Climate Change. Strategies of the GHG's emission reductions and adaptation of the Polish economy to the changed climate.* Warsaw.

References

- Valentova, M. 2007. *Low power mode electricity consumption in Hungarian households: how big is the problem and what is the potential to mitigate it?* Master of Science thesis. Budapest: Central European University: Budapest.
- Várfalvi, J. and Zöld, A. 1994. Energiatudatos épületfelújitás. [Energy conscious building renovation]. Budapest: TERRANOVA.
- van Vuuren, D. 2008. Bottom-up and top-down: a bit of an introduction. Presentation delivered at the Workshop "Bottom-Up and Top-Down greenhouse gas emissions reduction potentials: a comparison". 27 March, Utrecht, the Netherlands.
- Vedantam, Sh. 2008. On Climate, Symbols Can Overshadow Substance. Lights-Out Event More Showy Than Practical. *The Washington Post* (Washington D.C.), May 17.
- Von Weizsäcker, E., Lovins, A.B. and Lovins, L. H. 1997. *Factor four: doubling wealth, halving resource use*. London: Earthscan Publications.
- Vorsatz, D. 1996. *Exploring U.S residential and commercial electricity conservation potentials : analysis of the lighting sector*. PhD dissertation. Los Angeles: University of California.
- Waide, P. 2006. High-rise refurbishment. The energy efficient upgrade of multi-story residences in the European Union. IEA information paper. Paris: OECD/IEA.
- Weiss, W., Bergmann, I. and Faninger, G. 2007. *Solar heat worldwide. Markets and contributions for the energy supply 2005*. Austria: AEE INTEC.
- World Business Council for Sustainable Development (WSCSD). 2007. *Facts and trends: Energy efficiency in buildings. Business realities and opportunities. Summary report.* Conches-Geneva, Washington, DC: WBCSD:

References

- Živkovi, B., Todorovi, M. and Vasiljevi, P. 2006. Energy savings for residential heating in two pairs of buildings achieved by implementation of actually consumed energy measuring. *Thermal Science* 10 (4): 79-88.
- Zöld, A. and Csoknyai, T. 2005. Refurbishment of blocks of flats. In *Proceedings of the 7th Symposium on Building Physics in the Nordic countries*. 13 -15 June, Reykjavík.
- Zöld, András, Professor, Budapest University of Technology and Economics. Personal communication. Budapest, February 2008.