Blowing in the wind

A brief history of wind energy and wind power technologies in Denmark

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Combined Heat and Power

Heat Infrastructure Planning in Denmark – A Short History

The Quiet Life of District Heating in Denmark

The small Scandinavian country of Denmark is ranked among the top-countries in the world according to the World Energy Council (WEC) energy trilemma of energy security, energy equity and sustainability.

Within energy- and engineering communities, Denmark is known for its wind power technologies and for integration of wind power in the grid, with wind power now supplying almost 50% of the national electricity consumption. In comparison, combined heat and power plants (CHPs), district heating technologies and the underground network of district heating infrastructures throughout urban and rural parts of the country have lived a more quiet and anonymous life. However, these underground and rather inconspicuous collective heat infrastructure networks and CHPs are fundamental for the energy efficiency of the Danish energy system and for the top WEC ranking of the country.

From their primitive beginnings, electricity- and thermal energy infrastructures throughout Denmark evolved to include electricity- and heat generation plants combined. Centralized multi-utilities typically serve the urban and suburban areas while de-centralized CHPs and heat only production plants serve the more rural areas. Utilities vary in terms of size and scope, technical combinations and solutions, fuel use and fuel combinations, ownership structures, heat supply areas and end-user types.
The nationwide collective heat supply infrastructures - and the widespread integration of CHPs in these - may be viewed as the result of multiple historical events, subsequent societal trends and political priorities. These comprise a national history of energy import dependency, collective experiences of energy scarcity, the cooperative culture and mindset, welfare state ideologies, a pragmatic approach to solving local energy supply challenges, bottom-up initiatives, top-down policy support and – notably - nationwide electricity- and heat infrastructure planning initiatives. This brief historical account summarizes this story.

Text Box 1: District Heating - Energy Efficiency, Energy Flexibility and Fuel Diversification

The fundamental idea of district heating is to harvest otherwise wasted heat from, for example, the production of power in combined heat and power plants (CHPs) and from other industries. District heating systems enable the integration various fuels into the energy system, for example renewables, such as wind, solar and biomass, and relatively low quality fuels, for example household waste. District heating systems enable short-term (daily) and long-term (seasonal) thermal energy storage, and the technical solutions, combinations and fuel usage in individual district heating systems can be adapted to specific local contexts, and to the locally available fuel resources. All of these characteristics may improve energy systems efficiency overall and facilitate the energy flexibility necessary for integration of more intermittent renewable energy resources into the energy system.

The First Combined Heat and Power Plants

The city of Hamburg suffered a cholera outbreak in 1882, and adjacent towns prohibited the import of waste from Hamburg in order to protect themselves from the epidemic. The citizens of Hamburg now turned to burning household waste in the streets. To solve this growing waste management problem, the city of Hamburg constructed a waste incineration plant that generated heat for heating purposes.
In neighboring Denmark, household waste management also became a growing challenge as populations increased due to industrialization and urbanization processes. In the municipality of Frederiksberg, adjacent to Copenhagen, the emergent industrial sector attracted workers from afar. Waste piled up on street corners and in the small open spaces, and the now 75,000 inhabitants were keenly aware of the health risks associated with these mountains of waste. In Copenhagen municipality, the population was also growing rapidly, and therefore land for landfills was expensive. Moreover, landfills within close proximity of densely populated areas were also associated with the risk of epidemics.

Inspired by the example from Hamburg, Frederiksberg Municipality set out to solve this problem and constructed the first primitive waste incineration plant in Denmark. Inaugurated in 1903, this waste incineration plant produced heat *and* electricity. Horse-drawn carriages transported the household waste to the waste incineration plant. Via tunnels and in the form of steam, heat from the incinerator was transported to a newly established hospital, an orphanage and a house for the poor nearby.

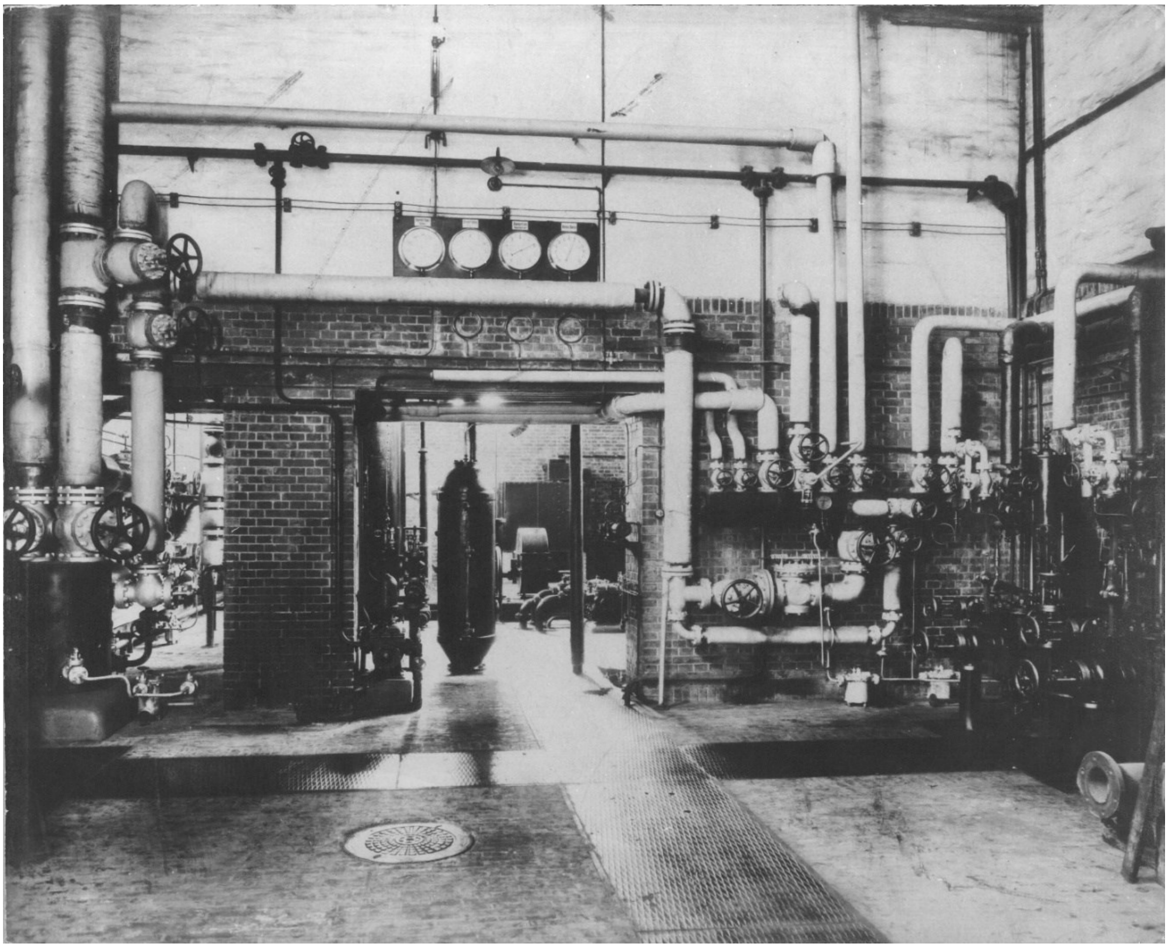

Figure 1. The incineration plant. 1903. Printed with permission from Frederiksberg Forsyning.

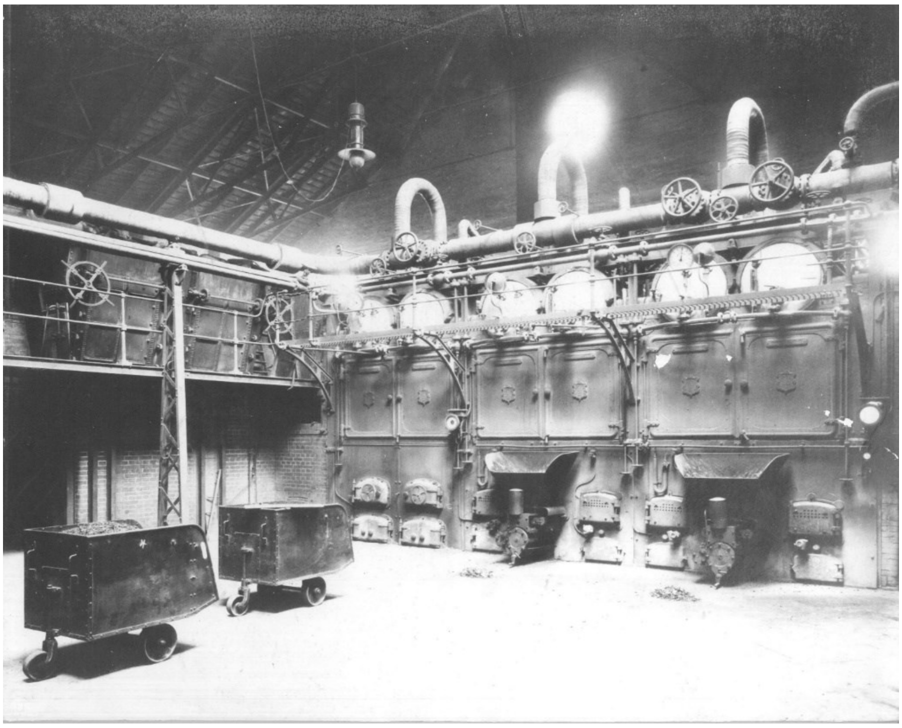
Figure 2. The incineration plant. Ovens. 1903. Printed with permission from Frederiksberg Forsyning.


Figure 3. The incineration plant. 1903. Printed with permission from Frederiksberg Forsyning.

Throughout the country, this first primitive CHP proved inspirational. Fuel import dependency and experiences of energy resource scarcity during WWI called for energy efficiency initiatives and motivated the integration of CHPs into the energy system. District heating emerged in the larger Danish cities in the 1920s. Power plants throughout Denmark were due for renovation, and many municipalities converted their power plants to CHPs that provided heat for dwellings or institutions close by.

From the early days, the Danish cooperative movement found new footing within the growing energy sector. Seeking to ensure local stability of heat supplies, local cooperative groups throughout rural Denmark jointly financed and managed local district heating plants.
In the small import-dependent country, WWII - again - led to an energy crisis. At some CHPs, heat-only boilers were constructed as heat supply backup. After the war, the existing district heating networks were expanded to integrate this new and additional heat production capacity. Coal was still the prioritized fuel.

Text Box 2- District Heating Technologies improve

The very first district heating pipes corroded easily. Insulation with mineral wool rectified this problem, but this solution was expensive, and therefore district heating was only viable for large-scale end-users such as institutions and industry. In the 60s, pre-insulated district heating pipes using a non-corrodible plastic jacket provided the solution. Initially, the heat tolerance of these pipes was only about 90 ^{0}C. As this material – again - improved, the heat tolerance rose to approximately 120 ^{0}C. Some district heating suppliers also advocated lower supply temperatures in the 60s. Lower supply temperatures were subject to less regulation and control. This reduced the need for employees at the heat generation plants and lowered the price of district heating.

50s and 60s - The Welfare State and Population Growth

Industrialization, social, and economic change reshaped the country in the decades after WWII. Small-scale agricultural productions were no longer viable and land was scarce. From all over the country, workers and their families migrated to the cities searching for work.

The Danish public sector grew in the 50s and 60s. As did the role and importance of the growing Danish welfare state. All citizens, poor and rich, were viewed as eligible for social welfare, and social welfare comprised all societal sectors. All through the country, municipal institutions were established. Growing populations and urbanization led to the growth of the suburbs. Increasingly popular due to the improved district heating technologies, many of the new suburbs were planned with underground district heating infrastructures. Municipalities, sometimes jointly, invested in large centralized CHPs. For the end-users, district heating provided affordable, accessible, stable and convenient heat supplies that required little in the form of service and maintenance.

Figure 4: Compensator in Søndre Allé, Århus, Denmark. 1928.
Printed with permission from Affaldvarme Århus.

Figure 5: Installing 300 mm main pipes across Aarhus Creek, 1955.
Printed with permission from Affaldvarme Århus

Figure 6. Printed with permission from Affaldvarme Århus

In the 60s, preliminary explorations for oil and gas had taken place in the Danish part of the North Sea, and the private entrepreneur, A.P. Møller-Mærsk, was awarded the concessional rights to explore and to exploit these reserves of oil and natural gas. In 1972, the first oil was extracted from the oil platform Dan-field. That same year, the commercial transmission company for natural gas (D.O.N.G. A/S, now known as Ørsted/ Orsted) was established with the Danish state as the only shareholder.

The Global Energy Crisis and National Scale Collective Heat Infrastructure Planning

The energy import dependent country suffered during the global energy crisis in the 70s. Short-term and long-term remedial measures targeting energy efficiency were introduced. All members of society felt their effects and limitations. Thus, policymakers - and the Danish public - warmly welcomed the newly discovered oil and gas reserves within national sea territories. An alternative to the unstable imported oil, this discovery sparked hopes for energy independence in the future.

The Danish government now set out to create a long-term strategy for energy resource availability. The resultant Danish Energy Plan of 1976 focused ensuring stability of energy supplies via the overall energy policy goals: energy independence, fuel diversification, and energy efficiency. The multiple energy efficiency-, fuel-diversification- and energy infrastructure planning initiatives laid out in this plan focused on increased harvest of waste heat from industry, integration of CHPs into the energy system, integration of locally available energy resources into the energy system, and on the harvest of renewable energy resources.

Figure 7. The oil crisis, 1973. Credits: the Danish Energy Agency.

1903	First waste incineration and DH plant in Denmark built in Frederiksberg Provided heat and electricity for municipal institutions
1914	1914-1918: WW I
1920s	1920s-1930s: District heating infrastructures and CHPs develop
1939	1939-1945: WW II
1957	The Danish Association for District Heating is established
1962	Maersk awarded the right to investigate and exploit oil and natural gas resources in the Danish part of the North sea. Danish Underground Consortium (DUC) established
1973	1. International Energy Crisis
1976	The Danish Energy Agency (DEA) established. The Danish Energy Plan 1976 prepares for long-term energy policy
1979	2. International Energy Crisis
1979	1st Heat Supply Act: Natural gas integrated into the heat supply infrastructures via the planning concept of 'zoning'. Focus on power generation via CHPs. Aimed for harvest of waste heat from other industry
1981	National scale heat planning throughout the country starts
1984	Extraction of natural gas from the Danish part of the North Sea begins
1986	The political co-generation agreement. Emphasis on small-scale CHPs
1990	Energy 2000: The first plan for low-carbon energy transitions in the world. 2nd Heat Supply Act. Heat infrastructure planning decentralized. Specific prerequisites regarding fuel choice and co-generation sent to a number of Municipal Counties
2000	3rd Heat Supply Act: Improved conditions for small- and medium-sized decentralized CHPs and bare field plants

Table 1: The First Century of District Heating in Denmark

1979: 1st Heat Supply Act

The first Heat Supply Act (HSA), adopted in 1979, provided the legal framework for the heat planning initiatives ahead. The purpose of this Heat Supply Act was to promote the most socio-economic use of energy for heat provision and hot water and, given the above, to reduce energy import dependency. An additional purpose of the Heat Supply Act was to integrate the newly discovered Danish North Sea oil and natural gas into the national energy system.

National scale heat- and energy infrastructure planning ensued. As a part of this energy planning, a process referred to as **'zoning'** strategically identified and mapped out non-overlapping heat supply areas (or zones) for natural gas infrastructures and district heating infrastructures. To ensure the most efficient heat supplies for the citizens, the zoning process compared the costs of natural gas networks, district heating networks and individual household boilers within given geographical areas, and it ensured that heat from CHPs and waste incinerators supplied local district heating systems via transmission systems. In short: 'zoning' prevented internal competition between the two heat supply sources; it ensured a healthy economy throughout the heat-supply infrastructure system, and that the overall objectives of the Heat Supply Act were met.

The Danish public supported the government energy planning and policy initiatives targeting energy efficiency and energy independence. Perhaps due to the collective memories of and grievances associated with the global energy crisis, people were ready for change.

Text Box 3 – The Heat Supply Act, General and Specific Executive Orders

The Heat Supply Act empowers the relevant minister to determine the criteria for municipal heat planning via general and specific executive orders. **General executive orders** ensure that the policy ambitions of the Heat Supply Act are met in municipal heat planning. These may specify criteria for heat supply provision, for example issues related to security of heat supplies, environmental concerns, economic concerns, fuel supply criteria, technological change, time-frames for conversion schemes, geographical boundaries for different heat supply sources, and the 'social economy' of heat supply infrastructures over all. **Specific executive orders** concern specific and named geographical areas. These may determine criteria for fuel choice, limitations to or boundaries between different types of heat supplies etc.

The Non-profit Principle for Heat Pricing and the Obligation to Connect

The **"obligation to connect"** to collective heat supply infrastructures was adopted in 1982. The obligation to connect allowed Municipalities to mandate the connection of municipal building stock to the collectively planned local heat infrastructures. This ensured a stable group of end-users/heat consumers, and thus a stable economy for the heat suppliers. Citizens subject to the obligation to connect were obliged to pay the annual subscription fees - but not to *consume* district heating. Not all municipalities enforced the obligation to connect, and some only enforced it partially.

The underground district heating infrastructures were typically financed via very favorable and long-term loans (e.g., 20 – 50 years) afforded by the **Municipal Credit Bank,** owned and managed by the Danish Municipalities. The **non-profit principle/the principle of necessary costs determined** the final price of heat for the end-user. It still does. According to this pricing principle, the final price of heat service provision for the end-user comprises the total and necessary costs of heat service provision. These include heat generation-, transmission- and distribution; heat infrastructure investments, management, service etc.

80s - The Scramble for Oil and Gas: State vs Maersk

In 1980, American experts estimated that the Danish North Sea oil and gas could provide Denmark energy independence up to 20 years, and activist groups mobilized public support for the argument that rights to these natural resources belonged to the Danish State. Not to Maersk and the Danish Underground Consortium (DUC).

The Danish Government initiated negotiations regarding return of national territorial subterranean resources to the Danish State. 294 days on, and the parties were no closer to an agreement. Slightly stricter concessional terms were later agreed upon, however. The Danish state demanded faster extraction of the natural resources and secured rights to 40% of the production. Natural gas production began in 1984, and Danish North Sea oil and gas generated revenue for the first time in 1988.
In the following decades, the state-owned transmission system for gas from the privately owned North Sea oil fields were gradually incorporated in the national heating infrastructures. Tax revenues from the oil and gas benefitted the struggling Danish economy and financed the growing costs of the Danish welfare state.

90s - Energy Independence and Growing Environmental Awareness

The Danish Energy 2000 Action Plan from 1990 was widely considered the first strategy for greenhouse gas reductions in the world, and it set the scene for the low-carbon energy transitions and sustainable development initiatives ahead. This plan aimed to reduce energy consumption levels and $C0_2$ emissions nationally, planned for phasing out coal, suggested subsidies for energy efficiency initiatives and for renewables integration into the grid; introduced environmental taxes, suggested energy labelling of buildings, control of heat-related infrastructures, and increased energy regulation in larger building stock.

By the 90s, the economy of the natural gas project was not doing well.

The 2nd revision of the Heat Supply Act in 1990 integrated the objectives of the Energy 2000 Action Plan. Among other initiatives, these were to increase the number of CHPs in the national heat supply infrastructures and to support the economy of the national natural gas project. With the 1976 Energy Plan heat infrastructure planning ambitions more or less reached, future heat infrastructure planning was decentralized. Local councils were now the relevant heat planning authorities, and future heat infrastructure planning initiatives would take place on more of a project-to-project approach. In practice, future heat infrastructure planning activities ensured the logical continuation of the previous 'zoning' practices. The use of natural gas and biomass was encouraged.

In September 1990, the Energy Minister sent general executive orders (national level) to all of the Danish municipalities. These concerned the choice of fuels, co-generation (CHPs), criteria for the conversion of existing heat production plants into co-generation plants, and for the construction of new ones. Local councils in some Danish municipalities received specific executive orders (municipal level). Some of these mandated the conversion of specific and named heat production plants into co-generation plants or to biomass plants before 1998, and others the conversion of specific coal-powered plants.
Softening the vocabulary of these ministerial orders somewhat, the minister at the time rearticulated them as 'writings of precondition'.

Bare Field Plants

Following the revision of the Heat Supply Act, the nationwide district heating networks were extended with the popularly labelled 'bare field' plants. Typically, bare field plants were natural gas fuelled decentralized CHPS serving smaller towns or villages. Heat distribution networks were established at the same time as the heat production plants at these decentralized CHPs, and the heat was generated via a natural gas powered motor. In this way, the natural gas companies had none of the risks associated with a natural gas distribution network.
When the bare field plants were constructed, the price of electricity was high and the price of gas was low. Despite high rates of heat-loss in the heat distribution network, then, the economy of the bare field plants was sensible from the outset. However, the price of natural gas increased unexpectedly, and the economy of the decentralized CHPs suffered. For the end-users, this meant increasing heating bills.

Technologies that allowed for the use of biomass and biogas in the energy system matured rapidly during these years. The biomass agreement was adopted, and with this agreement also ambitious plans for biomass integration into the energy system by the year 2000.
In May 1998, Denmark was energy self-sufficient. The country no longer relied upon energy imports.

The Heat Supply Act was revised for the third time in the year 2000. With this 3rd revision of the Heat Supply Act, a political majority voted for supporting the bare field plants economically. The gas companies also contributed. Further economic support was granted in subsequent years.

2000s - Biomass- and Wind Power Integration in the Grid

As environmental awareness and concern grew, the policy focus on energy independence, fuel diversification and energy efficiency translated easily to the growing focus on sustainability and low-carbon energy transitions among policy makers and among the public. Green speak and calls for action that promoted the sustainability agenda were the order of the day.
The turn of the century marked an era of large-scale biomass- and wind power integration into the Danish energy system. For the national heat supply infrastructures and CHPs, this meant novel challenges and potentials.

From the outset, biomass was (and still is) tax-exempted and considered a low-carbon fuel. Throughout Denmark, transitions to biomass happened with incredible adaptability and transitional speed, but the use of biomass far outgrew locally and nationally available biomass resources. Biomass is now imported from several continents, and the sustainability of these large-scale biomass imports is debated.
Low-carbon energy transitions in Denmark relies heavily on wind power integration in the grid. Wind power is intermittent in nature, however, and subject to the logic of supply and demand. Rapid electrification of the grid has resulted in highly fluctuating and lower prices of electricity, thus challenging the traditional role and economy of CHPs in the Danish energy system.

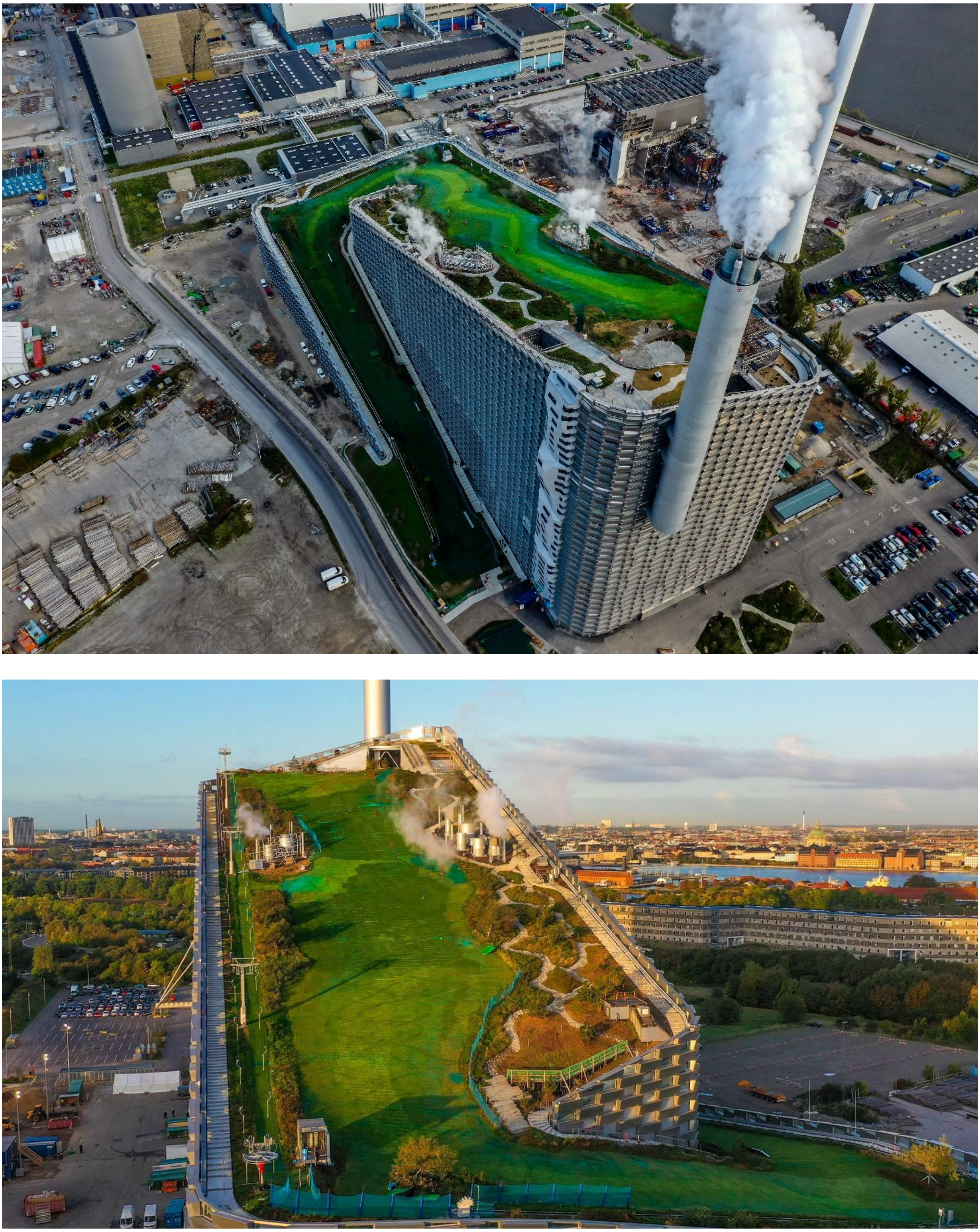

Figure 8. Combined heat and power waste-to-Energy plant, CopenHill. Copenhill is also an outdoor recreational facility with an artificial ski-slope and other outdoor activities on the roof. Copenhill opened in 2017. Credits: Press/CopenHill.

Change Readiness? Reflections from the Past and Looking into the Future

In the future, large-scale industrial heat pumps and the various short-term- and long-term thermal storage capacities of district heating infrastructures may facilitate the energy flexibility and sector coupling processes needed for the integration of increasing ratios of intermittent renewables into the Danish grid. Such and similar technical combinations are only just being integrated into the Danish energy system, however.

Visionary politicians and members of the public *did* push for environmental awareness in Danish energy planning and policy from early on, and the story of Denmark as a frontrunner in the global race towards low-carbon energy transitions is a popular and widespread narrative.
In this popular account of early climate change action, some key factors are sometimes strangely absent, however. For example, the role and importance of the collective societal experiences of the energy- and economic crisis in the 70s, and the importance of the Danish North Sea Oil for the Danish economy and for the Danish welfare state. Moreover, while prioritizing renewable energy technologies was an economic risk initially, as the potential for large-scale exports of these technologies and related knowhow grew, choosing the renewable energy route ahead proved environmentally *and* economically rational for policymakers.

As celebrated in the top WEC ranking of the Danish energy system, the energy infrastructures in Denmark now meet the policy priorities of energy security, energy equity and sustainability. The small country of Denmark also ranks among the top countries in the world on another list, however: carbon footprint per capita. Life-style and consumption levels are private matters for Danish citizens. These are not subject to any restrictions, and resistance to large-scale renewable energy infrastructure projects now seem almost more the norm than the exception.

Would national-scale and collective energy infrastructure planning processes similar to those in the 80s be possible – *and supported* – in Denmark today? Some authority experts involved in the energy planning processes at the time hold that it would not. Collective memories of the global energy crisis have faded through time. With this temporal distance, they subtly suggest, the wider public have come to take absolute security of supplies and the rights to consume energy for granted. Others emphasize that although end-users may not be very much aware of their everyday energy use, they have noticed increasing environmental awareness and concern among the public.
Climate activism among particularly younger generations around the globe in recent years, and the growing international push for further political focus on global resource limitations, support the latter. Perhaps local and national publics are, albeit slowly, mobilizing readiness for change.

Suggestions for further reading

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Suggestions for Text Highlights

The underground and inconspicuous collective heat infrastructure networks and CHPs are fundamental for the energy efficiency of the Danish energy system and for the top WEC ranking of the country.

The fundamental idea of district heating is to harvest otherwise wasted heat from, for example, the production of power in combined heat and power plants (CHPs) and from other industries.

District heating systems facilitate integration of an array of fuels into the energy system, short-term (daily) and long-term (seasonal) thermal energy storage, and their technical solutions and combinations can be adapted to specific local contexts.

For the end-users, district heating provided affordable, accessible, stable and convenient heat supplies that required little in the form of service and maintenance.

District heating systems may improve the energy efficiency of energy systems over all, and facilitate the energy flexibility necessary for integration of more intermittent renewable energy resources into the energy system.