Decarbonization of heating

AN INTEGRATED PERSPECTIVE

Danfoss Climate Solutions Public & Industry Affairs, March 2023

Introduction

This paper addresses the decarbonization of heating from an integrated energy system perspective, building the bridge between the demand and supply side of energy and decentralized as well as centralized solutions such as heat pumps and district energy grids. It considers the total cost of ownership on how to achieve the "sweet spot", where the societal cost of the energy transition is at its lowest level, making it a positive business case for consumers, energy suppliers, and technology providers alike.

Heating and cooling are an intrinsic part of society – from heating and cooling in our homes to industrial processes and cold chains of food production, medicine, vaccines, etc. For centuries, our society has been relying on fossil fuels to power heating and cooling. Either by using them as a primary energy source, with oil and gas being particularly relevant for heating purposes or to generate electricity, which is generally used to power cooling. However, to address climate change and limit global warming to 1.5°C, as set out in the Paris Agreement, the decarbonization of heating and cooling has to become a top priority. Heating and cooling account for half of the total final energy use in the world and the majority of global greenhouse gas emissions are related to the production and consumption of energy [1]. The aim of this paper is to summarise the main avenues towards decarbonization with a view to supporting the EU's and global energy and climate goals.

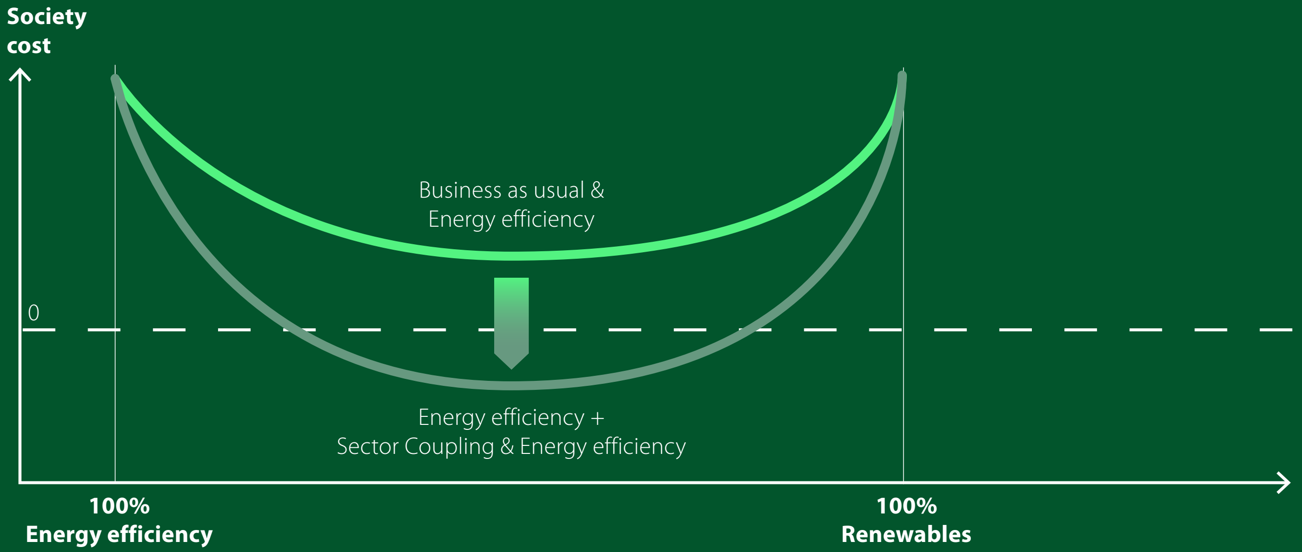
The decarbonization of heating and cooling must be seen in the context of an integrated energy system and consider financial challenges as part of the overall environmental and technical context. Main steps:

1. The energy supply needs to be decarbonized and electrified. This entails a massive shift away from fossil fuel-generated energy towards the use of renewable energies which needs to double between 2019 and 2030 according to the International Energy Agency [2]. This will require enormous capital investments in energy production and distribution with societal implications, calling for an increased focus on the demand side to keep the burden as low as possible.

2. The energy demand needs to be optimized via three main levers to enable the lowest capital investment in the energy supply sector:
   - **a)** Reduction of energy consumption
   - **b)** Adding demand-side flexibility to mitigate fluctuations in renewable energy supply and
   - **c)** Integration of heating and cooling in the energy system.

3. In short, optimizing operational cost (OPEX) via the three levers as per point two will lead to minimizing capital investments (CAPEX) as per point one, and thereby reduce total cost.

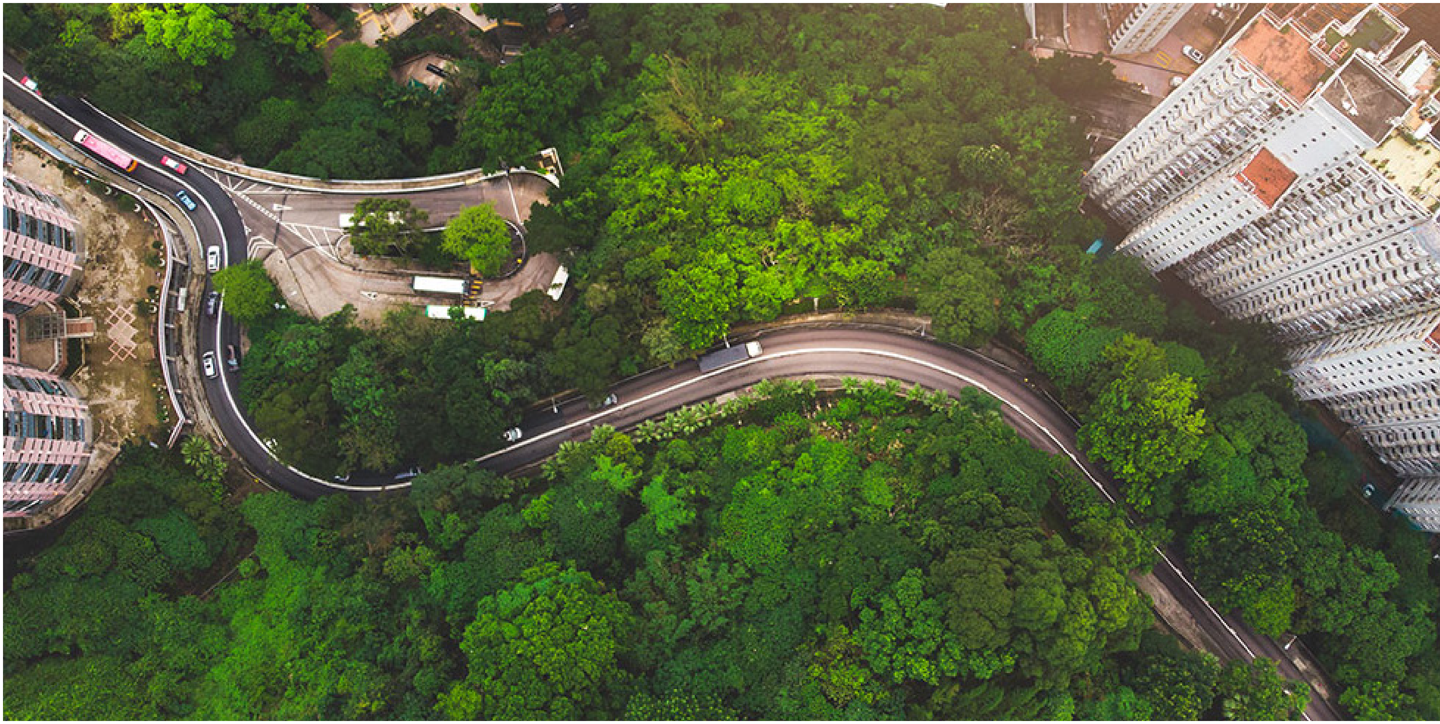
The following graph is a simplified way to illustrate this approach.



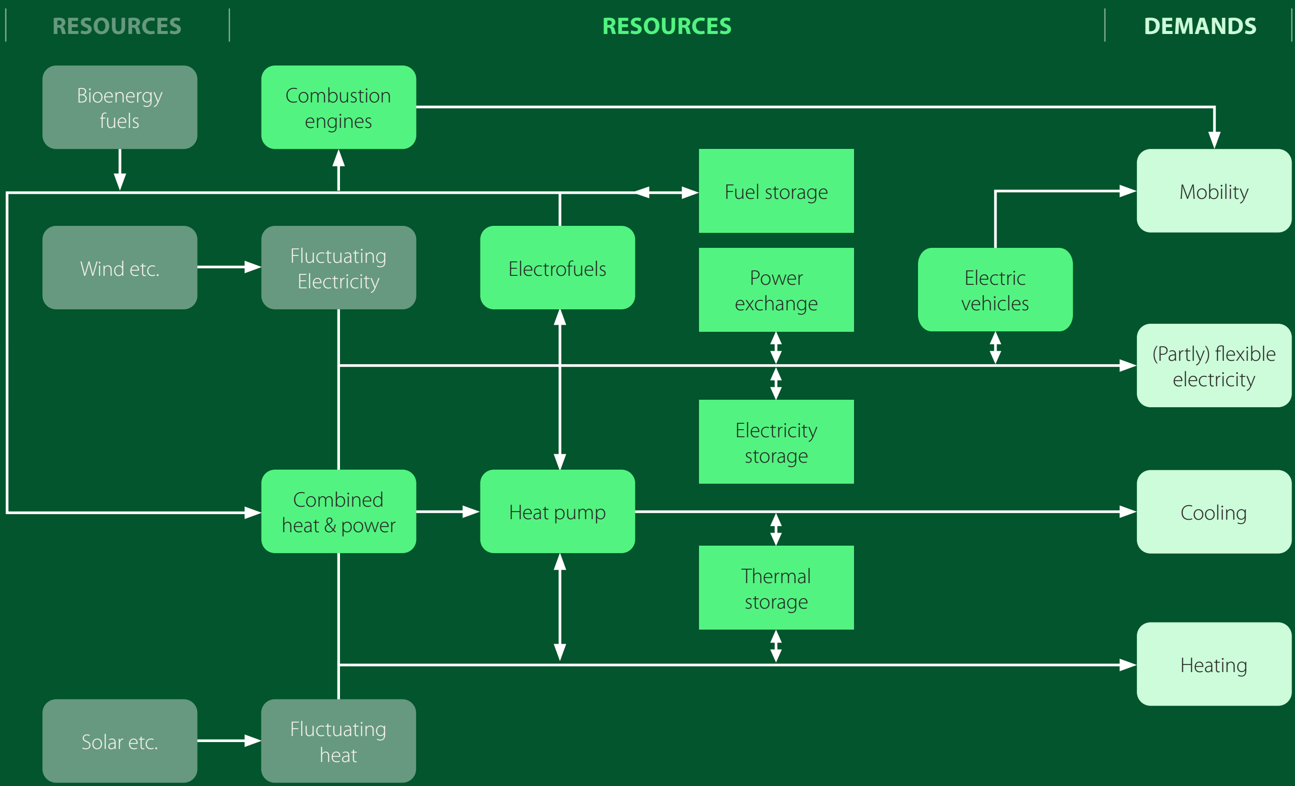
The graph plots energy efficiency and renewable energy supply versus the cost for society, illustrating the importance of combining both to keep costs at their lowest level. Focussing on energy efficiency measures alone would steer the market towards higher renovation rates and higher efficiency products. While this is a positive development trend per se, at its extreme, it would come at a high cost for society and benefits may be challenged due to rebound effects. On the other hand, focussing on renewable energy supply alone – also a positive development in itself – would, at its extreme, increase the average energy consumption and lead to overcapacity as utilities need to cater for peak demand. Therefore, a healthy dose of both is needed. As the energy system is transitioning towards renewable energies, implementing the right energy efficiency measures will lower the total cost for society. However, with an increasing share of renewable energies in the energy system, costs will start to increase, as energy efficiency alone will not be able to compensate for the growing cost of a reinforced electrified infrastructure (see the Business as Usual (BAU) Energy Efficiency (EE) Scenario). Peak demand driven by heat pumps and electrified transport is the governing factor, as utilities need to ensure the resilience and stability of the energy system, even at peak loads.

Lowering peak loads by combining energy efficiency measures and sector coupling to support the transition towards renewable energies, can reduce costs significantly while creating resiliency and a robust energy system. Sector coupling means an active alignment and control of energy supply and consumption. The most prominent example is demand side management (DSF) where e.g. heating is provided by a heat pump while electricity is cheap and green. Danfoss is committed to providing technologies for the "sweet spot" where societal cost is at its lowest level, making the energy transition a positive business case for consumers, energy suppliers, and technology providers.

This paper gives our best suggestions for solutions needed to achieve this 'sweet spot' goal. It looks at the key building blocks that enable a realistic smart integrated energy system, thereby contributing to the affordable decarbonization of heating and cooling while increasing the share of intermittent renewables. These are solutions that are verified and readily available in the market. They cover various aspects across energy generation, energy efficiency distribution, and consumption that are critical to the successful creation of a smart integrated energy system. They enable an 'end-to-end optimization' across the entire energy value chain, from heat emitter to energy source, turning energy-consuming sectors such as buildings into active parts of the energy system.



The following graph by Aalborg University provides an overview of such a system [3].



Principal interaction between sectors and technologies in a future smart energy system.

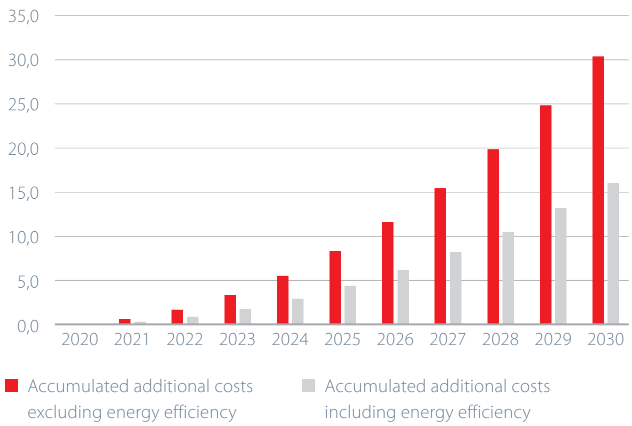
In the next chapters, we will investigate the different building blocks, from energy efficiency via solutions such as heat pumps, district energy, and the utilization of waste heat, as well as demand side flexibility and new business models based on the digitization of the energy system.

Energy efficiency first as a guiding principle

As a first step, energy efficiency is the main building block for an affordable energy supply [4]. Reducing energy demand through energy efficiency improvements will directly reduce the CO_2 emissions from fossil fuel-powered plants and therefore reduce unnecessary power investments in renewables. Indeed, improvements in energy efficiency can contribute more than 30% of the reduction of energy-related greenhouse gas emissions that is required over the next two decades to put the world on a path to meeting international energy and climate goals. [5]

Energy efficiency is governed by various regulations from technical systems to building directives. The challenge is finding the most cost-efficient solution, i.e. to address the coefficient of performance (COP) versus the cost. The solution depends on various factors. New buildings are covered by building directives and must comply with the latest efficiency standards. However, the vast majority of the building stock is old and inefficient. Directives such as the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) are stimulating renovation, but this will take time as deep renovation rates are still below 1% in the EU [6].

A study commissioned by Danfoss [7] for Denmark, shows how to achieve a 70% reduction in CO_2 emissions by 2030. The results are illustrated in the graph below which shows the abatement cost of CO_2 emission reduction. A negative value means that the implementation of the measure will have a direct payback. The graph shows that energy efficiency is the most cost-effective measure. In countries with lower energy efficiency of buildings, the difference will be even more striking.



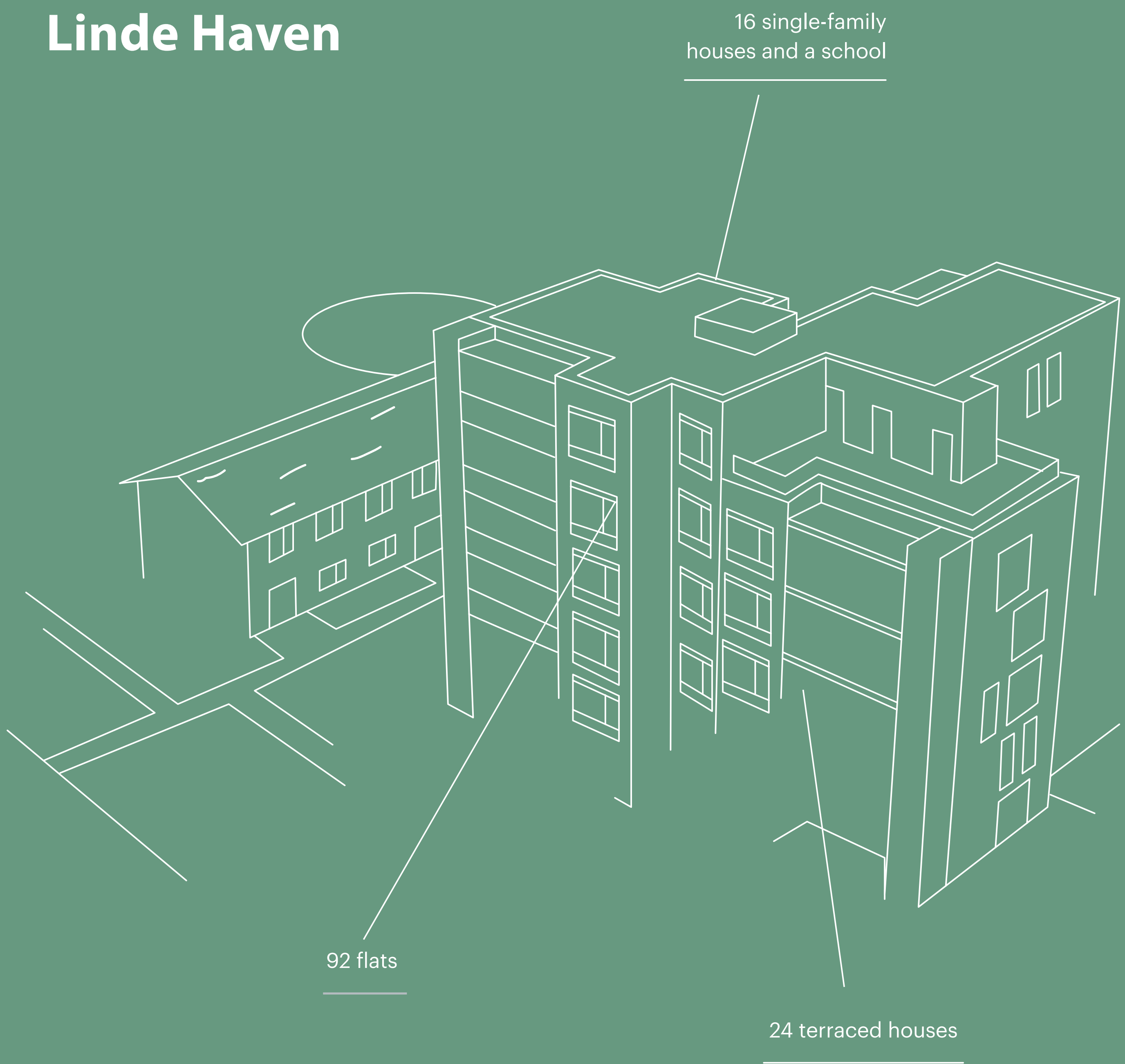
Accumulated additional costs for achieving a 66 percent reduction in grenhouse gases by 2030, including and excluding energy efficiency costs respectively. The costs do not include initiatives adopted by the 2018 Danish Energy Agreement; similarly, mitigation contributions from agriculture and the environment have not been valued. The reduction costs are calculated for 2030. The reduction plan and dosing procedure for initiatives between 2020 and 2030 has not been analyzed; the indicated costs presume a linear development in the cost process between 2020 and 2030.

The solution:
Zero-carbon-ready city areas

As the world grows, new city areas are added all over the world. How they are constructed is an important factor in the green transition. The new city area of Linde Haven in Sønderborg is built to meet the highest sustainability standards, not least regarding energy efficiency. Energy efficient design of the buildings allows Linde Haven to be supplied with low-temperature district heating.

Linde Haven will operate at low temperatures, which has the potential to reduce distribution heat loss by an estimated 31% compared to similar buildings operating at normal temperatures.

Linde Haven

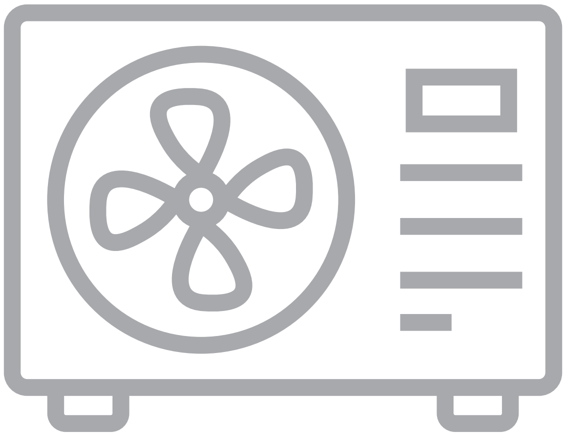

16 single-family houses and a school
92 flats
24 terraced houses

Electrification of heating using heat pumps

Moving away from traditional oil and gas boilers [8] towards heat pumps is a major factor to decarbonize heating. [9] A heat pump doesn’t generate heat. It just moves pre-existing heat around using a small amount of electricity and building on basic physics. That is what makes it so efficient, beating any combustion system.

Power-to-heat technologies, such as heat pumps, have a very high performance, using heat from the ground or from the air and delivering a thermal output several times higher than the electric input. This in itself increases the efficiency of the entire energy system. In addition, they benefit from the increasing decarbonization of the national electricity mixes across the EU which leads to further emission savings as they will run on clean electricity. There are several sectors that can be decarbonized easily, in particular: residential heating, district heating and heat used for industrial processes, such as steam.

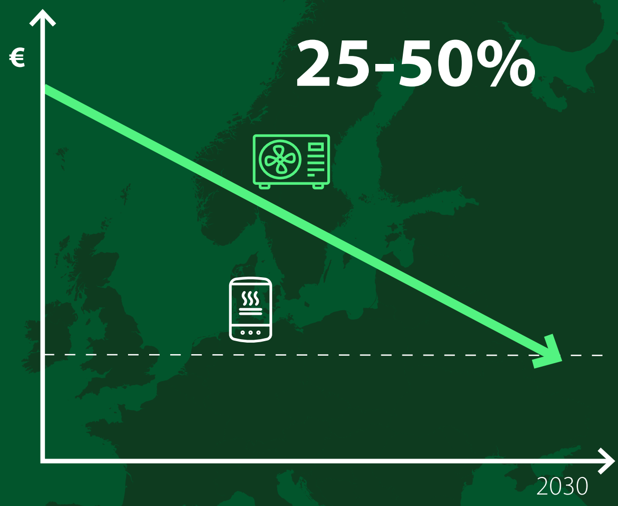
Residential heating is a well-established application sector that is growing tremendously, stimulated among others by rising gas prices. Domestic heat pumps are normally in the range below 12 kW and come in different versions using the air or the ground as a heat source. The heat can be delivered to the building either via the air or via a hydronic circuit, replacing a boiler.



Replacing boilers with heat pumps (the need for heat pumps for retrofitting the existing heating systems is substantially larger than for application in new buildings [10]) can lead to efficiency challenges due to the significant difference in the nature of the heat source: boiler efficiency depends on return temperature whereas the efficiency of the heat pump will depend on the temperature of the supply water vs the source temperature – i.e. the lower the supply temperature, the higher the Coefficient of Performance (COP) of the heat pump. Consequently, the hydronic system must be adapted to the heat pump and, for example, consider the need to balance the system and replace low-performing heat emitters (e.g. under-dimensioned radiators) while ensuring a high mass flow of the heated water at the lowest possible temperature. Doing so will lead to an attractive return on investment, where the cost of optimization is typically marginal compared to the overall investment.

According to different studies [11] [12] [13] [14] [15], the cost of installing a heat pump will decrease by 25-50% by 2025 which will lead to a comparable cost between heat pumps and gas boilers by 2030.

The current operational cost of an air-to-water heat pump is on average Euro 1500 / year for a home with 15,000 kWh annual heat demand (i.e. 100 sqm house with annual energy demand of 150 kWh/m^2, cost of energy below 30 cents/kWh working at COP of 3). In the future, this cost is expected to decrease significantly due to energy efficiency upgrades, heat pump efficiency, and smart tariffs being introduced.



The interplay of district heating and heat pumps

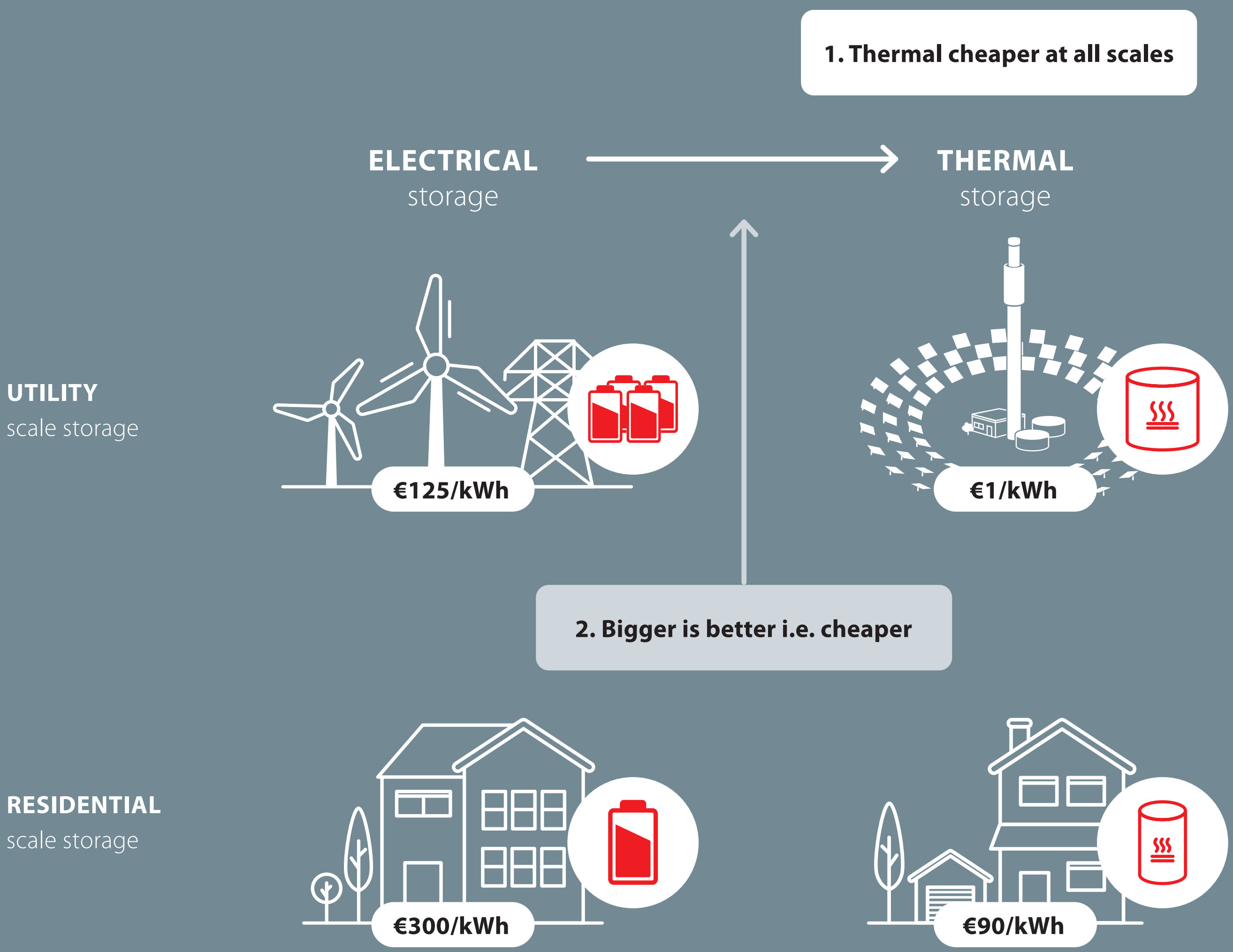
A study carried out in 14 countries in Europe [16] shows that district heating is an economically viable solution in most urban areas. More than half of the heat demand could be covered, ultimately also reducing greenhouse gas emissions and primary energy demand. The experience in both Sweden and Denmark shows that once district heating systems are established, decarbonization is a matter of heat planning and connecting available heat sources to the distribution grid, for instance by tapping into the potential of excess heat from cooling or wastewater plants, using geothermal or solar thermal energy, etc.

Consequently, district heating in conjunction with (industrial) heat pumps connected to the grids, is expected to play a key role in the future energy grid and energy supply. Approximately 25% of the energy demand in the district heating grid could be provided by heat pumps. With a wide deployment of both district heating and heat pumps, greenhouse gases could be reduced by as much as 70% compared to the current situation [17] [18]. (source see the AAU project EHPA)

In a decarbonized and fully integrated energy system, district energy can act as a virtual electrical battery and help balance the grid. For instance, in a scenario with an abundance of renewable-based electricity in the grid, the latter could be converted into heat via large-scale heat pumps, stored and used once there is a shortage of renewable electricity generation. The required investment costs of thermal storage are typically 100 times cheaper compared to electricity storage (i.e. batteries), while the lifetime is more or less unlimited [19] [20].

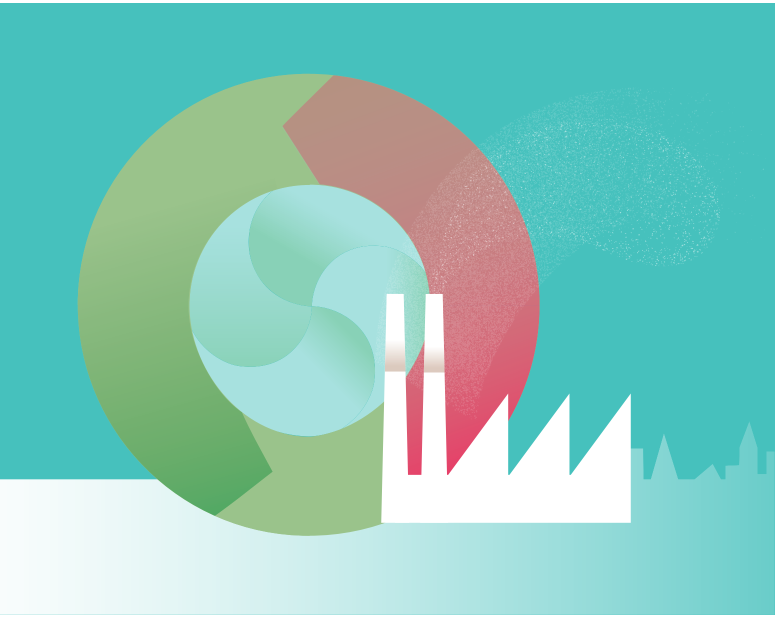
The CAPEX of the thermal storage is typically a factor 100 cheaper than electricity and the lifetime more or less unlimited.

Unit Investment Costs for Energy Storage



The opportunity of excess/waste heat

The word **waste heat recovery** was traditionally associated with waste-to-power technologies, where high-temperature excess heat mainly from industrial processes were used in co-generation engines, such as ORC (organic rankine cycle), and to produce low-temperature heat and electricity. Today the same definition is referring to both high-temperature and low-**temperature excess heat**. Substantial amounts of heat are also wasted through air coolers and water coolers for cooling low-temperature (<15°C) streams in many technologies.



In the same vein, in the past, heating and cooling were considered in "silos". This is unfortunate as all cooling devices produce heat that is released to the ambient (mainly outdoor air). This heat can instead very often be upgraded with the help of heat pumps, thus replacing fossil fuel heating. Good examples are supermarkets, using excess heat from cooling, whereby the heat recovery allows for space heating and sanitary hot water, and heat recovered from the cooling of data centers, through upgrading the waste heat and feeding it into a district energy system. Consequently, coupling heating and cooling in many applications reduce **the need of producing heat – and normally at a very attractive payback scenarios**.

Danish supermarket **cuts heating bill and CO_2 footprint**

A busy Danish supermarket reduced its annual heating bill by 89.7% and its CO_2 footprint by 6.7 tons a year by making use of the waste heat from its refrigeration system. Instead of letting the heat simply dissipate, as most supermarkets still do, a Danfoss Heat Recovery Unit (HRU) now recycles it to heat the store's 1,900 m^2 and provide plenty of hot tap water year-round.

District heating helps tap into synergies, for example with waste heat, as it facilitates the necessary distribution of high amounts of heat from sources such as industrial plants and data centers. However, it is important to think about district heating as a network where all heat contributors can connect. Decentralized connections in the outskirts of the network can be very powerful as they do not have the same number of losses or they may even be locally sufficient during low consumption periods in summer.

Some may say that excess heat has a built-in dilemma in the sense that it may occur from CO_2-emitting sources. While this can indeed be the case, from a pragmatic standpoint, and in the spirit of circular use of resources (resource efficiency), energy should never be wasted – especially as excess heat, unlike many other forms of renewable energy, is not directly weather dependent and represents a cost-effective way to meet fluctuating demand and contribute to baseload power production. However, the use of any non-decarbonized excess energy should become part of a local heat and decarbonization plan eventually aiming at full decarbonization. To learn more about the untapped potential of waste heat, see also the Danfoss Impact Paper: "The world's largest untapped energy source: excess heat". [21]

District Heating Funen Strategy and Heat Pump Central utilizing hyperscale data center surplus heat

CUSTOMER

Fjernvarme Fyn, One of the world's largest district heating grids:

- 70.000 connections/meters
- 120 km transmission lines (80-90°C)
- 2200 km distribution lines (70-75°C)

STRATEGIC TARGETS

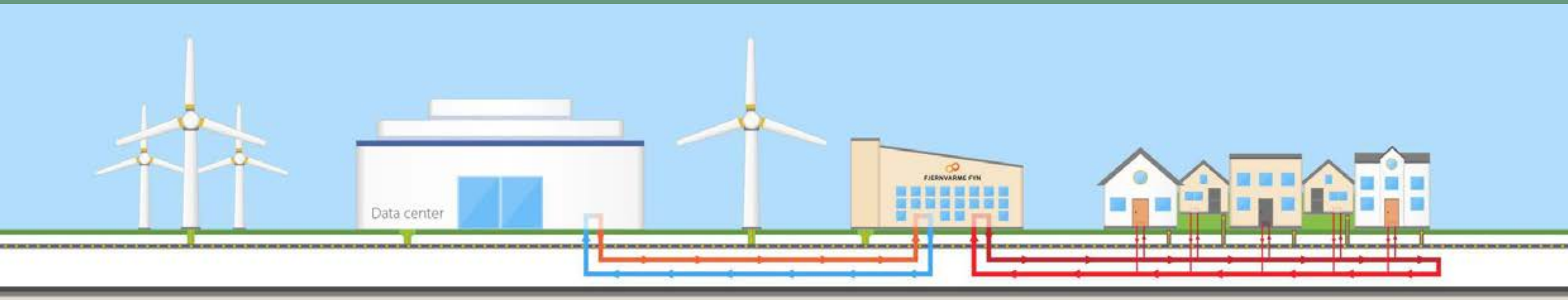
- Top 3 on the lowest price
- Phase out coal by 2024
- Carbon neutral by 2030

FACTS

- Data center owned and operated by hyperscale data center
- Heat pump plant owned and operated by Fjernvarme Fyn
- Both facilities supplied by renewable energy
- 160.000 MWh surplus heat ~ 11.000 households
- **Phase 1:** Investment decision in 2017; Operation started in 2019/2020
- **Phase 2:** Investment decision in 2018; Operation started in 2020/2021

Facts about the **heat recovery project**

Odense Data Center: Heat Recovery Process



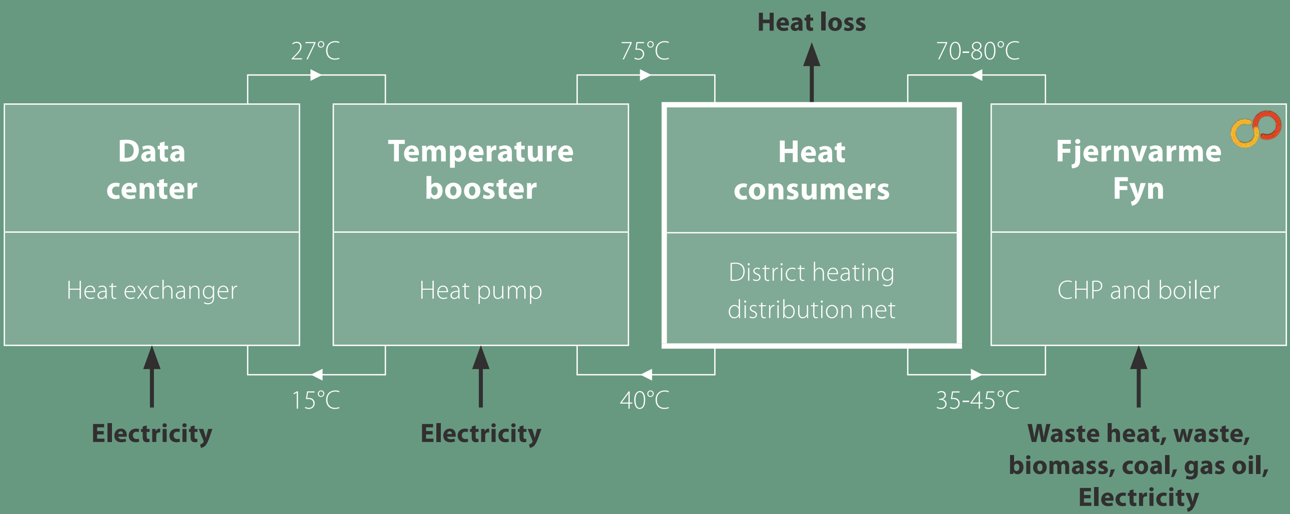
Wind turbines add renewable energy grid that supplies our data center and powers our servers

Hot air from the servers is directed over water coils to heat water

The warm water from the data center coupled with additional renewable energy is used in a heat pump facility to create hot water for the district heating network

The hot water delivers the heat to the community via the district heating network

Integration between **hyperscale data center and Fjernvarme Fyn**



Renewables, Demand side flexibility and disruption in the energy value chain

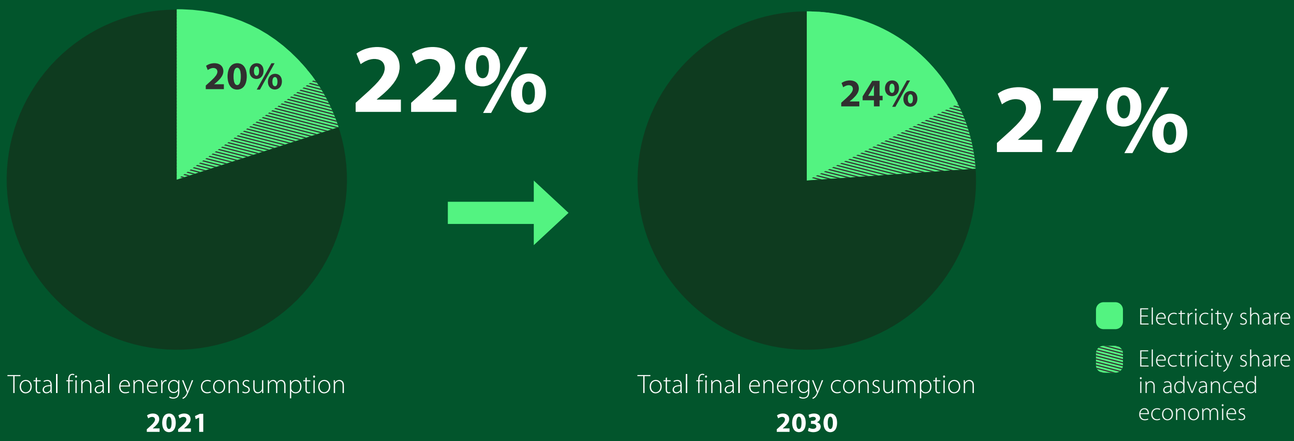
The decarbonization of power production (including heat) today focuses on retiring or converting non-renewable plants and capturing or mitigating the emissions from any remaining or additional fossil-fuel powered plants. Regulation has been the main driver for growth over the past years and, as a result, renewable energy sources have become powerful and cost-effective source of electricity. The costs of both solar and wind has fallen so drastically that in some regions of the **U.S.**, as well as in the **U.K. and Europe**, wind power has become cheaper than traditional high-carbon energy resources.

Given the strongly increased share of renewables in the energy mix, the nature of energy supply changes as renewables are intermittent energy sources. Intermittency per se conflicts with traditional consumption patterns and makes it necessary to establish response measures such as energy storage or to have backup resources that can respond to changes in the availability of electricity from wind and/or solar. The electricity markets can stimulate the demand side in various ways to plan consumption and avoid severe imbalance in the grid. However, short-term imbalance cannot be fully avoided and needs a fast backup resource. Today, these dispatchable sources of energy are still mostly delivered by traditional fossil fuel power plants, which are expensive to maintain and are running idle with low efficiency.

The wide implementation of renewable power generation is changing the energy value chain and heavily impacting the traditional paradigm of energy consumption. In addition, the electrification of all sectors (transport, buildings, industry) increases the amount of electricity needed. Especially the number of electric vehicles, heat pumps, or comfort cooling equipment are responsible for this increase. Industrial applications such as high-temperature heat pumps have just started their journey and are also expected to contribute significantly.

Electricity's share in total final energy consumption worldwide would rise from 20% in 2021 to 24% by 2030 due to the electrification of heating. In advanced economies, it jumps from 22% to over 27%. The share of electricity in the fuel mix for heating in buildings and industry globally would double over 2021-2030 to 16%.

In major heating regions, this adds little to electricity demand, roughly 1.5%-2.5% over 2021 levels by 2030, however, peak demand could grow substantially. For households adding a heat pump, this can nearly triple their peak demand during the wintertime if no other measures are in force (i.e. BACS and improved envelope).

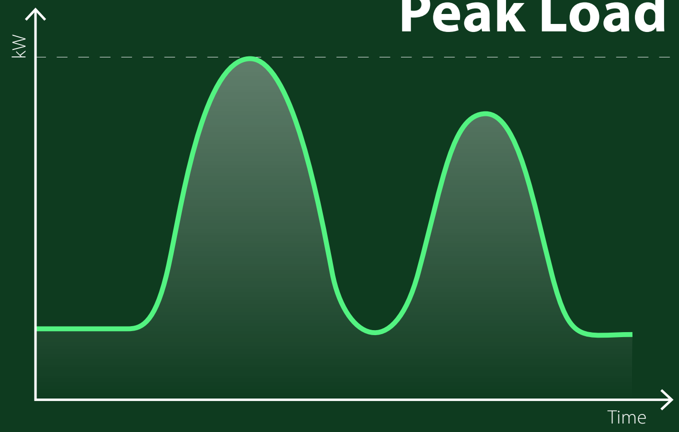


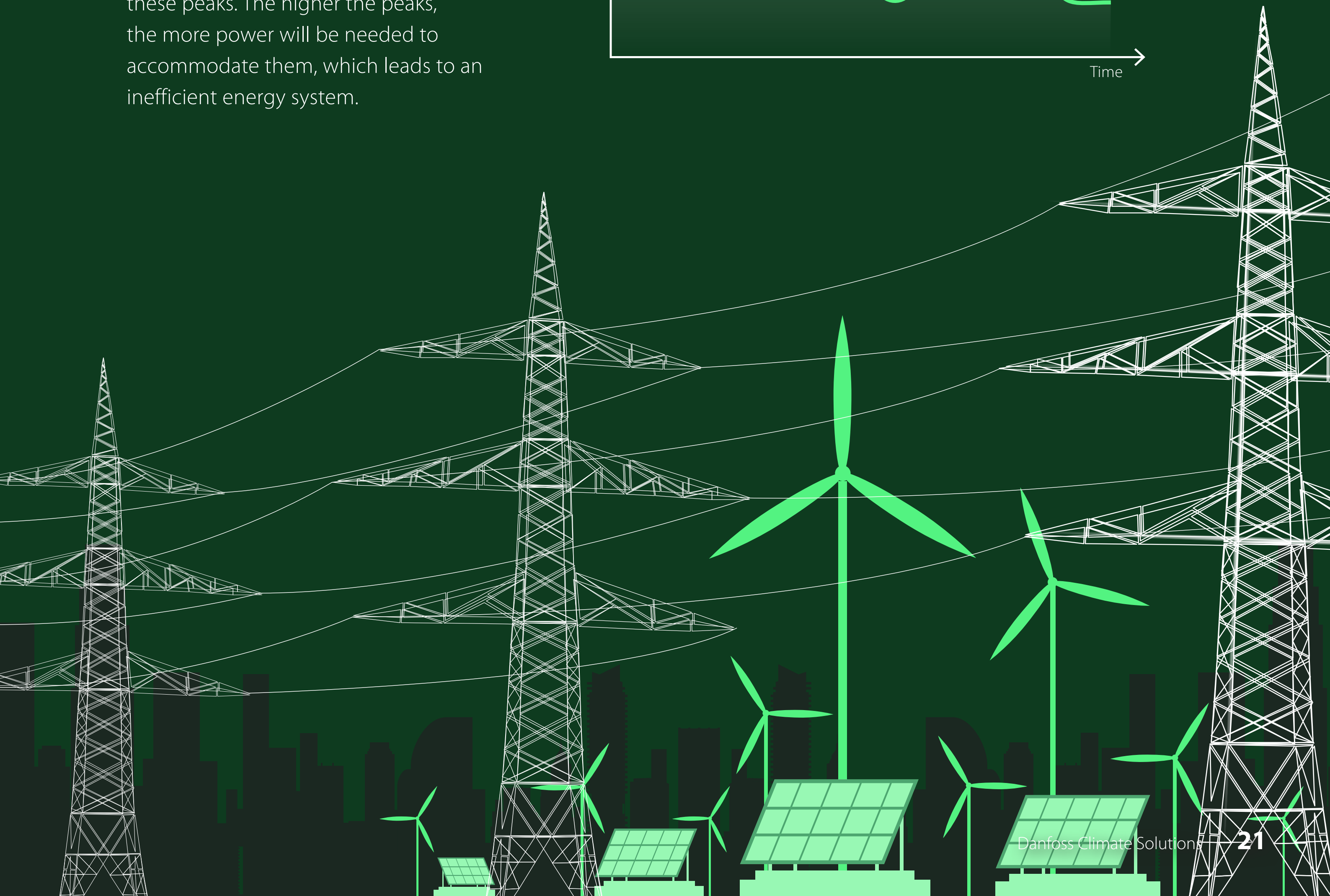
The consumption of electricity is well known to vary throughout the day and year. Uncontrolled demand side consumption will therefore often lead to critical congestion in the grid during peak hours. Expensive reinforcement of the grid seems unavoidable unless such uncontrolled consumption can be mitigated. Mitigation can be achieved via two main avenues: basic energy efficiency (see previous chapter) and demand-side flexibility (DSF).

Demand side flexibility [22] (DSF) shifts the energy consumption in time i.e. it moves the peaks or flattens them out. Assuming that comfort levels will be kept, this can only be achieved by storing energy. There are several options of storing energy like batteries or thermal storage. The thermal inertia of buildings can be used as a low-cost option for load shifting without impacting the comfort of the inhabitants. The control of when and how to perform storage and recharging the storage is a critical factor. Supermarkets are implementing DSF to reduce their cost of electricity by lowering cooling loads during peak hours. For example, to anticipate peaks, display cases are "under-cooled" so that the cooling load can be reduced during peak hours.

Power consumption peaks are important in terms of grid stability, but they also affect power procurement costs: In many countries, electricity prices are set with reference to the **maximum peak-load** [23]. The reason is simple: the grid load and the necessary amount of power production need to be designed to accommodate these peaks. The higher the peaks, the more power will be needed to accommodate them, which leads to an inefficient energy system.

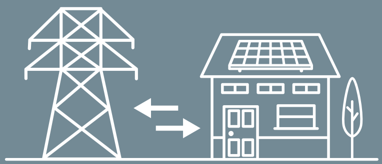
Peak Load





With **peak shaving**, a consumer reduces power consumption ("**load shedding**") quickly and for a short period of time to avoid a spike in consumption. This is either possible by temporarily scaling down energy demand, activating an on-site power generation system, or by relying on energy stored.

In contrast, load shifting refers to a short-term reduction in energy consumption followed by an increase in production when power prices or grid demand is lower. Dedicated generators or energy storage facilities owned by the consumer can be used to bridge high-price or high-load phases but play less of a role if production will eventually catch up again.



Demand-side flexibility (DSF) [24], is the ability of customers to adjust their energy generation and consumption in a dynamic time-dependent way, individually as well as through aggregation. Demand-side flexibility can be provided by smart decentralized energy resources, including demand management, energy storage, and distributed renewable generation to support a more reliable, sustainable, and efficient energy system.

According to IEA, **"Smart demand response"** (that indicates the ability to adjust consumption according to grid needs) could provide 185 gigawatts (GW) of system flexibility, meaning the equivalent power production can be saved, roughly equivalent to the currently installed electricity supply capacity of Australia and Italy combined.

The digitization of the energy sector

The digitization of the energy system is a fundamental premise to enable sector coupling, the electrification of heat and transport, and thereby also a viable future energy system. It implies data processing and interoperability between the stakeholders in the energy system. Digitization can, for example, facilitate the development of **distributed energy resources** by creating better incentives and making it easier for producers (both utilities and prosumers [25]) to store and sell surplus energy to the thermal and electrical grids.

The digital world has three fundamental elements:

Data

Digital information

Analytics

The use of data to produce useful information and insights

Connectivity

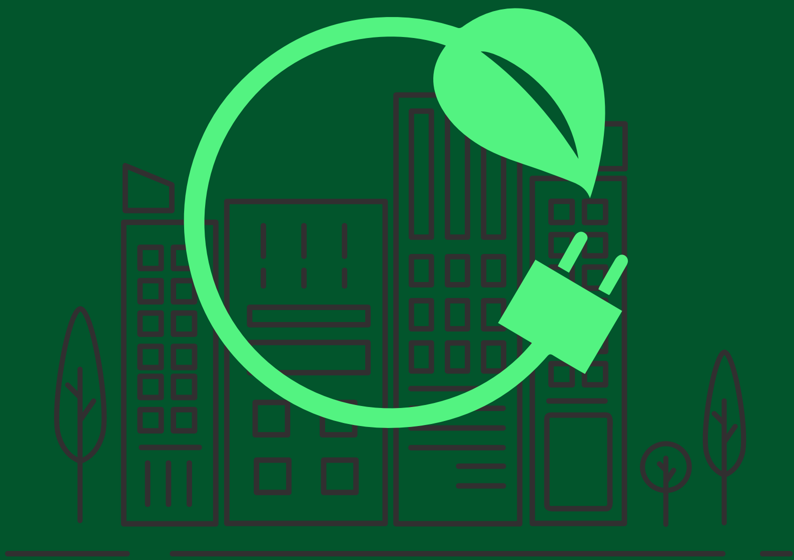
Exchange of data between humans, devices and machines (including machine-to-machine), through digital communications networks.

Digitization of energy implies new offerings to most energy users also known as **Energy as a Service (EaaS)** [26].

Heat as a service is the most common energy-as-a-service offering. The model usually shifts the burden of financing, owning, installing, and managing the performance of an energy asset from the customer to the service provider. Heat contract propositions (output and outcome) such as heat as a service, which can reduce the upfront cost and risk for end-users of switching from fossil boilers. For example, heat pumps, are emerging rapidly across Europe. They offer an attractive perspective to address the CAPEX hurdle and support the deployment of technologies where the investment cost is still higher than with traditional solutions [27].

Pursuing an EaaS model with the involvement of the utilities and other program administrators can help scale the size of the customer's project and increase its energy savings. The alliance between program administrators and service providers can support the connection of financing and providing energy efficiency services.

Heat as a service, and the range of service-based heat propositions, can play a key role in the decarbonization of heat in the existing buildings segment, potentially supporting the installation of a further 100,000 heat pumps per year or more across Europe's main markets by 2030 (*source IEA*). From a policy perspective, heat as a service can help overcome some of the major barriers to decarbonizing heat in existing buildings, tackling energy poverty or the so-called "split incentive", where building owners have no motivation to invest in decarbonized and energy efficient heating.



Danfoss ADR Solution for Supermarkets

To foster the green transition, Danfoss is now enabling consumers, to actively participate in stabilizing the grid in return for monetary rewards – all done automatically with minimum effort.

The concept is called Automatic Demand Response (ADR) which is enabling automatic communication across relevant parties to smarter balance the grid via a holistic management of both the supply and demand side.

Demand response programs are offered by many utilities nationwide to allow their customers to voluntarily reduce their electricity usage during periods of high power demand. When electricity demand is at its peak, utilities want to avoid buying power from less competitive power generation sites or firing up their own inefficient generating equipment. This creates a smart opportunity for customers like supermarkets who can cut electricity consumption when there are balancing problems in the grid and benefit by receiving compensation when they reduce electric consumption during a demand response event.

This enables to get the most out of energy to reduce costs and CO_2 footprint, gain additional profits, all without compromising food safety. The business case is almost selling itself, as it combines high profitability with a low effort service.

A lot of governments reward ADR participants with rebate dollars which can be used for any investment needed to advance ADR-capabilities like investing in the newest system managers. There is a lot of potential to scale similar solutions as ADR across the globe, however the local environment and its regulations differ heavily, and local partnerships with utilities must be established.

There are various ways our customers can benefit from energy flexibility, and with the capabilities developed for ADR, Danfoss has taken the first step in smarter managing energy for customers.

Demand Response Ecosystem

Energy Suppliers → **Energy Aggregator** → **Digital Service Provider** → **Consumer**

1 Request flexibility of consumers demand due to grid imbalance

2 **Aggregates** loads and **connects request** to consumers

3 Alsense responds by **safely adjusting consumers'** loads

4 Customers **benefit** from monetary **rewards**

Ending silo thinking to decarbonize heating

The decarbonization of heating is a massive task and there is no silver bullet to achieve this goal. Rather, it will be crucial to use all available solutions, depending on the regional and local context, and to combine them wherever and whenever possible. The single biggest challenge here is moving out of silo-thinking. From a technology perspective from a user perspective and from a policy perspective. For example, manufacturers in the field of heating technologies will need to cooperate with experts in digitization. Users will need to open their eyes and tap into the potential of available thermal energy. Policymakers will need to remove administrative barriers, create incentives and enable sector coupling and new business models such as "Energy as a Service" (EaaS).

Enercity

Danfoss Leanheat® Building wins AI software-as-a-service deal for 5.000 buildings in Hannover, scaling Leanheat outside its home market and unlocking the potential of cold rent markets. The lighthouse project with Enercity lead to 20% peak load reduction and 9% energy savings.

Enercity AG, one of Germany's biggest public energy providers, has successfully installed a Danfoss Leanheat® solution.

The pilot project was set up in two stages:
In the first phase, the standard solution by Danfoss Leanheat® was utilized. This included the installation of Sigfox indoor temperature sensors and connecting five ECL296 controlled substations to the Leanheat cloud. The key focus in phase one has been to increase energy efficiency by adjusting the supply temperature to the actual demand and to guarantee an optimal indoor climate. Through the intelligent control of the substation, the apartments achieved normalized energy savings of more than 9 percent and a lower primary side return temperature of up to 10K in 2019.

Based on the successful first phase, Enercity decided to install the system in 20 more substations. This time, the sensorless version (without indoor room temperature sensors) was chosen with the primary goal of peak load optimization. The first results of the connected multifamily houses show a projected energy saving of nearly 5 percent and a peak load reduction of almost 20 percent.

This project is a major success, as it proves the potential to sell the Leanheat Building solution in cold rent markets, directly to Utilities, and thereby offers great potential to scale it across other markets.

"We are very happy with the results of the project. Danfoss Leanheat® enabled us to effectively advance the digitalization of our district heating network and to integrate the customer side in the optimization process. The cooperation shows us a path towards more flexibility, higher energy efficiency, and lower return temperatures in the network to the benefit of all stakeholders. We are looking forward tofurther collaboration with Danfoss."

A Digital Services Lighthouse project

enercity
positive energie

Significant savings during pilot:

Peak load reduction of almost 20%

Energy Savings 9%

Reduced return temp. 5-10 Kelvin

Total deal value over 5 years:

Software 3M€

Hardware 2M€ (primarily controllers)

Danfoss Leanheat®

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