

NEW DIRECTIONS IN DEVELOPMENT OF CITY ENERGY SYSTEMS

by

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Original scientific paper

DOI: 10.2298/TSCI120127060C

At the world level, the 20th century saw an increase from 220 million urbanites in 1900 to 2.84 billion in year 2000. The present century will match this absolute increase in about four decades. Developing regions, as a whole, will account for 93% of this growth.

Until now humankind has lived and worked primarily in rural areas. But the world is about to leave its rural past behind. Today we are witness, for the first time, that more than half of the globe's population is living in towns and cities. The number and proportion of urban dwellers will continue to rise quickly. Urban population will grow to 4.9 billion by 2030. At the global level, all of future population growth will be in towns and cities.

Two centuries ago there was only one city on the planet that could say it had a million inhabitants – that was London. Today more than 400 cities can boast that – 408 to be precise, according to the Earth Policy Institute. But today a population of 1 million people means nothing; we are moving into the era of megacities of 10 million (and more) people. Today, there are 20 so-called megacities, whose population, and therefore energy needs, easily exceed some countries population, according to Earth Policy Institute. More people now live in Tokyo than Canada, for example.

Despite only occupying 2% of the world's surface area, they are responsible for 75% of the world's energy consumption.

Key words: *Denmark, energy planning, combine heat and power, Copenhagen*

International Energy Agency estimates the energy demand in next 30 years will increase by 40%. [1] This is the emergency bell for future behavior of state governments, as well as local administration, up to each and every person, to accept the coming future with rational and wise decisions related to inevitable growing energy demands.

Developed countries and societies have different approach to the upcoming energy assignment, but all of them aiming a same target:

- energy production free of fossil fuels,
- sustainable energy future,
- renewable energy solutions – biomass, wind, sunlight, geothermal, tide ..., and
- environmental friendly sources, free of CO₂ pollution.

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Among those countries is Denmark, the European leader in energy saving and implementation of most advance energy solutions. With its enviable tradition in energy development, with crucial governmental decisions starting 1970's, accepting the reality that future begins from today, they built the most energy awareness society.

Following the European environmental targets "20-20-20", agreed in European Parliament and the Council in December 2008, Denmark accepts the implementation: by 2020, to reduce by 20% the emissions of greenhouse gases, increase by 20% the energy efficiency and to reach 20% in total energy consumption from renewable sources. Today results are showing that Denmark is beyond the EU targets, putting in front the most ambitious plan:

- energy supply to be 100% independent of fossil fuels till 2050,
- greenhouse-gas emissions in 2020 to be reduced by 40% compared to 1990 levels,
- electricity and heating supply must be provided by renewable energy by 2035,
- oil burners and coal must be phased out no later than 2030, and
- 50% of Denmark's traditional electricity supply must come from wind power by 2020 [4].

To provide incentives, various acts have been issued by Danish authorities related to taxes, subsidies and different mechanisms.

Production and development of renewable energy are subsidized. *Energinet.dk* is the Danish national transmission system operator for electricity and natural gas, owned by the Danish state, is also obliged to charge a fee called a PSO (public service obligation) to the consumers through the electricity bill. The PSO funds are used for research and development, as well as to subsidize environmentally friendly electricity production.

Denmark accepted "Decentralized Energy" principles, where production is at or near the point of use. Denmark is also the world leader in implementation of Decentralize Energy (DE) concept (fig.1).

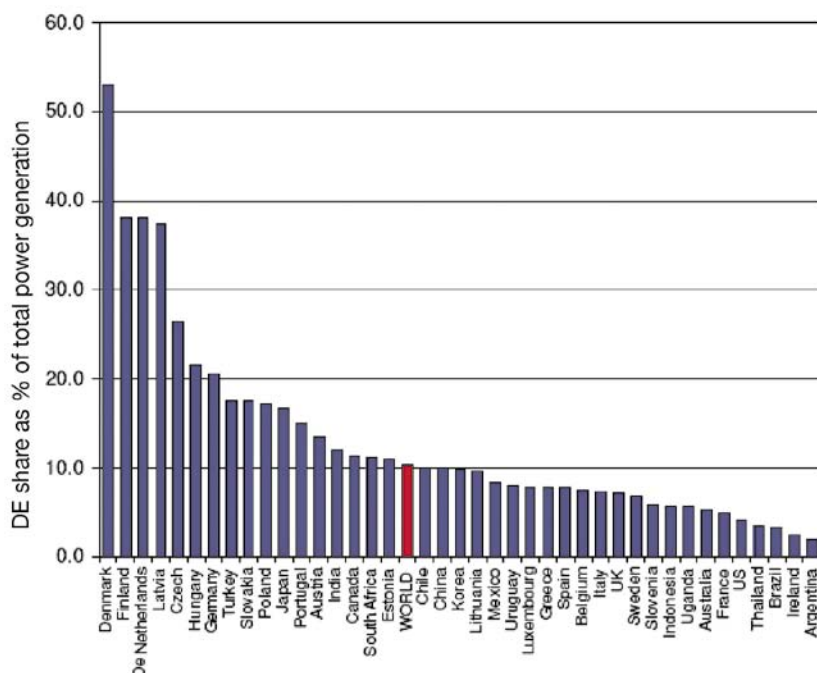


Figure 1. Decentralize energy share in % of total power generation

Decentralization started in mid 1980's. Today, as a consequence of the *co-generated heat and power* (CHP) and wind policy programs, electricity is supplied from a much larger array of smaller scale units based mainly on CHP (fig. 2). About 80% of District Heating (DH) is co-produced with electricity [2].

This ambitious plan, which require an enormous phase-in of renewable energy, also require the “Smart Grid” – to avoid large investments to the new cables and connections and to optimize capacity expansion, respectively to the fluctuations in production and consumers' electricity usage. Last year the Smart Grid Network has been established by Danish authorities and recommendations for future actions and initiatives has been given. The urban areas start existence as a “Smart Cities”, as a part of Smart Grid, with its own energy production and distribution [3].

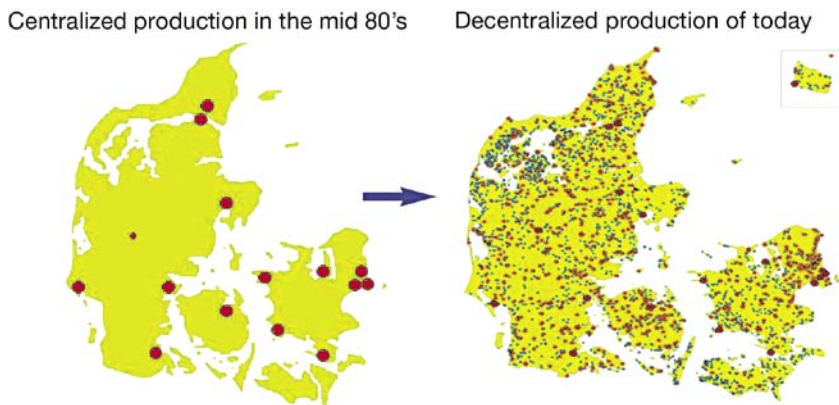


Figure 2. Centralize (middle 80's) and today's decentralize production of energy

Structures like “Smart Energy City Concept”, “Smart Grid” and “Intelligent Buildings” are supported with large number of Danish legislation and acts, regulating energy savings and implementation of new strategies in production and distribution of electricity, district heating and district cooling, as well as regulations in building energy efficiency.

In “Smart Energy City Concept” it is important to focus on *integrated solutions*, including building envelope, building installations, district heating and power system. It is also important to utilize all possible renewable resources in greater city area, following principles of Smart Grid, as a precondition for efficient, flexible and cost-effective use of renewable energy.

Integrated solutions and Smart Energy City concept rely on:

- National power grid – real time market prices;
- City district heating – optimal use of low carbon fluctuating sources, CHP and renewable energy sources; storage tanks,
 - lower temperature of supply water < 110 °C,
 - lower returned temperature (25-35 °C),
 - more new customers,
 - more individual heating pumps, and
 - new preinsulated pipe system;
- City district cooling – optimal use of free cooling and storage tanks,
 - higher temperature of cooling (12-15 °C);
- National natural gas grid – gas to CHP, single family house and poverty area; gas storage
- Buildings – low temperature heating and high temperature cooling; optimized building envelope; internal micro grid for low consumption electronics.

Energy labeling is statutory when selling and letting buildings and obligatory every five years for large buildings [4]. Energy labeling of buildings serves two purposes:

- The energy label should make visible the energy consumption of the building and thereby function as informative labeling when the building is sold or let.
- The energy label should give an overview of which energy-related improvements will be cost-effective to implement: their objective, implementation costs, and the savings to be made on electricity and heating bills.

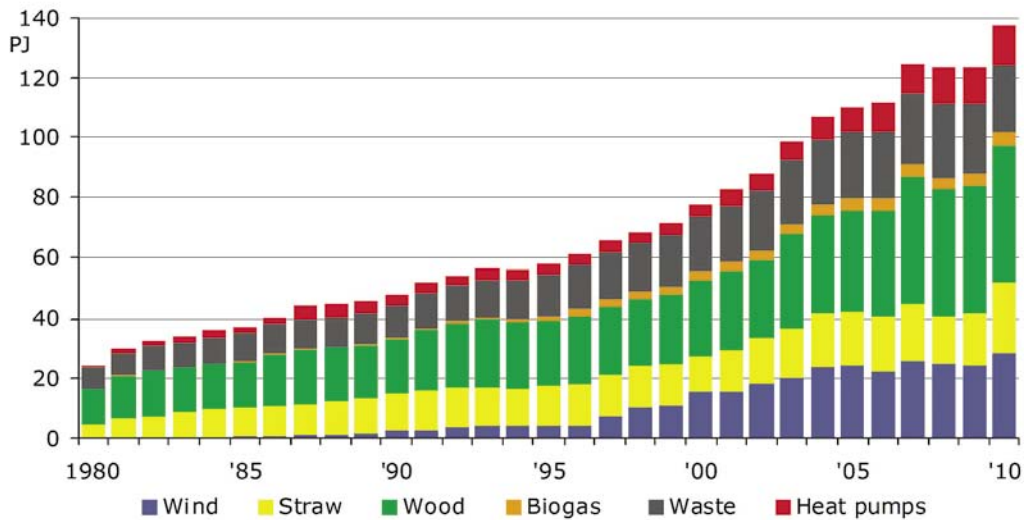


Figure 3. Production of renewable energy

In 2009, the total production of *renewable* energy in Denmark was 122 petajoules (PJ) (fig. 3), which corresponds to the energy needs of about 1.2 million single-family houses or 19.7% of total energy consumption. The share of renewable energy grew from 20.1% to 22.3% in 2010 compare in 2009. Production of electricity from renewables accounted for 33.1% of Danish domestic electricity supply in 2010. Of this figure, wind power accounted for 20.7% [4].

Denmark has become a global leader of installed wind power per capita and the Danish wind turbine industry exports serves about 1/3 of the world market (fig.4).

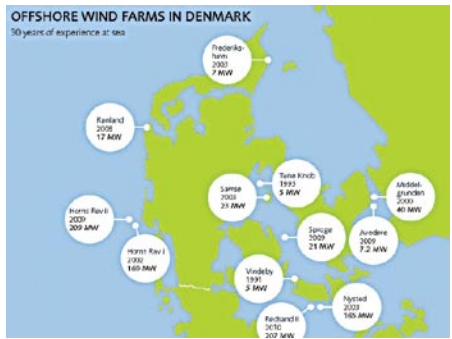


Figure 4. Offshore wind farms in Denmark



Figure 5. Solar collectors for water heating

Large scale of solar heat will cover 8 million m² in year 2030 (fig. 5).

Practically all CHP plants in Denmark are equipped with heat accumulator. They are used for short-term storage of water-based energy (figs. 6 and 7).



Figure 6. Pit heat storage



Figure 7. Heat accumulators in Avedøre CHP

Individual solar heating, as well as wood stows, are many times more expensive and less efficient than District Heating solution. Denmark is leading in utilizing biomass (fig. 8), as well as straw (fig. 9), as an energy resource for CHP. About 1.5 Mt of straw is used annually for energy production. Straw consumption for electricity production in CHP and power plants has reached almost 1 Mt per year through the implementation of the Danish Biomass Action Plan [4].



Figure 8. Wood and walnuts



Figure 9. Straw

Copenhagen – all large-scale power plants are located close to major cities (fig. 10 and tab. 1) [5].

Incineration has a great tradition in Denmark. First incineration has been established in Frederiksberg, the central municipality of Copenhagen, in year 1903 [6].

In February 1902, it was decided to establish an incineration plant, with three steam boiler units as well as two coal-fired steam boilers, a hot water system and an electricity generator so that the incineration plant in effect became a combined heat and power plant. The plant was commissioned in September 1903. It was not only Denmark's first waste incineration

plant, but also Denmark’s first district heating plant, even in the form of a combined heat and power plant [7].

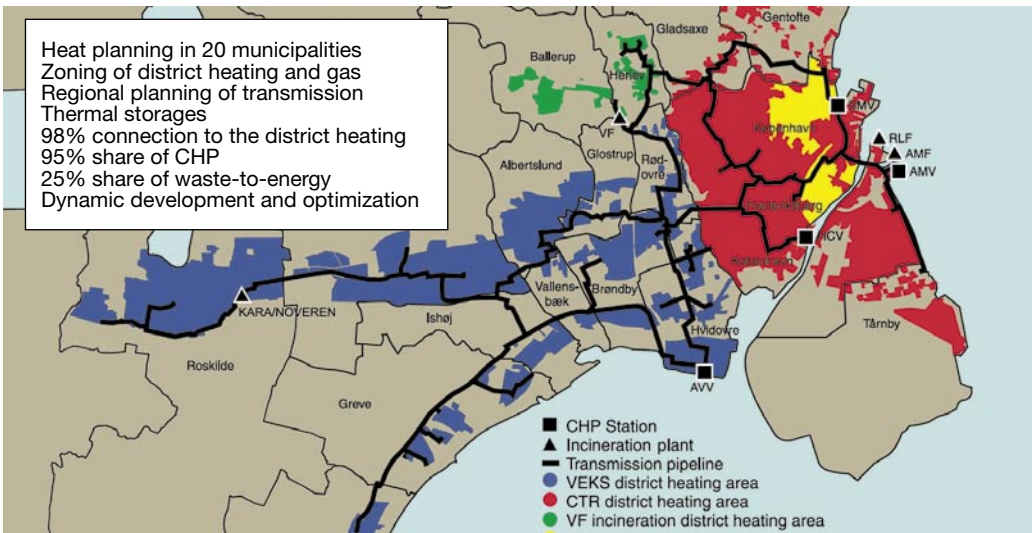


Figure 10. Copenhagen district heating network

Table 1. The major CHP and waste incineration plants in greater Copenhagen area

CHP plants		Fuel	Capacity (heat)	Capacity (electricity)
			[MJ s ⁻¹]	[MW]
Amagerværket (AMV)	Unit 1	Biomass, coal, fuel oil	250	80
	Unit 2	Biomass, fuel oil	166	95
	Unit 3	Coal, fuel oil	331	263
Avedøreværket (AVV)	Unit 1	Coal, fuel oil	330	250
	Unit 2	Gas, biomass, fuel oil	570	570
H.C. Ørsted Værket (HCV) (fig. 14)		Gas	815	185
Svanemølleværket (SMV) (fig. 16)		Gas, fuel oil	355	81
Waste incineration plants				
Amagerforbrændingen (AMF)		Waste	120	25
Vestforbrændingen (VF)		Waste	204	31
KARA/NOVEREN		Waste	69	12

Today, Copenhagen start building the new waste-to-energy facility, which will replace adjacent 40 years old Amagerforbraending plant (figs. 17 and 18). The building reflects the progressive vision for a new type of waste treatment facility. The roof of the new Amagerforbraending is turned into a 31.000 square meter ski slope of varying skill levels, mobilizing the architecture and redefining the relationship between the waste plant and the city by expanding the existing recreational activities in the surrounding area into a new breed of waste-to-energy plant [5].



Figure 11. Avedøre CHP (AVV)

Avedøre CHP (figs. 11 and 13)

Located at suburb of Copenhagen

CHP multi-fuel gas:

- coal 40.26%,
- oil 10.44%,
- natural gas 23.28%,
- straw 5.08%,
- wood pellets 20.94%,

Heat accumulators $2 \times 22.000 \text{ m}^3$

Waste water treatment plant

Wind

Electricity for 1.3 million homes

District heating for 200,000 homes

Amagerværket CHP (fig. 12)

Located at suburb of Copenhagen

CHP biomass, coal

Capacity, electricity: 4.552 MW

Capacity, heat:

2.660 MJ/s (heat)

1.712 MJ/s (steam)

Waste-to-energy

Geothermal energy

Waste water treatment plant

Sludge incineration

Wind

Biogas to city gas

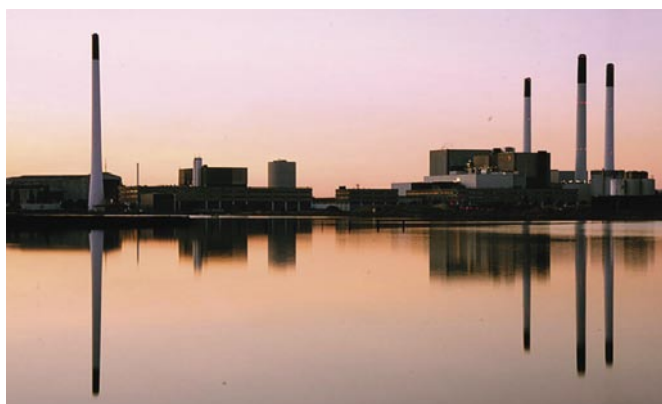


Figure 12. Amagerværket CHP (AMV)

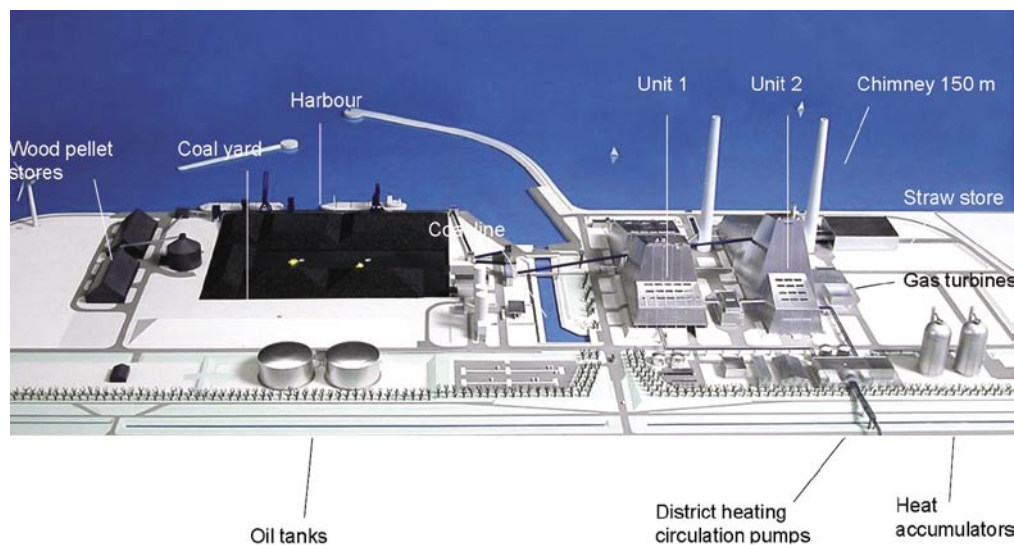


Figure 13. Avedøre CHP (AVV) plan



Figure 14. H.C. Ørsted Værket (HCV)



Figure 15. Offshore wind turbine near Copenhagen



Figure 16. Svanemølleværket (SMV)



Figure 17. New Amager waste-to-energy plant

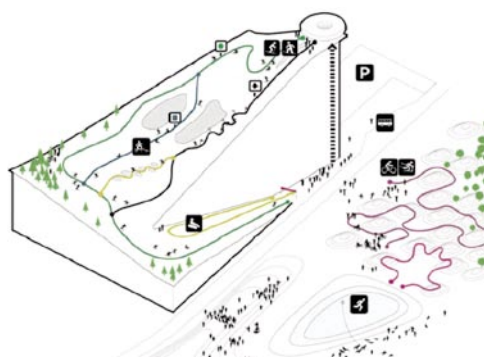


Figure 18. Ski slope roof of new Amager plant

Vestforbrænding (VF) (fig. 19)
Largest waste-to-energy in Denmark
4 incineration units
Max. 600.000 tons of waste per year
All waste from the region
23% elec. eff. CHP
100% total efficiency with flue gas condensation
100% use of surplus heat



Figure 19. Vestforbrænding waste-to-energy

Kara/Noveren CHP (fig. 20) Waste-to-Energy plant in Roskilde, west Copenhagen, starting within 2013 and supply electricity for approx. 65.000 homes, and heat for approx. 40.000 households.

Between 30% and 40% of total Danish energy consumption is used for heating, ventilation and lighting in buildings (fig. 21 and 22). New sustainable buildings interact with the energy infrastructure: district heating, district or ground source cooling, low energy electronics and efficient digital infrastructure. Special attention is paying in laying the correct size cables to facilitate different demands including charging stations for electric cars, also to buffer tanks installation to increase the flexibility of possible heat-pump installation and architectural design to increase volume of natural light [3].



Figure 20. Kara/Noveren waste-to-energy

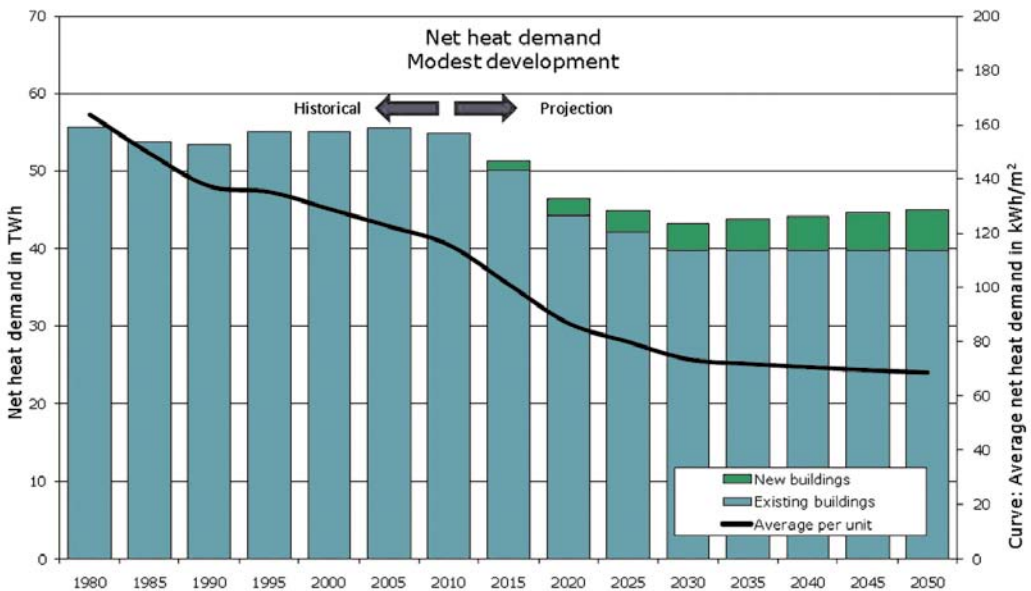


Figure 21. Total heat demand and net heat demand for buildings in kW/m^2

Beside the district heating, buildings of the future must be prepared for the electricity-consuming and electricity-producing appliances that will play a central role in the Smart Grid. It is important to focus on establishing a basic digital infrastructure in both new and existing buildings in the form of data-communication options and digital building management.

According to the regulations, a supplier may not charge any more or any less for heat than it costs to produce it. These costs include the following: fuels, installations, grids and

pipelines, buildings and inventory, installation and grid maintenance, operation/administration salaries, insurance, CO₂ taxes, energy taxes and taxes on fuels (fig. 23).

Copenhagen is an example that district heating, in interaction with CHP, will be an instrument to secure high energy efficiency in large cities which are densely populated and developed similar to Copenhagen. District heating is also an effective mean to increase the share of renewable energy. District heat supplied from biomass CHP, geothermal heat plants, heat pumps, solar heating and industrial surplus heat can be implemented effectively in the district heating system.

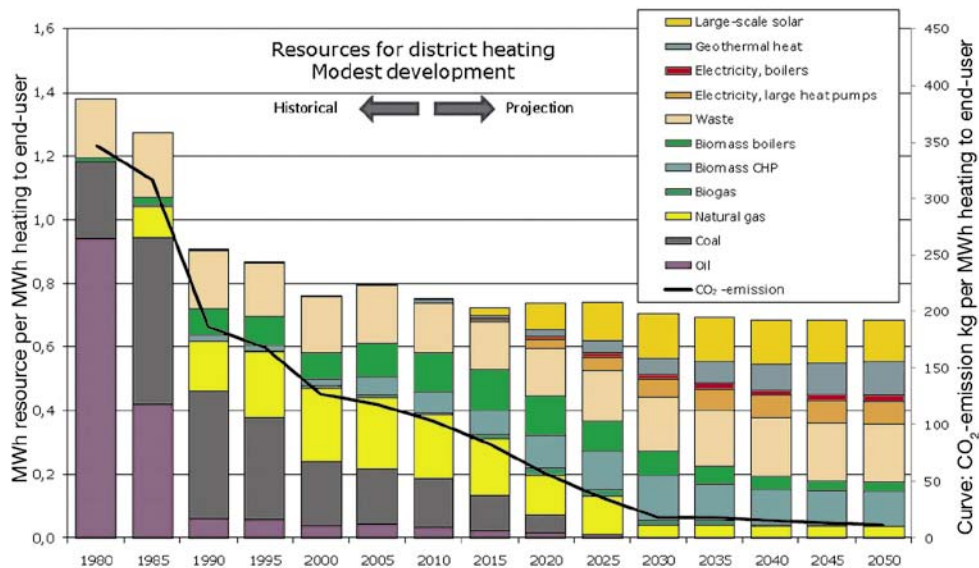


Figure 22. Fuel consumption per unit of district heating delivered to end user [7]

DKK in current price

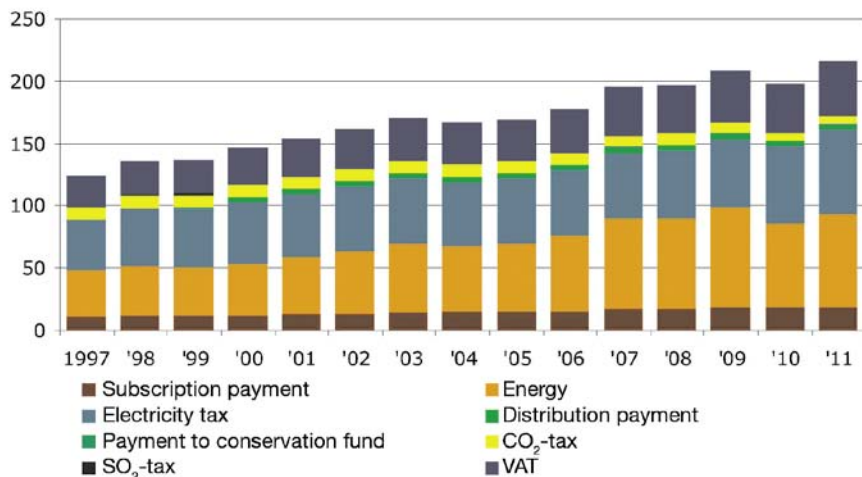


Figure 23. Electricity price structure for households

Denmark has the lowest energy consumption per unit of GDP in EU and highest contribution to electricity from new renewable in the EU. Denmark has achieved a de-coupling of economic growth and energy consumption since 1980: GDP grew 78% in 2007, but the primary energy consumption was only 7.4% higher in 2007 than in 1980 and CO₂ emissions per capita have been reduced substantially: 20.5% lower in 2007 compared to 1980. The de-coupling has been driven by the policies to promote district heating and energy savings as well as renewable energy [7].

In Denmark, thanks to the high development of different and decentralized energy sources, the intelligent energy system is more about the interaction between diverse system components than about the components themselves.

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