Heat saving and district heating potentials for TIMES-DK

WholeSEM Annual Conference 2015

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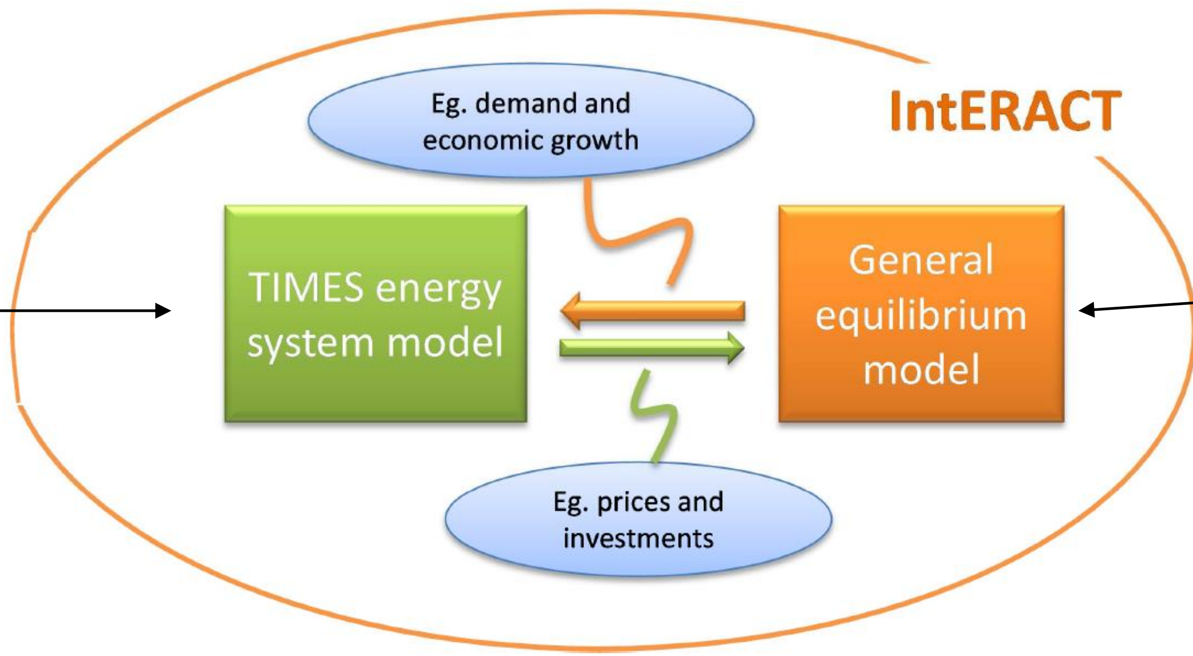

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Danish heat atlas as a support tool for energy system models

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A B S T R A C T

In the past four decades following the global oil crisis in 1973, Denmark has implemented remarkable changes in its energy sector, mainly due to the energy conservation measures on the demand side and the energy efficiency improvements on the supply side. Nowadays, the capital intensive infrastructure investments, such as the expansion of district heating networks and the introduction of significant heat saving measures require highly detailed decision-support tool. A Danish heat atlas provides highly detailed database with extensive information about more than 2.5 million buildings in Denmark. Energy system analysis tools incorporate environmental, economic, energy and engineering analysis of future energy systems and are considered crucial for the quantitative assessment of transitional scenarios towards future milestones, such as EU 2020 goals and Denmark's goal of achieving fossil free society after 2050. The present paper shows how a Danish heat atlas can be used for providing inputs to energy system models, especially related to the analysis of heat saving measures within building stock and expansion of district heating networks. As a result, marginal cost curves are created, approximated and prepared for the use in optimization energy system model. Moreover, it is concluded that heat atlas can contribute as a tool for data storage and visualisation of results.

1. Introduction

Before 1973, the time of first oil crises, Denmark was totally dependent on the imported oil, with oil making for 92% of the total primary energy consumption. Almost entire transportation sector and residential heating was oil-based, while share of oil in electricity production was 78%; the rest of electricity production was based on coal [1]. Sudden rise in oil prices forced Danish authorities to pursue different energy planning strategies than just building new production, transmission and distribution facilities and thus serving consumption that was increasing from year to year.

Denmark drastically changed appearance of its energy system during past decades – total primary energy supply remained unchanged while total energy used for heating buildings was reduced by 26%. In the same time period, total heated area grew up for more than 50% [2]. This is done by constantly improving energy efficiency and introducing energy saving measures. Wall [3] identified analogous strategy for designing energy systems as the proper direction towards sustainable society, while [4] found that energy conservation is crucial for reducing harmful environmental impacts. Energy efficiency was mainly affected by introducing large number of CHPs (Combined Heat and Power) in the system, technologies which are using waste heat from electricity production as a heating source for residential buildings or industrial processes. Energy savings in buildings were achieved by using materials with smaller heat conductivity in the buildings' envelopes. Along with reduction in the primary energy consumption and fighting the issue of resource depletion, energy savings and efficiency measures have decreased harmful environmental impact of energy systems. Also, use of oil for covering heat demand is reduced from more than 90% in 1972 to about 10% in 2011, thus improving security of energy supply and making complete energy system less prone to changes in oil prices.

The environmental impact of improved energy efficiency is even more evident when considering the current Danish heating system: 52% of the total net heat demand in Denmark is covered by district heating, of which 76% is produced in the CHPs [1]. One third of energy produced in CHP processes in 2007 was based on renewable energy [6] – this fact shows how the environmental impact is reduced by the use of CHPs and district heating technologies. Lund and Andersen [7] observed that CHP-based district heating is essential for implementation of climate change response objectives in many countries. Similarly, positive global environmental effects have been observed in [8]. In line with this, in 2008, Denmark, as one of EU members adopted long term targets in the area of renewable energy and energy efficiency: (1) 20% reduction in emission of greenhouse gasses by 2020 compared with 1990, (2) by 2020, 20% of final energy demand should be covered by renewable energy, such as wind, solar and geothermal

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Article

Model for Determining Geographical Distribution of Heat Saving Potentials in Danish Building Stock

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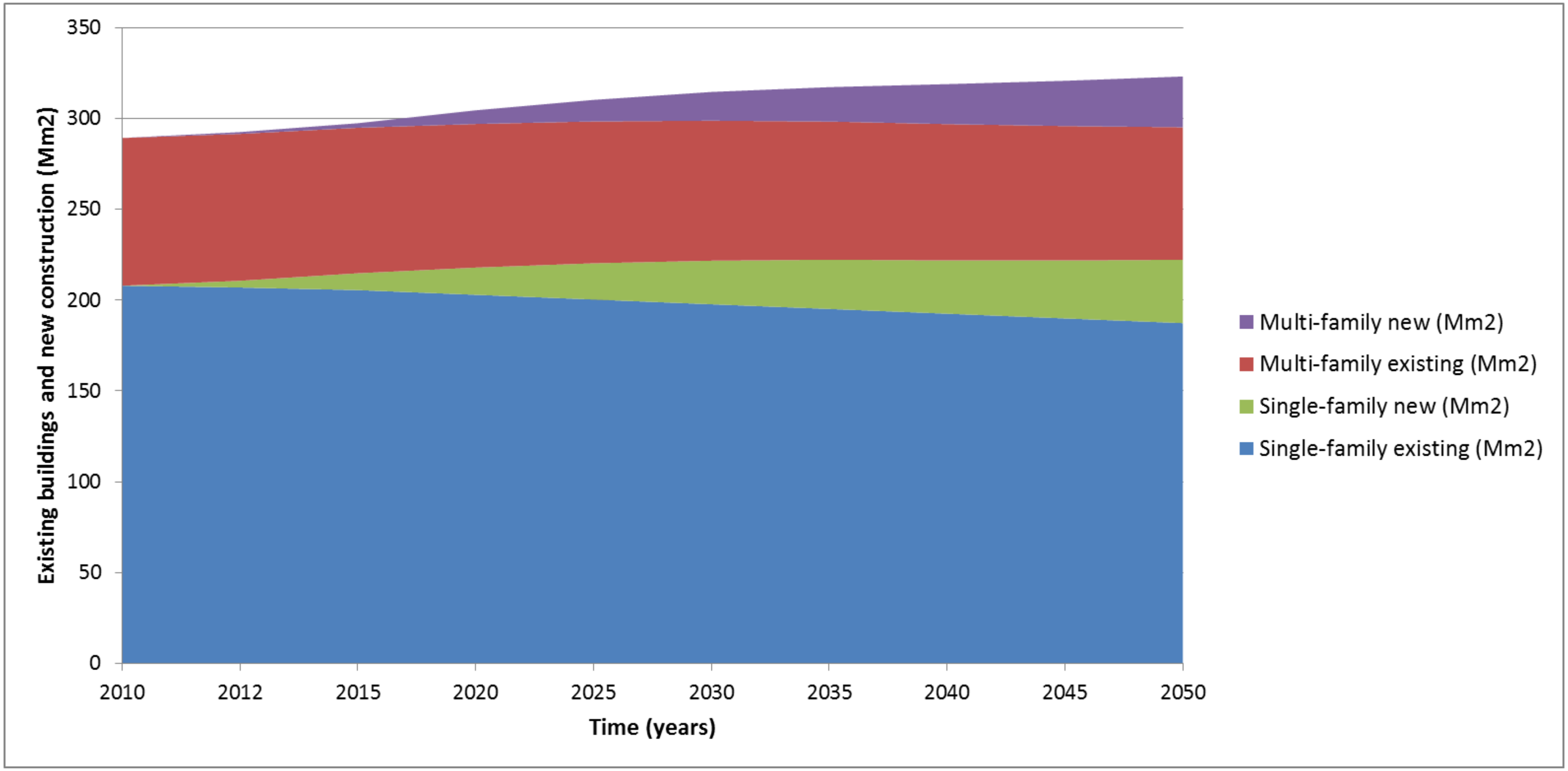
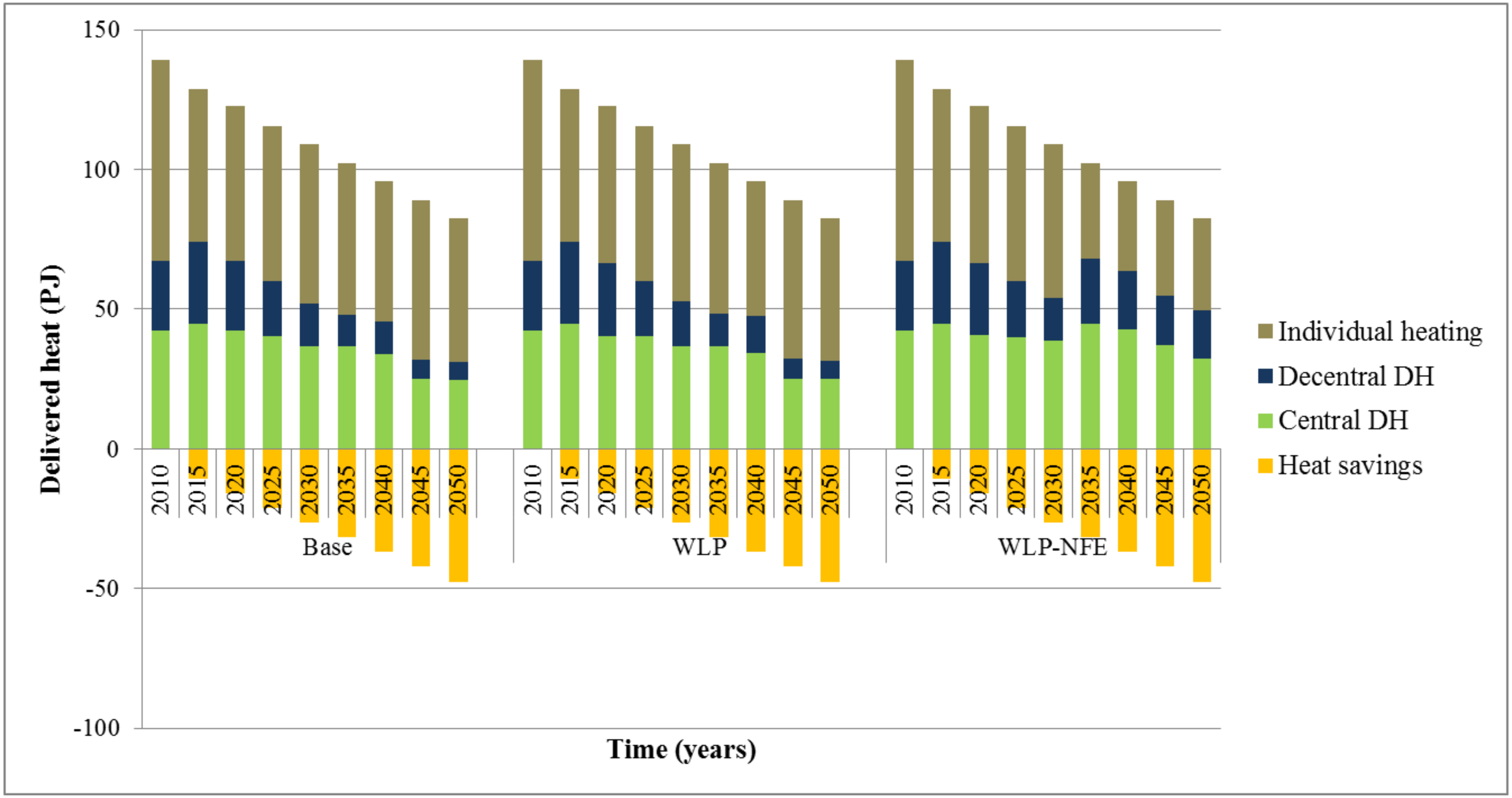
Abstract: Since the global oil crisis in the 1970s, Denmark has followed a path towards energy independency by continuously improving its energy efficiency and energy conservation. Energy efficiency was mainly tackled by introducing a high number of combined heat and power plants in the system, while energy conservation was predominantly approached by implementing heat saving measures. Today, with the goal of 100% renewable energy within the power and heat sector by the year 2035, reductions in energy demand for space heating and the preparation of domestic hot water remain at the top of the agenda in Denmark. A highly detailed model for determining heat demand, possible heat savings and associated costs in the Danish building stock is presented. Both scheduled and energy-saving renovations until year 2030 have been analyzed. The highly detailed GIS-based heat atlas for Denmark is used as a container for storing data about physical properties for 2.5 million buildings in Denmark. Consequently, the results of the analysis can be represented on a single building level. Under the assumption that buildings with the most profitable heat savings are renovated first, the consequences of heat savings for the economy and energy system have been quantified and geographically referenced. The possibilities for further improvements of the model and the application to other geographical regions have been discussed.

Keywords: heat demand; heat savings; GIS; energy conservation; heat atlas

Heat savings in existing buildings are important!



Heat savings are socio-economic feasible! District heating stays important!



How can this work benefit the energy system modelling community?

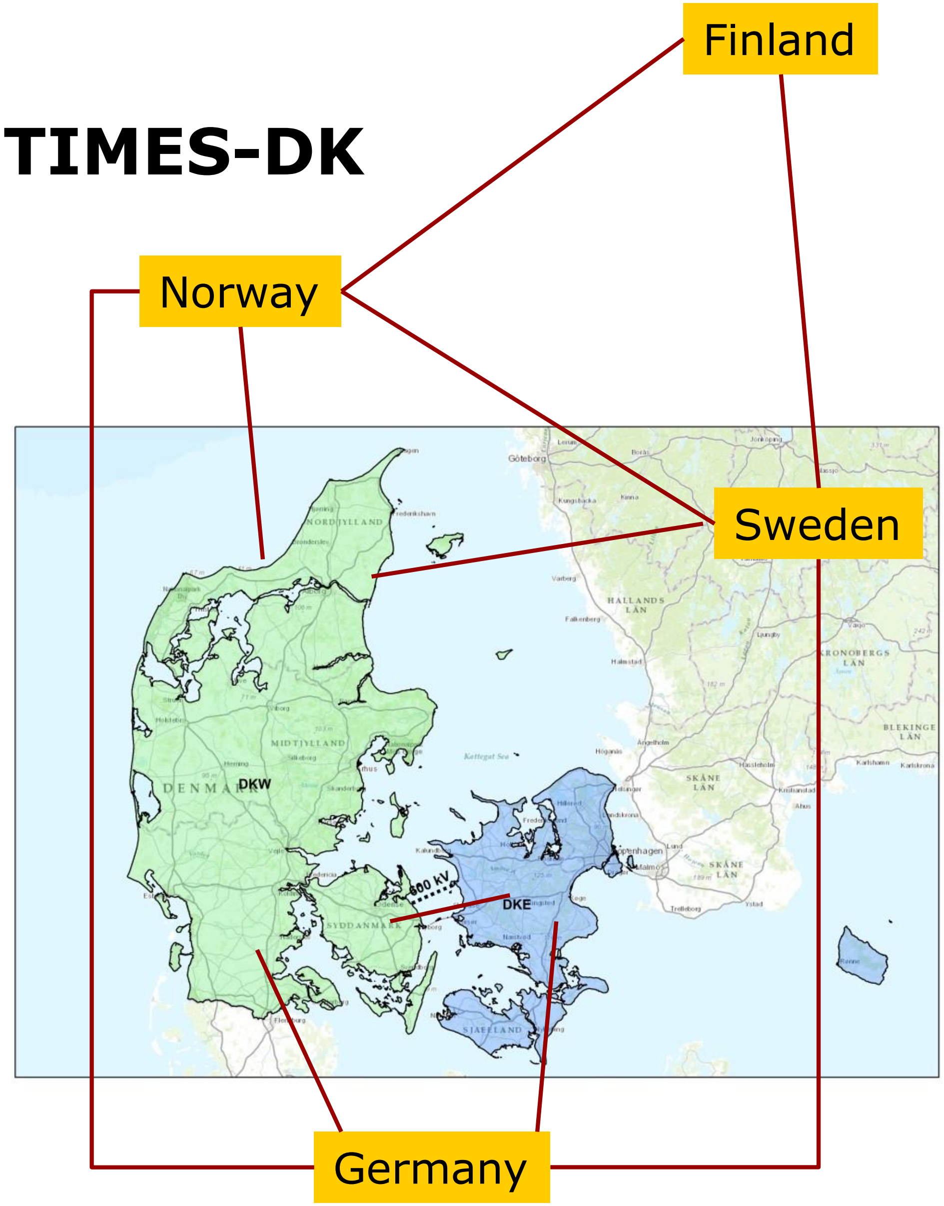
- General methodologies which can be adjusted to any region

- Open source and documented data-models and TIMES files

- It illustrates benefits from a close cooperation between research and authorities

- We are very interested in joining projects with others within this area

TIMES-DK



Two versions:

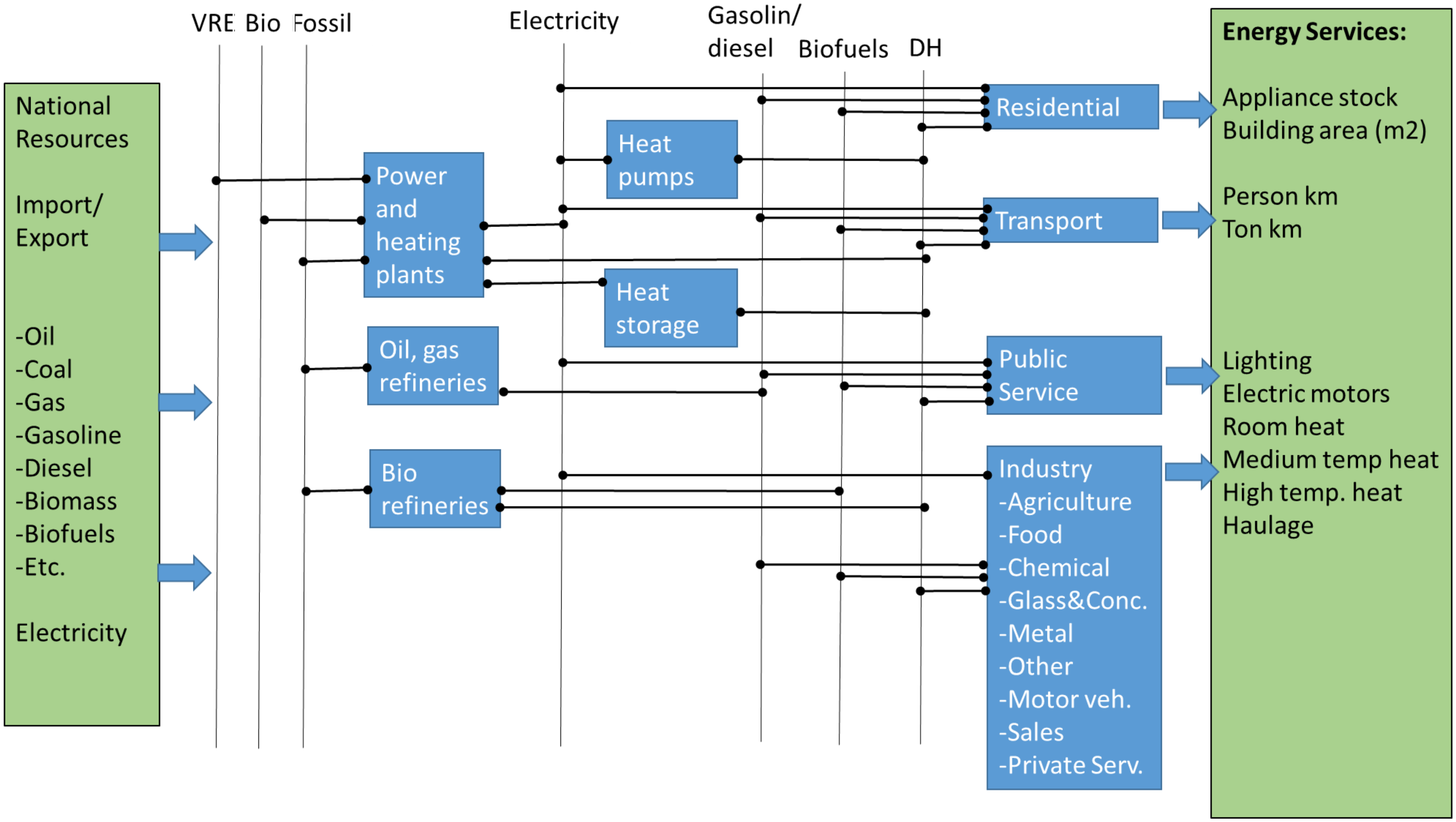
TIMES-DK stand-alone

All power trade are modelled with exogenous price profiles for each region (except DK East and DK West)

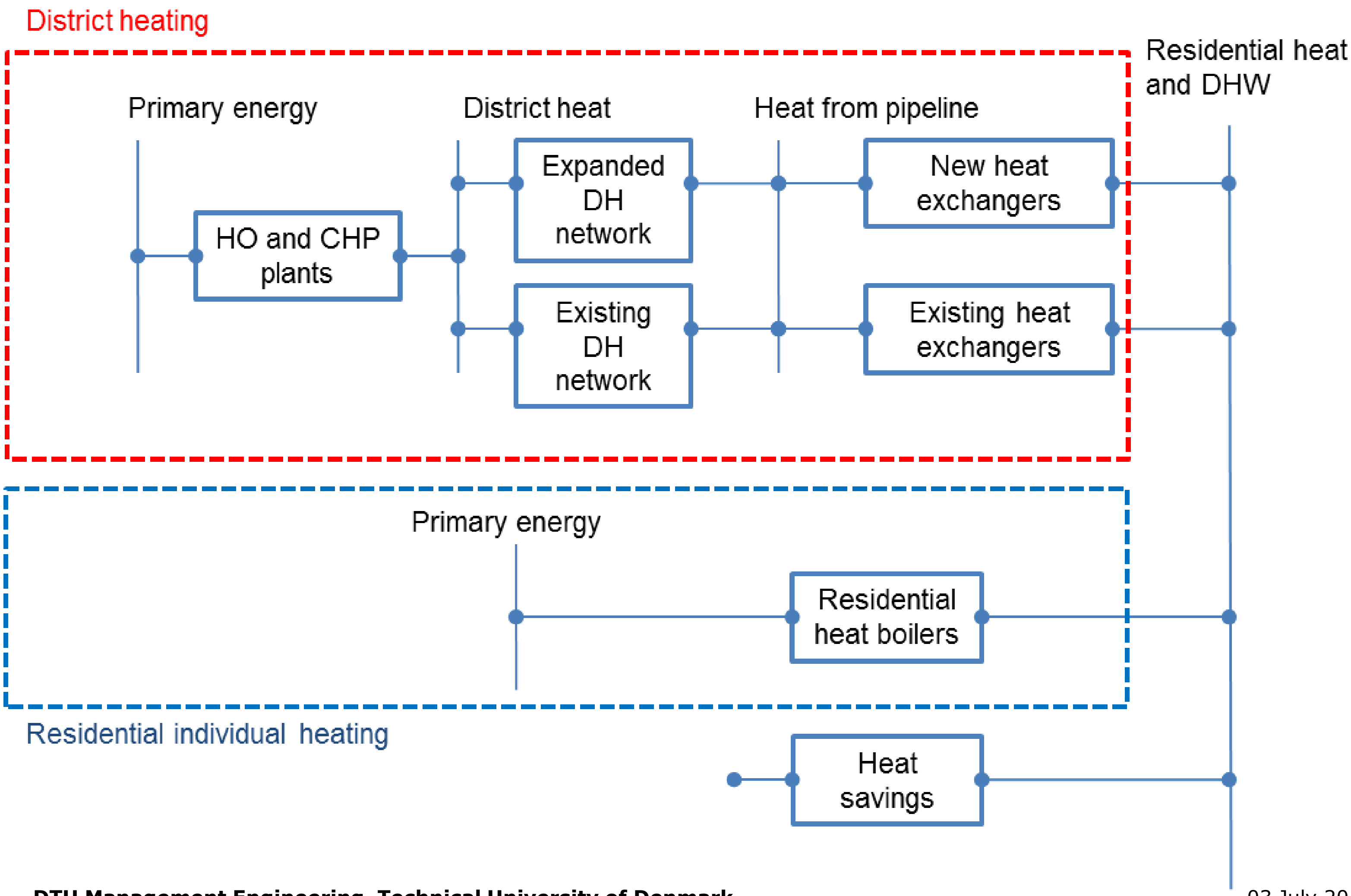
TIMES-NordPool

Same as in TIMES-DK stand-alone except that the power supply system are modelled for Norway, Finland and Sweden thus given endogenous investments and power prices in these regions

TIMES-DK


VRE
Bio
Fossil
Electricity
Gasolin/
diesel
Biofuels
DH
National
Resources
Import/
Export
-Oil
-Coal
-Gas
-Gasoline
-Diesel
-Biomass
-Biofuels
-Etc.
Electricity
Power
and
heating
plants
Heat
pumps
Heat
storage
Oil, gas
refineries
Bio
refineries
Residential
Transport
Public
Service
Industry
-Agriculture
-Food
-Chemical
-Glass&Conc.
-Metal
-Other
-Motor veh.
-Sales
-Private Serv.
Energy Services:
Appliance stock
Building area (m2)
Person km
Ton km
Lighting
Electric motors
Room heat
Medium temp heat
High temp. heat
Haulage

Energy savings and district heating in TIMES-DK



GIS as a tool for creating input to energy system models

Data with spatial nature:

Buildings

Measured demand

Power and heating plant

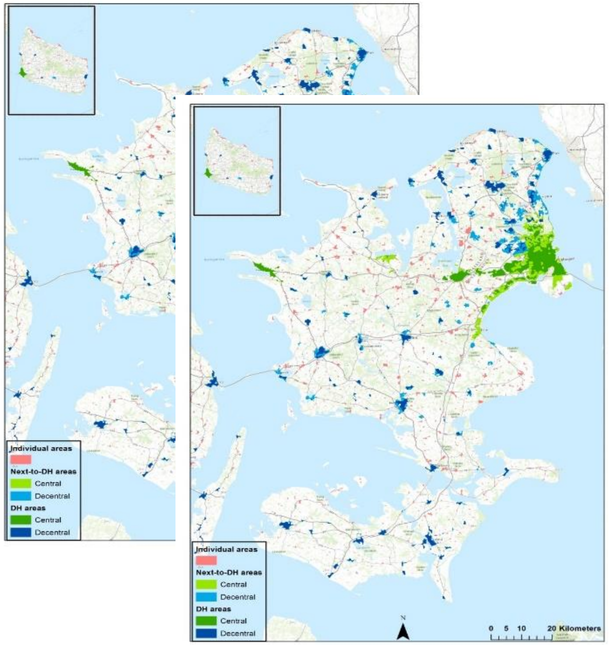
District heating grids

Power grids

Biomass potential

Wind/solar

DTU Energy Atlas



Model inputs:

Heat demand on building groups

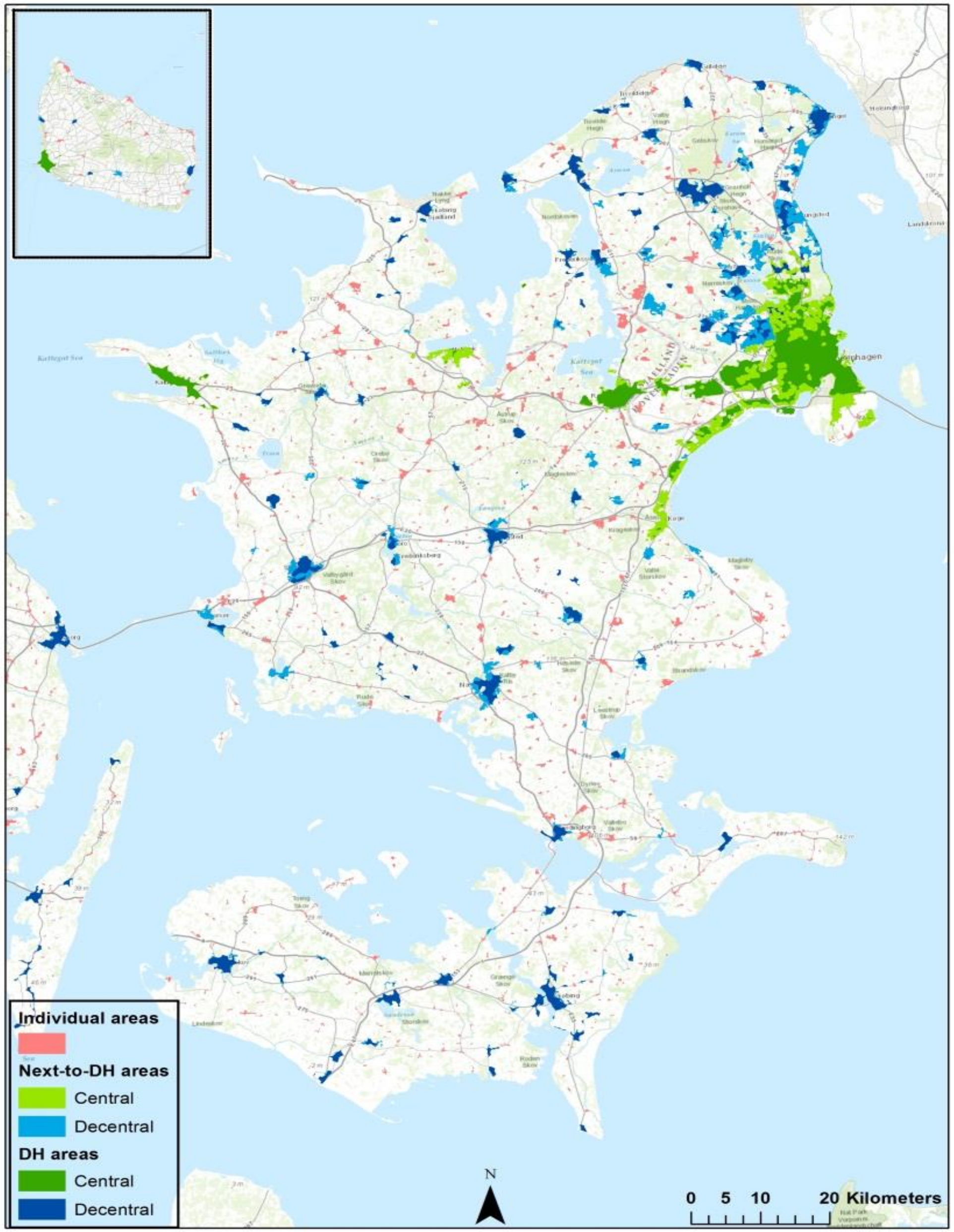
Building physics: Saving potential

Resource constraints:

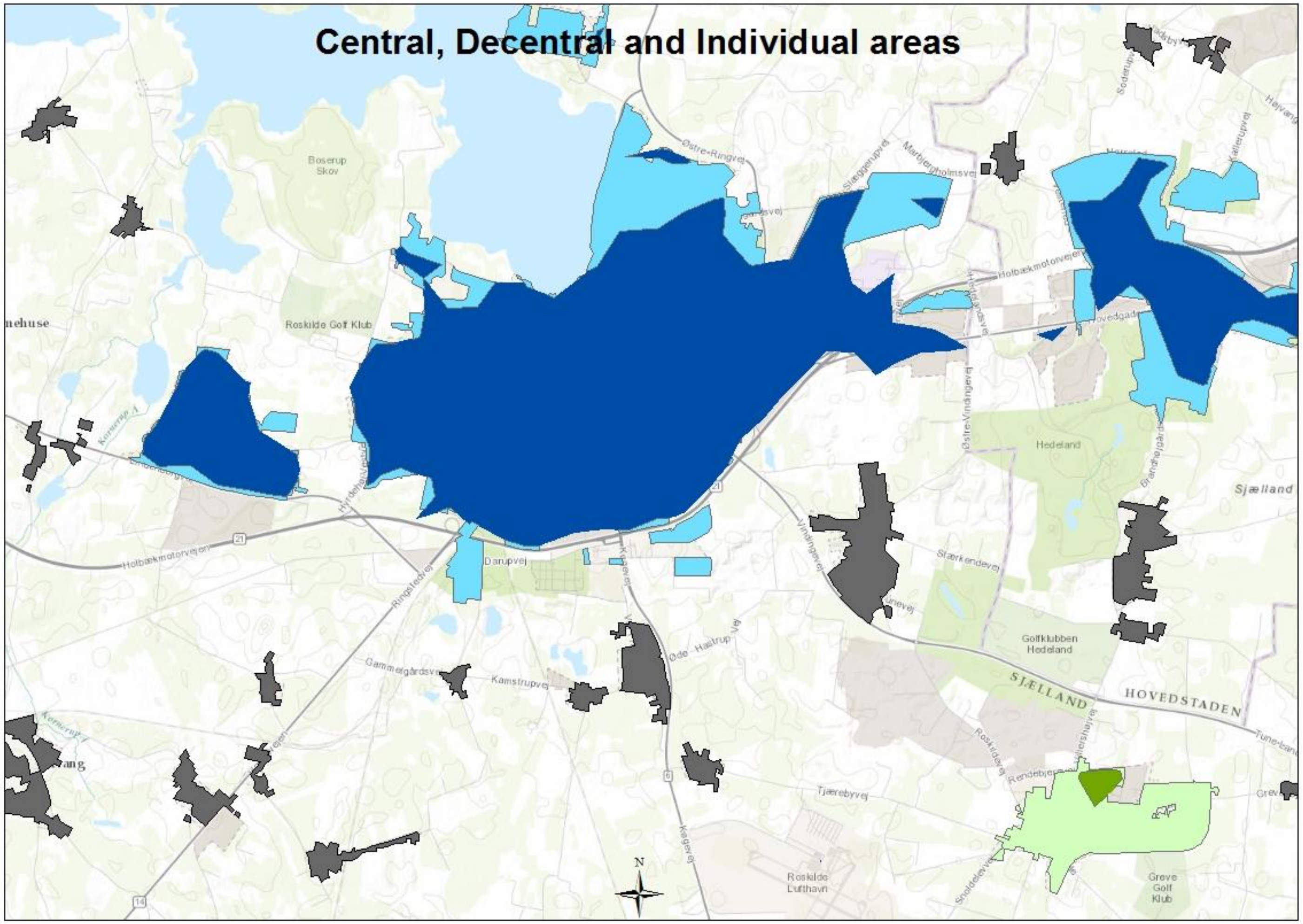
Solar, PV, HP

District heating in TIMES DK

- Two geographical regions: DKE and DKW
- Two types of district heating networks: Central and Decentral
- Two types of district heating areas: DH and Next-to-DH areas
- Two types of expansion of DH – within existing DH areas and to Next-to-DH areas



A closer look at the areas

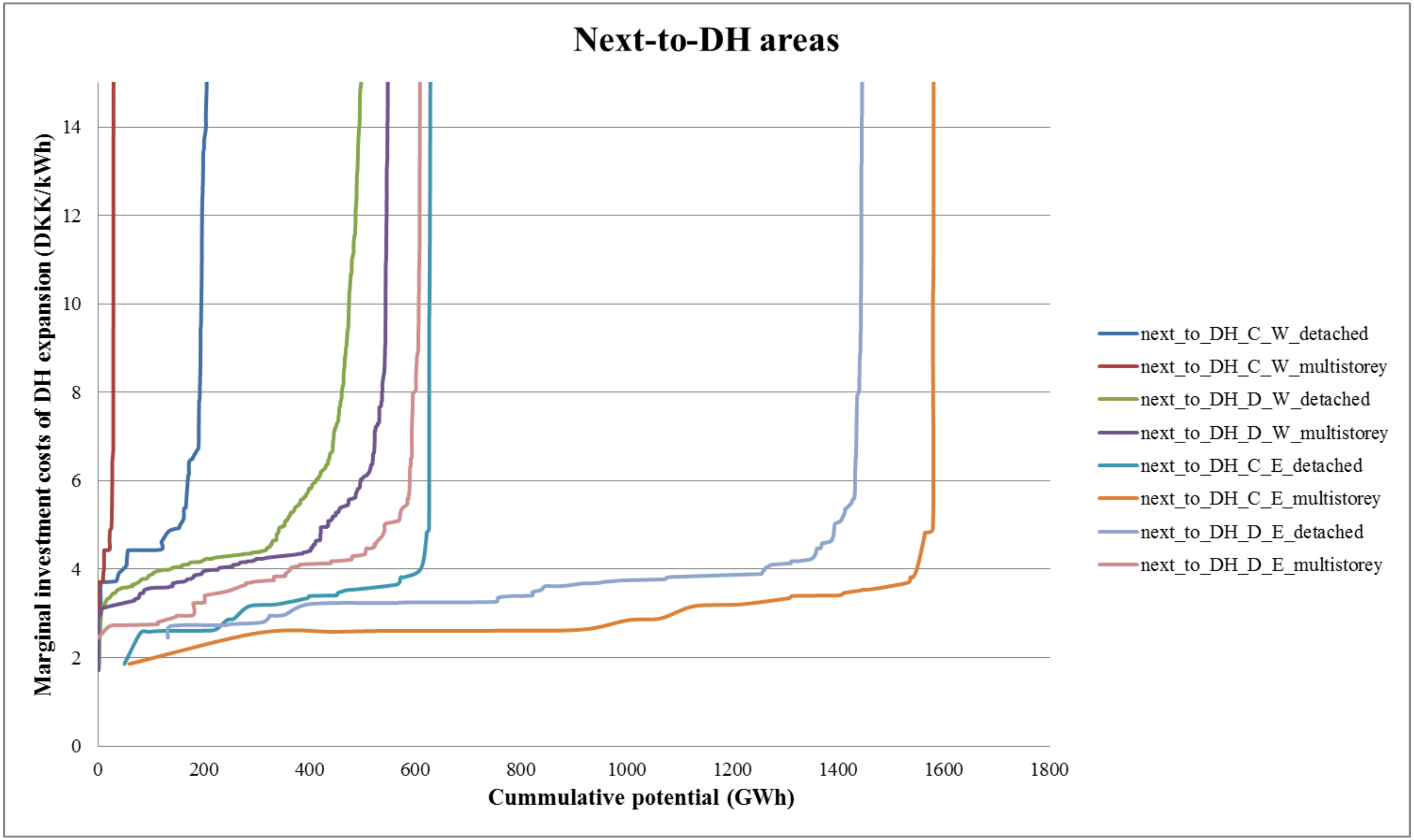


Costs of expanding district heating

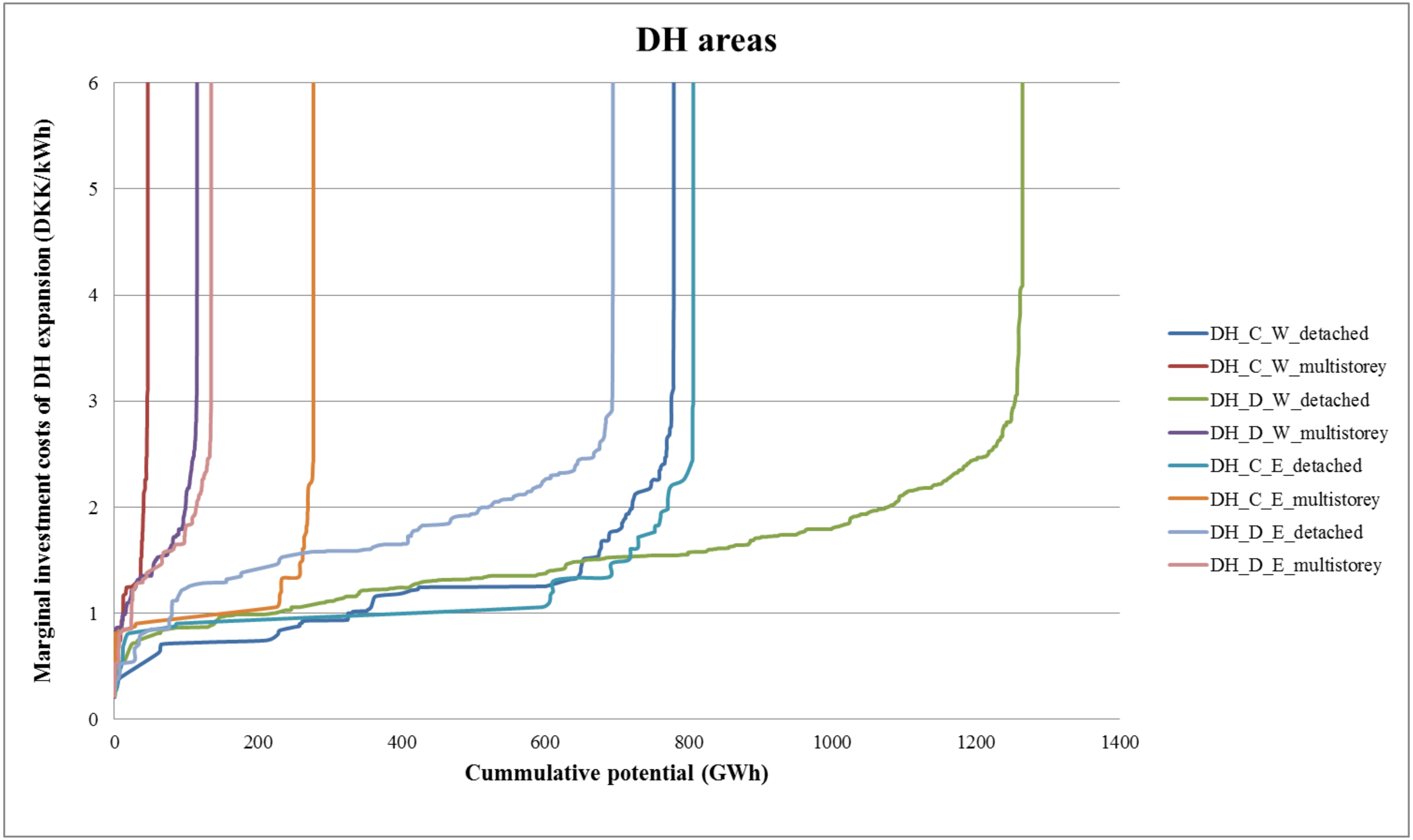
$$C = C_T + C_D + C_C =$$

$$= c_T \cdot l_T + c_D \cdot S_D + (c_{HE,s} + c_{CONN,s}) \cdot n_s + (c_{HE,m} + c_{CONN,m}) \cdot n_m + (c_{HE,l} +$$

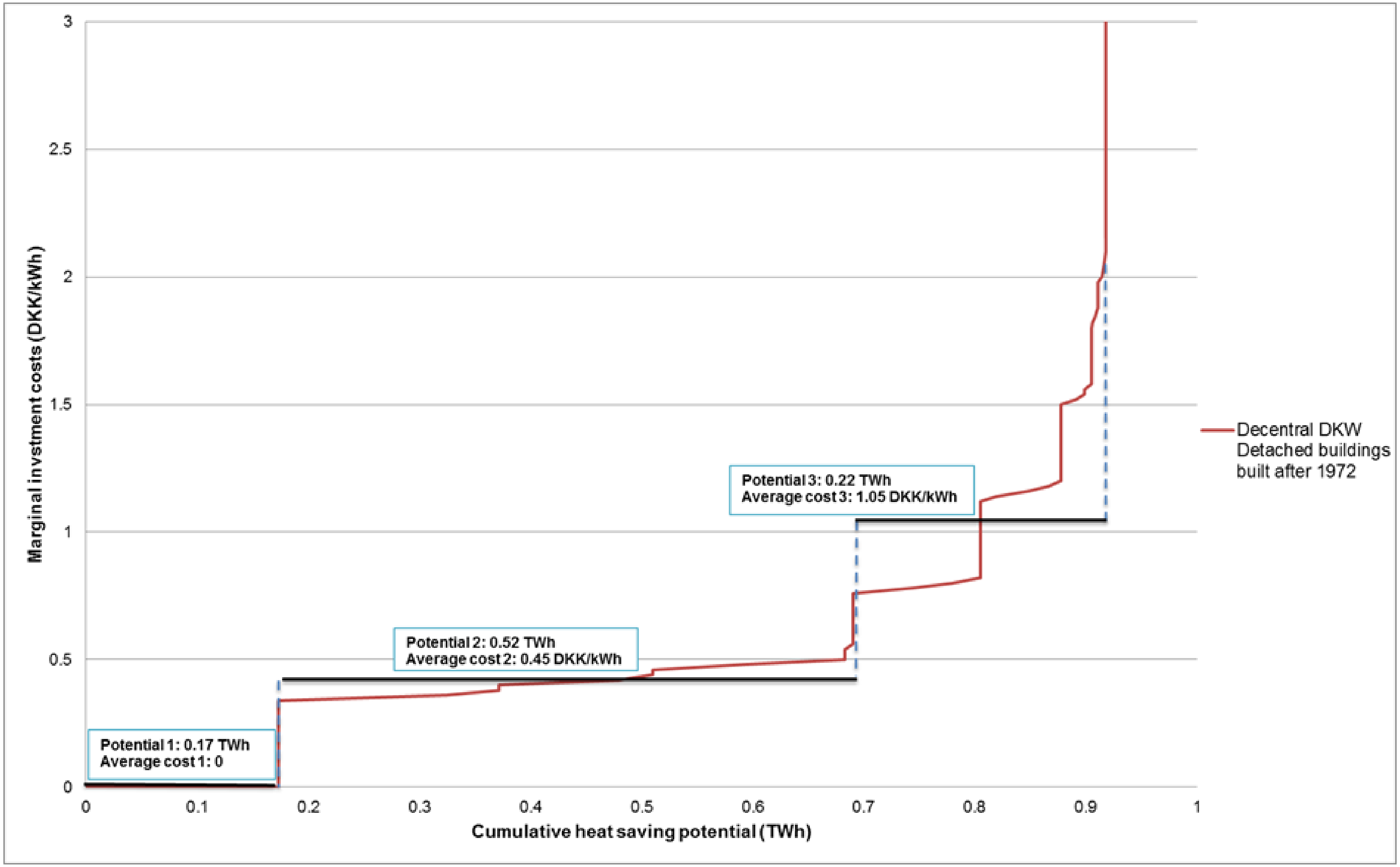
Cost of connecting houses in "next to DH" areas



Cost of connecting houses within district heating areas



Aggregated cost curve for district heating expansion (distribution piping) for a certain building type and area



Input to the energy system model

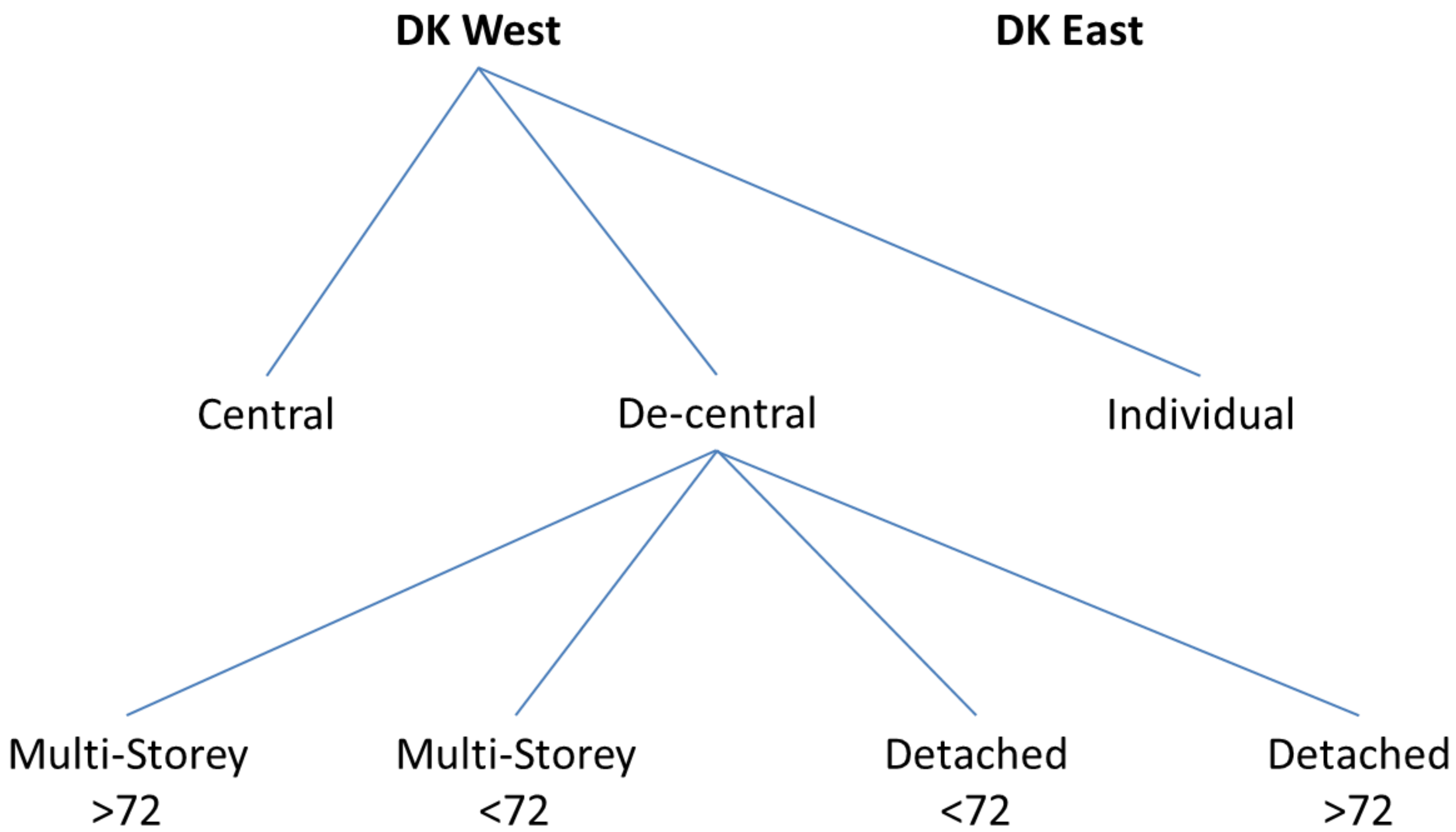
Distributions pipes:

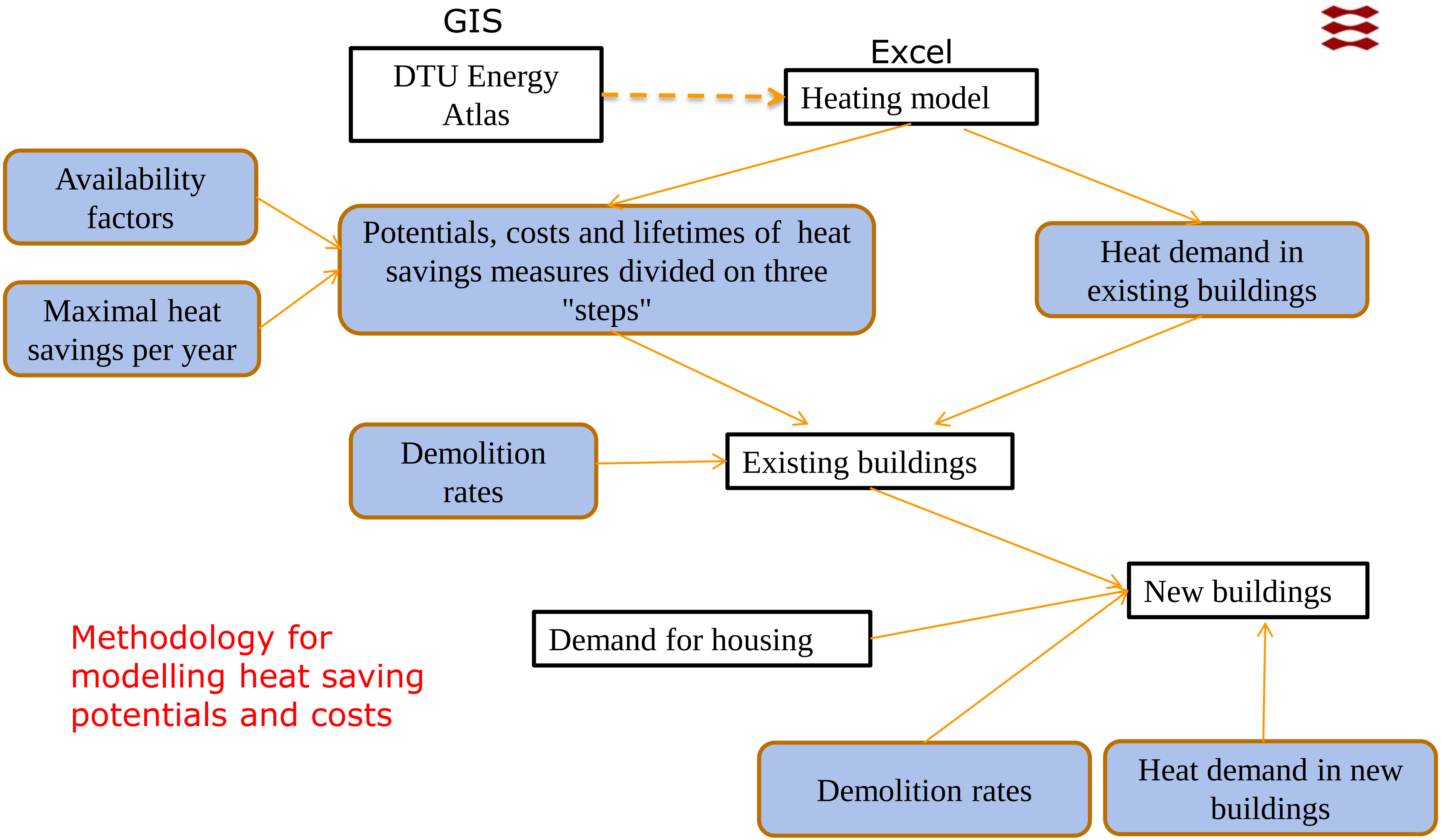
		Potential 1 (GWh)	Potential 1 (MW)	Costs 1 (MDKK/MW)	Potential 2 (GWh)	Potential 2 (MW)	Costs 2 (MDKK/MW)
East	Central	900	513.70	2.82	97.34	55.56	13.79
	Decentral	1500	856.16	3.60	649.94	370.97	7.46
West	Central	100	57.08	2.94	59.27	33.83	30.41
	Decentral	700	399.54	6.11	295.06	168.42	16.08

Connection pipes and heat exchangers:

		Potential (GWh)	Potential (MW)	Inv_costs_conn_pipes (MDKK)	Spec_inv_cost_conn_pipes (MDKK/MW)	Inv_costs_HE (MDKK)	Spec_inv_cost_HE (MDKK/MW)	Spec_InvC_pip+HE (MDKK/MW)
Central	Detached	1320.29	753.59	568.72	0.75	474.49	0.63	1.38
	Multistorey	652.83	372.62	214.12	0.57	226.87	0.61	1.18
Decentral	Detached	3443.76	1965.61	1257.04	0.64	1048.33	0.53	1.17
	Multistorey	981.28	560.09	362.17	0.65	336.64	0.60	1.25

Building categories





Methodology for modelling heat saving potentials and costs

Heat loss calculated for 360 building types

$$Q_{heat}(c,u,t) = Q_{tr}(c,u,t) + Q_{vent}(c,u,t) - Q_{add}(c,u) + Q_{DHW}(c,u)$$

$$Q_{tr}(c,u,t) = \sum_{m}\sum_{elem} u_{elem} \times A \times f_{elem} \times (t_{ind} - t_{out,m)} \times d_m \times k_{24} \times k_{elem}^{t}$$

$$Q_{vent}(c,u,t) = \sum_{m}(1-\eta) \times \rho \times c \times q \times \left(t_{ind} - t_{out,m}\right) \times d_m \times k_{24}$$

$$Q_{add}(c,u) = Q_{int} + Q_{sol} =$$
$$= \sum_{m} p_i \times A \times d_m \times k_{24} \times \eta_h$$
$$+ F_s \times F_a \times F_g \sum_{m} p_{sol} \times A \times f_{win} \times d_m \times k_{24} \times \eta_h$$

Assumptions/input

Excel heating model

Building physics - room height etc.

Indoor temperature before and after renovation

Costs of renovation:

	Marginal costs		Full costs	
	Fixed	"Additional thickness"	Fixed	"Additional thickness"
	DKK/m2 of element	DKK/(mm*m2 of element)	DKK/m2 of element	DKK/(mm*m2 of element)
Walls	200	7	1500	7
Roofs	50	1	100	1
Floors	350	0	350	0

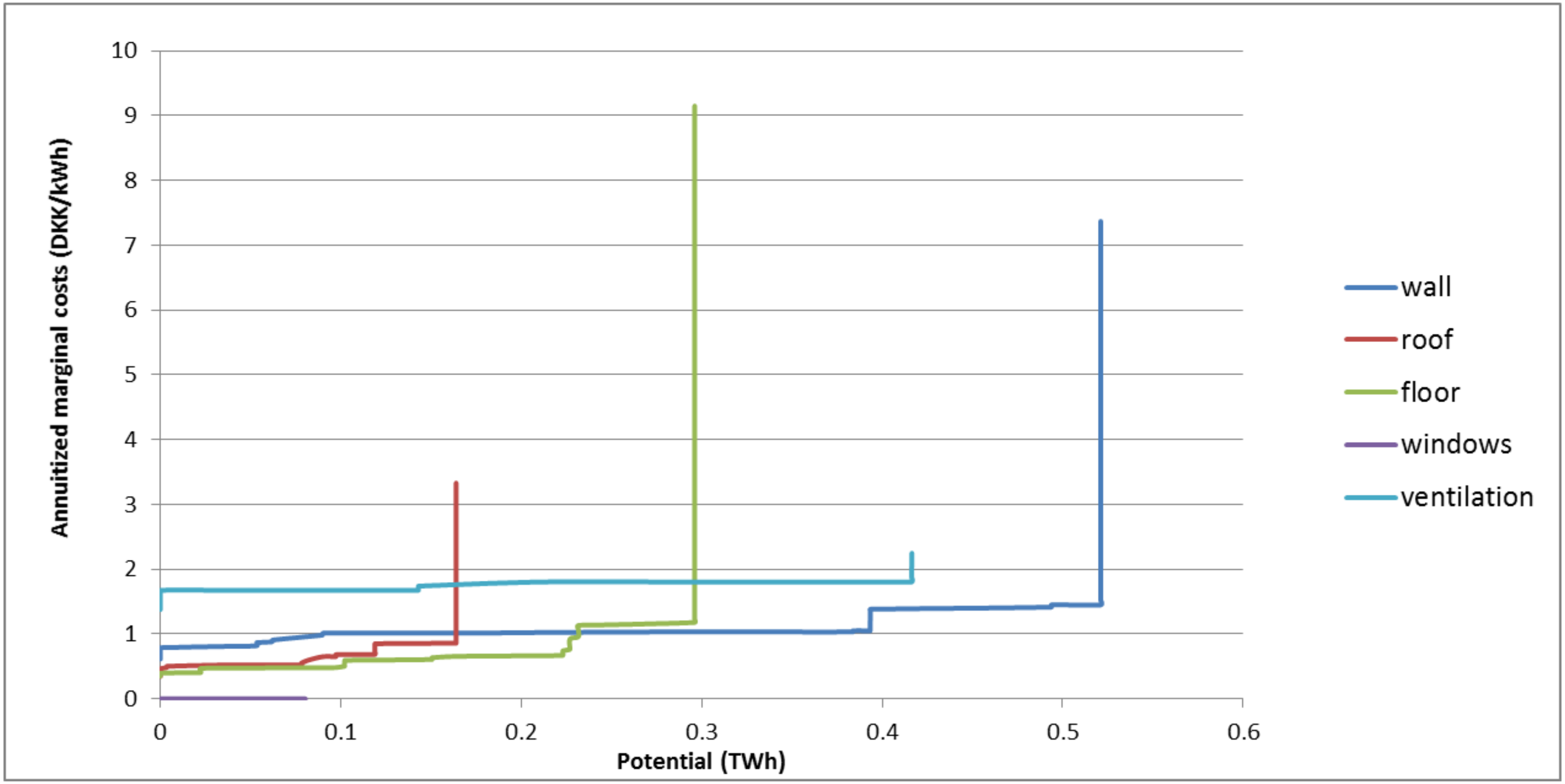
TIMES-DK

Demolition rate

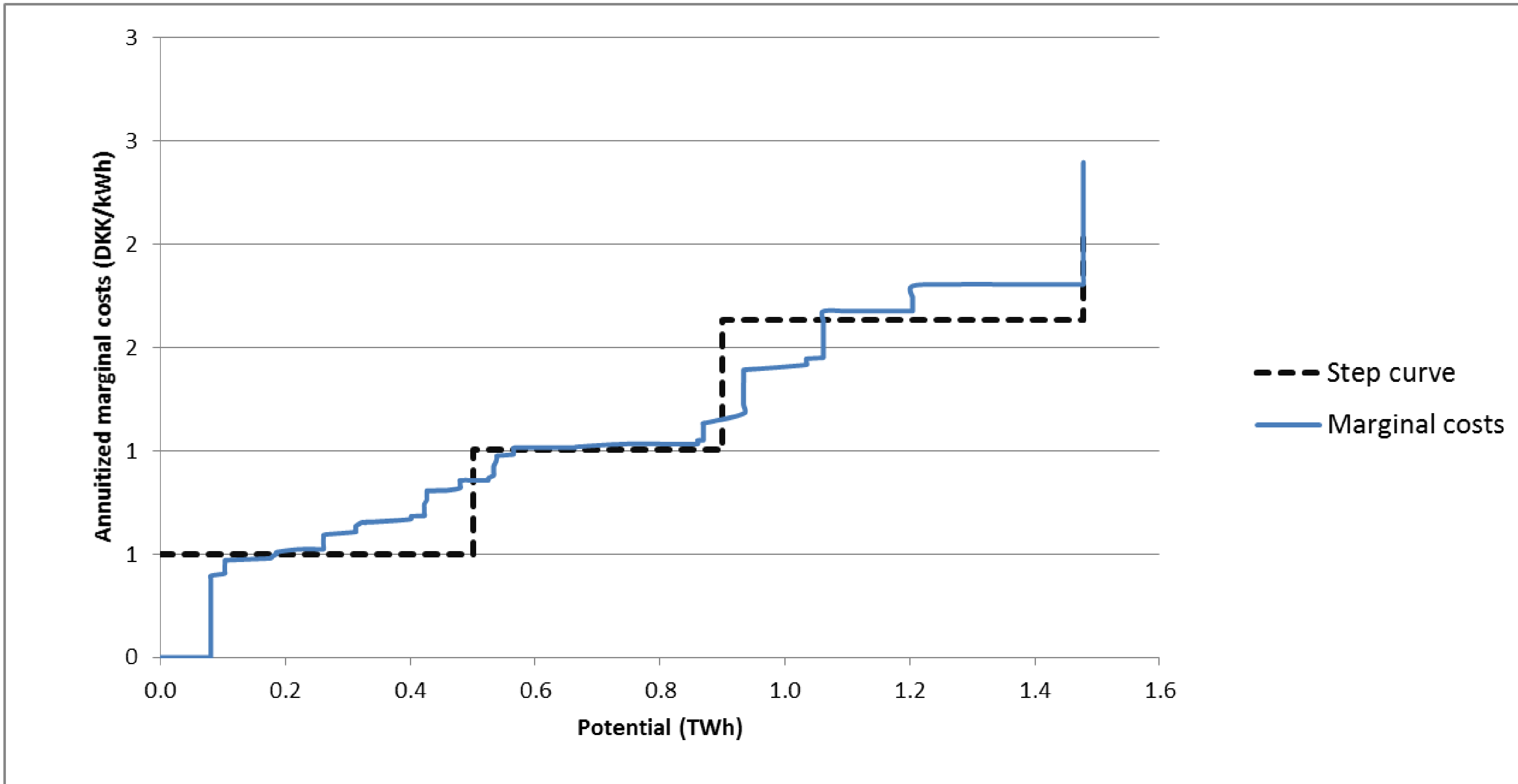
Growth in build area

Renovation rate

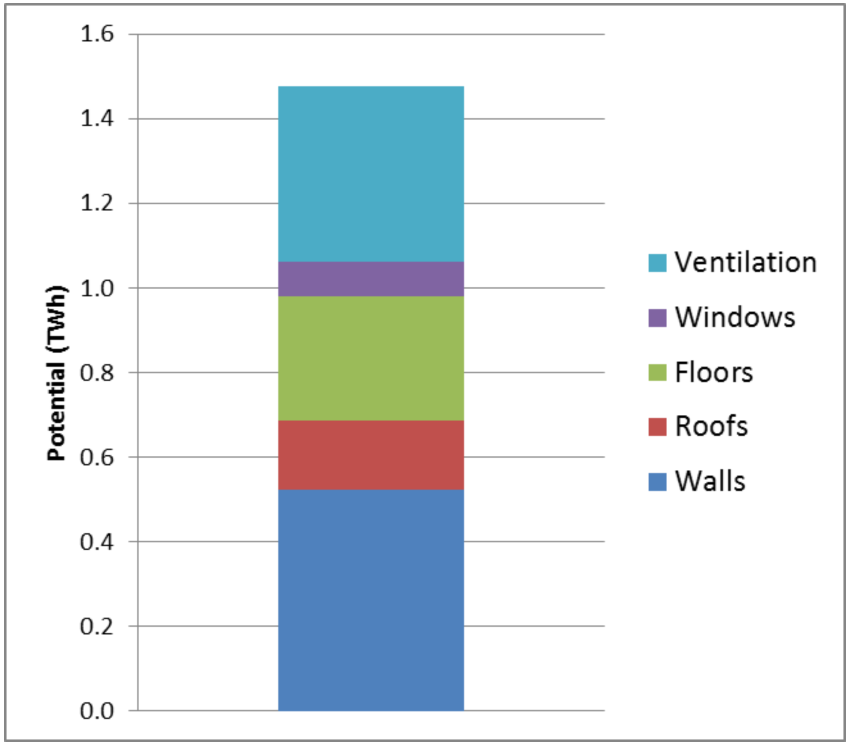
Cost curves for heat savings in single family houses build before 1972 (marginal costs)

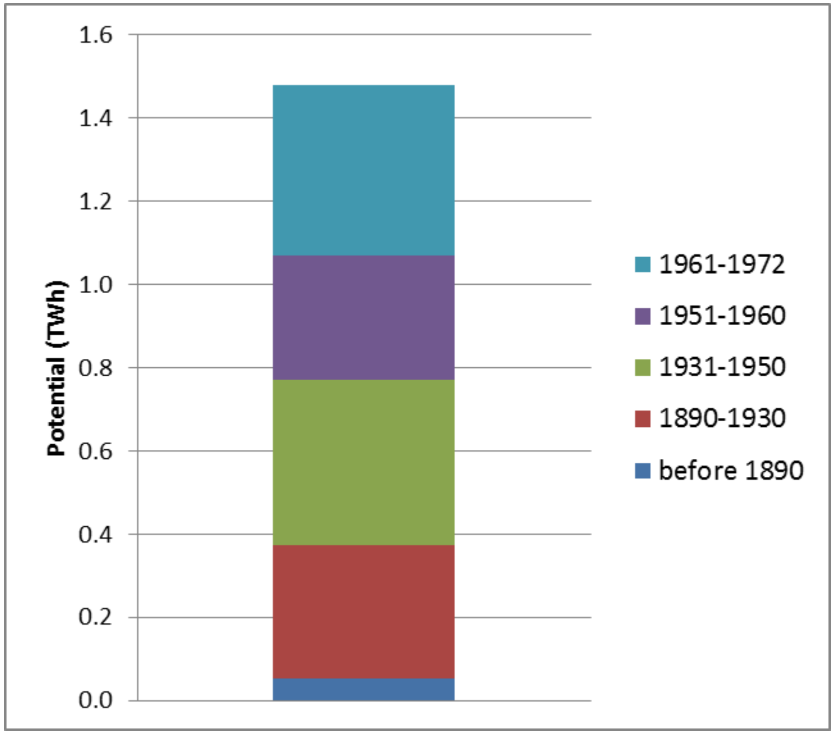


Aggregated cost curve for single family houses build before 1972

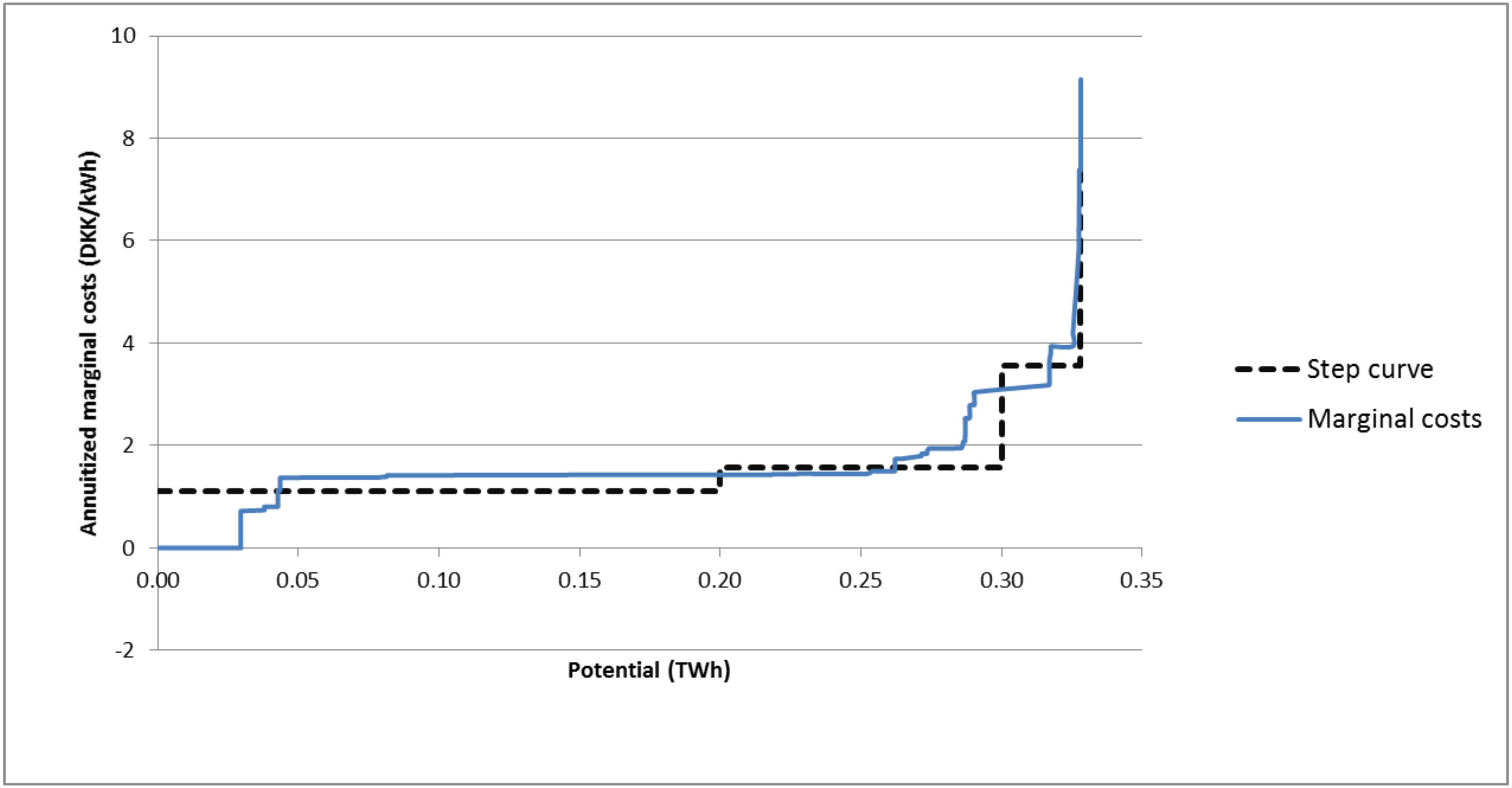


Where are the savings in single family houses?

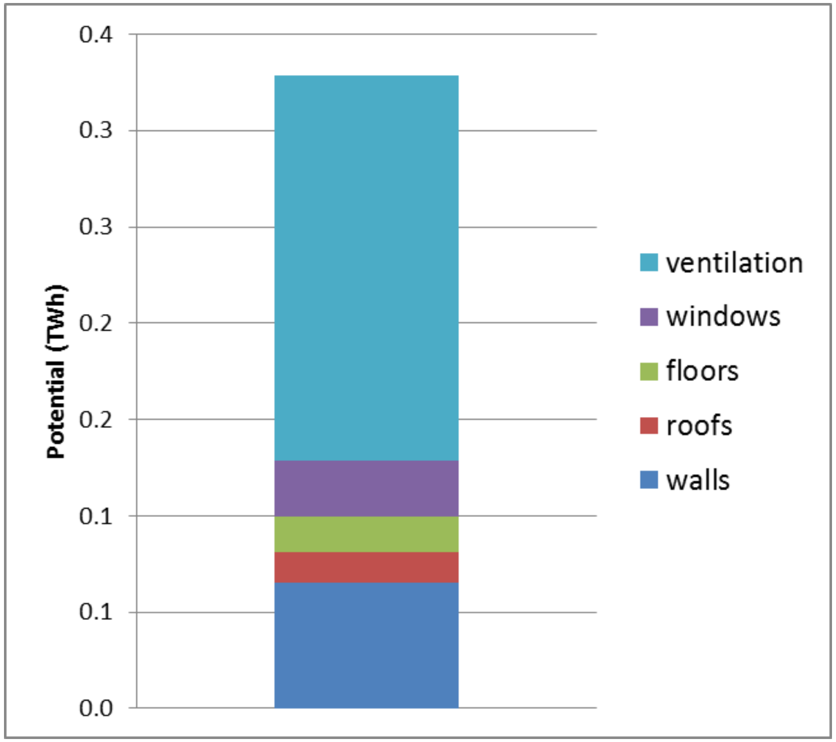


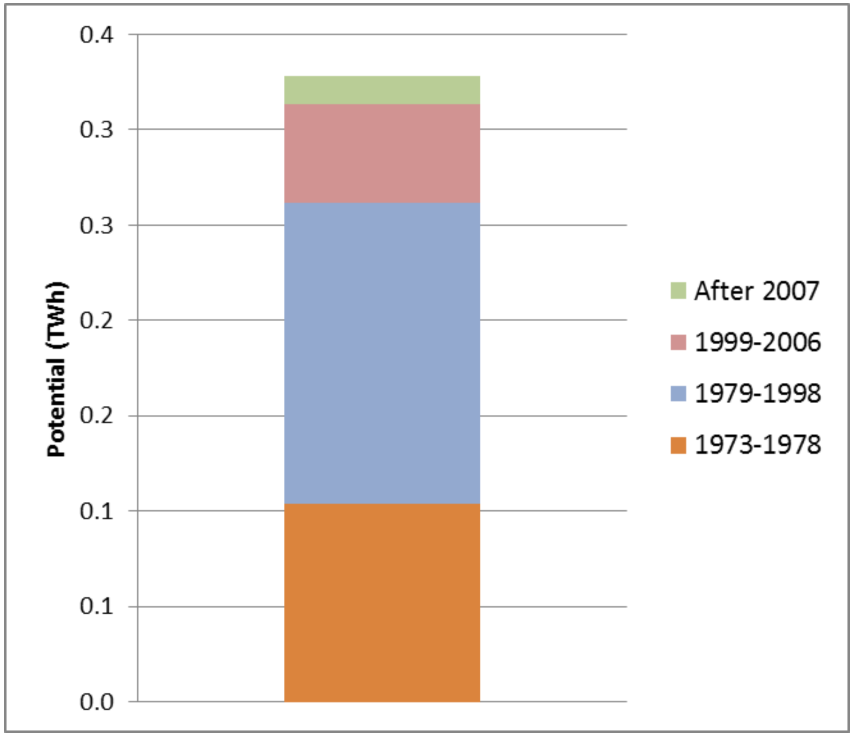


Aggregated cost curve for multi family houses build after 1972



Where are the savings in multi story buildings build after 1972?

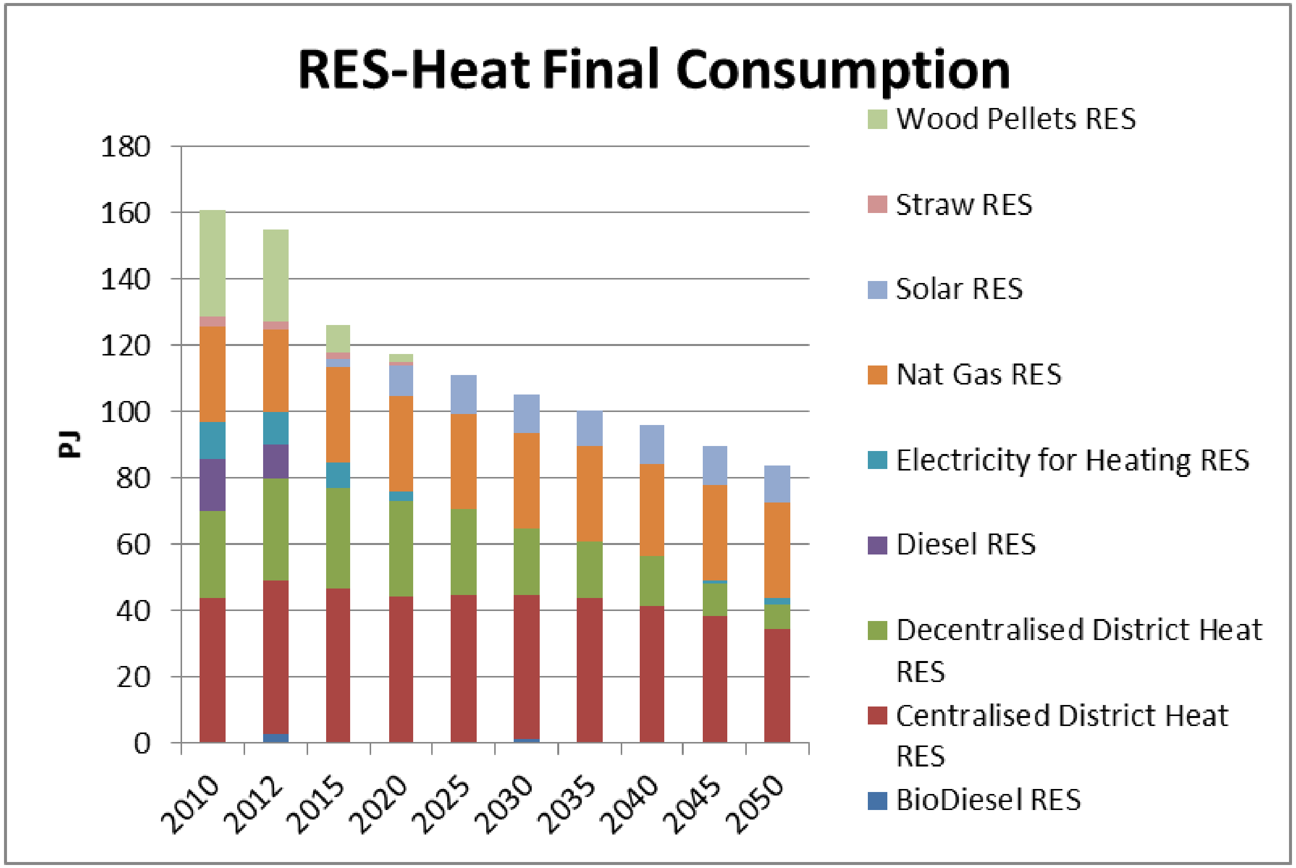




Input to the energy system model

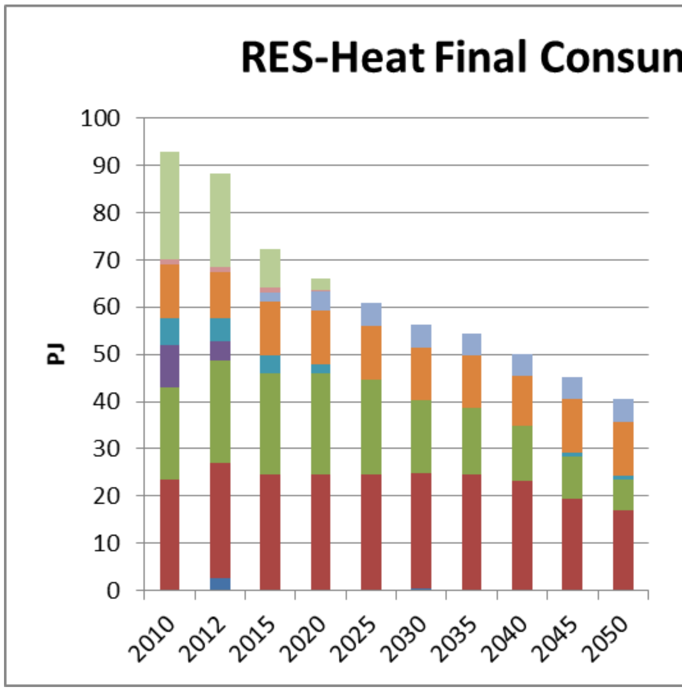
		DKE											
		C				D				I			
		SFh		MFh		SFh		MFh		SFh		MFh	
		B72	A72	B72	A72	B72	A72	B72	A72	B72	A72	B72	A72
Step 1	Potential (TWh)	1.80	0.36	6.12	0.72	1.08	0.72	0.72	0.36	1.80	0.72	0.07	0.04
	Aver. inv. cost (DKK/kWh)	0.50	0.79	0.50	1.12	0.37	0.79	0.40	1.08	0.46	1.21	0.36	1.28
	Aver. lifetime (years)	36.25	32.79	37.92	22.35	33.93	32.84	36.46	22.98	35.06	26.36	35.53	22.53
Step 2	Potential (TWh)	1.44	0.18	2.88	0.36	2.52	0.72	0.72	0.18	2.52	0.36	0.11	0.01
	Aver. inv. cost (DKK/kWh)	1.00	1.68	1.30	1.57	1.08	1.69	0.81	1.53	1.02	2.00	0.80	2.26
	Aver. lifetime (years)	39.44	20.00	26.12	27.48	39.43	20.00	39.60	27.54	39.73	28.98	38.01	34.18
Step 3	Potential (TWh)	2.08	0.59	0.98	0.10	1.48	0.76	0.63	0.03	1.70	0.13	0.07	0.00
	Aver. inv. cost (DKK/kWh)	1.64	2.28	1.55	3.56	1.74	2.50	1.48	3.54	1.72	3.64	1.56	3.90
	Aver. lifetime (years)	26.07	29.83	20.00	40.00	20.00	33.48	20.19	40.00	23.19	39.95	20.69	40.00

Results including DH and savings

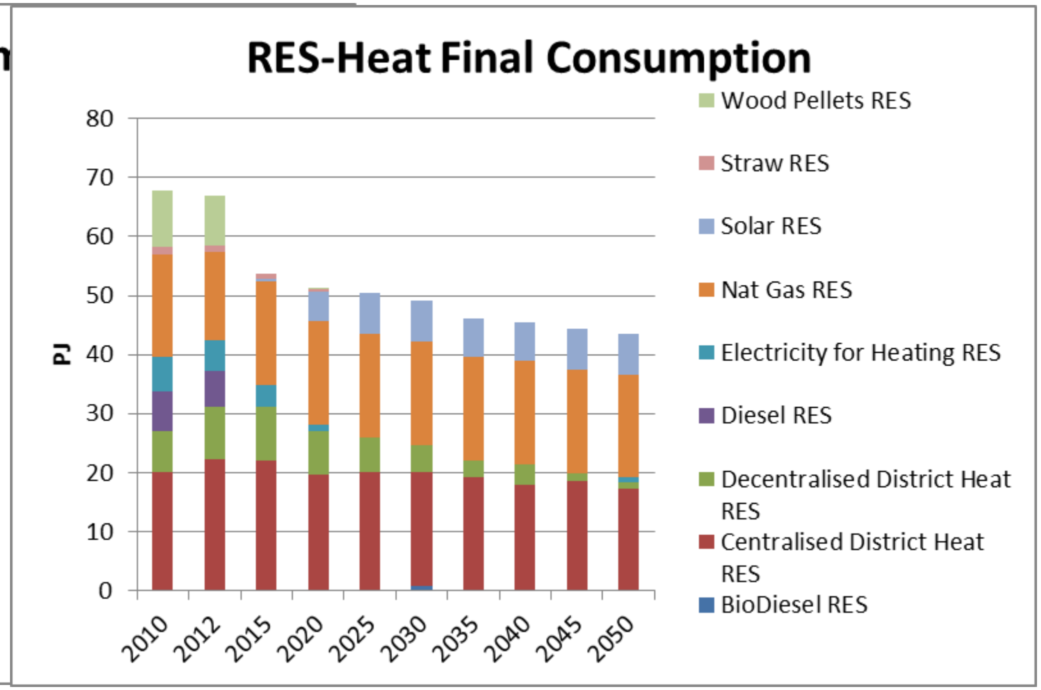


Heating of residential buildings

DK East



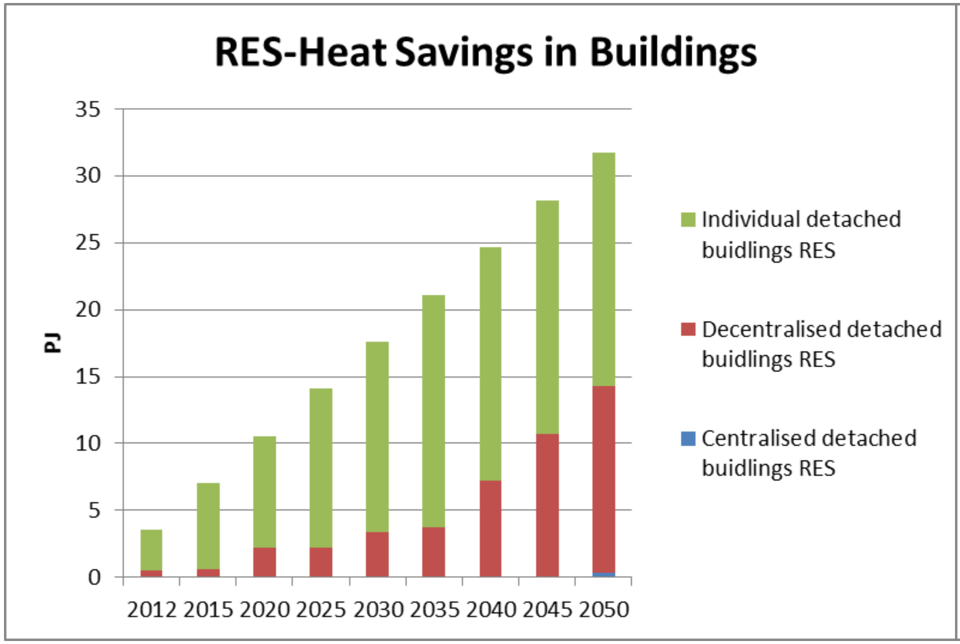
DK East

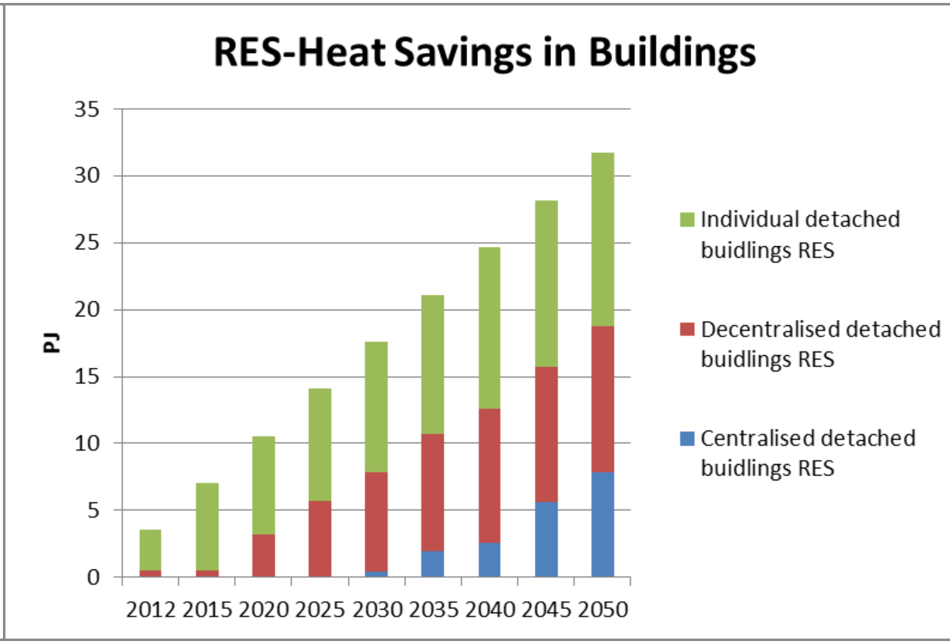


Heat savings in residential buildings

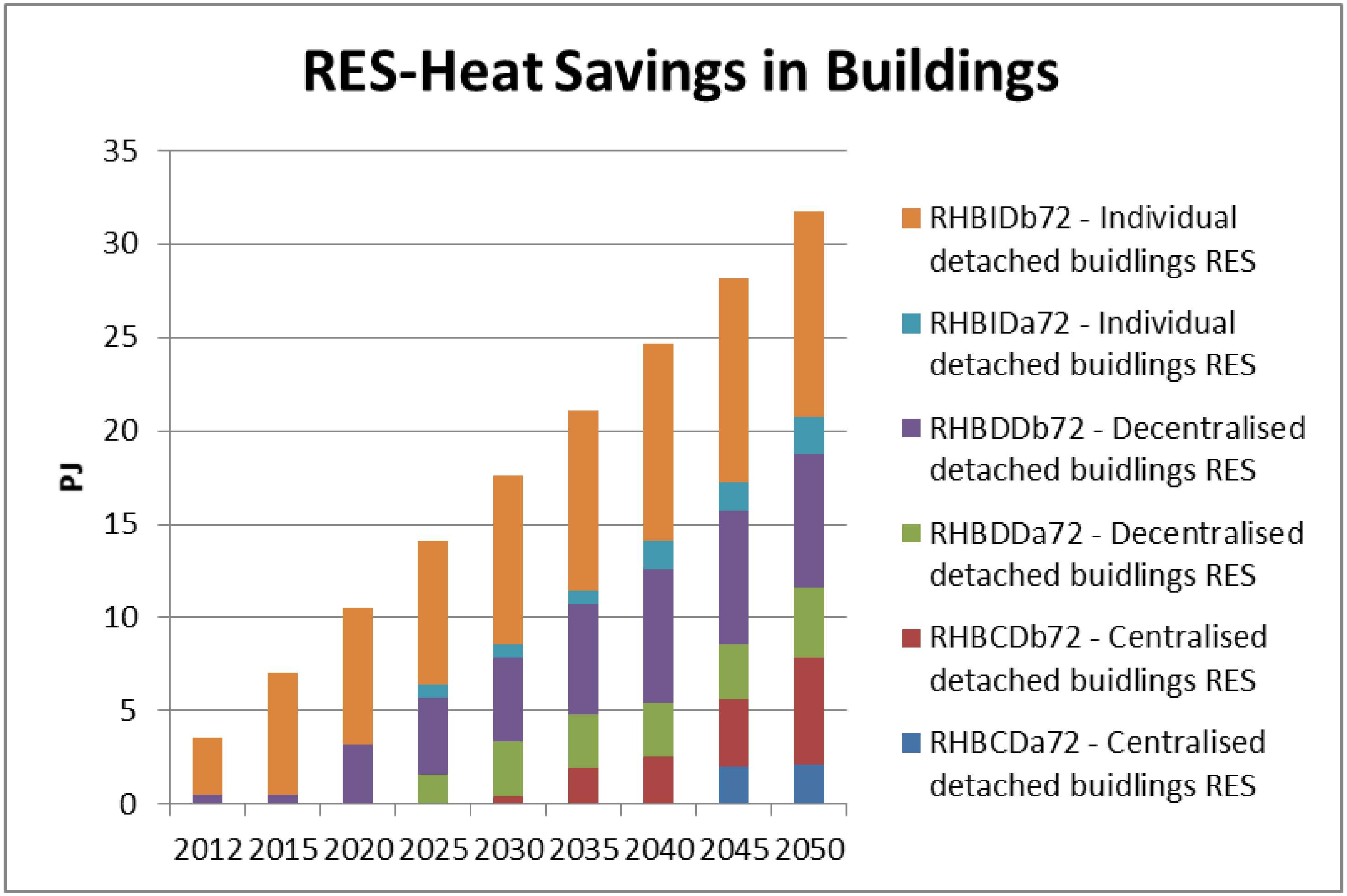
WLP-NFE

BASE

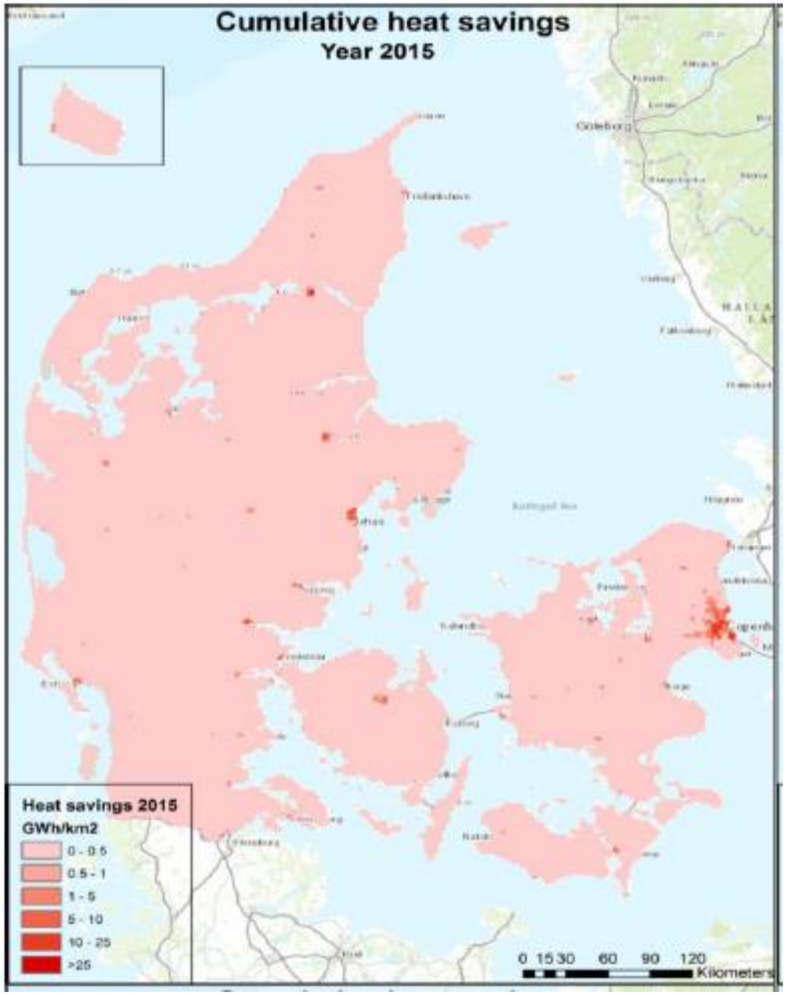


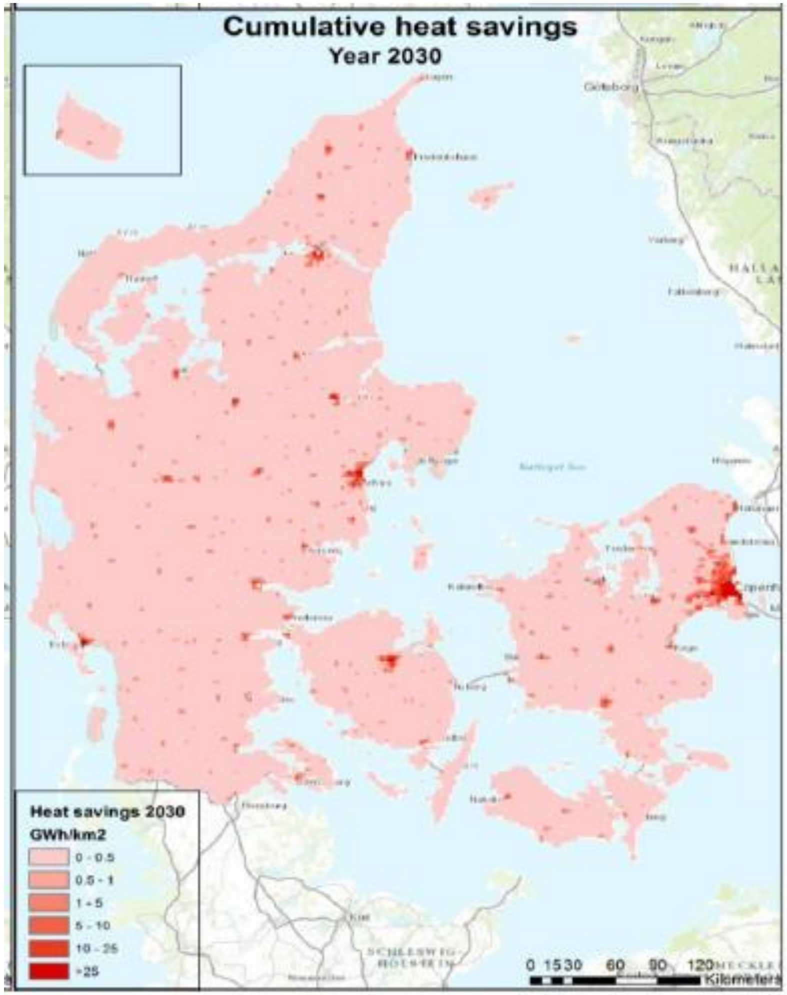


Heat savings in residential buildings



Going back to GIS with the results





Work to be done

- More flexible constraint on how fast heat savings can be implemented - is it a labour problem, an investment problem or something else?
- Include value of houses and other parameters for evaluation of financing investments in the building
- Full costs versus marginal costs - make both available in same model run
- More flexibility in the Excel tool plus include demolition and new buildings
- Move results back to GIS for presentation of results