Sector coupling

Unlocking renewable energy's full potential

INSIDE THIS WHITE PAPER

SECTOR COUPLING

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FRONT PAGE PHOTO

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Executive summary

Sector coupling offers a transformative approach to harnessing the full potential of renewable energy and energy efficiency, driving decarbonisation and achieving climate goals. By integrating energy systems across sectors, sector coupling unlocks unprecedented efficiency and resilience, paving the way for a low-carbon, resource-efficient future.

Sector coupling is an innovative approach that involves the integration of various energy sectors to maximise the utilisation of renewable energy sources in an energy-efficient way. The approach facilitates the flexible transition from fossil fuels to renewable energy, addressing the urgent need for decarbonisation and climate change mitigation. By connecting electricity, heating, cooling, water, gas, Power-to-X and storage technologies, sector coupling creates a more efficient and resilient energy system.

At the heart of sector coupling is the concept of electrification, where renewable electricity is used to power a wide range of applications across different sectors. This not only reduces greenhouse gas emissions, but also enhances energy efficiency, energy security, and economic stability. Electric vehicles (EVs) and heat pumps can significantly cut emissions in the transportation and heating sectors when powered by renewable electricity. These technologies, furthermore, help balance the grid, smoothing out the variability of renewable energy sources such as wind and solar power when integrated in a smart and flexible way.

For sectors that are hard to electrify, decarbonising through indirect electrification will be needed. Here, the use of Power-to-X (PtX) technologies, which convert renewable electricity into other forms of energy carriers like hydrogen, synthetic fuels and chemicals, supports the principle of sector coupling and allows for the energy carriers to be utilised in sectors like maritime, heavy industries and farming. The same is true for X-to-Power technologies where, for example, sludge from wastewater can be used to produce biogas which in turn can be transformed into heat or electricity, thus utilising resources in the most flexible and efficient manner.

Denmark stands at the forefront of sector coupling, leveraging its abundant renewable energy resources and advanced technological capabilities. Through collaborative efforts involving government, industry and academia, Denmark is in the process of developing a framework for sector coupling that can serve as inspiration for other countries. The Danish approach to sector coupling underscores the importance of holistic planning and cross-sector collaboration. By aligning regulatory frameworks and market incentives, Denmark demonstrates how to effectively integrate innovative green technologies to achieve higher efficiency and greater sustainability. Key initiatives include the expansion of smart grids, the deployment of large-scale energy storage solutions and the promotion of green hydrogen production.

Moreover, the role of digitalisation in sector coupling cannot be overstated. Advanced data analytics, AI and IoT technologies are pivotal in optimising energy flows and ensuring seamless integration across sectors and between energy producers and consumers. These digital tools enhance the flexibility and responsiveness of the energy system, enabling real-time adjustments and predictive maintenance that further improve efficiency and reliability.

Sector coupling represents a paradigm shift in how we approach energy management and decarbonisation. By breaking down silos and fostering synergies between different energy sectors, we can unlock the full potential of renewable energy, boost energy efficiency, drive emissions reductions and create a resilient, sustainable energy future.

Denmark is spearheading this domain, offering valuable insights and practical solutions that can inspire and guide global efforts towards a green and sustainable transition.

FOREWORD

Doubling energy efficiency progress through sector coupling

BY DR BRIAN MOTHERWAY, HEAD OF ENERGY EFFICIENCY AND INCLUSIVE TRANSITIONS, INTERNATIONAL ENERGY AGENCY (IEA)

There are strong signs that the clean energy transition is accelerating. This was cemented in 2023, when every government at COP28 committed to work together to collectively double the global average annual rate of energy efficiency improvements and recognised the role of energy efficiency as the "first fuel" in the clean energy transition. Actions to promote sector coupling, such as the electrification of buildings, transport and industry, are key to unlocking efficiency gains and fully exploiting the growing potential of cheap renewable electricity. But seizing these opportunities also requires a rethink of how the power grid and end-use sectors interact with each other.

Of all the energy-related goals agreed at COP28, doubling energy efficiency progress has the potential to provide the greatest emissions reductions by 2035, but only if governments act today. We know the steps we need to take to achieve the doubling. It means much more efficient cars, buildings and industrial processes everywhere, and consumers that are able to use energy when it is cheapest and most convenient. Electrification is the common enabler to all of this. In 2022, electricity accounted for 20 percent of global energy consumption. By 2030, that share rises to nearly 30 percent if the COP28 goals are fully implemented, as demand for heat pumps and electric vehicles soars, and consumers enjoy greater access to high-efficiency appliances.

All that power moving in new and complex patterns around our energy systems requires a new approach to energy efficiency, as technologies that allow us to shift demand also allow us to move beyond a static view of energy savings. Heat pumps use much less energy than the systems they replace, but they can also provide a valuable source of flexibility. With millions of new installations on the horizon, we must develop our thinking to better encapsulate this new, dynamic picture.

In this more interconnected world, we must strengthen the interlinkages between sectors that have historically been distinct from each other. By integrating energy and data flows across sectors we can deploy the technology that will ultimately diversify our energy supply – maximising our use of renewables while reducing our dependence on fossil fuels. Not only does this lead to a smaller energy system overall, but also a smaller price tag – along with better, more comfortable homes, more breathable air and greater resilience to future energy shocks. We need to see more governments and industries setting a strong example of action on sector coupling.

The IEA is committed to supporting these initiatives and facilitating global cooperation to drive the energy transition forward.

Dr Brian Motherway
Head of Energy Efficiency and Inclusive Transitions, International Energy Agency (IEA)

FOREWORD

Achieving ambitious climate goals through sector coupling

BY LARS AAGAARD, DENMARK'S MINISTER FOR CLIMATE, ENERGY AND UTILITIES

Denmark stands at the forefront of the global effort to combat climate change, with some of the most ambitious climate targets in the world. Our commitment to reducing greenhouse gas emissions by 70 percent by 2030 and achieving climate neutrality before 2050 is unwavering. Reaching these targets requires a fully decarbonised, green, efficient and flexible energy system.

Sector coupling is crucial in this endeavour. It allows us to maximise the use of renewable energy, enhance energy efficiency and create a more flexible and resilient energy system. By linking different sectors, we can optimise resource utilisation and ensure that renewable energy is effectively harnessed and used where and when it is needed.

Denmark's vast renewable energy potential, particularly in offshore wind, uniquely positions Denmark to lead the way in sector coupling. The wind power potential in Danish waters is more than three times higher than the electricity supply needed in a fully electrified Denmark. Such an abundance creates potential for Denmark to convert surplus renewable energy into hydrogen and other renewable fuels, facilitating the decarbonisation of sectors that are challenging to electrify directly.

The Danish experience moving toward an integrated energy system can be described in three phases: the establishment of district heating and combined heat and power plants, the ongoing direct electrification efforts and the emerging Power-to-X initiatives. Each phase builds upon the previous one, creating a comprehensive and interconnected energy system that supports our climate goals, strengthens our resilience to external shocks and reduces our dependence on fossil fuels.

International collaboration and knowledge sharing are essential to realising the full potential of sector coupling. Denmark is committed to working with global partners to develop robust regulatory frameworks, foster innovation and accelerate the deployment of integrated energy solutions. By sharing our experiences and expertise, we can collectively advance the global energy transition.

I hope you will be inspired.

Lars Aagaard
Denmark's Minister for Climate, Energy and Utilities

Index

CHAPTER 1

Understanding sector coupling

Breaking down silos and cultivating collaboration

With decades of global focus on addressing the climate crisis, the main challenge has become evident: Replace all fossil energy sources with renewable energy. In Denmark, this transition is well underway, and Denmark is renowned for its high share of renewable energy, especially wind, in its energy mix. In 2023, almost 44 percent of Denmark's actual energy consumption was covered by renewable energy (source: Danish Energy Agency).

As the shift towards renewable energy picks up pace, the focus on how to build a much more integrated energy system that allows for renewable energy to be efficiently utilised by flowing between energy sectors has intensified accordingly.

Essentially, energy production and energy consumption need to be tied together in a much tighter and more intelligent way. The entire energy system must be interconnected in innovative ways, breaking down traditional boundaries between heating, cooling, water, gas, e-fuels and electrical power in the planning and development of the future green energy system.

Fostering new ways of collaboration
Sector coupling involves dismantling traditional silos between different forms of energy, fostering partnerships and collaborations across sectors and industries both locally, nationally and internationally.

In Denmark, there is a long-standing tradition of close collaboration between the public and private sector, and between players of different industries. That collaboration is founded on developing mutually beneficial solutions to a common challenge through knowledge sharing and partnerships.

About this white paper
This white paper presents highlights on sector coupling in a Danish context with a focus on energy. Coupling sectors establishes new streams for renewable energy to displace fossil fuels on the path toward carbon neutrality. Using concrete examples of application, it presents an overview of how Denmark works to utilise renewable energy in sectors such as heating, cooling, transport, production industries and farming, while at the same time securing a high degree of energy efficiency and security of supply.

What is meant by sector coupling?

Terms like sector coupling, sector integration, smart energy systems and industrial symbiosis are often used overlappingly to refer to a holistic approach with an interconnected energy system. This white paper uses the term sector coupling and focuses on energy in the scope of resources and application areas:

Energy and utilities resources

- Electricity
- Thermal energy
- Water
- Gas
- Liquid e-fuels

Application areas

- Transport
- Buildings
- Industrial processes
- Agriculture
- Water management
- Storage/Power-to-X

The concept of sector coupling entails the connection of sectors within and across both perspectives to optimise the future energy system to the highest possible level of reliability, sustainability and carbon neutrality.

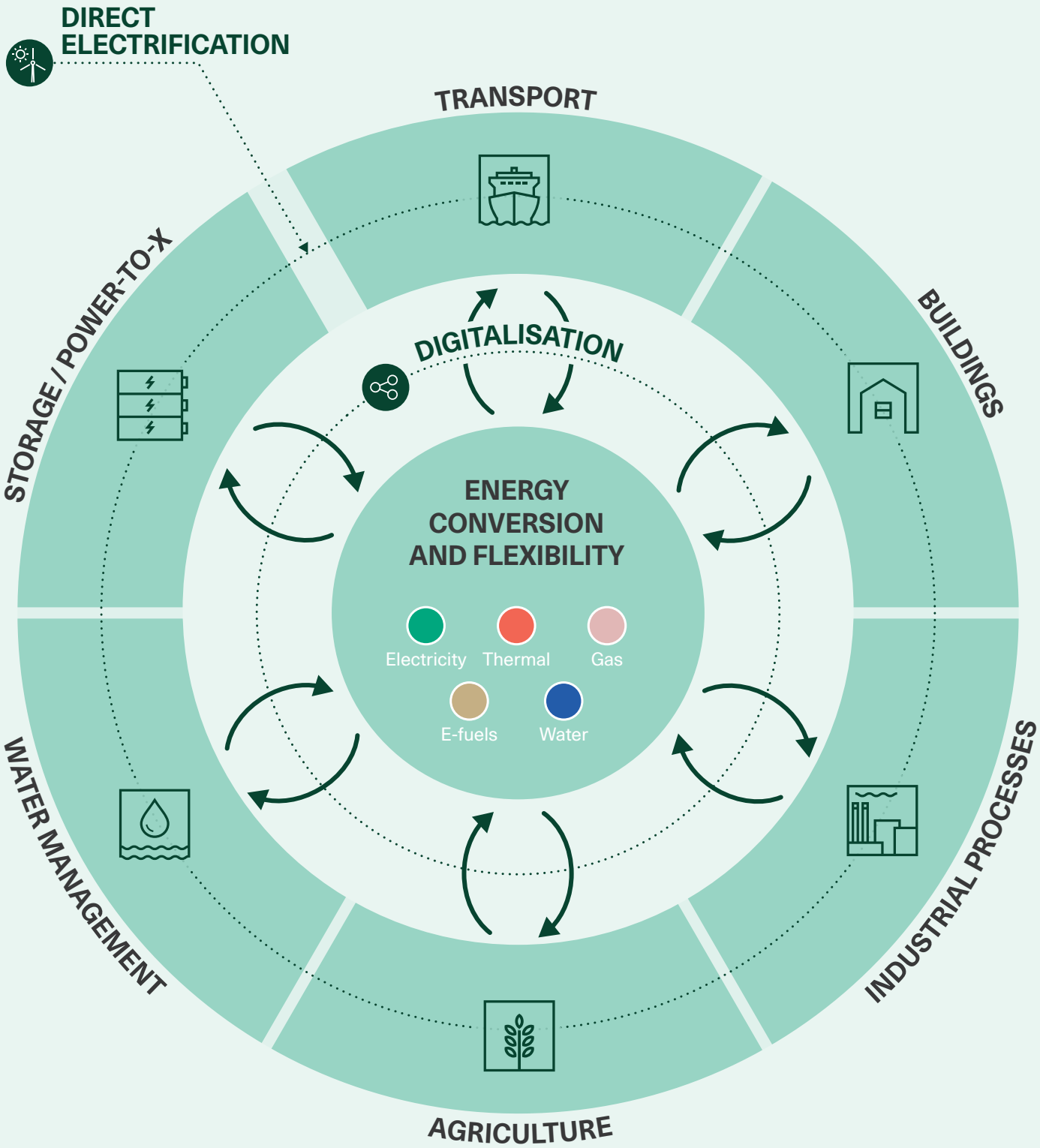
Reading guide

This figure presents a simplified model of sector coupling with a focus on energy. The primary driver for decarbonising our energy consumption is replacing fossil fuels with green electricity through direct electrification. This is represented by the green line connecting the model's six application areas: transport, buildings, industrial processes, agriculture, water management and storage/Power-to-X.

In instances where direct electrification is not feasible, energy conversion and flexibility become essential. These processes enable the utilisation of other renewable energy sources, such as biogas, green hydrogen, liquid e-fuels, thermal energy and wastewater, as depicted in the model's inner circle. These resources replace fossil fuel streams using new approaches, technologies and solutions that generate energy flows of input and output across the six application areas, as shown by the arrows running back and forth.

Digitalisation and comprehensive data exchange between sectors, actors and assets is crucial for smooth energy management. The integrated interaction ensures that consumption and supply are tied closely together, facilitating a balanced and flexible energy system. This concept is illustrated by the green line running between the six application areas and the inner circle, which represents the energy and utility resources.

Throughout the white paper, you will see graphical elements representing the application areas and energy and utilities resources mentioned in the different chapters. Use this model for reference to navigate the terms and categories.


DIRECT ELECTRIFICATION
TRANSPORT
BUILDINGS
INDUSTRIAL PROCESSES
AGRICULTURE
WATER MANAGEMENT
STORAGE / POWER-TO-X
DIGITALISATION
ENERGY CONVERSION AND FLEXIBILITY
Electricity
Thermal
Gas
E-fuels
Water

CHAPTER 2

Digitalisation as the foundation of sector coupling

Digitalisation is vital to efficiently harness the opportunities in sector coupling as it requires fast and reliable interactions in a complex environment with multiple actors, assets and environmental factors on both the energy demand and supply sides.

Recognised as one of the most digitalised countries in the world, Denmark has comprehensive databases with public data. This puts Denmark in an advantageous position for sector coupling. Achieving an integrated interaction between sectors necessitates advanced digitalisation to ensure seamless communication and coordination. Digital technologies enable real-time data exchange and intelligent decision-making, which is essential for optimising the performance and efficiency of the entire energy system.

Balancing the energy system through data

A key aspect of sector coupling is its ability to help cost-effectively balance energy production and consumption, which is particularly important when the energy system is based on renewables that are inherently variable. Digitalisation, thus, plays a vital role in balancing due to its ability to encompass very complex systems and multiple factors. For instance, smart meters as well as grid and IoT devices can monitor energy usage and production in real-time, utilising AI and machine learning to predict and adjust upcoming demand based on weather, season, prices and time of day. This capability can help stabilise the grid and prevent blackouts or energy inefficiencies.

Data is the all-important enabler of digitalised sector coupling. It provides the foundation for smart control systems and helps optimise infrastructure, planning, business cases and production processes. By leveraging big data and advanced analytics, energy systems can become more responsive and efficient.

Flexible energy markets across sectors

Looking to the future, digitalisation will drive the development of new flexibility markets across sectors. These markets will allow different energy sectors to trade flexibility services, such as demand response and energy storage, to balance supply and demand more effectively. Advanced digital platforms and algorithms that can manage and optimise these transactions in real-time will facilitate this cross-sector collaboration. In this regard, it is important to be aware of cybersecurity risks, data privacy concerns and the need for substantial infrastructure investments, all of which must be addressed to fully realise the potential of digitalisation in sector coupling and achieve a sustainable, resilient energy system.

Photo credit: Energinet/Maria Tuxen Hedegaard

Photo credit: TREFOR

Improving grid capacity through real-time monitoring of electrical transformer stations

The integration of renewable energy sources combined with rising electrification from electric vehicles and heat pumps is putting unprecedented strain on our electricity grid.

To tackle these challenges, Digital Energy Hub, a Danish energy and utility innovation platform established by the non-profit Center Denmark, has developed two innovative micro-services that boost transformer station capacity. The solution lies in digitalisation.

One is an IoT data service that uses built-in technology to deliver live-streaming data on electrical and temperature conditions of transformer stations. The second solution is an analytics service that provides forecasts that predict when transformer stations will reach their maximum safe temperature and load capacity. Together, these allow the Distribution System Operator (DSO) to safely run the transformer at 120 percent capacity for short periods, thus minimising potential energy waste and reducing the need for expensive infrastructure upgrades.

The Danish DSO TREFOR made their data available for the two companies Linc Systems and AI-nergy to conduct a proof-of-concept. Using TREFOR's grid, they documented better surveillance of the transformers' capacity load, which enables the DSO to make qualified decisions regarding the operation and future investments.

CONTRIBUTORS

Digital Energy Hub/
Danish Industry Foundation
AI-nergy
Center Denmark – Intelligent Energy
Linc Systems
Technical University of Denmark (DTU)
TREFOR (Danish DSO)

LOCATION

Fredericia, Denmark

Public-private collaboration to strengthen cyber resilience of critical infrastructure

The green transition in Denmark requires the integration of renewable energy sources and smart technologies into critical infrastructure sectors such as electricity, water and transport. This transition involves significant digitalisation, making these sectors more vulnerable to cyber-attacks. Ensuring the cybersecurity of these interconnected and critical systems is essential to maintaining their functionality and reliability. Both the public and private sectors must collaborate effectively to secure the infrastructure against emerging threats.

SektorCERT is a non-profit association founded in 2020 as a collaboration between Danish public and private actors within the critical infrastructure sectors. SektorCERT's purpose is to monitor, detect and respond to the increased cyber threat and highly advanced, multi-tier attacks on critical infrastructure. The association provides real-time attack detection and comprehensive security training to ensure ongoing protection against evolving threats. Additionally, SektorCERT collaborates with other European Computer Emergency Response Teams (CERTs) and security organisations to acquire and disseminate comprehensive and essential knowledge to prevent future cyberattacks.

SektorCERT has successfully identified and prevented disruptions from dangerous cyberattacks through sector-wide monitoring that surpasses the capabilities of individual entities.

CONTRIBUTORS

Danish District Heating Association
Danish Water and Wastewater Association
Energinet (Danish TSO)
Green Power Denmark

LOCATION

Copenhagen, Denmark

Photo credit: Kamstrup

Improving distribution grid performance with data

The green transition is placing great demands on the stability of the electrical grid. With more electric vehicles and heat pumps in new suburban areas, the grid faces unprecedented strain from household electrification.

Therefore, ensuring enough electricity for all consumers requires knowledge of precisely where the strains arise and where grid reinforcement is needed to avoid problems with over- and under-voltage in the grid.

Using Kamstrup's Power Flow and Power Quality Monitoring analysis tools, the multi-utility company Energi Ikast has gained a much better overview of their grid, enabling them to monitor the state of their grid components and their load, which ultimately means that they save vast amounts of time, extend the lifetime of their equipment and make more informed investment decisions on grid expansions.

This is achieved by extracting data from 9,000 intelligent Kamstrup meters and by monitoring the exact amount of power consumed by each individual household, measuring the load on cables, cable cabinets and transformers and detecting faults before they cause major damage. With reduced maintenance time, fewer repairs and better investment planning, the solution has quickly paid for itself.

CONTRIBUTORS

Kamstrup
Energi Ikast

LOCATION

Ikast, Denmark

CHAPTER 3

Building the integrated energy system of tomorrow

To pave the way for Denmark's legally binding climate targets, the Danish Parliament has introduced new initiatives and measures to build a more integrated energy system that allows for renewable energy to flow between sectors.

Since the oil crisis of the 1970s, the Danish energy sector has developed significantly. In the mid-1980s, Denmark had a centralised structure for heat and power production. Large plants were located close to the larger cities or deep-water harbours. A decade later, Denmark built most of the 700 local combined heat and power plants (CPH), which are now spread across the country. These plants were placed closer to smaller cities and villages to avoid transporting hot district heating water over long distances. In addition to its district heating infrastructure, Denmark also has an extensive natural gas grid that delivers gas to many of the smaller decentralised CHP plants, as well as households and industry.

Future integrated energy system based on renewable energy

The Danish Parliament has set a legally binding target to reduce greenhouse gas emissions by 70 percent by 2030 (compared to 1990 levels) and to become climate neutral by 2050. An interim target is to ensure that at least 55 percent of total energy consumption and 100 percent of total electricity consumption is covered by renewable energy by 2030.

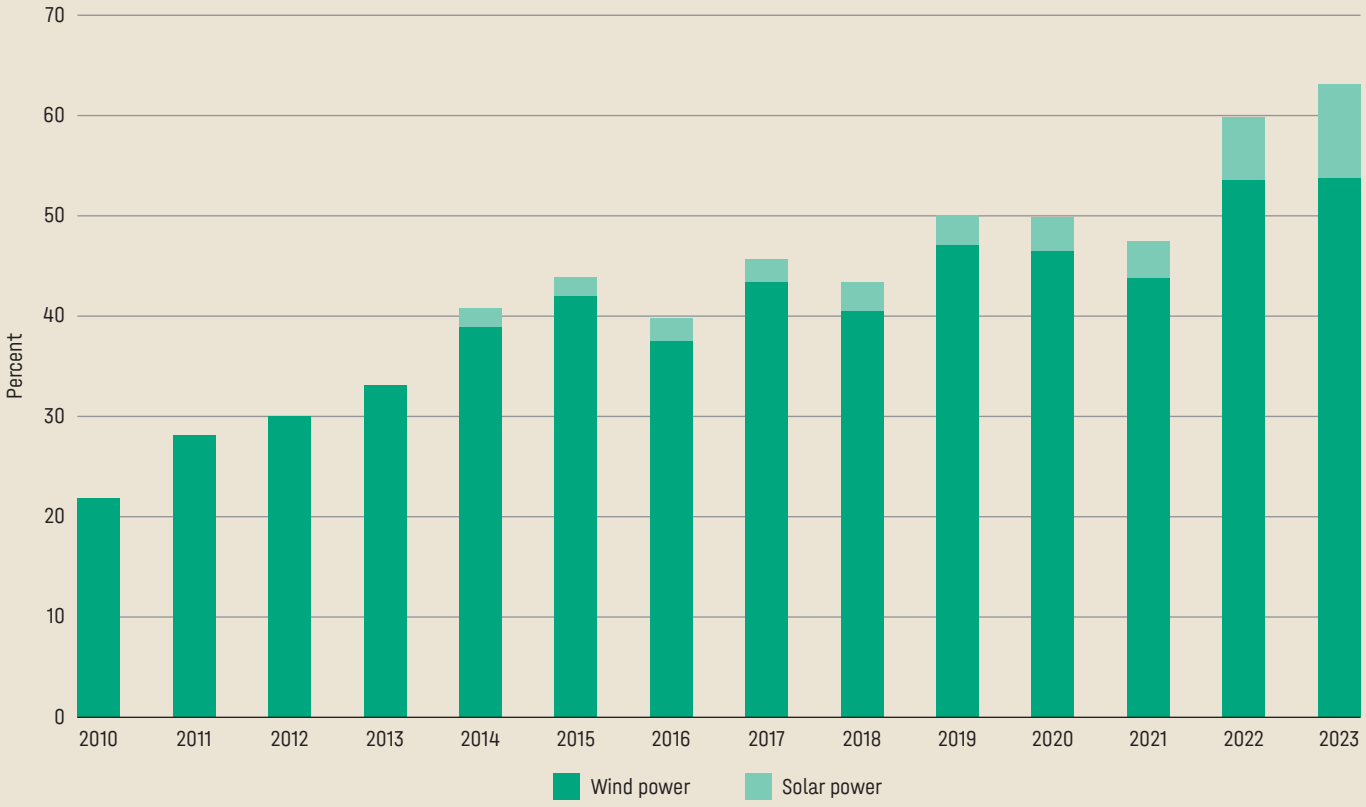
To meet these political targets, the future energy system will need to be much more integrated with other sectors, and energy supply such as electricity, heating, gas and transport fuels will primarily be based on variable renewable energy. A successful transition requires extensive integration, balancing and storage efforts, as well as new infrastructure.

The road to climate neutrality

As electrification is one of the primary drivers to reach climate neutrality, new technologies and new infrastructure need to follow suit. When working with long-term planning, it is therefore important to have an early focus on initiatives that will have a future impact. The focus on electrification can be separated into different phases - with the first phase focusing on direct electrification. There are already market-ready technologies focusing on direct electrification, and this is where emissions can be cut immediately, for example through the roll-out of electric heat pumps and electric vehicles.

The next phase will focus more on indirect electrification, which means converting green electricity to green fuels through Power-to-X. Although still in its early phase, Power-to-X technologies convert renewables – namely wind and solar PV in the Danish case - into gasses or liquids, making it possible to decarbonise hard-to-electrify sectors such as agriculture, heavy transportation and even aviation.

Share of Denmark’s electricity consumption covered by wind and solar



Denmark's climate goals

2030

70%
reduction in greenhouse gas emissions compared to 1990 levels

55%
of total energy consumption covered by renewable energy

100%
of total electricity consumption covered by renewable energy

2050

Denmark must be a climate-neutral society, emitting no more greenhouse gases than it absorbs.

Photo credit: Danfoss

EnergyLab Nordhavn – smart components in integrated energy systems

As cities aim to lower their carbon emissions, integrating intelligent energy systems that can adapt to the fluctuation of renewable energy is vital. Nordhavn, a newly developed district in Copenhagen, exemplifies future city districts by showcasing and testing flexible energy system solutions.

Intelligent energy components, designed by Danfoss, enable the intelligent and efficient transport of heating and cooling between buildings. This includes district heating substations with ultra-low temperatures, remotely controlled radiator thermostats for regulating building heating, and the utilisation of excess heat from a supermarket's cooling system. These solutions communicate their dynamic energy flexibility to the overall system control, responding to signals about time shifts, energy carriers and function changes. The technology company ABB has contributed with a battery energy management system supporting grid fluctuation, along with a real-time data collection and management system, reducing heating consumption by 68 percent.

EnergyLab Nordhavn demonstrates how the integration of electricity, heat, energy-efficient buildings and electric transportation in city districts can significantly reduce carbon emissions.

CONTRIBUTORS

Danfoss
ABB
Balslev/M&E Engineering
Technical University of Denmark (DTU)

LOCATION

Copenhagen, Denmark

Photo credit: TVIS

Large-scale transmission network as key to utilising surplus heat

As a regional district heating transmission company, TVIS, in collaboration with its public and private partners, has made a strategic decision to base its district heating supply in four municipalities entirely on surplus heat. By integrating different energy sectors, the company is now able to harness excess heat from multiple sources, including an adjacent Power-to-X plant, and redistribute it through a large-scale district heating transmission network, significantly improving efficiency and reducing carbon emissions.

Local partnerships with municipalities and businesses enable TVIS to efficiently capture and utilise excess heat generated by local industries that would otherwise be wasted. By working closely with municipalities, TVIS ensures that the district heating infrastructure is robust and extensive, reaching a wide range of consumers and optimising the transmission network for maximum efficiency and minimal energy loss.

Industries benefit from reduced cooling costs and an improved sustainability profile, while TVIS gains a reliable source of heat. This symbiotic relationship fosters a strong regional business environment by reducing energy costs for consumers and businesses alike and supporting the competitiveness of the local industry.

TVIS provides over 7,000 TJ of heat annually to its shareholder municipalities, and projections indicate a relatively steady increase in the municipalities' demand for heat.

CONTRIBUTORS

TVIS
Crossbridge Energy
Energnist
Everfuel
Ørsted

LOCATION

Fredericia, Denmark

HIGHLIGHTED APPLICATION AREAS AND RESOURCES IN THIS CHAPTER:




Electricity Thermal Water

CHAPTER 4

Decarbonising buildings and industry through electrification

The role of energy efficiency is changing with the increasing share of renewables in the energy mix and the increased electrification of society. Buildings and industrial processes consume large amounts of energy, making them key areas for decarbonisation through electrification and demand-side flexibility.

The International Energy Agency (IEA) has identified energy efficiency as the most significant factor in achieving global CO_2 reductions, with the potential to reduce emissions by 37 percent on the path to climate neutrality by 2050. Currently, energy efficiency represents the most financially viable solution for achieving these reductions.

To unlock the full potential for decarbonisation, demand-side flexibility solutions for both buildings and industries optimise the use of electricity and heat, ensuring greater grid stability, higher shares of renewables, and savings in grid investments and maintenance.

At COP28 in 2023, an international target was set to double the average annual rate of energy efficiency improvements from two to four percent by 2030. Achieving this goal will require a combination of measures, including increased electrification, digitalisation, demand-side flexibility, conversion, storage and sector integration. Given that the necessary technologies and best-practice policies already exist, the target could be achieved cost-effectively if strong policy packages that include information, regulations and incentives to support investments in energy efficiency are adopted globally.

Smart building designs for balanced consumption
Technological innovations and thoughtful building design are crucial to enhancing energy efficiency in buildings, which account for 30 percent of global energy consumption, according to the IEA. Integrating renewable energy sources, such as solar panels and geothermal systems, directly into buildings boosts efficiency by generating clean energy onsite and minimising transmission losses. To ensure flexible and balanced consumption, Building Automation Systems (BAS) help control energy consumption by integrating various digital systems and optimising their operation for better efficiency. Regulatory measures that enforce standards for energy-efficient buildings and foster improvements through incentives should support ongoing innovation and adoption of best practices in building design and technology

Utilising excess heat from industrial processes
Electrifying industrial processes and heating, for example, by using heat pumps to replace fossil fuels, can significantly improve efficiency and reduce the carbon footprint of energy-intensive industries. It is essential to harness any excess heat from sources such as wastewater, industrial processes, or data centres, using it onsite and ensuring that any remaining heat is transported, stored or converted into valuable energy in the future integrated energy system.

Unlocking the potential of a decarbonised food and beverage sector

More than 50 percent of the total energy consumption in the Danish food and beverage industry is currently derived from fossil fuels. This presents a significant opportunity for the electrification of these industries, accelerating the green transition.

In partnership with Danish business organisations, companies and the Technical University of Denmark (DTU), the consultancy firm Viegand Maagøe spearheaded the project "Electrification of the Food and Beverage Industry", exploring the potential for electrification and energy optimisation through 20 case studies from Danish food and beverage industry. Viegand Maagøe conducted on-site visits to each company, mapping their unique production processes.

Based on their assessments, Viegand Maagøe provided technical advisory services identifying potential areas for electrification and energy optimisation, including the utilisation of excess heat from production phases. Evaluations form the basis for creating business cases, presenting multiple financially viable options along with cost-benefit analyses. The project demonstrates that converting industrial processes from fossil fuels to electricity will, if done correctly, reduce energy consumption and substantially lower CO_2 emissions.

CONTRIBUTORS

Viegand Maagøe
Danish Agriculture and Food Council
Danish Industry (DI)
Danish Industry Foundation
Green Power Denmark
Technical University of Denmark (DTU)

LOCATION

20 different locations throughout Denmark

Photo credit: Arla Foods

From gas-fired boilers to electric heat pumps

At the world's largest whey protein factory in Videbæk, Denmark, Arla Foods is building an electric heat pump facility to cut greenhouse gas emissions by 14,500 tonnes annually. The heat pump, operational by 2025, will reduce the need for current gas-fired boilers.

Arla Foods aims for carbon neutrality by 2050 and 100 percent renewable electricity by 2025. The Danmark Protein site in Videbæk covers 80,000 m^2 and is highly energy-intensive due to its round-the-clock production of whey ingredients. The new EUR 32 million heat pump facility will enable a shift to heat production by electricity rather than gas. The shift is expected to cut the site's greenhouse gas emissions by an estimated 22 percent compared to 2023 and make a significant contribution to the company's CO_2 reduction target.

Once operational, the facility will convert 2.8 MW of electricity into 8 MW of heat and 5.7 MW of ice water for cooling. This system will provide hot water for various processes, replacing gas-fired boilers and supporting the transition away from fossil fuels. Construction began in January 2024, with a future expansion to 12 MW capacity planned to support production growth. This project serves as a blueprint for other Arla Foods sites globally.

CONTRIBUTORS

Arla Foods

LOCATION

Videbæk, Denmark

City district becomes living laboratory for flexible use of renewable energy

Increasing utilisation of renewable energy through electrification requires innovative approaches to create a more flexible energy consumption and leverage excess energy production through storage, thereby keeping prices stable and low for consumers.

Energy FlexLab Ørestad is an example of an innovative project making an entire city district available for large-scale testing of intelligent energy solutions through collaborative efforts among major businesses with large buildings. IBM Denmark and the energy utility company Andel Energi have joined forces to develop an intelligent data solution called The Flex Platform, which uses AI, IoT and blockchain technology to connect a hub of buildings and relevant electricity infrastructure that can leverage each other's demand and supply to create a living lab. Participating building owners include the supermarket chain Salling Group, Copenhagen Municipality and the telecom towers of TDC NET. By making their buildings available and coordinating energy usage, the companies can optimise, store and even produce renewable energy within existing infrastructures. This implementation will ensure a stable and secure power supply while simultaneously reducing CO_2 emissions and generating additional benefits.

The Flex Platform reduces brownouts, network constraints and the need for grid expansion by activating flexibility and creating value from solar, batteries, ventilation, heat pumps and EV chargers from both housing and companies, for which they are compensated. The platform offers easy, plug-and-play integration with existing systems and a short return on the onboarding investments.

CONTRIBUTORS

Andel Energi
Bellagroup
Copenhagen Municipality
IBM Denmark
Salling Group
TDC NET
Ørestad Innovation City Copenhagen (ØICC)

LOCATION

Ørestad, Copenhagen

Photo credit: Danfoss

Heat pumps help hospitals save energy and enable profit from excess energy

To contribute to The Region of Southern Denmark's climate goal of reducing energy consumption by 20 percent by 2030, the region's hospital, Sygehus Sønderjylland, aims to become completely independent of fossil fuels while simultaneously improving energy efficiency to cut energy costs.

The turnkey provider Energy Machines, in collaboration with Danfoss, has provided an integrated solution to make this transition possible by replacing the hospital's gas and oil-fired heating system and boilers with two energy-efficient large-scale electric heat pumps. The heat pumps enable the hospital to use the heat recovered from the cooling facilities of its scanners, outpatient clinics and wards, to meet its process and comfort heat loads. Excess heat is sold to the district heating utility, Sønderborg Varme, to channel into its grid for use in heating private homes. During winter, when the cooling load is low and the heating demand is high, the hospital can use the bi-directional heat exchanger to supplement the heating delivered to the hospital through the grid.

The hospital's annual energy consumption based on fossil fuels is expected to be reduced by around 12,500 MWh annually, and once the system is fully implemented the hospital expects to sell back 15,800 MWh of excess heat to the grid. This amount could cover the heat consumption of more than 930 average Danish households.

CONTRIBUTORS

Danfoss
Energy Machines
Rambøll
Sønderborg Varme
Sygehus Sønderjylland

LOCATION

Sønderborg, Denmark

HIGHLIGHTED APPLICATION AREAS AND RESOURCES IN THIS CHAPTER:



Electricity Thermal Water Gas E-fuels

CHAPTER 5

Energy storage – making the most of renewable energy

Energy storage is revolutionising how we think of energy and raising the bar for what is possible with renewable energy sources.

Energy storage plays a critical role in optimising the use of renewable energy by enabling the movement of energy across time, location and medium. This versatility is essential for balancing the inherent variability of renewable energy sources such as wind and solar power. By storing surplus energy produced during peak generation periods and releasing it during periods of low production, energy storage systems help maintain a stable and reliable energy supply while ensuring that we make the most of the renewable resources available. This capability is vital to ensure that renewable energy can consistently meet demand, regardless of the fluctuations in production.

Making storage systems cost-effective
The more charge/discharge cycles a storage system undergoes, the better its business case becomes, as it maximises the use of the stored energy and the ability to take advantage of price fluctuations.

The cost of energy storage has dropped significantly over the past decade. For example, the cost of lithium-ion batteries has decreased by 90 percent since 2010, and their energy density has increased (IEA, 2024). In addition, energy storage helps stabilise the power grid by balancing the supply of electricity and acting as a backup, both of which are crucial to maintaining the stability of the power grid and significantly improving the investment appeal of storage systems. Energy storage can often improve the business case for other renewable energy projects, such as solar power or EV charging stations, by taking advantage of fluctuating electricity prices and selling flexibility services back to the grid.

Storing for direct and indirect electrification
While the most efficient method of storage is to store energy as electricity in batteries, conversion to energy sources such as heat, gas or methanol through Power-to-X technologies can also be highly valuable when seeking to couple different sectors together.

Power-to-heat, for example, is a cost-effective storage solution that also supports the heating sector, which is a significant energy consumer. By integrating energy storage with heating systems, large amounts of renewable energy can be used more efficiently, reducing dependence on fossil fuels and cutting greenhouse gas emissions.

Energy storage should be considered with a wide lens, as there is significant potential in the electrification of industry, buildings and transport. Buildings can function as thermal batteries, storing heat in their structures and materials, while EVs and other transport solutions offer mobile storage options. These applications increase the flexibility and capacity of the energy storage network, allowing renewable energy to be stored and used more effectively. As the adoption of EVs and smart buildings increases, the integration of energy storage with these technologies will play a central role in maximising the benefits of renewable energy and advancing the green transition.


12
Clever

Photo credit: XOLTA

Battery system helps waterworks increase security of supply and lower carbon footprint

Bornholm's Energi og Forsyning (BEOF), the utility company serving the Danish island of Bornholm, sought to improve the operational reliability of its waterworks while reducing the carbon footprint. The waterworks had traditionally relied on diesel generators for backup power, but there was a desire for a more sustainable solution. BEOF also wanted to reduce operating costs and explore new potential revenue opportunities.

BEOF has now installed battery systems and solar panels from battery producer XOLTA at several of the island's waterworks. With a total capacity of 400 kW across several sites, the batteries secure supply during power outages. The solar panels generate clean energy to charge the batteries, ensuring that the water supply continues even during grid overloads or disruptions in the cable connection to Sweden.

By partnering with XOLTA, BEOF is able to improve their security of supply and even generate income by participating in grid support services by aggregating the batteries across different sites. This income helps to finance the investment in the battery systems and improve the return on investment.

The investment in batteries and solar panels is expected to result in both improved security of supply, a reduced carbon footprint and optimised production costs.

CONTRIBUTORS

XOLTA
Bornholms Energi og Forsyning (BEOF)
Phlit

LOCATION

Bornholm, Denmark

Photo credit: Aalborg CSP

Large-scale thermal storage saves heat for a cold day

In Høje Taastrup, Denmark, the green transition necessitated a reduction in heating costs. The potential to harness renewable heat sources and improve the efficiency of district heating water was identified through heat storage and reuse. This project is part of Denmark's extensive efforts in thermal energy storage (TES), with a particular focus on Tank TES (TTES) and Pit Thermal Energy Storage (PTES) technologies.

The PTES in Høje Taastrup is a 70,000 m^3 and 16-metre-deep thermal storage unit functioning as a thermal battery with a capacity of 3,300 MWh, able to store hot water of up to 90°C-95°C for months. The thermal battery is charged by heat from the transmission grid and discharged into the district heating network when heating demand increases. Heat is stored when the price is low and utilised later when prices rise. This allows pricing to range from as low as EUR 4 per kWh to less than EUR 1 per kWh. The PTES solution and its insulation lid from Aalborg CSP efficiently prevent rainwater and moisture accumulation inside the insulation, enhancing storage efficiency, reliability and long-term durability.

This reservoir is a prime example of efficient and flexible sector coupling between the electricity and heating sectors. It showcases a solution that not only benefits the climate but is also cost-effective for consumers.

CONTRIBUTORS

Aalborg CSP
Høje Taastrup District Heating
Per Aarsleff
PlanEnergi
Technical University of Denmark (DTU)
Vestegnens Kraftvarmeselskab (VEKS)
Wicotec Kirkebjerg

LOCATION

Høje Taastrup, Denmark

Photo credit: European Energy

The world's largest green methanol plant fuels green shipping and industry

In the coming years, sectors like shipping, aviation and the chemical industry must significantly reduce their CO_2 emissions. A range of cooperations, such as the Danish shipping company Maersk, recognise the challenge, and aim to achieve CO_2 emissions reductions that exceed current legislative requirements. A key component is large-scale production of green fuels such as e-methanol.

The world's first large-scale commercial green methanol plant is currently under construction in Kassø, Southern Denmark, where power from a solar plant will be converted into e-methanol. The plant features three 17.5 MW electrolysers that will annually produce 6,000 tonnes of green hydrogen from 90,000 tonnes of water sourced from its own boreholes and a local water company. The hydrogen is combined with biogenic CO_2, and through an in-house developed methanol synthesis process, the plant produces up to 42,000 tonnes e-methanol per year. Apart from Maersk, the e-methanol is shipped to off-takers such as the toy company LEGO and medical company Novo Nordisk, where e-methanol can substitute fossil fuels in production processes.

Excess heat from the e-methanol production is harnessed for sustainable district heating in the local area, with the potential to supply heat to 3,300 households, ensuring that the vast amount of energy used in this process is reused elsewhere.

CONTRIBUTORS

European Energy
Aabenraa District Heating
Aalborg University (AAU)
Maersk
University of Southern Denmark (SDU)

LOCATION

Kassø, Southern Denmark

Production of green ammonia at industrial scale

Green ammonia represents a crucial medium for energy storage, enabling the integration of renewable energy in hard-to-electrify sectors such as shipping, which roughly accounts for three percent of global energy-related CO_2 emissions (European Commission, 2018).

Topsoe, Vestas and Skovgaard Invest have joined forces in the REDDAP-project, which aims to realise the potential of green ammonia as a cost-effective, versatile and high-energy-density green fuel capable of being produced at industrial scale.

REDDAP, short for Renewable Dynamic Distributed Ammonia Plant, seeks to create the world's first dynamic green ammonia plant at a commercial scale of 10 MW in Lemvig, Western Jutland. Renewable energy from a connected 12 MW onshore wind farm and a 50 MW solar plant will drive the Power-to-X plant, producing hydrogen which will then be converted into ammonia. This dynamic approach connects wind and solar energy directly to the Power-to-X facility, making it more cost-effective by eliminating the need for battery or hydrogen storage, due to the plant's ability to operate at loads ranging from five to 100 percent. Surplus renewable energy will be fed into the national grid, thereby contributing to sector coupling.

The plant, expected to be operational by the end of 2024, will produce over 5,000 tonnes of green ammonia annually, preventing 8,200 tonnes of CO_2 emissions each year.

CONTRIBUTORS

Topsoe
Skovgaard Energy
Vestas

LOCATION

Lemvig, Denmark

HIGHLIGHTED APPLICATION AREAS AND RESOURCES IN THIS CHAPTER:

Electricity Thermal Water

CHAPTER 6

Heat planning and sector coupling in district heating

The Danish Parliament has agreed on a target to reach 100 percent renewable energy in the energy grids by 2030. Electrification of the heating sector through sector coupling and flexibility solutions is key.

Heat planning is an important tool in developing district heating in Denmark. The first Heat Supply Act in Denmark was adopted back in 1979, and through several revisions, it is still being used actively to ensure that new developments in the sector increase consumer benefits.

Decentralised, local heat planning
Municipalities in Denmark are responsible for making their own heat plans, including determining which areas receive district heating and who should invest in other green solutions like individual heating. District heating is not cost-efficient everywhere, and heat planning helps prioritise heating solutions. Municipalities must also approve new district heating projects, including new heating production units and heat supply areas. The approval process compares the socio-economic value of proposed projects with other solutions. The Danish Energy Agency provides a clear framework and guidance to assist municipalities and stakeholders in the heat planning process. It is decentralised but not hands-off.

In 2022, all municipalities were tasked with developing heat plans, including determining which natural gas supply areas should receive district heating due to the international gas crisis. The new district heating areas are expected to be rolled out by 2028. This initiative is an important part of the Danish response to the global energy crisis.

Transitioning to "demand adjusted to supply"
The future Danish power supply will mainly come from large offshore wind farms and solar PV farms. To reduce the remaining carbon footprint in the heating sector, electrification through, for example, large-scale heat pumps in the district heating sector and small heat pumps outside it, will replace the remaining fossil fuels. Since wind and solar power are highly fluctuating, there will be a need for a transition from "supply on demand" to "demand adjusted to supply". This will require sector coupling and flexibility solutions both in the district heating system and for buildings in relation to the electricity grid. Robust data-driven solutions are being developed for future buildings and for the energy grids to support future sector coupling and flexibility requirements.

Developing next-generation district heating
Denmark's district heating is developing from third-generation district heating (<100°C) towards fourth-generation low-temperature district heating (<70°C), which is considerably more cost-effective. There are numerous advantages to be achieved from this, such as lower heat loss and the ability to use plastic pipes instead of steel. Further advantages include utilisation of more excess heat sources from industry, more efficient heat extraction from renewable sources such as geothermal and solar, higher efficiency of heat pumps, greater heat storage capacity, and more electricity generated per unit of recycled heat (IEA, 2021). With the development of low-temperature district heating, Denmark will achieve a greener heating sector, and sector coupling will play an increasing role in the heating supply.


Photo credit: HOFOR

Decarbonising district heating using large heat pumps

As Copenhagen continues its path toward carbon neutrality, a significant challenge is to fully electrify the city's already mostly carbon-neutral district heating system. HOFOR, the Greater Copenhagen utility company, has made substantial investments in collective electric heating pumps that harness renewable energy from wind, excess heat, seawater and wastewater to generate district heating.

These investments have fostered industrial collaboration, financed research, and made it possible to demonstrate practical use of heat pumps through smart system integration. By 2033, up to ten heat pumps will be spread across Copenhagen, with a collective capacity of up to 300 MW of heat. Before establishing the new heat pumps, HOFOR dedicated several years to accumulating valuable knowledge and integrating advanced technology through three smaller heat pump projects with a combined capacity of 10 MW.

Electrified heating provides greater flexibility across the entire energy system by allowing further energy integration. The heat pumps enable the use of renewable power when it is available and source heating through sustainable biomass when it is not. This project facilitates the phasing out of fossil fuels in the heating system, increasing security of supply and significantly contributing to Copenhagen's plans to become climate-positive by 2035.

CONTRIBUTORS

HOFOR District Heating
Alfa Laval
Dansk Miljø & Energistyring
Innoterm
Metropolitan Copenhagen Heating Transmission (CTR)
Technical University of Denmark (DTU)
Vestegnens Kraftvarmeselskab (VEKS)

LOCATION

Copenhagen, Denmark

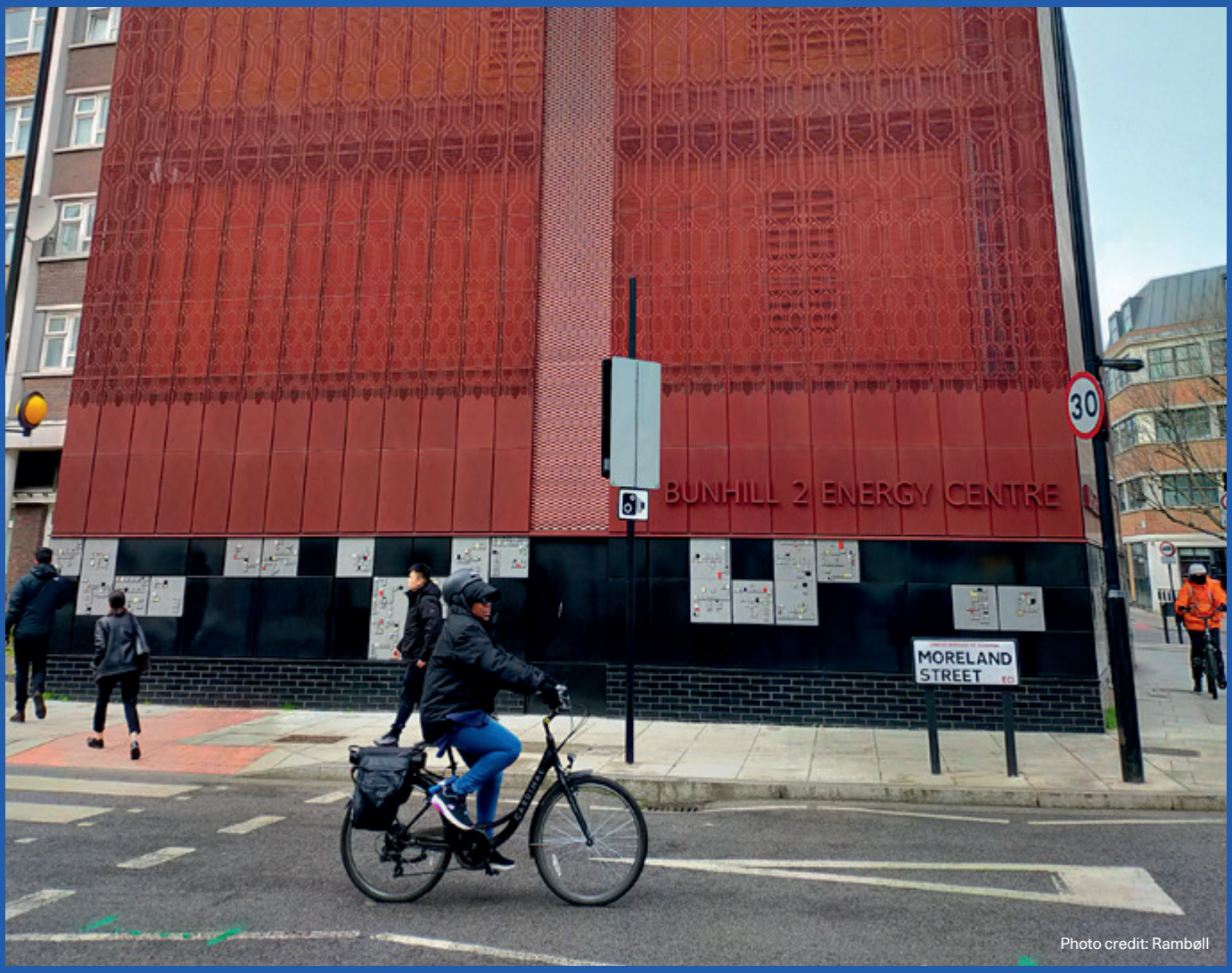


Photo credit: Rambøll

From waste heat of the London Underground to green district heating and energy

The Bunhill heat network began operating in 2012, using a combined heat and power (CHP) plant that generates both heat and electricity. In 2016, the network was expanded, and a new energy centre was built - the Bunhill 2 Energy Centre in the north London borough of Islington. To supply the network, a pioneering scheme was implemented to effectively use the surplus heat generated from the London Underground.

The centre, located on top of an old, unused station, uses state-of-the-art technology to extract warm air from the metro tunnels below through a large underground fan. The warm air is used to heat water, which is then pumped to buildings in the surrounding neighbourhood. This system has enabled an additional 550 homes and a school to be connected to the existing Bunhill Heat and Power district heating network, with the potential to eventually supply heat to up to 2,200 homes.

As well as providing cheaper, greener heating, the centre's CHP technology also generates green electricity to power communal lighting and the lifts in an adjacent tower. In addition, the two-metre fan, installed to extract warm air, can also be reversed to help provide clean air and cool the tube tunnels in the summer months. The centre represents a unique approach to utilising waste heat and acts as an ideal blueprint, that can be recreated anywhere in the world.

CONTRIBUTORS

Rambøll
Colloide Engineering
Cullinan Studio
GEA
Gleeds
Islington Council

LOCATION

London, United Kingdom

Photo credit: EMD International

Resilient and sustainable district heating using multiple heat sources

For the green transition to succeed, consumer prices for district heating must remain low, regardless of the energy source. The district heating system in the city of Hvide Sande features multiple energy sources, including a solar thermal plant, a heat pump, three 3 MW wind turbines and heat storage tanks. While the combination allows for cost-effective renewable district heating, managing daily operations and electricity procurement is challenging due to the fluctuating nature of renewable energy.

To tackle the challenge, the global software and consulting company EMD International has successfully installed and implemented an energyTRADE software solution at the district heating plant in Hvide Sande. This intelligent control system continuously calculates the most optimal operational approach for the plant in real-time, enabling optimal decisions on which units to activate and whether to sell or purchase electricity across the different markets. Through a single interface, the plant manager is provided with a detailed overview of the optimal operational approach and production schedule for the upcoming week, based on forecasts for the renewable energy generation, the anticipated charging and discharging cycles of heat storage tanks, and whether the generated electricity should be converted into heat or sold to the grid.

The energyTRADE solution provides Hvide Sande District Heating with an overview of the most efficient operational schedule for the entire plant. As a result, the residents of Hvide Sande paid only one-tenth of the annual average heating price in Denmark in 2022, and Hvide Sande District Heating produced 92.4 percent of the heat using renewable energy sources.

CONTRIBUTORS

EMD International
Hvide Sande District Heating

LOCATION

Hvide Sande, Denmark

Photo credit: PlanEnergi

Sustainable district heating through solar heating plants and thermal storage

In recognition of the need to shift from natural gas to renewable energy, Dronninglund District Heating set a goal back in 2005 to have solar heat cover 50 percent of its annual energy production. Today, Dronninglund has a solar district heating solution consisting of 2,982 solar panels covering 37,573 m^3.

In the summer, the solar thermal plant produces more energy than the city needs. To save energy for a cloudy day, the surplus heat is stored in a pit thermal storage tank that holds a total of 60,000 m^3 of water. In autumn, the stored heat is gradually released to meet the city's district heating needs. To further utilise the storage, the system has an integrated heat pump to cool the storage by using the heat before the next summer. The heat pump was initially an absorption heat pump supplied with heat from a biooil boiler located at a heating centre nearby. It is now replaced by a compressor heat pump located at the pit thermal storage, where it uses both ambient air and the stored heat as an energy source.

The combination of a large seasonal storage tank and a heat pump enables 40-50 percent of the annual heat demand to be met by solar thermal energy. It has also reduced CO_2 emissions by two tonnes per household per year.

CONTRIBUTORS

PlanEnergi
Arcon Solar
Dronninglund District Heating
NIRAS

LOCATION

Dronninglund, Denmark

HIGHLIGHTED APPLICATION AREAS AND RESOURCES IN THIS CHAPTER:

CHAPTER 7

Biowaste to gas, fertiliser and other renewable energy sources

The conversion of biowaste from households, agriculture and wastewater into biogas and other renewable energy sources, including pyrolysis, presents a compelling avenue for coupling sectors such as agriculture, water management and biowaste management with energy.

Biogas production, in particular, is crucial to the transition and decarbonisation of the energy system, displacing natural gas in processes that are difficult or still in the early stages of electrification, such as industrial high-temperature processes.

Replacing natural gas with biogas
The production of biogas has increased rapidly in Denmark, currently substituting more than 40 percent of the natural gas consumption. This makes Denmark's gas consumption the greenest in the world. Current projections indicate that by 2029, the Danish gas grid will run entirely on biogas.

Denmark's swift transition has strengthened competencies and innovation within the sector. A large part of the production comes from centralised plants, which efficiently handle large volumes of waste and side streams from agriculture, industry and households. Typically, the biomethane from these plants is upgraded and injected into the gas grid, thereby replacing fossil natural gas in the energy system. This is done safely, cost-efficiently and reliably from Denmark's more than 50 biogas plants through a standardised module concept that measures and controls the gas quality. The production offers both local and global flexibility to the renewable electricity production.

In addition, decentralised solutions that are not part of the standardised module concept also contribute to reducing CO_2e emissions and greening the gas supply in local industries, such as farms, food processing and beverage factories, utilities and water and waste management.

The water sector also contributes cleverly to the production of biogas, as anaerobic sludge from wastewater treatment plants is another valuable source to produce biogas. Biogas can also be converted into electricity, heat and, in some cases, injected directly into local or national gas grids.

Combined, these approaches foster a balanced energy ecosystem, reducing fossil fuel dependence, promoting sector coupling and positioning Denmark as a renewable energy leader.

Pyrolysis – turning biowaste into green fertiliser
Biowaste and even residual biomass from biogas production can serve as feedstock for pyrolysis, which offers another avenue for converting biowaste and cheap power from renewable energy sources. Integrating biogas production with pyrolysis constitutes advancements towards sector coupling and the comprehensive closure of the carbon cycle.

Pyrolysis involves heating organic materials without oxygen, resulting in the decomposition of biomass into biochar, bio-oil and synthetic gas. This process extracts even more renewable energy and produces carbon-rich biochar that can be used as fertiliser to improve soil health and carbon sequestration. Pyrolysis thus enhances overall efficiency and resource utilisation, promoting a more sustainable energy system with the added benefits of increased resilience, flexibility and environmental benefits.

Photo credit: Nature Energy

Photo credit: GreenFarm

Local solution reduces carbon footprint and turns waste into a resource

An agricultural school and production facility in southern Denmark had the ambition of reducing its carbon footprint and turning the facility's waste into an energy resource.

In 2023, the company GreenFarm installed a system that significantly reduces the facility's CO_2 emissions by using manure from its production to generate heat, electricity and optimised fertiliser - all of which is utilised locally on the farm.

In early 2024, an innovative carbon capture and storage (CCS) system was integrated, capturing the entire biogenic CO_2 stream from the power units' post-combustion exhaust. This enables carbon-free power and heat generation from the biogas facility.

The GreenFarm system's overall impact includes reducing the plant's greenhouse gas emissions, decreasing local water pollution and creating optimised fertiliser as a byproduct for crop production. Annually, the facility processes 11,000 cubic metres of manure, with initial calculations showing a reduction of 1,500 tonnes of CO_2 emissions.

CONTRIBUTORS

GreenFarm
Graasten Agriculture College
Welltec

LOCATION

Graasten, Southern Denmark


Photo credit: Stiesdal SkyClean

Turning agricultural residues into carbon capture and green energy

Leveraging state-of-the-art pyrolysis technology, biomass from the farming sector can be transformed into valuable carbon capture and energy production, while simultaneously supporting circularity in the continued production of food and feed.

The agricultural sector is in dire need of green solutions to reduce greenhouse gas emissions. While other sectors can transition through electrification, the agricultural sector requires additional innovative approaches. While Danish agricultural practices aim to reduce greenhouse gas emissions from production, some emissions remain challenging to abate.

Currently, large volumes of agricultural residues are left unused, leading to emissions as they decompose.

At Agri Energy Vraa, Stiesdal SkyClean demonstrates how residue fibres from the co-located biogas plant are turned into biochar and heat via pyrolysis. Fibres are separated from the degassed slurry and used as feedstock in the pyrolysis process. The pyrolysis process decomposes any trace of pathogenic elements, hormones, pesticides, microplastics and other unwanted substances from the feedstock. Subsequently, biochar is distributed onto agricultural fields, supporting circularity of nutrients and acting as an irreversibly stored carbon sink that further reduces nitrogen emissions from the field to the aquatic environment.

The pyrolysis gas is combusted to generate steam for a pressurised drying process. By condensing the process steam, energy is released to supply the biogas upgrading facility of the biogas plant. This significantly reduces the fossil energy consumption of the biogas plant and improves the greenhouse gas footprint of the biomethane production.

CONTRIBUTORS

Stiesdal SkyClean
Agri Energy Vraa
KK Wind Solutions
Oestergaard
Runarsson

LOCATION

Vraa, Denmark

Photo credit: HOFOR

Supplying Copenhagen with green gas from wastewater

With the low-hanging fruits of transitioning to green gas already addressed, reaching carbon neutrality becomes increasingly challenging. HOFOR, the Greater Copenhagen utility company, currently supplies 65 percent of the city's gas as carbon neutral.

HOFOR and the system supplier Biogasclean are testing biological Power-to-Gas technology at BIOFOS' wastewater treatment plant at Avedøre Holme in Copenhagen. The technology can convert biogenic carbon dioxide and hydrogen from the biogas production of BIOFOS' wastewater treatment into e-methane. This green methane can be distributed through the existing gas network to areas beyond HOFOR's district, extending the benefits of renewable energy to a broader community.

By adding the biological Power-to-Gas technology to the existing biogas production, the production of green gas from wastewater is expected to increase by 66 per cent. Trials have been successful, and the plan is to invest in a full-scale facility.

While there may be a marginal increase in gas prices, the long-term benefits of carbon neutrality outweigh the initial costs, ensuring a greener future for Copenhagen.

CONTRIBUTORS

HOFOR
Biogasclean
BIOFOS
Nature Energy
University of Southern Denmark (SDU)

LOCATION

Copenhagen, Denmark

HIGHLIGHT CASE

Photo credit: GreenLab/Eurowind

GreenLab Skive - A green and circular industrial cluster

GreenLab is a green and circular industrial cluster for companies that want to contribute to the green transition and help shape the energy system of tomorrow. Here, everything is to be connected by an intelligent network of energy, infrastructure and data, called the SymbiosisNetTM. It provides a direct connection between renewable energy production and the companies in the cluster, allowing them to share their surplus energy and resources with each other to reduce waste as much as possible.

Challenge

The green transition is highly complex, especially for hard-to-electrify sectors and industries. Nearly two-thirds of the energy used in industrial processes is wasted. Success requires large investments in emerging technologies, new collaborations between very different stakeholders and the willingness to lean into uncertainty without a guarantee of high returns. GreenLab wants to be a facilitator of green solutions to prove that it can be done.

Solution

GreenLab was established in 2019 as a public-private partnership between the Municipality of Skive, energy company Norlys and the private investment funds Spar Vest Fonden and Klimafonden. In 2021, the Danish Energy Agency granted GreenLab official regulatory test zone status, allowing it to test new circular business with an exemption from the Danish Electricity Supply Act. This enables GreenLab to create a direct connection between renewable energy production and industrial consumption, meaning that renewable energy is supplied directly to the companies located in the industrial park and its Power-to-X test site. The test zone permit is unique in Europe, providing valuable insights for the green transition of industry, including energy conversion, storage, green fuels and agriculture.

GreenLab acts as a facilitator for complex projects, taking responsibility for collaboration agreements with several stakeholders, liaising with state-owned companies, and overseeing steering committee meetings and off-take arrangements.

By practicing sector integration, GreenLab brings together energy producers from various sectors with industrial energy consumers. The co-location concept increases the likelihood of reaching energy parity and reduces the need for transportation of energy, which is often very expensive.

PART OF THE CLUSTER

GreenLab
Elnetselskabet N1
Eurowind Energy
Green Hydrogen Systems
GreenLab Skive Biogas
Nomi4s
Quantafuel
Stiesdal SkyClean
Vestjyllands Andel

LOCATION

Skive, Denmark

Result

GreenLab is set to be the first site in Denmark to establish a direct connection between renewable energy production and energy consumption in industry and Power-to-X. The seven companies located in the GreenLab cluster minimise energy waste through the SymbiosisNet infrastructure that connects everything in the cluster. The companies in GreenLab work with technologies like pyrolysis and electrolysis to create marine protein, biochar, biogas, naphtha, green hydrogen and other green products. GreenLab and its site partners have created local green growth, created more than 100 jobs, and attracted over DKK 3 billion in investments, including an 84 MW renewable hybrid energy park located near the green industrial park.

GreenLab's international recognition as a frontrunner is exemplified by its contribution to a report published in August 2023 by the United Nations Industrial Development Organisation, which presents guidelines for developing green industrial hydrogen clusters.

GreenLab

About

GreenLab is a green and circular industrial cluster seeking to create the energy system of tomorrow and demonstrate how different energy sectors can be integrated in a unique interplay between different energy forms, industry and internal energy infrastructure.

Dicover GreenLab at stateofgreen.com

HIGHLIGHT CASE

Photo credit: Kalundborg Symbiosis

Kalundborg Symbiosis - The world's first industrial symbiosis

In the Kalundborg Symbiosis, industrial companies collaborate across sectors to share surplus energy, water and materials, thereby reducing waste. This approach ensures that a waste stream or excess energy from one company becomes a crucial resource for another, leading to significant environmental and economic advantages.

Challenge

It takes approximately 1.5 years to replenish what we consume in a single year. This necessitates a shift in our mindset and economic framework, promoting circular business models and resource reuse. This is precisely the goal of the symbiosis model. By focusing on resource reuse in a mutually beneficial manner, it aims to reduce consumption and save money. An industrial symbiosis is a collaboration among various industries and businesses to share resources including energy, water, materials and expertise.

Solution

Established back in 1972, Kalundborg Symbiosis is the first industrial symbiosis in the world. With its circular approach to production, Kalundborg Symbiosis remains one of the world's leading industrial symbioses and is now a partnership between 17 public and private companies in the municipality of Kalundborg, Denmark. The partnership enables companies to synergistically leverage each other's energy and water waste streams, sharing and reusing resources to cut costs and minimise energy waste.

By thoroughly assessing and systematically aligning the individual energy needs of each company, the symbiosis breaks down siloed thinking and optimises valuable resources like renewable energy to their fullest extent.

For example, biotech companies such as Novonesis and Novo Nordisk contribute their residual biomass to Kalundborg Bioenergy, a biogas plant owned and operated by Bigadan. This biogas production process exemplifies sector coupling in Kalundborg Symbiosis, providing a stable and continuous energy solution. Here, biogas is produced and refined into biomethane by removing carbon dioxide and hydrogen sulphide. Biomethane, being carbon neutral, serves as a cleaner alternative to natural gas and can be distributed to local companies and end consumers through the existing gas grid.

PART OF THE CLUSTER

Kalundborg Symbiosis
APM Terminals
Argo
AVISTA Green
Boehringer Ingelheim
Gyproc – Saint Gobain
COMET
Intertek
Kalundborg Bioenergy / Bigadan
Kalundborg Municipality
Kalundborg Refinery
Meliora Bio
Novo Nordisk
Novonesis
Schultz Shipping Group
Unibio
Ørsted

LOCATION

Kalundborg, Denmark

The sulphur extracted from the hydrogen sulphide is collected and reused in fertiliser products, along with the gasified biomass residuals.

Result

The integrated approach of connecting different industries and sectors within Kalundborg Symbiosis illustrates the advantages of adopting a holistic approach to industrial process design. By sharing excess energy, optimising the use of renewable resources, and integrating waste management, participating industries can reduce costs while at the same time significantly reducing CO_2 emissions and promoting sustainability. This concerted effort has resulted in an impressive reduction in collective CO_2 emissions by 80 percent since 2015, amounting to 586,000 tonnes annually. Today, the local energy supply in Kalundborg is completely CO_2 neutral, underlining the symbiosis's commitment to environmental stewardship and sustainable energy practices.

Kalundborg SYMBIOSIS
Surplus from circular production

About

Established in 1972, Kalundborg Symbiosis is the world's first industrial symbiosis with a circular approach to production. The symbiosis' main principle is to share and reuse resources to achieve savings and minimise waste, benefiting both environment and the economy.

Dicover Kalundborg Symbiosis at stateofgreen.com

Perspectives: Creating the legal framework to support Power-to-X

With the widespread adoption of green hydrogen across sectors, Denmark is preparing the legal framework to enable its use in the energy system, based on EU regulation.

The new EU Hydrogen and Decarbonised Gas Market Package, negotiated between 2021-2024, strives to remove barriers for the development of cost-effective, cross-border hydrogen infrastructure and create a competitive hydrogen market, which is a prerequisite for the uptake of hydrogen production and consumption.

The gas package creates a level playing field, based on EU-wide rules, for the emerging hydrogen market and infrastructure, while removing barriers that impede development. It also creates the favourable conditions for reusing natural gas infrastructure for hydrogen, enables cost reductions, and promotes decarbonisation. The regulatory framework will ensure the management of the upcoming EU hydrogen network and facilitate the trade and supply of hydrogen across EU borders. Additionally, the package allows for up to two percent blending of hydrogen into the methane gas system. The gas package is expected to be formally adopted in 2024 and will take effect in 2025.

Allowing injection of e-methane into the gas system
As of 2024, Denmark is actively progressing towards establishing the legal framework for the injection of e-methane into its gas grid. E-methane is produced by adding hydrogen to carbon dioxide, which originates from the cleansing process of biogas before it is injected into the gas system as biomethane. The legislation will enable biogas producers to utilise a carbon dioxide resource, which is otherwise unexploited.

Building a Danish hydrogen backbone
To ensure vast amounts of Danish-produced green hydrogen are transported from producers to end users, an efficient transportation system is necessary. With the rapid scale-up of hydrogen projects throughout Denmark, pipeline infrastructure will be the most cost-effective, and for larger projects, the only viable means of transportation.

A political agreement concluded in April 2024 sets the regulatory framework for the Danish hydrogen TSO (Energinet) and DSO (Evida), which is currently being implemented in Danish legislation. The political agreement also outlines the economic framework that allows Energinet to access Danish state capital to develop Denmark's first hydrogen backbone.

The backbone is a large-scale hydrogen transport system connecting the underground gas storage facility in Lille Torup, Jutland, to future large-scale hydrogen production sites. A hydrogen interconnection point will be established at the German border. The Danish hydrogen backbone will become an integral part of the European hydrogen network and may connect to hydrogen distribution systems in Denmark, as well as offshore hydrogen pipelines to Denmark and other Northern European countries.

The Danish hydrogen backbone is expected to be constructed through a combination of converting existing natural gas transmission pipelines and building new hydrogen pipelines. The installation of compressors will also be needed to reach high capacity in the future.

Explore relevant white

Explore Denmark's journey to decarbonise and energy optimise its buildings
With a holistic approach, Denmark is on a journey towards decarbonising its buildings. Get an introduction to the green policies and energy-efficient cases that pave the way for greener building stock.

Sustainable Industries - An efficient and sustainable use of energy, water and resources.
Get insights into Denmark's experience within energy, water and resource efficiency in industries, ensuring sustainable industries. This white paper presents cases and solutions to showcase efficiency measures across a wide range of industrial sectors, including food & beverage, resource-intensive industry, manufacturing, life science and pharmaceutical, and industrial symbiosis.

Green hydrogen is Danish hydrogen
Get a full overview on how hydrogen can produce green fuels for transport and industry, create value for electricity supply and the electricity grid, and deliver heat for district heating - provided the input is green energy.

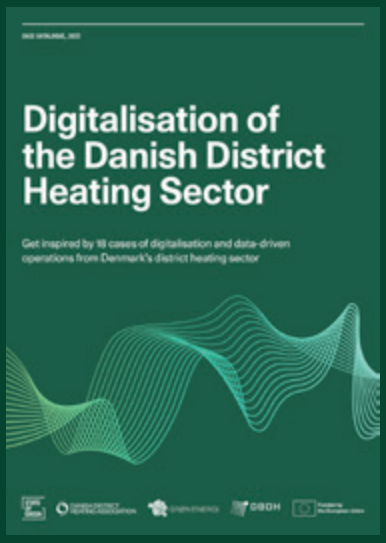
Unlocking the potential of wastewater
Treatment and management of wastewater are essential components of sustainable water resource management and play a key role in the success of the green transition. Wastewater should not be viewed as waste or a byproduct but as a resource. From phosphorus recovery to biogas production, Denmark demonstrates the potential of wastewater as a source of renewable energy and critical materials.

District energy - The backbone of a flexible, resilient and efficient energy system
This White Paper draws on competences built up through more than 100 years of experience with district energy in Denmark and around the world. It highlights some of the main learnings to consider when wanting to expand the use of district energy, such as the system, regulatory framework, planning, efficiency and flexibility of energy source, storage and future perspectives, by including relevant cases from around the world.

Digitalisation of the Danish district heating sector
With a transformation of the energy system, Denmark is heading away from fossil fuels and towards using renewable energy and excess heat as an integrated part of the energy mix. Get inspired by 18 cases of digitalisation and data-driven operations from Denmark's district heating sector.

Producing more with less
Transforming agrifood systems worldwide is a crucial competency in the global green transition. From known resource and energy-efficient practices to new ground-breaking technology, the Danish agrifood cluster aims to continue leading the way globally, produce more resilient food products with a lower climate and environmental footprint, and drive the transition towards climate neutrality by 2050.

papers



Exlpore these and other white papers from State of Green at www.stateofgreen.com/publications

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