Danfoss Impact
Issue no. 3

Roadmap for decarbonizing cities

The battle against climate change will be won – or lost – in cities

Foreword by Mika Kulju
President, Danfoss Power Electronics & Drives

Skyscrapers, traffic jams, shopping malls, and air conditioners. It is not hard to see why cities account for two-thirds of global energy consumption and more than 70% of annual global carbon emissions.[1] With more than half of the world's population living in cities today – a number expected to increase to almost 70% in 2050[2] – we will not reach the goals of the Paris Agreement without a deep decarbonization of cities.

Many cities all over the world have committed to ambitious climate targets and are taking steps to reduce their emissions. However, as the most recent IPCC report exposed, the 1.5°C target is moving out of reach, and it's likely that the world will exceed 1.5°C of warming in the near term if we "keep walking instead of sprinting."[3] Climate change has already resulted in negative impacts on human well-being and key infrastructure in cities. For instance, heatwaves and air pollution have intensified in cities.[4] To prevent the worst of the climate crisis, rapid, deep, and sustained change is necessary. Or as UN Secretary-General António Guterres puts it: "Our world needs climate action on all fronts — everything, everywhere, all at once."[5] The ambition of this whitepaper is to demonstrate how "everything, everywhere, all at once" can be done in cities.

Cities offer some of the best possibilities to optimize urban planning and accelerate a green transition, and there are already accessible, cost-efficient technologies out there capable of cutting emissions sufficiently to meet global climate goals.[6] By offering a roadmap for a green urban transition, it shows how cities can act as ambitious, inspirational front-runners that showcase green technology and create attractive places to live and work. In the coming chapters, we take a deep dive into the carbon footprints of all major aspects of our lives in cities: the heating and cooling of the buildings we live in, the construction sites that build our homes, roads, and workplaces, the transport that gets us to work, the infrastructure that supplies our goods and handles waste, and the data centers that constitute the digital backbone of the city. In the next few years, the battle against climate change will be won – or lost – in cities. The solutions are there, but political leaders need to take action in scaling them. Let's get started.

Danfoss Impact
Issue no. 3

> **"Our world needs climate action on all fronts — everything, everywhere, all at once."**
> António Guterres, UN Secretary-General

With evidence from credible sources, Danfoss Impact is written to show how existing efficiency technologies can lower the cost of decarbonization and accelerate the electrification of our economies.

This special, longer issue of Danfoss Impact aims to provide a concrete roadmap for mayors, local decision-makers, and urban planners on how to eliminate all major drivers of the carbon footprint of cities. The paper explores how available technologies can improve the livelihoods of citizens while at the same time making our economies more resilient and creating jobs. It offers a holistic and concrete view of the major opportunities for decarbonizing cities.

However, the solutions presented are not exhaustive and the paper will not explore the provision and build out of renewable sources of energy. Crucial as this is, it is a theme well-researched and analyzed. In addition, although they fall outside the scope of this paper, urban planning measures such as creating walkable cities, parks and open spaces, wetlands, and urban agriculture to reduce flood risk and heat-island effects should also be implemented.[7]

In cities, the transport sector and the building sector are the largest contributors to carbon emissions, and therefore the paper focuses on all major levers for decarbonizing those two sectors – reducing energy waste through efficiency measures, electrifying, and integrating sectors to reuse otherwise wasted energy.

The paper was prepared by Case and Analytics in Group Communication and Sustainability at Danfoss. Comments or questions can be addressed to Head of Analytics, Sara Vad Sørensen at: sara.sorensen@danfoss.com.

Danfoss Impact
Issue no. 3

Only got 2 minutes?

These are the key takeaways

Energy efficiency. If all urban areas and cities in Europe, the US, and China invested in energy-efficient heating and cooling of buildings, this would contribute 20% of the emissions reductions needed in urban areas to reach the 1.5°C target of the Paris Agreement.[8] Reducing energy waste is possible across sectors and the technologies to do this are already accessible.

Electrification of urban transport needs a drastic acceleration. Similarly, an urgent political focus on the potential of electrifying the whole transport sector – including both maritime transport and heavy vehicles – is pivotal. **If all urban areas and cities in Europe, the US, and China electrified their private and public transport, this would contribute 28% of the emissions reductions needed in urban areas to reach the 1.5°C target of the Paris Agreement.**[9] As we will see, technology for the electrification of cars, buses, and trucks, as well as marine equipment and transport such as city boats, ferries, and cranes already exist.

Sector integration is an enabler of energy efficiency and electrification and can together with the build-out of renewables decarbonize the power supply to cities. In urban areas, the high density of buildings, infrastructure, and services makes it possible to connect urban energy-consumers with energy-producers and convert and store energy. Supermarkets, data centers, and wastewater facilities can all be turned from heavy energy consumers into energy suppliers.

Implementation of existing technology for buildings, transport, and sector integration can **bridge half the gap** in the urban GHG emissions reductions needed for a 1.5°C pathway.[10]

The carbon footprint of cities – a roadmap

On the left is a roadmap for decarbonizing cities.

In the following three chapters, we will explore concrete areas that come together to constitute the main levers in decarbonizing cities.

In Chapter 1, we look at the emissions from the heating and cooling of the buildings where we live, work, and spend our free time.

In Chapter 2, we review the opportunities for decarbonizing the transport sector – from heavy-duty construction vehicles and the cars and buses that get us from A to B, to the infrastructure and traffic at the ports of the city.

In Chapter 3, we look at some of the often-overlooked aspects of the carbon footprint of cities, such as wastewater facilities handling sanitation, supermarkets providing us with food and household supplies, and data centers that serve as the digital infrastructure of cities. What is common for these three sites is that they all showcase the potential of utilizing the world's largest untapped source of energy: excess heat.

Chapter 4 sums up the three main levers of decarbonizing cities, while Chapter 5 presents concrete policy recommendations that can accelerate the deployment of these technologies.

Decarbonizing heating and cooling in the city

Our roadmap for decarbonizing cities starts in the buildings where we live, work, and spend most of our time. Our homes, offices, hospitals, schools, and factories all require energy for power, heating, and cooling. Globally, buildings are the second largest source of energy-related carbon emissions. In total, 28% of global energy-related CO_2 emissions come from day-to-day energy consumption in buildings.[11] And in urban areas, buildings can often account for over 50% of emissions.[12]

As climate change progresses and temperatures inevitably rise, demand for energy in buildings to maintain ambient conditions is predicted to increase further. High temperatures and heat waves have already begun to drive demand for air conditioning and will continue to do so.[13] As the world's population continues to grow, so will the expanse of buildings needed to house and service growing communities. Reducing emissions from buildings is therefore critical if we are to meet the goals of the Paris Agreement.

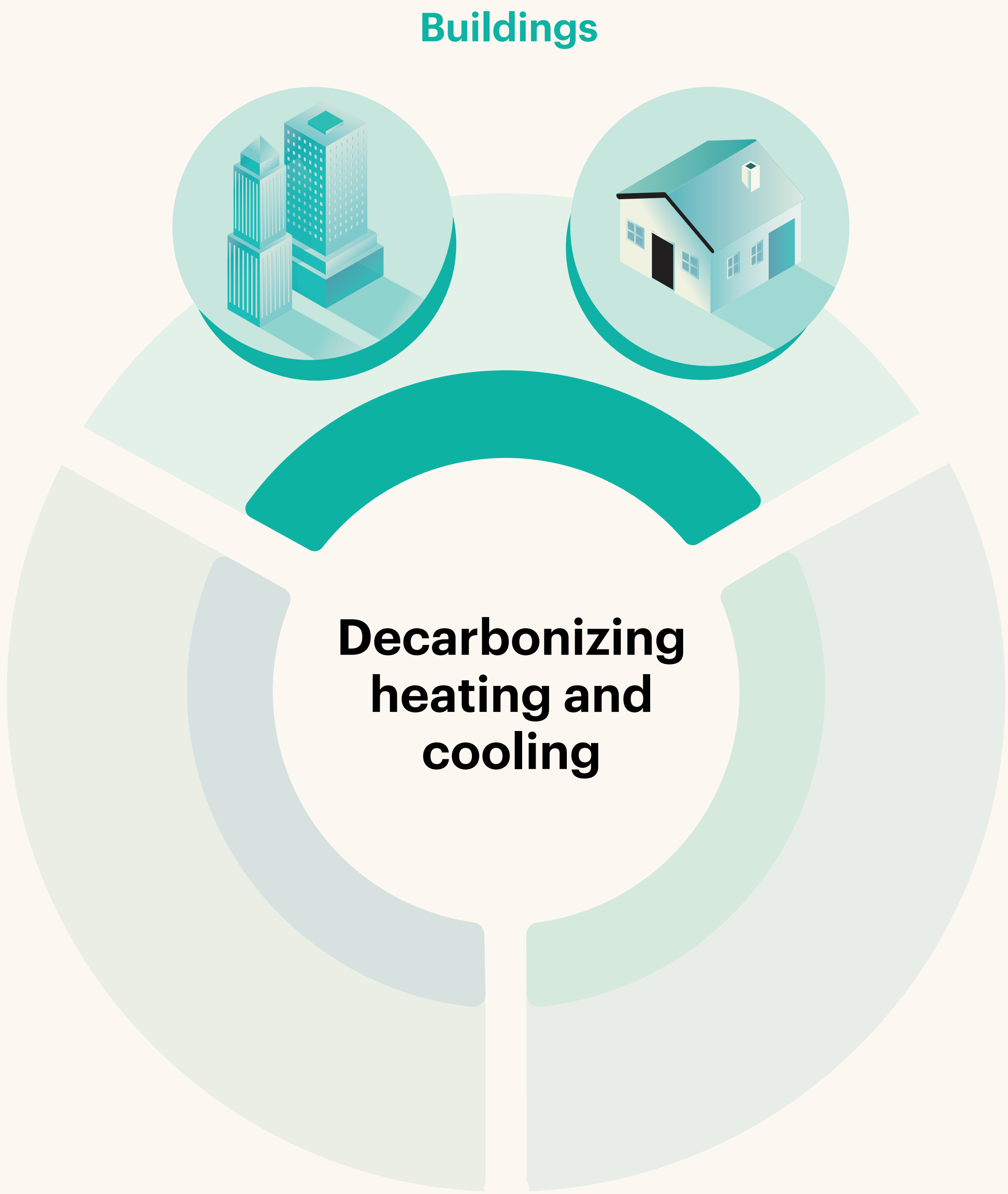
An effective strategy for decarbonizing buildings must address both the energy supply and demand requirements. We must simultaneously ensure that energy sources for heating and cooling buildings are decarbonized, while also making efforts to reduce the overall demand for energy from buildings.

According to the IEA, if we are to achieve net-zero emissions by 2050, nearly 85% of buildings must be zero-carbon-ready, meaning highly energy efficient and using decarbonized energy.[14] To achieve this goal, most existing buildings would require retrofits by 2050 and all new buildings must be built as zero-carbon-ready by 2030. But we are currently off track: as of September 2022, retrofitting rates for existing buildings were around 1% and need to double, and only 5% of new buildings were zero-carbon-ready.[15] However, solutions to reach the necessary efficiency in buildings already exist.

To reduce the energy intensity of buildings we need to look at both passive and active measures that span space heating and cooling, lighting, ventilation, and water.

Passive measures, such as architectural design or improvements to the building envelope, can play an important role in reducing the demand for heating, cooling, ventilation, lighting, and other energy-intensive processes. In this paper, however, we will focus on active measures.

Active measures achieve energy savings by measuring, monitoring, and controlling a building's energy usage. While installing energy-efficient lighting or heating is essential to reducing overall energy use, active measures must also be implemented to ensure that the lighting or heating is only switched on according to demand. Whether we look at retrofitting existing buildings or create new, active measures can have an enormous, fast, and cost-attractive energy-saving potential that is far from realized today. In the following pages, several existing technologies with large energy-saving potential are presented. And while geographic location often dictates which active measures make most sense (e.g., heating vs. cooling), the following examples are particularly relevant in the context of heating buildings.



Thermostats

Save 7% of final energy in a multi-family building

One of the simplest ways to save energy is to maintain a room's temperature level automatically by using a thermostat. Simple as they may be, thermostatic radiator valves save up to 7% of final energy in a multi-family building with a payback time of one year.[16] However, many buildings still do not utilize this simple measure. Across the EU, thermostatic radiator valves have the potential to save 130 TWh of heating energy per year without affecting the thermal comfort of households.[17] The energy savings can be increased even further with an electronic thermostat which is regulated digitally and can be set according to occupant behavior - for example, by lowering the room temperature when a building is empty.

Hydronic balancing

Save 10% of final energy in a multi-family building

Many heating or cooling units utilize a hydronic system that transfers water through pipes and radiators to heat or cool buildings. The flow resistance inside the system is – unless controlled – fluctuating. This causes radiators closer to the pump to become warmer than their intended temperature, meanwhile radiators further from the pump are cooler. This inefficiency means that water is often overheated and larger pumps are installed to accommodate people living far from the pump. Besides installing thermostats, the installation of automatic balancing valves with differential pressure control leads to ideal indoor temperatures, reduced operating costs, and higher efficiency.

In a multi-family building, a hydronic balancing system can save up to 10% on final energy with a payback time of one year.[18]

Danfoss impact
Issue no. 3

Model predictive controls

Save up to 20% in a building's energy costs

Model predictive controls are driven by artificial intelligence using building, weather, and user data to predict heating and ventilation demand. By utilizing such controls, buildings can pre-heat ahead of peak hours, or lower heating when the sun is about to shine on the building facades, thus saving energy. Observations on 100,000 flats equipped with this technology based mainly in Finland show the energy consumption of heating and ventilation was reduced on average by over 7% and 10% respectively.

Meanwhile, by shifting the consumption to the most economical period the system ensures up to 20% savings in a building's energy costs.[19] In 2021, a London Local Authority installed model predictive controls in eight residential buildings. In the first 11 months of operation, the technology paid back its initial cost and saved 600 MWh of heat – the equivalent of heating 50 homes in the UK for a year.

Heat pumps

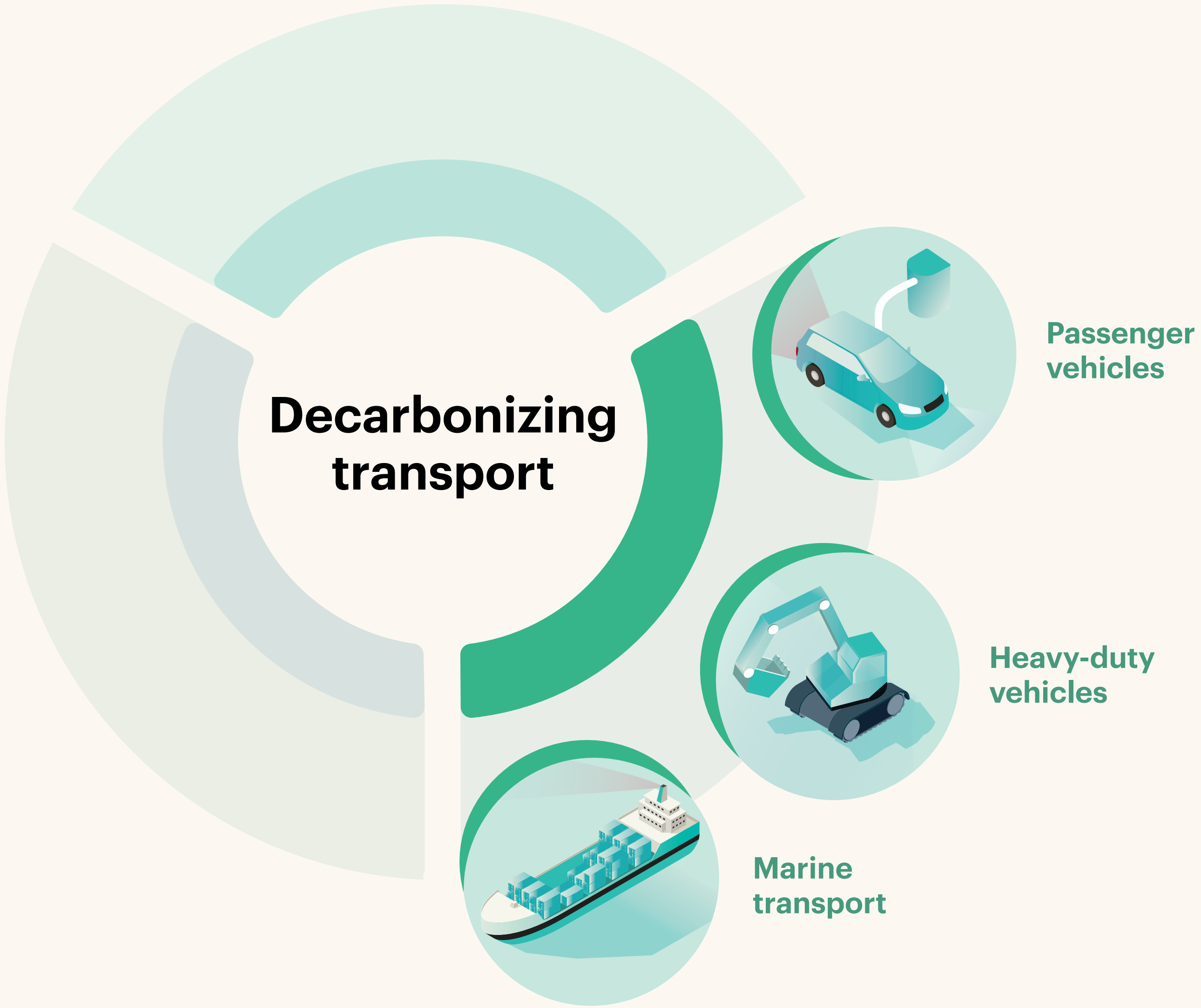
Save 2/3 of the electricity used compared to traditional electric equipment

Heat pumps upgrade the low temperature heat stored in the air, bedrock, ground, or groundwater to a usable temperature level. Buildings are consuming this by heating our living spaces, offices, and water. Because they upgrade heat instead of generating it, on average heat pumps can keep a building warm with only a third of the electricity used by traditional electric equipment.

Heat pumps can also provide cooling, eliminating the need for a separate air conditioner for the 2.6 billion people who will live in regions requiring both heating and cooling by 2050. The IEA estimates that heat pumps have the potential to reduce global CO_2 emissions by at least 500 million tons in 2030 – equal to the annual CO_2 emissions of all cars in Europe today.[20] Although heat pump adoption has increased in recent years, it still represented less than 10% of global heating equipment sales in 2021, while fossil fuel equipment accounted for 45%.[21] And this is despite lower energy costs for the average household or business using a heat pump than for those using a gas boiler.[22]

Decarbonizing urban transport

Transport – whether driving the car to work, transporting the goods we consume, or off-highway vehicles constructing the city – depends on vast amounts of energy. Transportation accounts for 37% of CO_2 emissions from end-use sectors and has the highest reliance on fossil fuels.[23] In major cities, 33% of all greenhouse gas emissions are generated by transport.[24] Urban transport also has a negative impact on human health by emitting noise and air pollution in cities, as well as generating around half of the global nitrogen oxide (NO_x) emissions.[25] Each year, 7 million people die prematurely due to air pollution.[26]



In this section, we assess the challenges and possibilities for curbing emissions from urban transport. More specifically, we zoom in on three major components of urban transport emissions: passenger cars, heavy-duty vehicles,[27] and the transport in and on the ports of the city.

Electrifying passenger vehicles

Road transport accounts for 77% of transport emissions.[28] Most of this comes from passenger vehicles,[29] which contribute more than half of global transport emissions.[30] Fortunately, the sales of electric cars have seen exponential growth in the last few years. Electric cars are becoming more affordable with faster charging, and they are expanding in performance. Global electric car sales grew to 14% of total car sales in 2022, up from only 1% in 2017, and are on track to make up 18% of sales in 2023.[31] IEA expects electric cars to make up around one in three new cars by 2030, which would mean a cut in annual emissions equivalent to Germany's entire economy. In China, Europe, and the US, the average share of electric cars in total sales is set to rise to around 60% by 2030.[32]

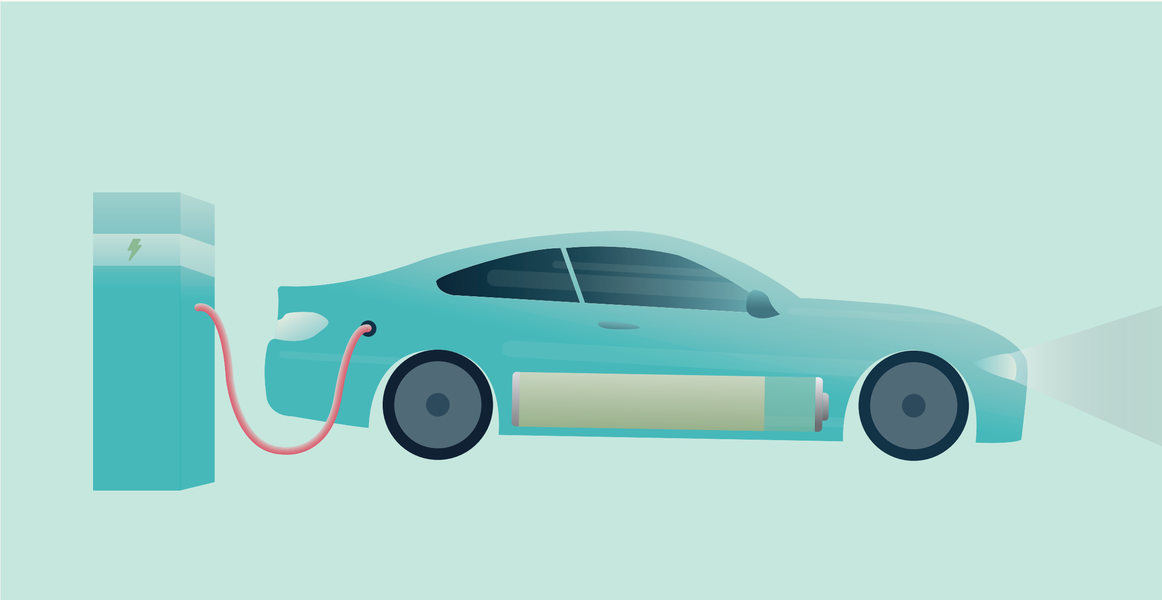
Affordable electric passenger vehicles and accessible charging infrastructure are pivotal for achieving sustainable transportation in cities. Indeed, the transition to electric cars is already being pushed by governments. For example, the Norwegian government aims for all new passenger cars to be electric, plug-in, or hybrid cars by 2025,[33] while the Californian government aims for 2035.[34]

Despite these encouraging recent developments, some obstacles to the electric car transition still lie ahead - in particular, the critical minerals used in the batteries of electric vehicles. Modern batteries are made of many minerals, such as lithium, nickel, and cobalt. The limited availability of these elements is expected to pose a challenge to worldwide adoption of electric vehicles.[35] One analysis looking at electric vehicle uptake in China – the world's largest market for electric vehicles – suggests that the high prices of critical materials could hinder electric vehicle uptake in China, driving a 28% increase in carbon emissions from road transport over 2020-2060. Furthermore, a cost surge on lithium, cobalt, nickel, and manganese would cause the percentage of vehicles on China's roads that are electric to drop from 49% to 35% in 2030 and 67% to 51% in 2060.[36]

However, as can be seen in the case on electrification of cars, energy efficient technologies exist that can accelerate the market uptake of electric vehicles and reduce the stress on mineral resources.

> **"Policy makers, industry executives, and investors need to be highly vigilant and resourceful in order to [...] ensure sustainable supplies of critical minerals."[37]**
>
> Fatih Birol, IEA Executive Director

Case: Energy efficiency can accelerate the electrification of cars



The power electronics used in an electric car can have a significant impact on the energy efficiency of the car. More specifically, energy efficient power modules can impact the amount of power that is lost when power is transferred from the battery to the motor.[38] In an electric car, electricity is stored in a battery and then passed through a drivetrain, while the power module controls the flow of power between the battery and the electric motor. New generation modules made from silicon carbide – the so-called SiC power modules – reduce the power lost as heat and offer 60-80% less energy loss compared to traditional ones. SiC modules can also help reduce the weight and size of other components such as the cooling system, which can further reduce the overall weight of the vehicle and thereby make it more energy efficient.

Energy efficient power modules can effectively reduce the size of the batteries by 5-10% depending on the technical specifications and application of the car. Alternatively, the lower power loss increases the driving range by 4-10% without even modifying battery sizes, further growing the acceptance of electric mobility in society.[39,40,41,42]

5-10%

reduction in battery size possible through energy efficiency measures

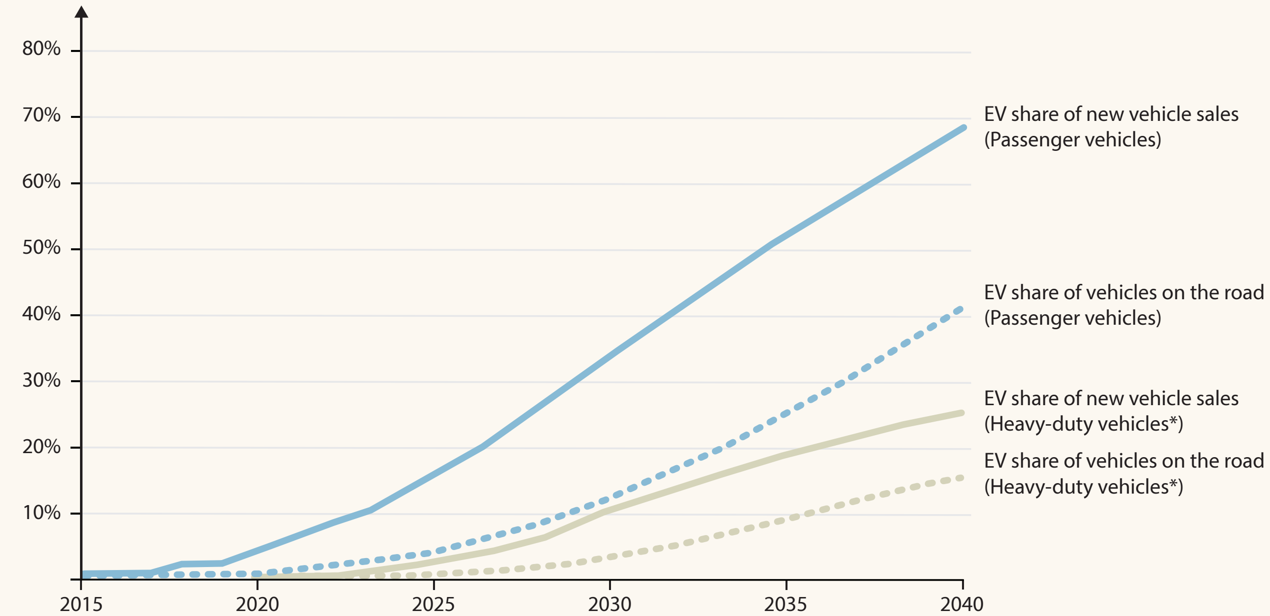
Decarbonizing heavy-duty vehicles

While the sales of passenger cars have seen a drastic acceleration, the same is not true for heavy-duty vehicles. Trucks, city buses, and long-distance buses are responsible for over 6% of total EU GHG emissions and more than 25% of GHG emissions from road transport.[43] The picture is arguably the same across the rest of the world. In China for instance, heavy-duty vehicles emitted about half of GHG emissions across all vehicle types.[44]

In 2022, nearly 66,000 electric buses were sold worldwide, representing only about 4.5% of all bus sales. Electrifying municipal bus fleets presents a unique opportunity to reduce emissions in the transportation sector while improving air quality in cities.[45] Moreover, if we are to reach the goals of the Paris Agreement, investment in e-buses will need to double during the next two decades.[46]

Looking at other heavy-duty vehicles such as construction machinery, there is also far from the same progress in electrification compared to electric passenger vehicles (see Figure 1). Immediate attention to the possibilities for reducing carbon emissions from heavy vehicles is necessary to reach global climate goals. Energy efficiency is the key to cut emissions immediately and paves the way for electrification of heavy-duty transport. Let us take a look at construction machinery, and more specifically the excavator, to understand the challenges and opportunities.

Figure 1: Passenger vs. Heavy-duty vehicles



Source: BNEF. 2021
*Heavy-duty vehicles are off road vehicles above 15 tonnes.

Construction machines worldwide emit 400MT of CO_2 per year,[47] as much as the emissions from international aviation.[48] 50% of that comes from excavators.[49] At first glance, it may seem simple to follow the same path as passenger cars: make them battery-electric and charge them with energy derived from renewable sources. But this is easier said than done.

First, compared to passenger cars, excavators need to work much harder and for much longer between charges, meaning that they need extremely large batteries to match the productivity of the diesel equivalent. As a result, fully electric excavators consume a lot of resources for the battery and are expensive to buy, so the total cost of ownership over their lifetime still exceeds the diesel machines by a large margin.

Second, not all excavator work sites have enough charging energy to support a fleet of electrically powered excavators. Those sites that do have lots of electrical power onsite are often very big, like quarries, and require battery-swapping in the field at the beginning and end of every shift and charging those back in the depot. Given that the batteries weigh tons, this poses operational challenges.

Third, there is not unlimited green energy in the grid and the amount of additional green energy needed for electrifying the excavator fleet is not trivial: a rough estimate says that if all the world's excavators were electric, they would consume as much energy as is generated by all the world's offshore wind turbines today.[50]

Despite these challenges, the industry is already pushing on electrification. Today, very small electric machines up to 3 tons exist and often work in city-center locations. However, to make a substantial impact on CO_2 emissions in the sector, solutions for larger machines over 10 tons are needed, as these machines account for only 56% of units sold but contribute 92% of CO_2 emissions.[51]

The key to decarbonizing these machines are energy efficient technologies that can immediately reduce the diesel use in excavators and at the same time address some of the challenges for electrification. Improving efficiency reduces the size of batteries required, reduces the amount of charging power required, and reduces the amount of renewable energy generation required to make the same impact.

In the case on construction sites, we take a look at the excavator to understand which solutions can be employed today to reduce energy waste and diesel consumption in heavy vehicles, paving the way for a full electrification of these vehicles, as can be seen in Figure 2. Until recently, low-emission construction sites seemed unattainable, but market innovations are gathering speed and changing the construction industry. Many cities around the world are now prioritizing different ways to reduce emissions and pollution from the construction sector. However, the pace needs to increase instantly if we are to reach global climate goals.

Case: Decarbonizing construction sites

The scale of global construction activity is set to increase significantly in the decades to come, and decarbonizing heavy-duty vehicles such as excavators is critical if cities are to curb GHG emissions.

Today's excavator systems are only 30% efficient, meaning that 70% of the energy the engine produces is wasted instead of helping the excavator bucket move any earth. To identify the energy losses in a heavy vehicle, it is not enough to look at the engine of the vehicle. In construction machines, a hydraulic system consists of a pump that pressurizes fluids (oil) to transmit the power from the engine to perform work such as lifting or digging. Whether the vehicle has an electric motor or combustion engine, the energy consumption of the vehicle can be reduced significantly by introducing energy efficiency measures. For instance, energy consumption can be reduced significantly when the vehicle is not operating through solutions such as variable displacement pumps, digital displacement, variable speed pumps, and decentralized drives. In addition, the losses on the hydraulic system that are essential to many off-highway vehicles can be reduced significantly with existing technologies, and energy recovery systems can recycle energy in the system.

Such energy efficiency measures enable excavators to deliver more work with a smaller engine and less fuel and reduces the capacity of the battery needed to electrify them by up to 24.8%.[52]

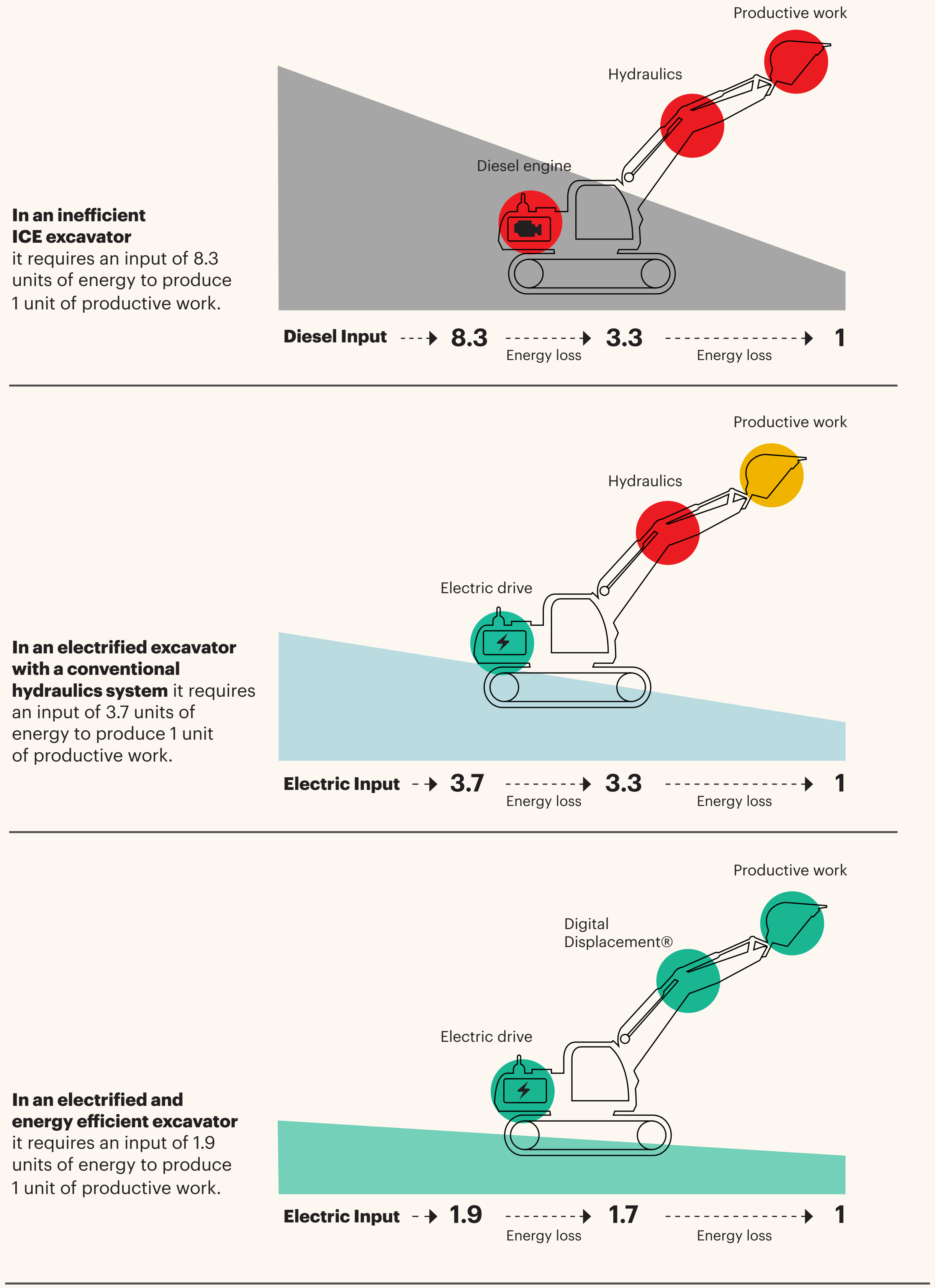
The technology is developing fast and some of these measures can deliver fuel savings of 15-30% in excavators over 15 tons while at the same time increasing the work capacity of the machines. Soon it will be possible to apply this technology on all sizes of excavators and even reach fuel savings of up to 50%.[53]

15-30%

fuel savings through energy efficiency

Figure 2. The fully electric excavator

By combining electrification and energy efficient solutions, only 25% of energy input is needed to shift the same amount of earth. This example highlights the potential in energy efficiency and electrification in a 16-ton conventional excavator.



Decarbonizing marine transport and equipment

Ports act as vital hubs for the transportation of goods and people in urban areas. Almost 80% of global trade by volume and 70% by value is carried out by international shipping and these goods all pass through ports every day.[54] The shipping industry contributes around 2.9% of global greenhouse gas emissions[55] and domestic shipping accounts for about one-fifth of this.[56]

There is a large untapped potential for decreasing the climate impact from the maritime sector, and the opportunities are ripe for the taking. Ships typically have a lifespan of 25-30 years and are commonly powered by diesel engines.[57] This carbon lock-in can be addressed by retrofitting the existing fleet, immediately reducing fuel consumption and thus the carbon footprint of the sector. In addition, the solutions already exist to fully electrify vessels as well as the operation at ports, and green shore supply can reduce the emissions from ships while they are at berth.

It is worth noting that while ports may not be included in a city's carbon budget, emissions from ports have significant negative impacts on the local environment and public health, and urban decision-makers often have a good possibility for working with port authorities to reduce emissions and pollution from ports.

Looking at the operation at ports, both straddle carriers and cranes operate at ports for many hours a day. A straddle carrier is a ground-based vehicle used for loading and unloading containers from ships and stacking and transporting containers for short distances. While both cranes and straddle carriers traditionally have been powered by diesel engines, it is entirely possible to increase the efficiency of these vehicles and fully electrify them with current technology.

For instance, Shanghai Zhenhua Heavy Industries Co. (ZPMC) is one of the largest port machinery manufacturers in the world. The company offers many hybrid and fully electric port machinery products. One such product is the electrified straddle carrier, which is already in operation at the Port of Barcelona in Spain and South Africa's Durban Port.

Electrifying port equipment can lower emissions, reduce noise levels, and lower operating costs compared to diesel-powered equipment.

Similarly, solutions for curbing emissions from marine vessels already exist. Electrification of vessels operating on short journeys close to shores, such as ferries, tugboats, and boats transporting food is possible already today. These vessels can fully operate on battery power and be charged while standing idle in ports using energy sources.

In Grovfjord, Norway, salmon farming is a major driver of the local economy. In the fjord, one of the world's first fully electric work boats – Astrid Helene - is now operating. The boat is packed with heavy equipment, including a crane. However, because the boat is fully electric, it operates with no engine noise and no diesel fumes. This can be copied in work boats in cities all over the world.[58]

In many cities, ferries are vital for the transport of passengers, goods, and vehicles over short sea and inland routes. In 2019, an estimated 4.27 billion passengers and 373 million vehicles were transported by ferries worldwide, most of which are in Asia.[59] Most ferries burn diesel, which emits carbon and pollutes the air – a significant problem as many ferries operate close to city centers. Existing and cost-effective solutions make it possible to build new ferries that are fully electric, as well as to retrofit existing ferries to save emissions.

Technological and battery improvements are now enabling larger vessels to operate on longer routes by using fully electric or hybrid-electric power. Furthermore, there is a large potential in reducing emissions from the ships while they are at berth, as can be seen in the Schevengingen Harbor case.

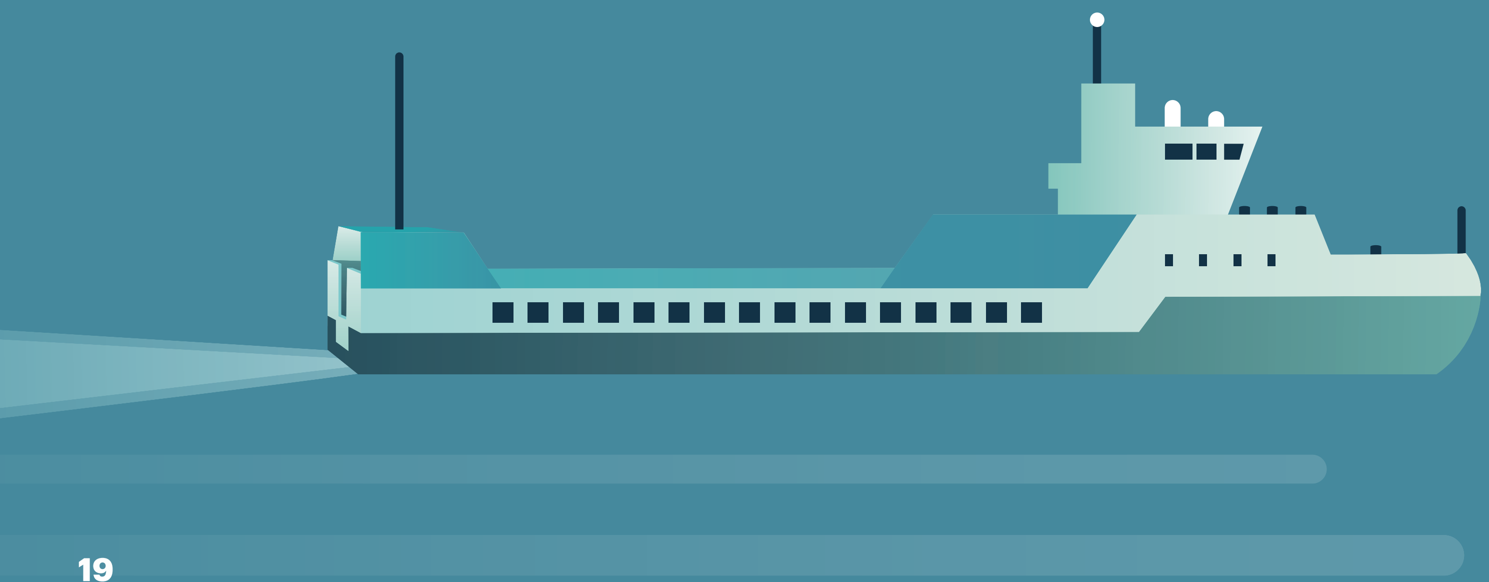
Retrofitting ferries in Taiwanese ports

The lifetime of vessels like ferries is between 25-30 years – and sometimes even more. Therefore, retrofitting ferries through hybrid solutions is crucial for reducing emissions from sea transport. The Taiwanese port city of Kaohsiung relies on marine ferries to move goods through its busy port and the emissions from these ferries contribute significantly to local air pollution.

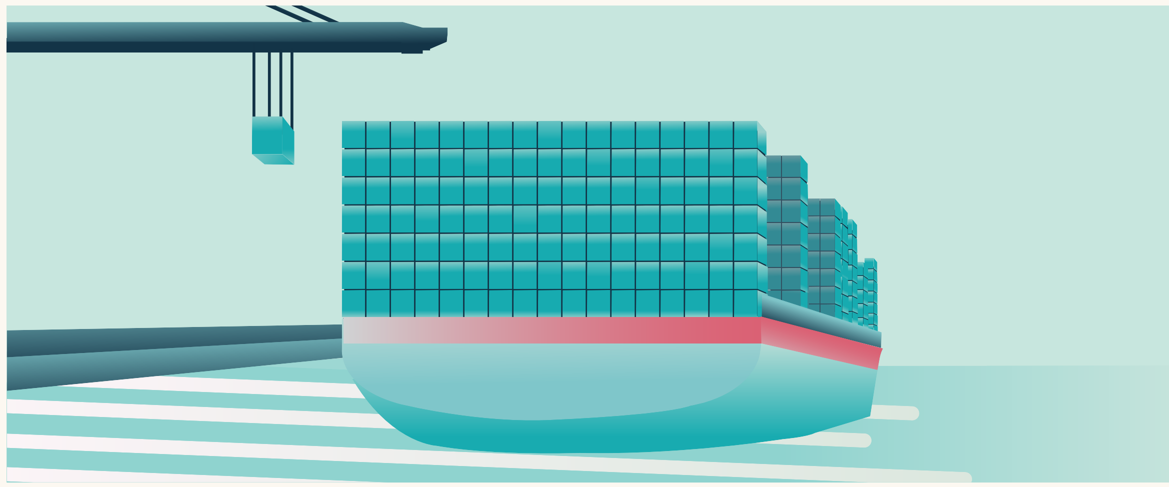
To improve air quality, the city government mandated a Taiwanese shipping company to reduce emissions from its ferry fleet. That included the popular Cijian Island passenger ferry route. As a result, the 100-ton, 23-meter-long ferry "Happiness," which carries around 15,000 commutes every day, became Asia's first hybrid-electric ferry in 2017.[60] The ferry's new system ensures pure electric cruising for half the ferry's operation time. Because of the initiative, Happiness has reduced its diesel fuel consumption by more than 30 percent,[61] and it is estimated that the fuel saving could be cut by as much as a half compared to the original diesel-powered ferry.[62] Lowering diesel consumption reduces both GHG emissions and helps to improve air quality in the region. Happiness now sources energy from shore power charging, a source that can be decarbonized.

Ellen, the world's longest ranging fully electric ferry

Between the islands of Ærø and Als in Southern Denmark, passengers and vehicles are transported by "Ellen" - a fully electric, medium-sized ferry. In operation, Ellen saves 80% of CO_2 and 75-95% of air pollution when compared to the best technological alternative at the time of the evaluation, and 87% CO_2 and 86-99% of air pollution when compared to an existing older ferry.[63] The operational costs of Ellen are significantly lower than conventional alternatives, which ensures a payback time for the additional investment of 5-8 years of operation.[64]



Case: Green shore supply in Scheveningen Harbor, Netherlands



Shore supply can charge the batteries of fully electric and hybrid vessels using electric power from the grid while in port. Shore supply can also supply electricity from local grids to vessels powered by fossil fuels, instead of using the diesel generators on board, to power everything from ship coffee machines and communication equipment to lighting and ventilation.[65] Using shore supply means no consumption of diesel while at berth, which in turn means significantly less local air and noise pollution. As ports are often located close to urban environments, this has a positive impact on local residents.

Scheveningen Harbor is centrally located on the Dutch coast close to The Hague and provides berths for more than 7,500 vessels each year. It consists of three harbor areas. While shore power in the Second Harbor already exists for cutters, small fishing boats, and pleasure vessels, a major new industrial-scale installation in the other two harbors extends capacity to many more vessels including large commercial vessels.

Thanks to the new shore power installation, ships can stop using noisy, pollutive diesel generators while berthed in harbor. This eliminates air pollution and reduces the noise and vibrations when ship engines are idle. On average, ships in Scheveningen Harbor consume more than 100 MWh per month via the new shore power supply.

At an average of one liter per three kWh, this translates to a monthly savings of more than 33,000 liters of high-quality marine diesel.[66] This results in dramatic reductions of air pollution and about 60% CO_2 equivalent savings with the current Dutch electricity mix.[67]

33,000
liters
of high-quality marine diesel saved per month

The future of decarbonized transport

- The relevance of electrification spans far beyond electrifying passenger cars. The technology for the electrification and decarbonization of buses, trucks, and excavators, as well as marine equipment and vessels such as cranes, straddle carriers, city boats, work boats, and ferries already exists.

- Improved efficiency can accelerate the electrification of transport. Both in passenger cars, heavy-duty vehicles, and in marine transport, efficiency measures can reduce the size of the batteries needed thus limiting the raw material requirements. Increasing efficiency can also bring down the demand for charging infrastructure and increase the productivity and range of the vehicle.

- Electrification is not a question of "all or nothing." For some vehicles that cannot yet be fully electrified, such as construction machinery and larger ships, it is possible to downsize the diesel engine and electrify critical components of the machine, creating a significant benefit from the increased efficiency of an electric system.

- Vessels can be supplied with sustainable energy while at berth with technologies readily available, significantly reducing emissions and pollution in urban areas.

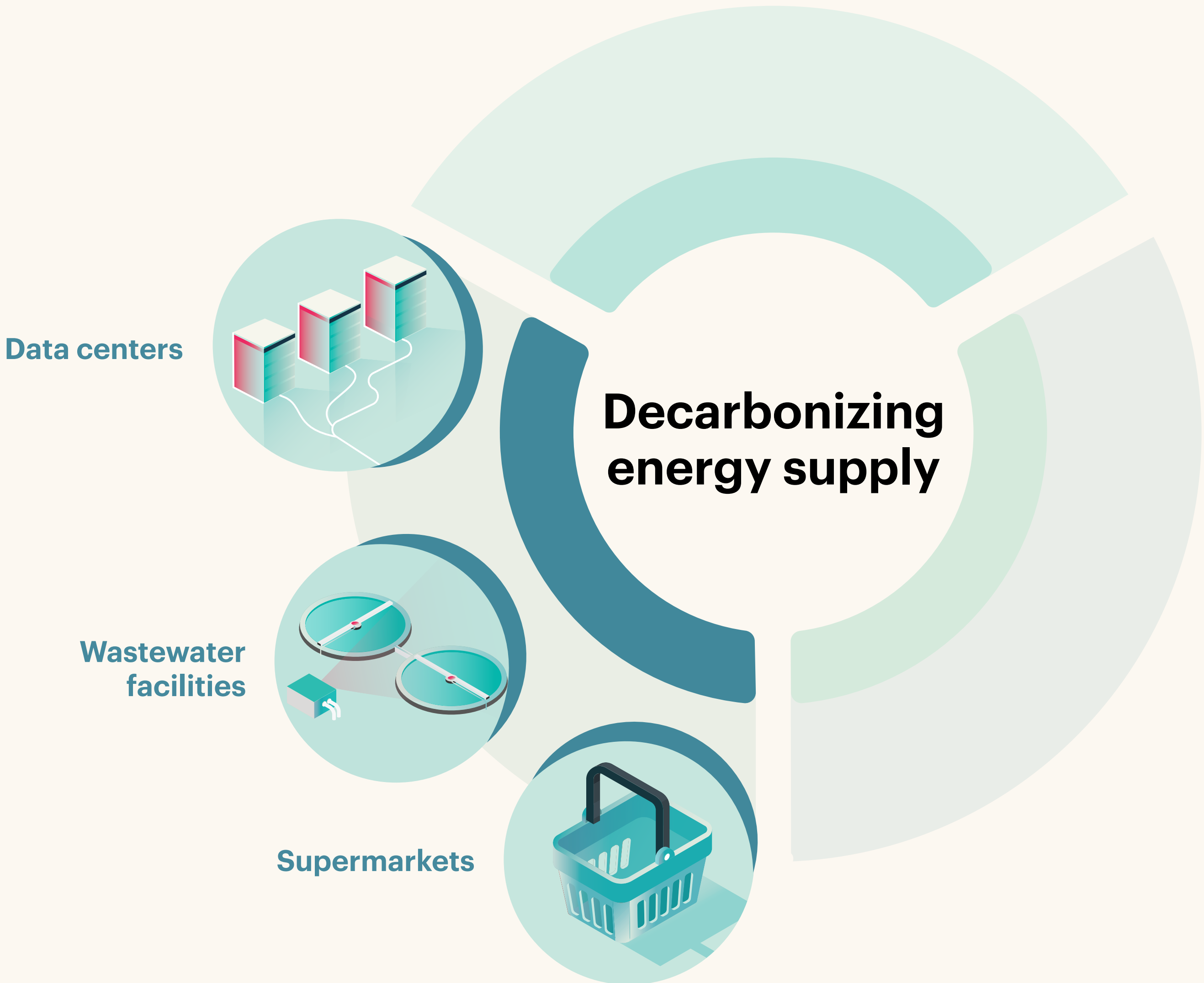
"Energy efficiency is about more than reducing demand. Without it, cities will not be able to accelerate electrification."

Kim Fausing, President & CEO Danfoss

Decarbonizing energy supply in cities

On the last stop of the decarbonization roadmap, we zoom in on the supply of energy to cities. We will see how activities that play an integral part of the life in cities – such as shopping and waste management – can be decarbonized by looking at the energy use in cities holistically.

The global energy crisis has triggered unprecedented momentum behind the build out of renewables. The world is now set to add as much renewable power in the next five years as it did in the past 20.[68]



Needless to say, scaling renewables will play a crucial role in decarbonizing cities, and even more renewable energy infrastructure is needed. However, if we are not efficient in our use of green energy, expanding the use of renewables at the current pace will not be even near enough to reach global climate goals.

Excess heat can provide for a substantial proportion of the heating and cooling needs in cities. In the EU alone, the amount of excess heat almost corresponds to the EU's total energy demand for heat and hot water in residential and service sector buildings,[69] and the picture is arguably the same globally. To utilize excess heat, a holistic approach to energy use in cities is crucial. You can read more on the potential of excess heat in Danfoss Impact Issue no. 2.

What is excess heat? Every time a machine runs, heat is generated. Just think of the warmth behind your fridge. The same is true on a larger scale with all the supermarkets, data centers, factories, and wastewater facilities in the city. As we will see, this heat can be reused.

Utilizing excess heat constitutes the third and crucial lever in the roadmap for decarbonizing cities. Below, we zoom in on three specific sources of excess heat in cities and explore how it can be used.

A holistic approach to urban energy supply

Historically, excess heat from the likes of steel and power plants has been reused due to the very high temperatures. But as technology has evolved, many more sources that produce excess heat at lower temperatures have become viable to reuse, and this means that also cities without a large industry have numerous sources of excess heat that add up to a considerable amount of energy. Excess heat from wastewater facilities, data centers, supermarkets, and metro stations are examples of excess heat sources present in all cities.

There are multiple ways to use excess heat. The simplest way to use excess heat is to reintegrate the heat into the same processes. One measure to use waste heat internally is by installing a heat recovery unit. Heat recovery units make waste heat usable for processes at a similar or lower temperature level. As can be seen in the supermarket case, the excess heat can be used to heat up the store and produce domestic hot water. However, the density of infrastructure in cities makes it possible to use excess heat even more systematically and in larger scale through sector integration and district energy.

Sector integration, or sector coupling, refers to the process of optimizing the combination of at least two different sectors of energy demand and production (i.e., electricity, heating, cooling, transport, and industrial processes). Sector integration is about maximizing synergies between sectors, as well as converting and storing energy. This can happen on a small and large scale through urban planning and district energy networks. Urban planning can leverage the potential of sector integration and excess heat by connecting energy producers with energy consumers through a smart grid. Large synergies can occur when a producer of excess heat, for instance a data center, is located close to entities that can buy and use large amounts of the excess heat (for example, horticulture). Looking at possibilities for such synergies between energy producers and users in urban planning is called industrial cluster planning and it contributes to decarbonizing our energy system. Furthermore, the collaboration between nearby companies has been shown to provide economic benefits to both the buyer and the seller.

The benefits of sector integration can be increased even further through district energy.

District energy: Decarbonizing urban heating and cooling

District energy is a collective system that supplies an entire area with heating or cooling. A district heating network taps into heat from a combination of sources, such as renewable sources (e.g., solar, geothermal, and biomass) and fossil sources (e.g., power plants) and distributes it through pipelines to end users in the form of heated water. A district cooling system, on the other hand, chills water at a central plant and then distributes it through pipelines to end users.

The vast majority of global district energy production today relies on fossil fuels. According to the IEA, the world needs to double the share of green sources in district heating by 2030 to reach net zero.[70] If we succeed, this will help slash GHG emissions from heat generation by more than one-third.

Today, district energy systems enable a decarbonizable heat supply. One of the main strengths of district energy systems is their capacity to integrate different heat sources that can push fossil fuels out of the heating and cooling mix. As the district energy technology evolves, more and more green heat sources are able to tap into the system. Today, the so-called 4th generation district energy system allows very low-temperature sources of heat to be integrated into the district energy system and provides heating for new buildings that can operate at low temperatures. The fact that more and more green sources of energy can be used in district heating and cooling puts district energy systems at the center of the green transition.

Another crucial benefit of district energy is that it supports balancing of the grid. One of the key challenges in decarbonizing our grid and increasing electrification is ensuring that supply matches demand. By looking at the energy system holistically and linking different energy sources, district energy allows for flexible use of power. It enables discrepancies in supply and demand to be evened out so we can exploit the full capacity of the grid. Balancing the peaks will be particularly important as we increase the use of renewables and electrification takes place.

Case: District cooling systems use half as much energy as air conditioners

In a district cooling system, chilled water is supplied from a central cooling utility to commercial and residential buildings through pipelines. The cold water for the district cooling is supplied by free, natural cold-water resources – sea, lakes, rivers, or underground reservoirs – or is produced from waste heat from power generation or industries, or via central electric chillers. The cold water in the district cooling system can be produced at night and distributed at peak hours during the day. This reduces the need for chiller capacity during peak demand hours and reduces operating costs, as electricity is cheaper and ambient temperatures are lower at night.

Around 10% of the world's electricity demand comes from space cooling and IEA estimates that by 2050, around two-thirds of the world's households could have an air conditioner.[71] According to international studies, the demand for cooling of commercial and residential buildings will grow exponentially in the years to come, especially in high-income countries and emerging economies in India, China, and Indonesia.[72] However, district cooling systems use half as much energy as air conditioners and will also reduce the consumption of the environmentally damaging F-gasses.[73]

Existing district cooling systems in cities like Paris, Dubai, Helsinki, Copenhagen, and Port Louis have proved that district cooling can be more than twice as efficient as traditional, decentralized systems.[74] In Dubai, for instance, 70% of electricity is consumed by air conditioners, and in order to meet the cooling demand, the city has developed one of the world's largest district cooling networks. By 2030, 40% of the city's cooling demand will be met by district cooling.[75]

Data centers: from energy users to energy producers

There are thousands of data centers across the world, many of which are in cities.[76] Data centers are simply buildings that provide space, power, and cooling for network infrastructure and are filled with varying amounts of servers. As data has become the lifeblood of today's global digital economy, data centers have become critical to the functioning of our day-to-day lives and activities. Data centers are also heavy consumers of electricity. Powering and cooling the thousands of servers requires a lot of electricity. According to the IEA, data centers consumed 220-320 TWh of electricity in 2021, or around 1% of global final electricity demand[77] – this is enough electricity to power about 20 to 30 million US households.[78] To reduce the carbon footprint, it is crucial to both optimize the energy efficiency of the cooling systems in the data centers and to use the excess heat from the data centers. There are multiple examples showing how excess heat from data centers can be reused to heat nearby buildings through a microgrid or can be exported to the broader district energy network.

In the city of Frankfurt am Main, there are several projects in the pipeline working towards assisting the city in taking excess heat from data centers and using it towards its entire heat demand of private households and offices. It has been estimated that the waste heat from the data centers in Frankfurt could, by the year 2030, cover the city's entire heat demand stemming from private households and office buildings.[79]

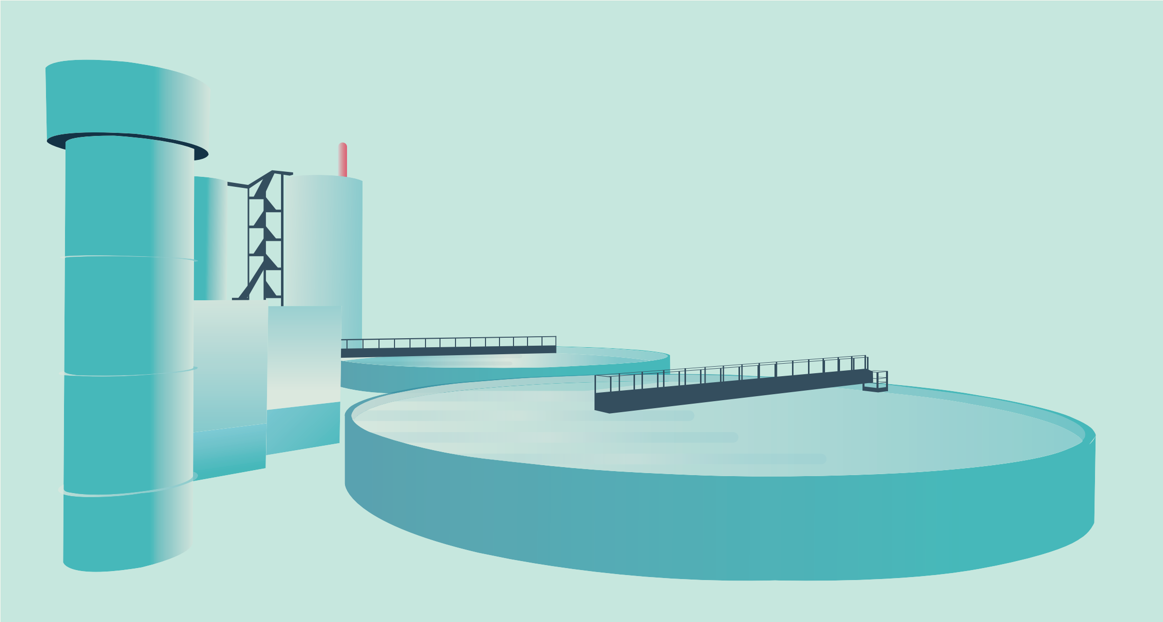
In Dublin, Amazon Web Services has built Ireland's first custom-built sustainable solution to provide low-carbon heat to a growing Dublin suburb. Initially, the recently completed data center will provide heat for 47,000m² of public sector buildings. It will also provide heat for 3,000m² of commercial space and 135 affordable rental apartments. This project will reduce the CO_2 emissions by 1,500 tons per year.[80]

Urban wastewater facilities as energy producers

The provision of water and sanitation is an indispensable yet often overlooked part of the urban infrastructure. It takes tremendous amounts of energy to provide citizens with access to clean drinking water and sanitation. Wastewater treatment plants are present in most cities around the world. And since they're often operated by municipalities, they can eat up 20% of municipal electricity bills.[81]

There is significant potential for energy savings in the water sector through a systematic use of excess energy. Wastewater contains significant amounts of embedded energy. Sludge can be extracted from wastewater and pumped into digesters. These produce biogas – mostly methane – that can then be burned to make heat and electricity. Before the cleaned water is released, it can be cooled down with a heat pump, which supplies heat to the local district heating network. Consequently, wastewater treatment plants have the potential to be turned from energy consumers to energy producers.

Case: Producing energy from wastewater



In the city of Aarhus, Denmark, the Marselisborg Wastewater Treatment Plant (WWTP), which is operated by Aarhus Vand, has managed to reduce energy consumption while simultaneously increasing energy production. In the period from 2016 and 2021, Marselisborg WWTP produced close to 100% more energy than needed for treating wastewater. The energy produced matched the needs for the entire water cycle of a 200,000-person city area, including both distributing drinking water and recovering wastewater from dwellings, thereby essentially decoupling water from energy. The return on this investment was 4.8 years. Process optimization and digitalization is estimated to have contributed to 70% of the improvements.[82]

The United Nations Sustainable Development Goal 6.3 advocates for a 50% reduction of untreated wastewater by 2030.[83] Equipping existing and future wastewater treatment plants with state-of-the-art technologies could save 300 million tons of CO_2 equivalent emissions per year. Furthermore, it would save a yearly 350 TWh of energy,[84] which is about one tenth of Germany's energy supply.[85] Lastly, surplus heat from effluents can be pumped to district heating networks, potentially providing 10 to 15% of the global residential heat demand.[86]

300
million tons
of CO_2-equivalent emissions can be saved per year

Case: Your grocery shopping can heat your home

Supermarkets are an integral part of cities around the world, providing convenient access to food and household supplies. However, they are also among the most energy-intensive commercial buildings.[87]

In the UK, supermarkets consume approximately 3% of the nation's electricity production.[88] Keeping food fresh in cooling displays and freezers accounts for most of the energy consumption in a supermarket. It might sound counterintuitive, but cooling displays, freezers, and fridges produce a significant amount of heat. Anyone who has ever felt the warmth behind their fridge can confirm that. These cooling systems generate significant amounts of excess heat, which is often released into the atmosphere.

But it does not need to be. Existing heat recovery technology can reuse the excess heat from the cooling displays to heat the water used in the supermarket as well as the building, and the excess heat not reused in the supermarket can be supplied to the district heating grid. In a small town in the Southern Denmark, the local supermarket SuperBrugsen has saved a considerable amount of energy by monitoring the cooling systems and by reusing and selling excess heat from the cooling systems. **Since 2019, 78% of SuperBrugsen's heat consumption has been covered by reused heat from cooling processes.** And the supermarket has sold 134 MWh to other local buildings through the district heating grid.[89]

78%
of heat consumption covered by reused heat from cooling processes

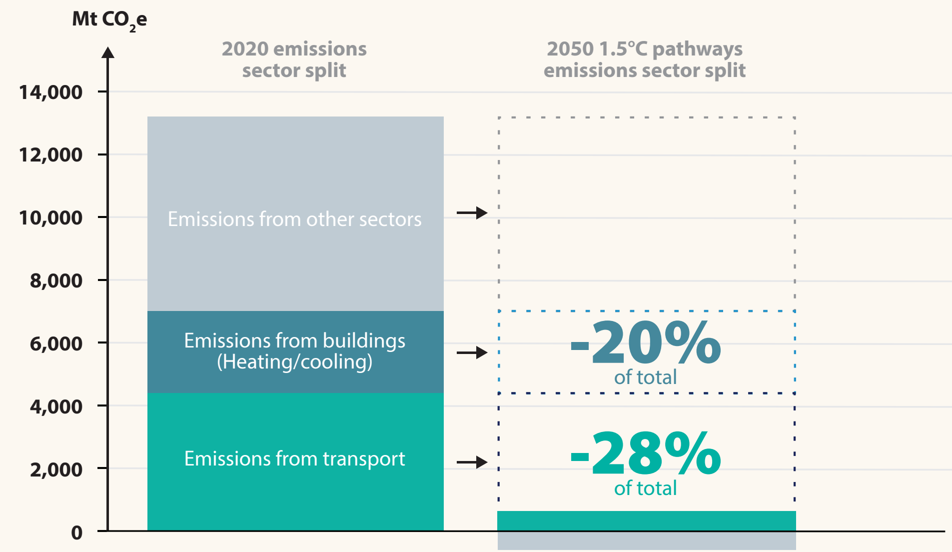
Save energy. Electrify. Integrate.

Three steps to decarbonize cities

Looking at the various examples and sectors examined above, we can see three key trends driving a successful a green transition in cities: 1) Save energy, 2) Electrify, and 3) Integrate.

Based on International Energy Agency (IEA) and IPCC scenarios, a Navigant analysis has quantified technology uptake on a 1.5°C pathway for a selection of cities in Europe, the US, and China.[90] Emissions from transport and from heating and cooling of buildings account for more than half of the urban emissions. For cities to reach the 1.5°C goal in 2050, 28% of emissions must be cut from transport, 20% from heating and cooling buildings, and 52% from other sectors, including electrification of heavy-duty vehicles. The study by Navigant reveals that energy efficient buildings and electrification of transport – both enabled by sector integration – can bridge half the gap in greenhouse gas emissions reductions needed for staying below the 1.5°C target. And this is considering only existing technologies. Adding to this, energy efficient measures in other sectors such as in heavy vehicles can contribute further. Let's take a closer look at these three main drivers of urban emission cuts.

Figure 3: Towards 1.5°C goal in urban areas



28% emission reductions will come from transport, 20% from heating and cooling buildings, and 52% from other sectors. Transport cannot reach zero emissions.[91]

Save energy

Energy efficiency measures can vastly reduce the amount of energy we use in our cities, save costs, and improve the health and well-being of urban citizens. Even though efficiency measures are often associated with buildings, reducing energy waste is possible across many aspects of our lives in cities. As we saw at the construction site, better system efficiency in heavy vehicles can reduce diesel consumption significantly and paves the way for electrification by reducing the size of the batteries needed in the more efficient excavator. The same is true with passenger cars, where efficient power modules can increase the range of the car, effectively increasing the market uptake of electric vehicles. Furthermore, everything from data centers to wastewater facilities and supermarkets can reduce energy consumption by monitoring and adjusting energy use.

However, if we look at buildings alone, they account for 28% of all global energy-related CO_2 emissions[92] and 40% of urban primary energy use.[93] Inefficient heating and cooling of buildings are thus major causes for emissions and air pollution globally.

For cities to stay below 1.5°C in 2050, 20% of the emissions reduction comes from buildings, including a range of energy efficiency measures as can be seen in Chapter 1. This would equal curbing 2,500 Mt of annual emissions in 2020 down to 0 Mt by 2050, which alone is 10% of today's annual emissions of urban areas worldwide. This will require the steep uptake of existing technology for energy efficient heating and cooling of buildings in cities. This means that the renovation rate of buildings – which is now often below 1% - will need to increase to approximately 2-3% for cities to reach the 1.5°C target.[94] As such, several cities would need to triple their current renovation activities. And even then, the transformation of the existing building stocks might take 30 years or more.

Energy efficiency is crucial for meeting our net-zero targets. In fact, at a global level, enhanced energy efficiency can provide one-third of the emission reduction needed for net zero.[95] Without a constant increase in energy efficiency, we simply cannot build out renewables fast enough to meet the global climate goals. Energy efficiency measures reduce the pressure on electricity grids and increase the share of renewable energy in the energy mix of cities. Furthermore, a stronger focus on energy waste will become increasingly important in the future battle against climate change due to growing populations and increasing demand for energy. For instance, cooling demands will increase significantly in cities, where the urban heat island effect can increase temperatures by 3-4°C relative to surrounding areas. Adding to this, the benefits of energy efficiency extend beyond climate. Enhanced efficiency and related avoided energy demand could help contribute to reducing global household energy bills by at least USD 650 billion a year by 2030,[96] while also promoting health and well-being for the billions of people who live in cities.

Electrify

Electrification will play a pivotal role in the green transition. Within urban transport specifically, there must be a drastic acceleration. Similarly, urgent attention is needed to accelerate the electrification of heavy transport as well as the marine industry. As we have seen, the required technologies already exist for full electrification of trucks, city boats, work boats, and ferries, as well as equipment operating at ports such as straddle carriers and cranes.

If all urban areas in Europe, the US, and China electrified their private and public transport, they would contribute 28% of the emission reduction needed to reach the 1.5°C target of the Paris Agreement.[97] This is without considering the potentials of electrifying heavy-duty vehicles. However, the contribution varies by region and by city – 17% in Europe, 24% in the US, and 37% in China.[98]

As we progressively decarbonize our electricity generation, we will also need to electrify the industries and buildings in our cities that have previously been powered by fossil fuels. For example, replacing fossil fuel boilers with more efficient heat pumps shows how energy efficiency and electrification are in many cases two sides of the same coin. Electrification can lead to emissions reductions both by replacing fossil fuel energy with renewable electricity generation, and by saving energy due to the higher efficiency of electric technologies. For instance, battery electric ships are almost twice as efficient as ships with an internal combustion engine, and the higher efficiency will offset the higher price of electric ships considering a lifetime of 20-25 years.[99]

By electrifying transport, we can reduce greenhouse gas emissions as well as air pollution, which increasingly threatens the health of citizens in cities. Electrification technologies that are currently available have the potential to reduce NO_x emission by 90% per passenger kilometer by 2050.[100]

Integrate

Sector integration is an enabler of energy efficiency and electrification. In urban areas, the high density of buildings, infrastructure, and services means that we can connect urban energy consumers with energy producers and benefit from by-products such as excess heat. Sector integration is thus an effective way to save vast amounts of energy, thereby increasing the share of renewable energy in the urban energy mix and accelerating the transition to an electrified energy system powered by renewable energy.

Sector integration – and more specifically district energy systems – are an effective way to convert and store energy and stabilize the grid, which will only be more important in the future as the fluctuating supply of renewable energy in the energy system will increase significantly. One of the key challenges in decarbonizing our grid and increasing electrification is ensuring that supply matches demand. By linking different energy sources, sector integration with thermal energy storage allows for flexible use of energy and enables discrepancies in supply and demand to be evened out, so we can exploit the full capacity of the grid.

As we saw in supermarkets, data centers, and wastewater facilities, there are many untapped sources of excess heat in our cities that can be used elsewhere. **In fact, according to a recent estimate, excess heat from accessible sources in urban areas can cover 10% of the European Union's total energy demand.**[101] By using excess heat for heating and cooling we can save the higher value (increasingly green) electricity for the transport and industrial sectors.

Danfoss Impact
Issue no. 3

Policy Recommendations

A deep decarbonization of cities requires a comprehensive and holistic approach that involves multiple stakeholders, including local governments, businesses, and residents. In the following, some of the crucial initiatives are presented, although the list is not exhaustive.

Systematic energy-saving strategies can save energy across sectors

- Reducing energy waste across sectors starts with mapping energy use to identify areas for improvement. Mandate energy planning, set ambitious and actionable short-, mid-, and long-term targets and plans, and a suitable regulatory framework to incentivize investments.
- Seize the quick wins first, as this can leverage finance for deeper renovation or sustainable new-build projects. Quick wins include optimizing the heating, cooling, and ventilation systems in the public building stock (see p. 10-11). These measures can be implemented immediately with very short payback times, and without compromising long-term energy-saving efforts.
- Design and implement mandatory building energy codes for new and existing buildings to accelerate the transition towards zero-carbon-ready buildings and to increase the renovation rate of the building stock.
- Set minimum energy performance standards to support the uptake of energy efficient equipment. Energy labels can further stimulate the market and are most suitable for off-the-shelf products with end consumers as main target groups.
- Set up long-term renovation strategies, including suitable regulation and incentives to stimulate renovation, to use renewable energy, and to boost renovation rates of existing buildings. Currently, renovation rates are often less than 1% and must rise to at least 2-3% per year in most regions to meet 1.5°C by 2050.[102]
- Incentivize the replacement of technical building systems running on fossil fuels for space heating, domestic hot water, and cooling with those using renewable energy, such as heat pumps or district energy networks.
- Ensure or facilitate access to funding for implementation. One way this can be done is by using or asking for innovative financial business models like ESCOs.

Electrify transport through investments, regulation, and incentives

- Invest in the electrification of the city's fleet now (vehicles, buses, city boats, ferries). Remember that also partial electrification of heavy transport entails significant cost and energy savings and can be done immediately.
- Investing in electric charging infrastructure and incentivizing the installation of charging points at (semi-) public locations like office buildings, parking facilities, supermarkets, and tourist attractions. Introduce parking incentives and other fiscal incentives for moving toward electrifying transport.
- If the national policy allows it, use local regulation and permitting options to create low or zero-emissions construction sites and electrify last-mile inner-city freight and goods delivery traffic.
- Use franchise agreements with public transport operators to enforce zero-emission goals for buses, taxis, and more.
- Incentivize the installation of shore supply in harbors and present a plan for how to address that all vessels use electric shore supply when at berth.

Holistic energy planning can leverage synergies between sectors

- In general, mandatory heat and cooling planning will enable cities to assess the potential and make the best use of locally available resources. The planning must cover all urban energy system components – residential and service buildings, heat and power, industry, transport, water, and waste treatment.
- Depending on the existing energy system, energy planning can reveal both small-scale potential (such as forming the right incentives for heat recovery) and the potential of larger-scale opportunities, such as the rollout of district heating. It is crucial that the scope of the heat planning is wide and detailed, and also includes potential future sources of excess heat, such as Power-to-X facilities.
- Expand and decarbonize district heating and cooling where possible, including combination with heat pumps, and lead the way by connecting public buildings.

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