Danfoss Impact
Issue no. 6

Competitive decarbonization

Powering the industries of tomorrow

“We want decarbonization to be a source of growth.”

Mario Draghi
Former President of the European Central Bank,
Former Italian Prime Minister
Author, *The future of European competitiveness*

Decarbonization is industry's greatest growth opportunity

Foreword by Kim Fausing
President & CEO, Danfoss

More and more companies around the world are already turning the challenge of decarbonization into a powerful driver of value creation and competitive advantage. Yet existing policies do not sufficiently support industrial decarbonization efforts. This paper provides a clear guide for companies to strengthen their competitive advantage through decarbonization and demonstrates how a political framework can accelerate the transition. In the following chapters, we outline the building blocks for a new industrial strategy of "competitive decarbonization".

Historically, the emergence of industry was inseparable from the rise of fossil fuels. In fact, the industrial sector accounts for 37% of global energy use, roughly 65% of which still stems directly from fossil fuels.[1] However, the industries of tomorrow are not the industries of yesterday. Now, the pressing need to reduce emissions is posing a challenge to economic growth and competitiveness. As a result, the traditional fossil-based growth paradigm is changing. But rather than seeing it as a burden, what if that challenge were instead seen as industry's greatest growth opportunity?

Several trends are driving this shift – trends that will only grow stronger in the coming years. First of all, energy makes up a good deal of industrial production costs. In many regions, high and unstable energy prices are eroding companies' competitiveness and challenging the resilience of business models long thought to be robust, while energy security is becoming a growing concern. Analysis suggests that certain regions will see 50% higher energy prices in 2050 compared to others – a trend which poses further threat to competitiveness.[2,3] In this context, sharpening a company's competitive edge by reducing energy waste – especially in energy-intensive industries and regions with high energy costs – is an obvious and impactful first step. Actually, **by adopting cost-efficient energy efficiency measures, manufacturing industries can reduce energy consumption significantly while increasing their economic output.**[4]

Second, we are fortunately entering the era of renewable energy. The cost of renewables has dropped sharply in recent years, and they will unquestionably dominate the future energy system. However, since renewables produce electricity, **a lack of preparedness for the transition to a predominantly electric energy system means companies will find themselves on the back foot** compared to competition.

Third, consumers' and regulators' expectations on decarbonization are changing. Indeed, demand for decarbonization technologies across industries is rapidly growing, creating significant commercial potential. Analysis shows that growing demand for net-zero offerings could generate more than $12 trillion of annual sales by 2030.[5] In the era of decarbonization, a clear message is emerging for companies: **decarbonizing your operations to attract investments and comply with rising environmental standards and regulation is not only the right thing to do but is simply good business.**

As we will see in the following chapters, we do not need magic to accelerate the decarbonization of the industrial sector: it's entirely achievable with proven and cost-efficient solutions and frameworks that *already exist today*.

While these technologies might not grab as many headlines as carbon capture or energy islands, their impact and benefits will be immediate. **It all starts with increasing the uptake of energy efficiency measures.**

"Decarbonization is a powerful driver of value creation and competitive advantage in industry."

Kim Fausing
President & CEO, Danfoss

A number of highly cost-efficient and impactful technologies that companies can implement today can immediately reduce fossil energy consumption and drive down costs. Next, **sectors and processes must be more closely integrated** to make the best use of the incredible amounts of wasted by-products generated every day by industries, such as excess heat. Finally, industries must **electrify wherever possible.** Not only is this a precondition for the transition to renewables, but it also increases efficiency, as electric technologies in many cases use far less energy than their fossil-driven counterparts.

Despite increasing recognition of the commercial value of decarbonization, emissions from the industrial sector are still rising. In fact, since 1990, industrial emissions have increased by more than 70%.[6] **Since the solutions already exist with favorable payback times, what can we do to accelerate their uptake?**

We must start by addressing knowledge gaps and abandoning short-sighted political distractions. Even in the most forward-looking companies, adopting new technologies poses significant challenges, such as organizational resistance and perceived production risks. Yet, our experience is that highly impactful efficiency technologies can be set up *in a matter of hours*. These decisions to forego investment in green technologies are often made in good faith and with the immediate well-being of the organization in mind. However, they also come at the expense of long-term profitability. So, while we've already seen much progress on industrial decarbonization, there are clear steps we can take to accelerate it without sacrificing competitiveness today or in the future.

At the political level, most attention has been focused on high-profile climate projects with high ambitions and long implementation timelines. And when immediate action plans are introduced, they're often hindered by "stop-and-go" dynamics, vulnerable to shifting political priorities. This creates uncertainty for companies about which policies will endure and which will fade. However, proven solutions already exist, and the potential for a more strategic policy framework that incentivizes companies to implement them is being overlooked. Politically, economic incentives will drive industries to invest in the green transition. **We need not simply less regulation, but effective regulation which can provide industry with the accessibility and versatility needed to engage in a global market.** Combined with economic incentives this can level the playing field and foster competitiveness. Policymakers must also prioritize creating certainty, resilience, and security, ensuring diplomatic ties and supply chains are not held up by bottlenecks. They should empower industry to help achieve the Paris Agreement climate goal.

Industry has a unique role to play in the battle against climate change, as many of the essential goods it produces – such as critical minerals, electric vehicles, and sustainable building materials – are core pillars of the green transition. By embracing the innovative solutions and technologies that already exist today, **industry can turn the greatest challenge of our time into its greatest growth opportunity.** Let's get to work.

Drawing on empirical evidence and data from various credible sources, Danfoss Impact Issue No. 6 creates an actionable and cost-efficient roadmap for industrial decarbonization. It highlights technologies with incredible energy- and emissions-saving potentials, which today are scarcely implemented in industry despite widespread accessibility and favorable payback times.

In this paper, the term 'industry' is used broadly to describe sectors in which the primary function is production and manufacturing of goods. This includes light industry (e.g., textiles, consumer goods, electronics) with relatively low energy demands, as well as heavy industry, which represents some of the most energy-demanding sectors in the global energy system (e.g., cement, steel, and chemical production).

A special thank you to Rasmus Magni Johannsen (PhD, Department of Sustainability and Planning, Aalborg University) for offering valuable input and comments on preliminary drafts of this paper.

The views expressed in this paper are those of Danfoss. Their completeness and accuracy should not be attributed to any external reviewers or entities.

Comments or questions may be directed to VP, Head of Public Affairs, Sara Vad Sørensen at sara.sorensen@danfoss.com.

Only got 2 minutes? These are the key takeaways.

Competitiveness and decarbonization go hand in hand.

The business case for industrial decarbonization is getting stronger every year as investors prioritize sustainability performance and as efficiency technologies become cheaper and more efficient. In fact, analysis shows that growing demand for net-zero offerings could generate more than $12 trillion of annual sales by 2030.[7] When it comes to building resilience to fluctuating energy costs, **manufacturing industries could almost double the gross value added from each unit of energy use by 2040 by adopting cost-efficient energy efficiency measures.** Similarly, the digital trends sweeping all industries will also enable companies to take energy efficiency to new levels in a future energy system based on renewable energy.

Reducing fossil energy consumption is necessary…and simple.

The industrial sector accounted for roughly one-third of global energy consumption in 2022, with an expected annual increase of 1.4% through 2030.[8] But to reach net zero by 2050, total industrial energy use must grow by less than 0.5% per year by 2030.[9] To lower consumption, industrial actors must seize simple and impactful efficiency technologies. For instance, realizing the full potential of variable speed drives on the motors in the EU industrial sector can lead to **€9.5-10.7 billion in savings on electricity costs while avoiding 12.5-14.1 million tons of CO_2e-emissions** – equivalent to the annual footprint of up to two million European citizens (see Appendix).

Deep electrification is a precursor to renewable energy uptake.

Renewable energy sources such as wind and solar produce electricity. To prepare for the future renewable energy system, companies must therefore electrify wherever possible. Estimates show that **existing technology can electrify 78% of industrial energy use,** with the possibility of reaching 99% electrification with technology already in development.[10] Currently, however, electricity only accounts for 23% of industrial energy consumption globally.[11] A widescale electrification of industry would cut GHG emissions by nearly 80% and mitigate almost all energy-related emissions in these industries.[12] Energy-efficient and cost-competitive electrification solutions lower energy consumption and drive down the energy bills, freeing up capital for further green investments and mitigating high renewable energy curtailment costs.

Integrate processes and sectors to reuse excess energy.

By 2030, up to 53% of the world's energy input will be wasted as excess heat,[13] making it the world's largest untapped energy source. But by strategically integrating processes and sectors, this **excess heat can be reused in the factory to produce heat and hot water, by other consumers close by through industrial microgrids, and even be sold into local district energy grids, providing low-emissions heating** for buildings and water in the area. Reusing excess heat is reusing energy already bought and paid for - the simplest method of lowering energy usage and cost.

The state of industry

The industrial sector accounts for 30% of global final energy consumption. Can it be transformed to meet the challenges of a net-zero future?

Despite its important role as a producer of many of the technologies necessary to bring forth the green transition, industry remains one of the most difficult sectors to decarbonize. In 2021, the industrial sector emitted 12.7 Gt of CO_2, or 38% of the global emissions from fuel combustion.[14] The sector accounted for 30% of the global final energy consumption.[15] Of this, direct use of fossil energy constituted 67%, while 22% was from electricity.[16]

However, from 1990 to 2020, global energy intensity decreased by 25%, meaning we have managed to use less energy per GDP. This is a trend the IEA expects to accelerate in the years to come as electrification and stronger efficiency standards take hold.[17] In other words, if industry continues investing in and making progress on energy efficiency, we can achieve global efficiency goals while maintaining a positive economic trajectory.

The industrial sector is often divided into light and heavy industries. Light industries, like textiles, food and beverage, and machinery production, emit 8% of the industrial emissions.[18] Heavy industries account for the vast majority of industrial emissions, and just steel, cement, and chemicals for more than half of industrial energy use and 70% of industrial emissions.[19]

The entire industrial sector is faced with the same pressing challenge to decarbonize. However, while the principles of industrial decarbonization – **increase efficiency, electrify, integrate** – are the same across the sector, the specific technologies needed to carry them out vary. Light industries are the simplest ones to decarbonize from a technological standpoint. In fact, most of the technologies needed to reduce emissions here already exist; the challenge now is to deploy them at scale across smaller and disparate sites.[20] Much of heavy industry is considered hard-to-abate, and while energy efficiency and electrification can cut a decent chunk of the emissions, green hydrogen and carbon capture and storage (CCS) will be necessary to go the final stretch.[21]

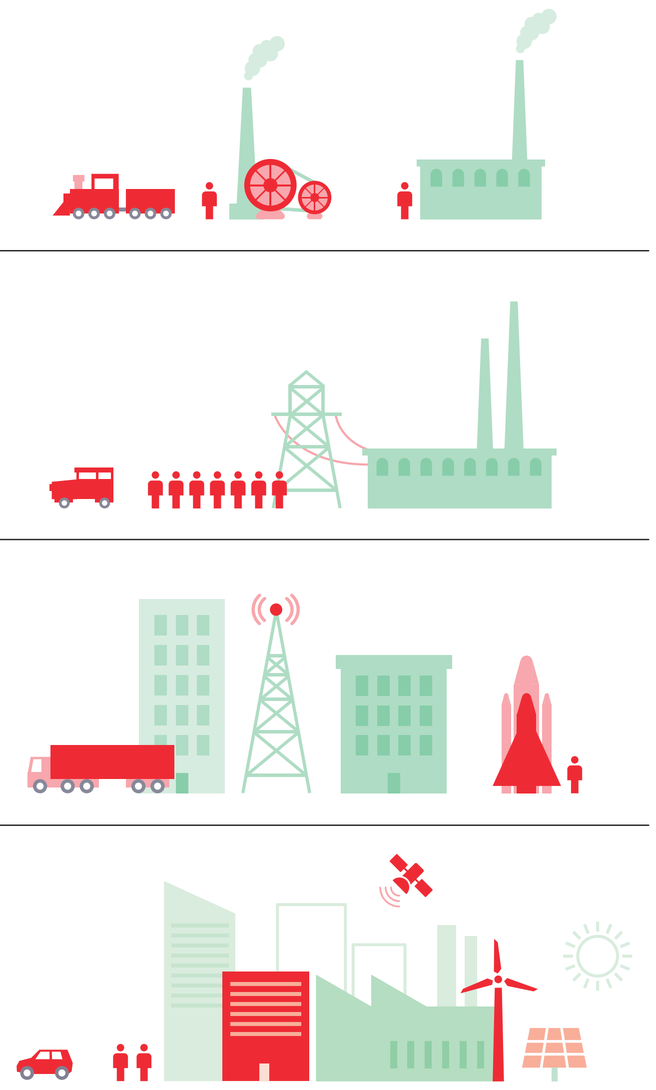
The potentials of transforming industry

There is a general consensus among experts on the most critical elements for an efficient decarbonization of industry. From researchers in Denmark[22] and China[23] to experts in the US Department of Energy,[24] the broad picture of cutting emissions is the same: reduce energy consumption and electrify wherever you can and use alternate fuels like hydrogen and technologies like carbon capture and storage for the most hard-to-abate sectors. As we will see in the following chapters, it is already possible to decarbonize the majority of industry using known and proven levers. Below is a brief overview of the overall potentials for business and society as a whole of deploying these measures.

Looking at the EU and UK, a recent study from Aalborg University finds that the industrial sector can feasibly be transformed to be powered 100% by renewables before 2050.[25] To achieve this in a cost-efficient way, investing in energy efficiency measures will lead to great energy- and CO_2-savings and actually, most of these investments will save money – even with conservative expectations for investment payback times. If industries scale up energy efficiency, electrify, and use hydrogen wisely, they can consume 37% less energy by 2050 than if the industries fail to transform. They can also achieve a 64% lower consumption of bioenergy and can save money at the same time. Actually, with only a €2 billion increase in investments, **the EU and UK industrial sector can save 20% of the total annual cost for fuel and investments by 2050. That translates to €43 billion saved annually** compared to a scenario with only little emphasis on energy efficiency and electrification. This is particularly pressing in the context of Europe's high energy prices relative to other regions of the world.

The four industrial revolutions

Year	Trends
1784	Fossil fuels, steam, water, mechanical production equipment
1870	Fossil fuels, division of labour, electricity, mass production
1969	Fossil fuels, electronics, IT, automated production
Today	Renewables, electrification, energy efficiency, AI, IoT, decarbonization



The picture is very similar in other major industrial regions of the world, such as China and the US. In China, industry accounts for 27% of emissions.[26] These emissions can be cut by 90% by 2050 with 64% electrification of final demand, 40% lower energy consumption through efficiency measures, and using hydrogen and CCS for the last deep decarbonization.[27] In the US, industry accounts for 33% of primary energy use and 30% of CO_2 emissions. The US Department of Energy identifies energy efficiency, electrification, low-carbon fuels such as hydrogen, and CCS as the four pillars of industrial decarbonization.[28]

To realize these potentials, the sector must systematically deploy existing energy efficiency and electrification measures across their operations. In the coming chapters, we present specific solutions and technologies that companies can deploy today to accelerate their green transition, increase resilience, and earn a profound competitive advantage.

Increase efficiency

To lower fossil energy consumption, industrial actors must seize simple and impactful efficiency technologies - many of which already exist today.

Reducing fossil energy consumption must be considered the first pillar of industrial decarbonization. This is not only because of the need to reduce industrial emissions, but also because mitigating high energy prices is at the forefront of many political agendas.[29] However, **solutions to increase energy efficiency while maintaining the same economic output already exist.** By reducing fossil fuel consumption, companies not only save money, but also accelerate the rate at which they can transition to renewables. Currently, global energy demand far exceeds renewable supply. However, if there is lower demand, the share of renewables in the energy mix increases, making it a cheaper and more abundant resource. Because of this, reducing energy consumption is the first important step in industrial decarbonization and necessarily precedes other critical actions, such as electrification, sector integration, and sourcing renewable electricity.

Energy efficiency measures for industry range from incredibly simple, low-tech solutions to advanced, high-tech solutions, all of which can be greatly impactful in lowering energy consumption and cost without negatively impacting productivity. In general, **all factories can benefit from a systematic approach to energy efficiency, which requires companies to holistically review all energy-intensive operations and processes.** Looking at this globally, three key focus areas for reducing industrial energy waste emerge: motors, water management, and air compression. In the industrial sector, motors account for more than two-thirds of industrial electricity consumption.[30] Similarly, 20% of the global freshwater consumption comes from the industrial sector,[31] while air compression accounts for about 10% of industrial energy usage.[32,33]

In this section, we will dive into the "low-hanging fruits" – those often-overlooked efficiency measures that can be implemented today at little cost – as well as no-brainer solutions like variable speed drives and efficient energy management. In the end of the chapter, we also present some of the areas where digital solutions can take energy efficiency to the next level in a future energy system powered by renewables.

Harvest the low-hanging fruits

Some of the best and most effective solutions for reducing energy consumption are the result of cutting-edge innovations in areas such as heating, cooling, or machine productivity. But some of them are not. In fact, common-sense thinking applied to traditional ways of operating or doing business can result in significant efficiency gains. These solutions – what we are referring to as the "low-hanging fruits" – present an opportunity for industrial actors to lower energy consumption today at little cost, while still planning for longer-term investments in energy-efficient production and operations. See the cases on pages 12 and 13 for concrete examples of "low-hanging fruits" leading to significant reductions in fossil fuel consumption.

Reducing fossil energy consumption must be considered the first pillar of industrial decarbonization.

Case: Saving big by switching off

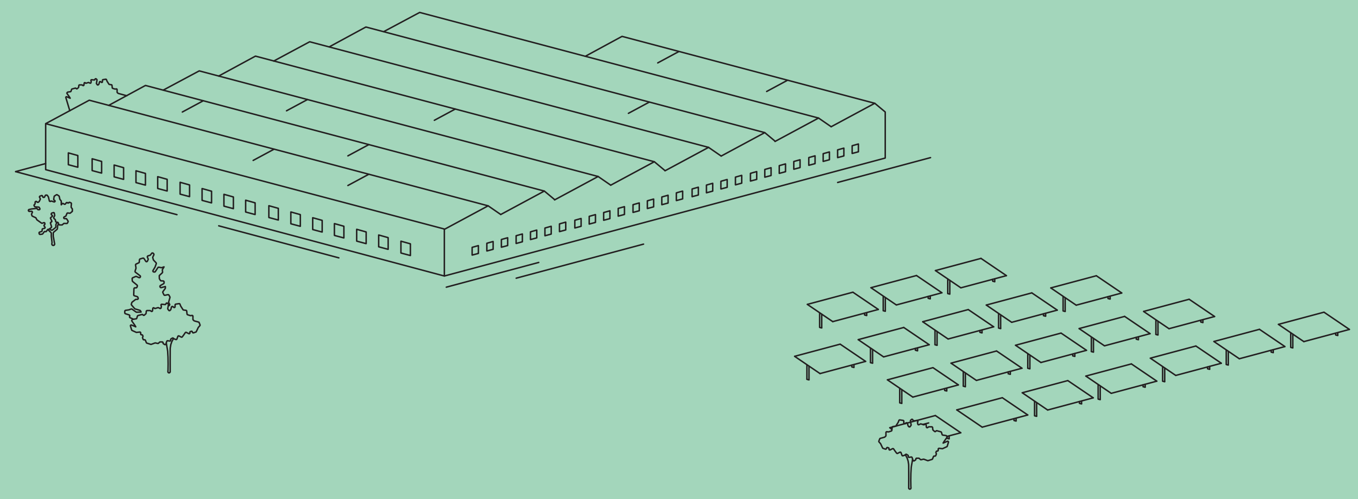
A standard practice in many industries with factory production is to leave large machines on standby when not in use. The thinking is that this increases productivity when production is to resume again. However, a recent pilot run by Danfoss Slovenia showed that **80% of the machines could be switched off when not in use** – without any effect on productivity.

The machines in the production facilities in Trata, Slovenia – everything from air handling units and compressed air systems to furnaces and heat, ventilation, and air conditioning (HVAC) systems – spend roughly 2,320 KWh per work shift when not in use. But with the "shutting off initiative," that number is 1,600 KWh, or a **30% reduction in energy consumption during off-production hours.** Two similar pilots at Danfoss' Polish factories in Grodzisk and Tuchom reveal a savings potential of 4,607 KWh and 800 KWh per day, respectively.

With successful results in the initial three pilot projects, Danfoss plans to expand the initiative to all 101 factories starting with 45 factories in 2024. As Sandro Terzic, Head of Energy Efficiency Office at Danfoss, says: "Once this initiative is fully rolled out, we expect savings in the range of 80 million kWh annually – between 8% and 10% of Danfoss' total energy usage, corresponding to €3-5 million. It will be among the biggest energy savings and emissions reductions for any single project in Danfoss history. The initiative will bring us an important step closer to reaching our CO_2-neutral factories by 2030 goal".

80%	30%	€3-5 million
of the machines could be switched off when not in use	reduction in energy consumption during off-production hours	annual savings on energy bill

Case: Reduce, reuse, re-source



The Danfoss headquarters in Denmark achieved CO_2 neutrality in December 2022 (Scope 1 & 2) by applying our 'Reduce, Reuse, Re-source' approach to decarbonize our operations and facilities.

At the 250,000 m^2 headquarters, Danfoss has **reduced** energy consumption since 2007 by moving away from an "always-on" state. By matching energy need with consumption, the facilities are using energy in a smarter and more cost-efficient way. Each facility has implemented control and monitoring technologies to manage use of cooling, heating, and lighting according to shifting energy needs. A key driver has been the optimization of ventilation systems, which reduced the need for heating by 79% from manufacturing processes and buildings, and electricity consumption by 41%.[34]

Energy savings related to the initial energy-reduction activities have helped lower temperatures in the factory site's heating network significantly from 145°C to 67°C. In addition to fewer transmission losses, lower temperatures in the heating grid make it possible to recover and **reuse** a significant amount of excess heat from the supermarket, datacenter, and manufacturing processes located across the campus. For example, the heat generated by the servers in the on-site datacenter can be captured and re-used to heat the building during the winter, ensuring that both the energy consumed and created by the datacenter is utilized in the most efficient way possible.

After reducing energy consumption and using excess heat to the furthest extent possible, the headquarters **re-sources** renewable energy for the remainder of the demand. This is supplied through a mix of heat recovery from manufacturing processes and the data center, green district heating, locally produced biogas, and grid balancing by help of an electric boiler. Remaining electricity demand is covered primarily by solar panels and through corporate power purchase agreements with suppliers of carbon-neutral energy.

When implemented in the proper sequence, this strategy – reduce, reuse, re-source – presents a viable, replicable, and cost-efficient pathway for industrial decarbonization.

Efficient energy management

When industries are planning their cost-efficient and competitive decarbonization journey, an over-fixation on only a few technologies and solutions can result in companies overlooking crucial energy- and resource-saving solutions. It is imperative to take a holistic approach to energy management, which includes considering industries' entire supply chain. **Apart from electricity and natural gas, water and compressed air make up some of the most important utilities in the manufacturing industry.**

From heating and cooling to powering manufacturing equipment and robotics, compression of liquids or gases is an important process that can contribute to the overall efficiency of systems. Implementing efficient pressurization solutions will contribute to the decarbonization of a whole range of processes. Pumps and compressors play a pivotal role and oftentimes are the first components to be considered when manufacturers are creating new equipment.

Air compression accounts for about 10% of industrial energy usage, making it one of the most energy-intensive utilities in the industrial sector.[35,36] In fact, energy usage makes up the majority of the total cost of ownership of air compression systems, while less than 25% stems from maintenance and initial investment costs. Procuring the right compression system for the desired use is essential.

Beyond air, water is also a critical utility in industry. Indeed, whether washing, cooling, producing steam, or disposing of garbage, nearly every industrial product uses water in some part of the manufacturing process. The requirements for the water purity can be very high, and actually, industries account for 20% of the global freshwater consumption,[37] though this varies from region to region. More industrialized countries have even higher industrial water consumption, sometimes up to 80%. Water consumption is an oftentimes overlooked footprint of our production but addressing it can improve overall system efficiency and lower energy consumption.

Compressed air

Air compression is a critical function in many industrial processes, such as in pneumatics and HVAC systems. In fact, compressed air is so widely used in industry that it is sometimes referred to as the "fourth utility" after electricity, natural gas, and water. Due to its ubiquity in industry, increasing the efficiency of compressors is essential to reduce energy demand and consumption.

One simple efficiency measure is implementing a variable speed drive on compressors, which can help the compressor optimize its performance depending on the specific need. Efficiency gains can come from a variety of system changes, such as opting for oil-free compressors, which cause less oil degradation on the rest of this system, thereby increasing the overall performance and durability. Similarly, compressors applying magnetic levitation can ensure next to no wear and tear on the rotor in a compressor, resulting in limited performance drop over time. Furthermore, digital solutions, such as intelligent monitoring, can detect early-stage leaks and ensure essential components are changed before major failures occur. Considering these measures of efficiency gains throughout the entirety of an industrial system process can deliver emissions and cost savings, making the business case for the specific industries more attractive and more competitive.

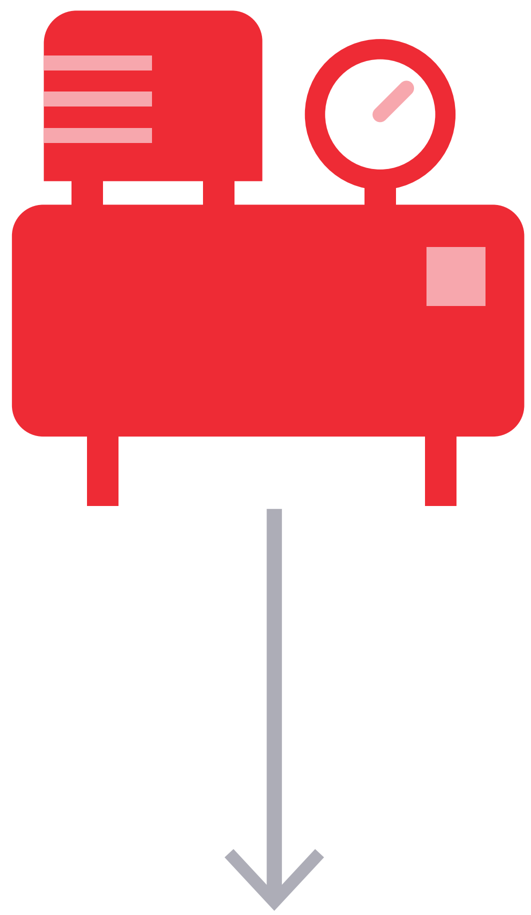
Industrial water pressure

It takes hundreds of liters of water to produce one liter of soda, thousands of liters to produce a pair of jeans, and hundreds of thousands of liters to produce a car. There is simply not enough freshwater to supply both industry and drinking water, so it must be produced in vast amounts globally. Ensuring the procured freshwater is produced efficiently is therefore essential to combat water scarcity issues and keep down the costs of this energy-intensive process.

To meet the growing demand for freshwater, more and more water is being produced through desalination. The most prevalent technology for desalination is reverse osmosis (RO), accounting for 69% of the global[38] and 91% of the EU desalination capacity[39] due to its high efficiency.

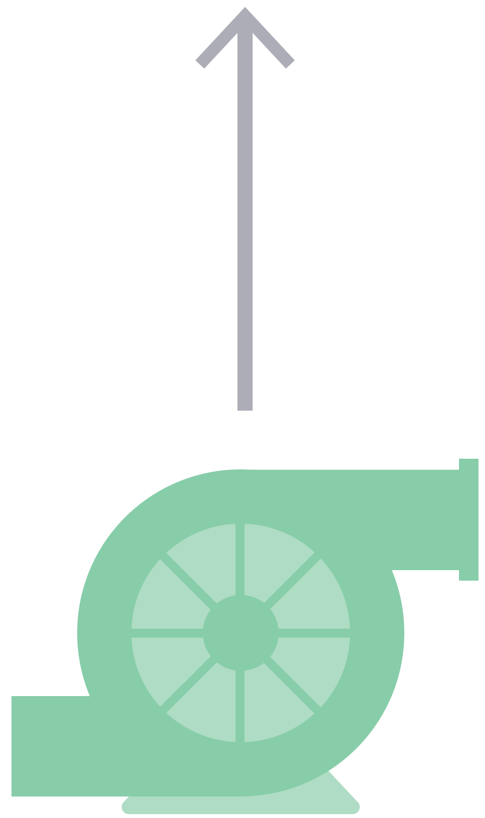
Desalination is energy intensive, so using the right technologies to produce freshwater can lower the operational costs, energy consumption, and reduce the GHG emissions. High pressure pumps are crucial components of the RO process and are among the most energy-consuming parts of desalination plants due to their substantial electricity use. Choosing the right high-pressure pump can lead to substantial increases in energy efficiency. Depending on the RO plant capacity, conventional RO technologies have efficiencies of 75-82%, while state-of-the-art technologies with energy recovery devices can reach 92% efficiency.[40] High pressure pumps can be fitted, and even retrofitted, with energy recovery devices, which reuse the energy contained in the pressurized desalination by-product.

Industries with a large freshwater consumption can lower both their freshwater and climate footprint by ensuring their supply of water is produced as efficiently as possible. Apart from the lower energy consumption and climate footprint, choosing the correct pumps can deliver operational expenditure savings. Adding to the business case, some of these pumps even have a payback period under two years when retrofitted.[41] Last but not least, water pressure sensors combined with variable speed drives can ensure an optimized and accurate pressure control, increasing efficiency while preventing pressure surges which can result in pipeline cracks and leakages.



Air compression accounts for about 10% of industrial energy use

Industries account for 20% of global freshwater consumption, and up to 80% in some industrialized countries



Increase efficiency in electric motor systems

In industry, electric motors power many essential technologies such as fans, pumps, compressors, conveyor belts, and endless other applications across factories and production sites. In short, the world as we know it today could not run without electric motors. However, as ubiquitous as they are, modern motors have one major problem: they use and waste vast amounts of electricity. Actually, motors use 10,700 TWh of electricity per year,[42] accounting for more than half the world's electricity consumption, and more than two-thirds of industrial electricity consumption.[43] The good news is that **we can drastically reduce motor energy consumption and cost of operation with highly efficient technologies that already exist today: variable speed drives** (VSD).

What is a variable speed drive and how does it reduce energy consumption?

Motors are often oversized for their purpose, meaning they operate at constant speed without adapting to the demand, or they simply don't meet modern efficiency standards. For example, in the US more than half of all motors are running inefficiently.[44] It has been predicted that about half the motors in the EU and the US are older than their expected lifetime – sometimes even twice as old.[45]

Instead of allowing a motor to run at a constant speed without adapting to the actual demand of the application, a VSD enables a motor to run at variable speeds, meaning it can be slowed down to match the demand (for a simplified explanation, see page 17). In doing so, it consumes far less energy without negatively impacting productivity. About 50% of all motors globally can benefit from VSDs because the required load is not constant and the motors are often oversized.[46] In these cases, a VSD can often deliver reduce energy consumption by 15-40%.[47]

Global energy-saving potential of VSDs

The global potentials of VSDs for lowering consumption, cost, and GHG emissions are substantial. For example, there are eight billion motors in use in the EU, which consume nearly 50% of the electricity produced,[48] amounting to 1,300 TWh per year.[49] Looking solely at the EU industrial sector, the electricity consumption of the motors is between 650 and 729 TWh per year. A conservative estimate is that about a third of all motors in the EU have major potential to reduce energy consumption through VSDs today. It is worth noting that this is beyond the motors that already have a VSD installed. In fact, this potential represents 47-53 TWh per year, up to 9% of Germany's electricity production – the largest producer in the EU. Even a conservative estimate shows **the electricity cost savings can reach €9.5-10.7 billion while avoiding 12.5-14.1 million tons of CO_2e-emissions – equivalent to the annual footprint of up to two million European citizens** (see Appendix).

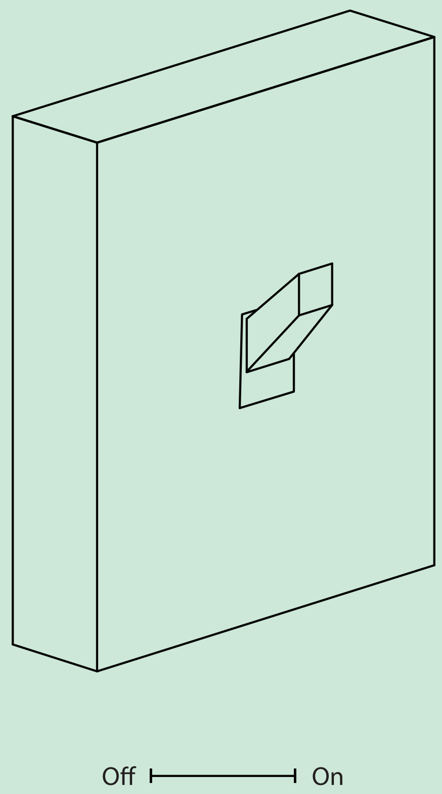
The potential savings from VSDs in the EU industrial sector is about 1.8% of the EU's electricity generation,[50] 10% of the EU's wind production, or almost 24% of the EU's solar production.[51] This renewable electricity could then abate fossil electricity generation in other parts of the energy system rather than powering inefficient motor usage. About one-tenth of the global electricity consumption by motors occurs in the EU.[52] All things equal, the global potentials for VSDs can conservatively be estimated to over 500 TWh, up to 5% of industrial global electricity consumption.[53] This estimate is only based on the *industrial* potential; because motors are omnipresent across nearly all other sectors as well, **the potential is arguably even higher.**

Over the lifetime of a motor, most of the cost is attributed to the energy usage. In fact, 95% of the total cost of ownership goes to energy to run the motor, whereas only 5% goes to purchasing it. So, if companies can achieve large energy and cost savings, why are VSDs not used everywhere? This question has two answers: first, there is a lack of awareness of the cost of running a motor versus buying it, and second, companies often have one department buying motors, and another department in charge of operational costs. The first department wants to save money on procurement and the latter department wants to save money on energy. As such, due to internal conflicting interests, companies often fail to choose the optimal solution.[54]

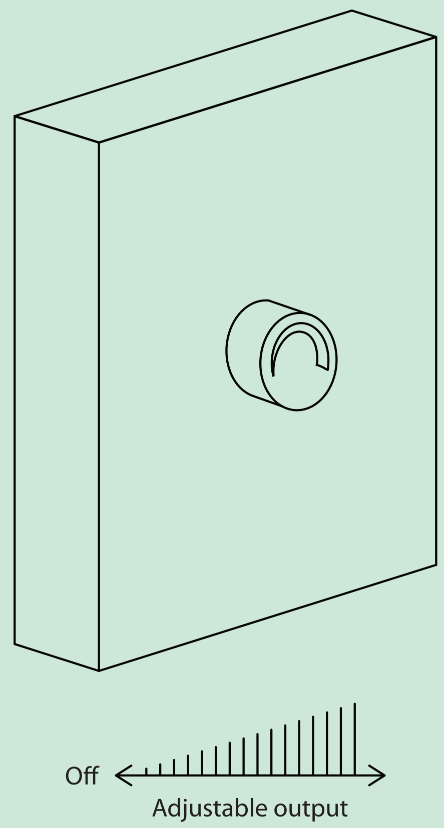
Understanding variable speed drives

By default, a motor can run at full speed or be turned off, much in the same way a standard light bulb can be switched either on or off. Oftentimes, it is necessary to lower the speed of the motor – for example, to slow the speed of a conveyor belt or a fan. A common way to lower the speed is to put brakes on the system. However, this means it's still consuming the same amount of energy as it does when it's running at full speed. This is equivalent to dimming the light by putting on sunglasses for bedside reading: it's still consuming the same energy, just with a lower output. Instead of lowering the speed of a motor with brakes, a VSD can control the speed of the motor, making sure that it runs at the required speed without wasting energy - just like a dimmer switch enables you to adjust the brightness of a lightbulb without wasting energy.

Without
variable speed drive



With
variable speed drive



Case: VSDs in heavy industry

VSDs have endless applications and can reduce the energy consumption across all industrial subsectors. However, while all sectors can benefit from VSDs, some demonstrate outsized potential for energy reductions. For example, in the global chemicals sector, optimizing motor system efficiency has been identified as the greatest lever for decarbonization. In fact, the sector can reduce its emissions by more than 270 million tons of CO_2e with a negative cost of €60 per ton through increased motor system efficiency alone.[55] One of the most influential elements in boosting motor system efficiency is VSDs (see US case on page 21).

Hydraulic systems use a significant portion of industrial electricity consumption. For example, hydraulic systems accounted for 11% of the German industrial electricity demand in 2017,[56] and the picture is likely similar across the world. Hydraulic systems are used widely across heavy industries, such as for injection molding processes.

Applying VSDs with hydraulic systems can significantly improve the efficiency and can bring energy savings of up to 70% compared to traditional hydraulic systems.[57]

Let's zoom into the US industrial sector. VSDs can lead to 44 TWh in electricity savings, $3.7 billion in cost reductions, and 31 million tons of CO_2 reductions all across the sector.[58] However, over two-thirds of the savings potentials can be realized in only six subsectors (see Figure 1). In fact, of all tools for increasing energy efficiency, VSDs can lead to the greatest or second-greatest amount of savings across these six subsectors. In primary metals, food, and plastics and rubber, the potential is greater from advanced motor technologies that exceed the performance requirements, but these motors come with a high upfront cost. In chemicals, petroleum refining, and paper, VSDs are the lever with the greatest decarbonization potential. Almost a quarter of the total VSD savings potential in the US can be realized in the chemicals subsector alone.[59]

Top six industrial subsectors in the US by annual VSD savings potentials

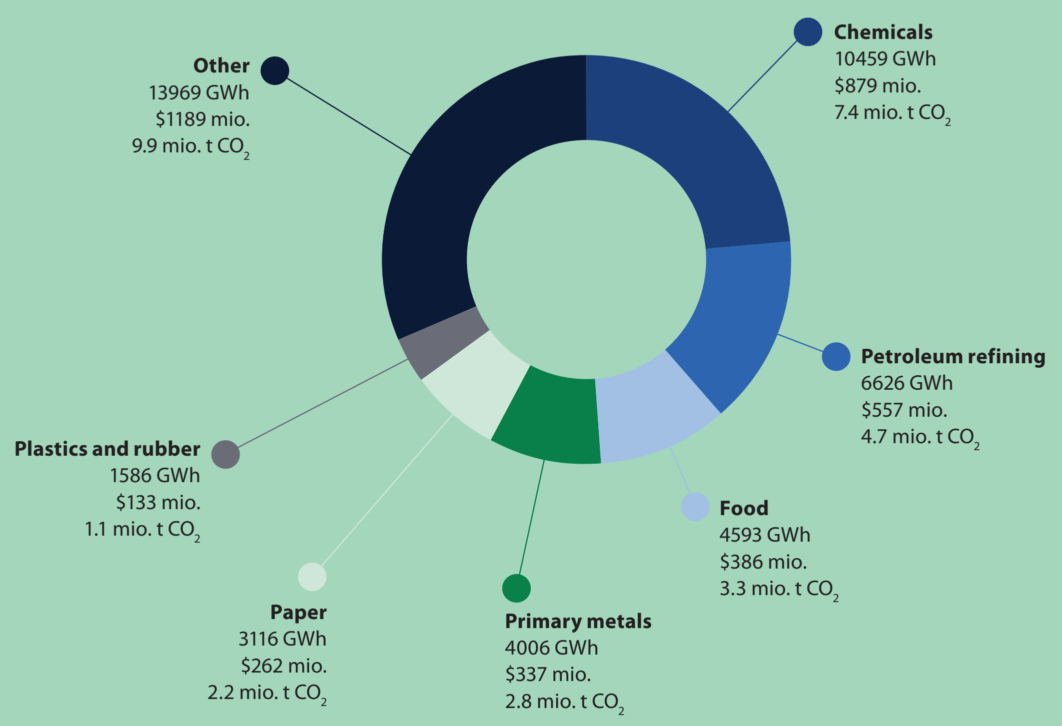


Figure 1: Electricity, cost, and CO_2-savings by subsector from an ambitious but realistic implementation of VSDs.[60]

VSD potential in the EU's Energy Efficiency Directive

Policy target potential

The EU's Energy Efficiency Directive sets ambitious targets to reduce the annual energy consumption by 1,174 TWh by 2030. This is an important pillar in the efforts to reach its climate goals.

By 2030, the annual savings from VSDs in EU industry can reach 21-52 TWh. This is on top of what installed VSDs in 2030 are already expected to save. In short, realizing **the full potential from this one technology alone can deliver 1.8-4.4% of the reduction goals** (see Appendix). With payback times as little as six months, this is one of the cheapest and most impactful ways for industry to reduce its energy consumption.

Levers to decarbonize motor systems in US industry

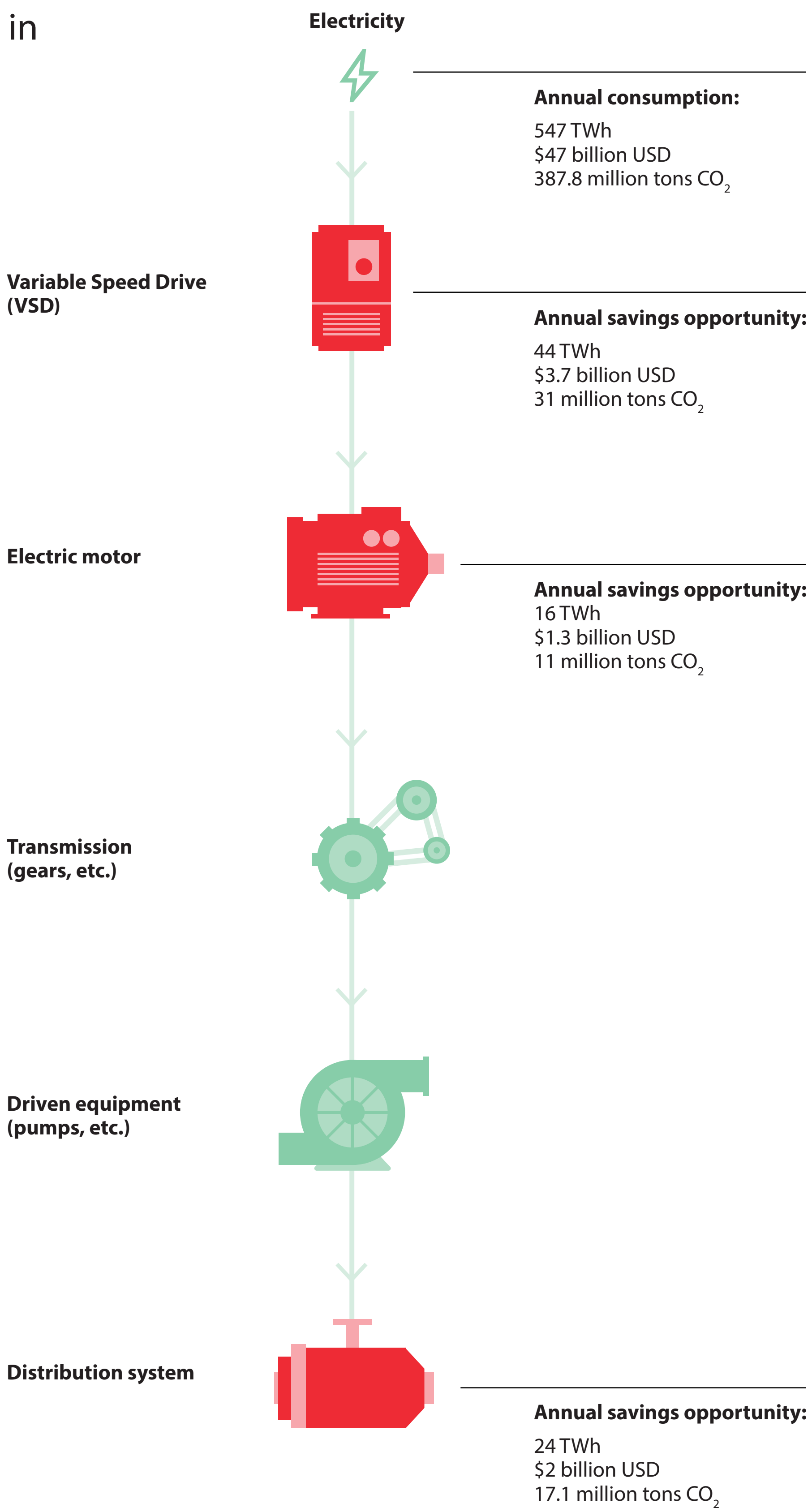


Figure 2: Variable speed drives can lead to savings of 44 TWh, $3.7 billion, and 31 million tons CO_2.
This is equivalent to 8% of the consumption from US industrial motor systems. Adapted from Rao, P. et al. (2022).

Case: How US industry can reduce cost, consumption, and emissions through VSDs

Electric motors in US industry use tremendous amounts of energy. They consume 547 TWh of electricity and account for 13% of the total US electricity consumption and 69% of the industrial sector's consumption. In industry, there are 11 million motors greater than 0.75 kW or 1 horsepower (hp) (on average 1.595 hp), many of which run inefficiently.[61] For instance, many of the motors are old,[62] need maintenance, are oversized, or run at different loads throughout their lifetimes.[63] This means that a targeted effort towards optimizing motor efficiencies can lead to a great deal of savings in electricity, thereby leading to financial savings and emissions reductions.

There are several levers to optimize a motor system, and no solution fits all. Looking across American industry, three solutions in particular can have a substantial impact: 1) replacing old motors with modern, more efficient motors, 2) optimizing the distribution systems, and 3) installing variable speed drives (VSD) on motors with a variable load profile. In fact, VSDs can typically reduce energy consumption to 15-40%,[64] and even up to 60% on variably loaded motor systems.[65]

VSDs show a massive potential to decarbonize American industry. 45% of the motors operate at variable load profiles, and only 16% have a VSD installed to optimize these motor systems.[66] **Installing VSDs on the rest of the motors with variable loaded systems can lead to 44 TWh in electricity savings, $3.7 billion in cost reductions, and 31 million tons of CO_2 reductions.**[67]

This is about 8% of what motor systems in the American industrial sector consume, cost, and emit. For comparison, optimizing distribution systems can lead to one-third of the savings, and replacing motor systems to meet the modern performance requirements can lead to half the savings of VSDs. Replacing motors with advanced motors that exceed the requirements can increase the savings, particularly in combination with VSDs, but these motors come with a high upfront cost.[68] Oftentimes it is not a matter of choosing between VSDs, more efficient motors, and other solutions; in combination, these solutions can lead to even greater savings.[69]

Of course, optimizing the motor systems requires some investments, but in many cases they also provide a great business case. Actually, at current VSD costs, **74% of the potential savings can be realized *while saving money*** with the investment requirements defined by the industry. This amounts to USD $2.8 billion in energy cost reductions, 33 TWh in energy reductions, and 23 million tons of CO_2 reductions.[70] For motor replacement, just 16% of the potential can be realized as good business cases at current prices.[71] The business case for massively rolling out VSDs is there, and the technology is proven. This can prove to be one of the most important tools in decarbonizing industry.

Digitalization enables industries to take energy efficiency to next level

Across all of industry – both light and heavy – one of the most prevalent trends driving energy efficiency is digitalization. There is considerable potential for digital technologies to reduce emissions across every aspect of industrial production, from increasing demand-side flexibility to automating HVAC and lighting systems. In fact, **digital technologies can reduce global emissions by 20% in the three highest-emitting sectors: energy, materials, and mobility.**[72] According to the analysis, one of the main drivers of these emissions savings are digital technologies that enable industries to improve energy efficiency, such as artificial intelligence (AI) and digital twins. Here, we explore several areas where digital technologies can take energy efficiency to the next level.

Motor systems

Digitalization is key to increasing the efficiency of various motor systems and applications. As explored in the section on motors and VSDs (see page 16), motors are ubiquitous across industry. And while VSDs themselves show great savings potentials, they can also be used to provide a digital dimension to industrial facilities, giving insight to take energy efficiency to the next level.

Sensors and data analytics for optimizing motor systems can deliver substantial electricity savings while bringing additional benefits such as lower maintenance and production costs. For example, in Europe, they can bring 50-100 TWh of electricity savings per year by 2030. These savings equal 5-10% of the total electricity consumption by motors in the EU.[73] While some fear that increased digitalization of motor systems will also lead to increased energy consumption and operational costs related to powering digital tools, a study from EMSA – an IEA-affiliated motor efficiency research organization – found that the energy expenditure for digitalization in motor systems never exceeded 1% across five real-world cases. The study claims that "the energy savings achieved through the digitalization of motor systems far outweigh the additional energy consumption resulting from the digitalization process."[74]

Demand-side flexibility

Demand-side flexibility is about using the renewable energy when it is plentiful and lowering demand during peak hours. It is about leveling out energy consumption, so we do not experience periods of simultaneous high demand and low supply – a key concern for grid stability and energy pricing in a fully renewable energy system. The primary methods of achieving this are demand-side flexibility measures such as load-shifting or peak-shaving. Both of these methods are about reducing peak energy demand either by shifting energy use away from peak consumption periods or by avoiding peaks altogether by reducing energy usage for one function to serve another. Essentially, equipment can be switched off or turned down during peak demand periods, instead choosing to use it at another time. And while this process can actually lead to higher energy use in some instances, it is less problematic – and sometimes even cheaper and greener – because the energy is being used outside the peak demand period. This reduces strain on the energy grid and saves money, as energy is cheaper in off-peak periods.

Case: Efficiency gains from motor system digitalization

Many modern VSDs are equipped with on-board microprocessors. This means that they can be used as sensor hubs to collect and process data about the motor system. It is now possible to connect legacy, analog motor systems to the cloud to gain insight about both component efficiency and overall system efficiency. In short, by gathering information on vibrations, pressure, and temperature and processing them in an AI-based cloud, VSDs can digitize an entire facility's systems and give companies deep insight into how to optimize operations.

A case catalogue from EMSA – an IEA-affiliated motor efficiency research organization – presents various cases on how digital technologies such as VSDs can boost industrial motor system efficiency.[75] For example, Hamilton Bonaduz – a large Swiss medical equipment manufacturer – implemented VSDs and sensors throughout an air compression system, providing insights into how to further optimize the system. By doing this, the company was able to reduce the system's electricity consumption by 16% while producing the same amount of air volume.

In addition to digital VSD capabilities, the EMSA catalogue also highlights other digital tools such as software and digital controls, which can further optimize a motor system. For example, at IKEA in Sweden, advanced controls combined with online performance monitoring optimized compressors and load shifting in chillers, resulting in 20% electricity savings. In Austria, BMW established a comprehensive data collection system to monitor electricity and compressed air consumption, which included visualizations of electricity consumption on production lines. Additionally, base load targets were set per line for non-production times in 2016 and 2019, leading to respective savings of 52% of the original electrical base load and 14% of the compressed air base load.

Across the cases presented in the EMSA review, digital solutions were applied to motors for pump systems, ventilation systems, air compressors, chillers, and production lines, providing significant savings in all applications. This evidence strongly supports the effectiveness of digital solutions in further increasing the energy efficiency of industrial motor systems.

Case: Automating heating with AI

Both load-shifting and peak-shaving processes can be automated with digital technologies that control how or when equipment or machinery use energy. This is achieved primarily through implementing digital tools known as model predictive controls. In buildings, for example, these **AI-driven technologies can save up to 20% in a building's energy costs by combining 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 that the maximum power usage was reduced by 10-30%.[76] Meanwhile, by shifting the consumption to the most economical period, the system ensures up to 20% savings in a building's energy costs without impairing the comfort of residents.[77]

While these technologies are currently aimed primarily at the residential building sector, their application is rapidly expanding in the industrial sector as well. **Early estimates from a Danfoss pilot show a potential to save 5% of energy used for heating in factories.** These savings are only expected to grow as the effectiveness of the technology in an industrial setting continues to develop.

Energy management systems

In today's rapidly evolving industrial landscape, factories and industrial production operations are made up of highly complex networks of people, devices, and systems. As the complexity of these devices and systems increases, so too does the difficulty of managing them. When systems are running sub-optimally, factories run the risk of consuming more energy than needed. Similarly, this can lead to more frequent maintenance issues, creating both inefficiencies and costly unplanned downtime. In this context, real-time data and insights on when, where, and how energy is being used can be critical for companies to make quick, informed decisions about where the greatest potentials for efficiency gains can be found.

Traditionally, industrial energy management systems (EMS) have been clunky platforms requiring a high degree of engineer involvement for installation, updates, and analysis. This results in slow feedback times and high operational costs. Moreover, while many individual components installed in a system may be highly efficient, their use in a system with other components may not be designed with overall "system efficiency" in mind. **Certain digital solutions allow developers to create the most efficient system without loosening a single bolt during development stages**. Essentially, this enables a process where efficiency, performance, and return on investment can be maximized digitally. As artificial intelligence and smart meters become more commonplace in industrial settings, EMS are becoming more practical, flexible, and user-friendly, enabling companies to adapt quickly to fluctuations in energy prices and changes in demand across facilities. In many ways, these platforms function similarly to digital twin technologies, enabling companies to choose and manage the best set of components in a system to help obtain the highest efficiency for the desired performance.

In the future, AI-powered EMS platforms will be able to make automatic adjustments to energy usage, as well as make recommendations to users about potential areas for energy savings. Additionally, users will be able to easily view the energy use from the entire production process in one digital dashboard, enabling early identification of energy mismatch or misuse.

While many newer machines and equipment are already equipped with smart meters, older ones may need to be retrofitted to streamline functionality with EMS platforms. Moreover, sensors can also be found in many of the machinery and technologies already present in factories. For example, many modern variable speed drives can play a key role in the information chain, using the advantage of built-in sensors, processing power, and storage capacity to enable companies to better understand the behavior of motor-powered systems. EMS platforms and smart energy technologies will continue to play a larger role in the future as digitalization penetrates more elements of industry.

Increase efficiency, at a glance

Chapter summary

Harvest the low hanging fruits for quick and cheap efficiency gains.

Companies can significantly lower their energy consumption by identifying energy waste. This can be done by holistically reviewing their energy-intensive operations and processes. Some of these operations and processes require cutting-edge innovations in areas such as heating, cooling, or machine productivity. But some of them do not. In fact, just tackling the low hanging fruits – such as shutting off machinery when not in operation – can result in significant energy savings already today at little to no cost (see page 10 for more).

Increase efficiency in electric motor systems.

Motors account for more than half the world's electricity consumption[78] and more than two-thirds of industrial electricity consumption,[79] in large part because they waste vast amounts of electricity. However, existing motors can be retrofitted with variable speed drives (VSDs) to drastically reduce energy consumption and cost of operation, often with short payback times. At a European scale, the industrial sector can save up to €9.5-10.7 billion on electricity costs while avoiding 12.5-14.1 million tons of CO_2e-emissions by realizing the savings achievable through VSDs – this is equivalent to the annual footprint of up to two million European citizens (see page 16 for more).

Digitalization takes energy efficiency in industries to the next level.

Digital technologies can reduce global emissions by 20% in the three highest-emitting sectors: energy, materials, and mobility.[80] Digitalization can reduce emissions across every aspect of industrial production, from increasing demand-side flexibility to automating HVAC and lighting systems. Some of the main drivers of these emissions savings are digital technologies that enable industries to improve energy efficiency, such as artificial intelligence (AI) and digital twins (see page 22 for more).

30%
The amount one Danfoss factory reduced energy consumption during off-production hours simply by shutting off machines

2/3
The proportion of industrial electricity consumption that goes to motors

€9.5-10.7b
How much VSDs can save EU industry per year on motor operation costs

Electrify

Electrification lies at the heart of industrial decarbonization. Without it, progress on energy efficiency and uptake of renewables will remain too low.

One of the single most energy-efficient measures we can take is to electrify all possible industrial processes. This is because in many cases electric technologies can generate the same output as a fossil-driven equivalent but with a much lower energy input, because vast amounts of energy are wasted as heat when we burn fossil fuels. In fact, according to a study from Oxford University, by transitioning to a fully electrified energy system, we could cut up to 40% of final energy consumption.[81] Electrification allows for full utilization of renewables and will both result in fewer curtailment costs and lower carbon-related taxes for companies.

Not only *can* we electrify industry, but it is also something we *must do*. Today, fossil fuels dominate many areas of industry that we can easily electrify. To reach net zero, boost competitiveness, and ensure energy security, industrial electricity demand must increase by 4,000 TWh, or 38%, by 2030, with 40% in heavy industries, to follow the IEA's net-zero pathway.[82] Fortunately, existing technology can electrify 78% of industrial energy use, with the possibility of reaching 99% electrification with technology already in development. This widescale electrification would cut GHG emissions by nearly 80% and mitigate almost all energy-related emissions in these industries.[83] These savings would also free up essential capital to reinvest in the green transition.

With commitments at COP28 to triple renewable energy capacity by 2030, the share of renewable electricity in the global energy mix is likely to increase.

If companies fail to invest in electrification, they will end up with expensive, outdated infrastructure, and will be on the back foot compared to competition who prepared accordingly for a future energy system based on renewables.

Within the context of industry, some of the most energy-intensive processes are related to heat generation. Heating makes up roughly two-thirds of all industrial energy consumption, and almost one-fifth of global energy consumption.[84] Currently, most of this heat is generated through the combustion of fossil fuels. As such, electrifying industrial heating can play a major role in reducing this outsized energy demand, while at the same time lowering companies' carbon footprints and energy costs. Both emission and costs reductions will be essential for the industries of tomorrow to stay competitive in an economic landscape influenced by differing market regulations and energy prices.

Because of the outsized energy demand of heat within industry, this section explores some of the most effective methods to electrify heating – both for easier-to-electrify, low-temperature heat and for hard-to-electrify high-temperature processes. It also presents pathways for low-emissions hydrogen to decarbonize other hard-to-abate processes within industry, such as chemical and steel production.

Electrification is at the heart of competitive decarbonization.

Electrify heating

Industries worldwide rely on thermal energy both for process heating and for non-process heating, such as space and water heating. The heat – mostly produced by burning fossil fuels – is used in all sorts of ways, from treating chemicals to melting materials, and ranges from ambient temperatures to thousands of degrees. However, tremendous amounts of energy are wasted through combustion. By instead electrifying these heat processes, it is possible to decarbonize the industrial heating supply and oftentimes save money at the same time.

Take industry in the US: in 2018, the process heating demand accounted for 68% of the total industrial process energy demand. Only 4% of the process heating was produced through electricity, with the rest stemming from fossil fuels. Additionally, one-third was wasted as excess heat.[85] The related emissions were 360 million tons of CO_2e, or 6% of the US emissions.[86] In the EU, the picture is the same: only 3% of the process heating is produced from electricity, while 78% is from fossil fuels.[87] The fossil fuels for heating emit 552 million tons of CO_2 per year, or 22% of the total net CO_2 emissions from the EU in 2021.[88] This is just the US and the EU. Imagine the problem on a global scale. With the global industrial heat demand set to grow by 16% by 2028,[89] it is simply impossible to reach the Paris goals without addressing industrial heating.

For many industrial processes, combustion-based energy can be substituted with electricity-based technologies such as heat pumps, electric arc furnaces, electric kettles, and blast furnaces. However, not all temperatures are easily generated via electricity, or at least not efficiently.

Industrial processes up to 160°C can already be electrified today while 200°C can be reached in near future. Indeed, most of the technologies are mature and ready for implementation. While it is *possible* to electrify heat at almost all temperature ranges, the story for electrifying high temperatures is more complicated. For example, it is possible to deliver almost 2000°C for metal processing with electric arc furnaces.[90] However, many solutions for heat over 200°C will not be developed in the short term,[91,92] making indirect electrification – namely, through green hydrogen – the most viable solution. You can read more about industrial applications of hydrogen on page 32.

The huge potential of industrial heat pumps

Heat pumps can deliver tremendous energy efficiency gains and if supplied with renewable electricity, can be a key lever in decarbonizing industries. **Industrial heat pumps can deliver 2-5 heat units with only one input unit of electricity,** depending on what output temperature is needed.[93] On the other hand, fossil-based process heating in US industry wastes roughly one-third of all energy input.[94] With such efficiency benefits, industries are able to decarbonize their operations while reducing energy bills and maintaining – and even at times increasing – their output.

In the EU, 37% of the industrial process heat is below 200°C (Figure 3) and 54% of this heat stems directly from fossil sources.[95] Delivering this heat with heat pumps can lead to reductions of 146 million tons of CO_2 emissions,[96] equivalent to 22% of Germany's net CO_2 emissions in 2021.[97] If the EU manages to decarbonize the electricity grid through renewables, the savings will be even higher, and with ambitious energy efficiency implementations, we can reduce the amount of renewable energy needed to meet demand.

In 2030, industrial heat pumps can supply nearly 40% of industrial process heating.[98] Through on-site heat recovery, industrial sites can utilize the excess heat from processes such as cooling and reuse it in process and space heating. The potential would be even greater if nearby facilities with high-temperature excess heat were utilized. In the paper, food, and chemical industries, a total of 60 billion cubic meters of natural gas were consumed in low-temperature processes that could be replaced with industrial heat pumps.[99] Read more about utilizing excess heat in industry on page 34.

In the EU and the UK, the potential of industrial heat pumps can lead to substantial savings in the paper, food, chemical, and refineries subsectors. Together, these subsectors consume half of the final energy consumed by the EU and UK industrial sector. The demand for process heat up to 200°C is 312 TWh annually and in producing this, an equal amount of heat is wasted. Industrial heat pumps can substitute much of today's heat production, and there is a realizable potential to implement over 4,100 heat pumps with a combined capacity of 23 GW. This can save between 87 and 147 TWh annually, leading to 37-53 million tons of CO_2 reductions. The emissions savings depend on how well the EU and UK manage to decarbonize the electricity mix.[100]

In the US, electrifying industrial heating is a great opportunity to decarbonize the industrial sector. Today, the emission factor of the US electricity mix is higher than natural gas, but because of the high efficiency of industrial heat pumps, electrifying hot water and steam generation can save 17 million tons of CO_2 today. With the mix potentially being fully decarbonized in 2050, the potential savings are 58 million tons of CO_2, equivalent to 5% of the emissions from US manufacturing.[101]

As is the case in many regions of the world, the greatest barrier for heat pumps in the US is low natural gas prices. Looking only at electricity and natural gas prices, industrial heat pumps are only cost competitive in some states.[102] However, energy efficiency is not the only benefit from heat pumps. These benefits lead to non-energy savings and include cheaper insurance and maintenance costs, better heat control, air quality, no need for carbon lock-in, and a more dynamic setup that can be scaled for future needs. When considering these non-energy savings, it has been estimated that **industrial heat pumps are cost-competitive with fossil-based heating already today while companies become more resilient towards future carbon pricing.**[103]

Final energy consumption in the EU

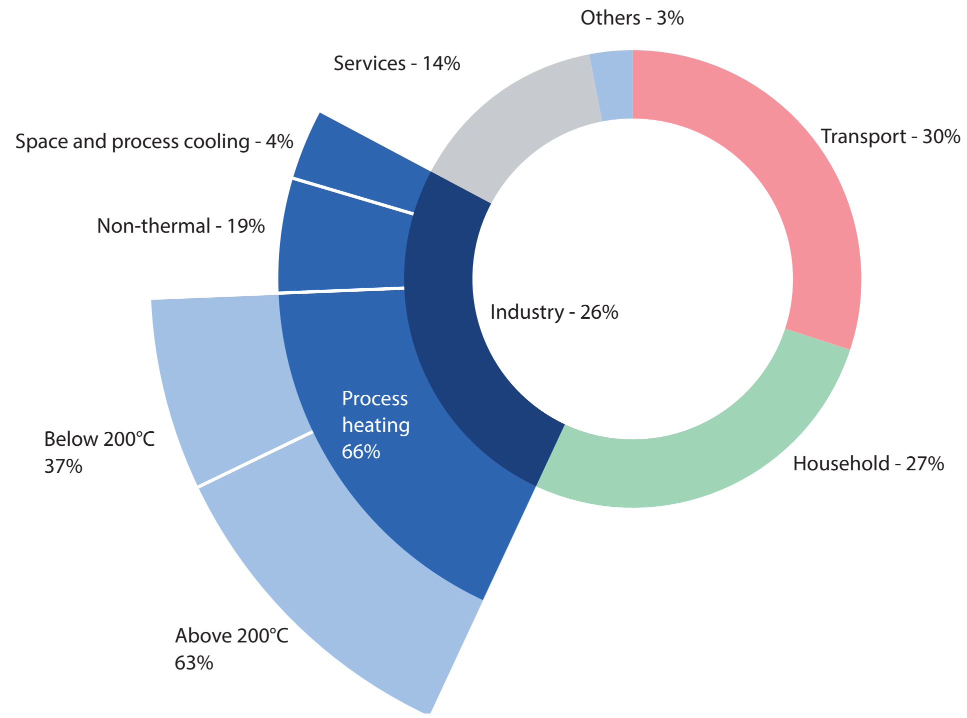


Figure 3: Final energy demand in the EU in 2015.[104] Process heating temperatures below 200°C accounts for 6% of all EU's final consumption and can almost entirely be electrified and thus decarbonized today. The distribution of energy consumption between sectors is almost unchanged from 2015 to 2022.[105]

Case: Electrifying China's industrial heat

China has experienced incredible economic growth in recent decades. As for anywhere on Earth, the expansion of the industrial sector has also brought with it a larger environmental footprint. Today, China's manufacturing sector emits around 20% of the global energy-related CO_2. This outsized contribution to global emissions puts it front and center in the global fight against climate change. Air pollution is also a concern following industrialization. In fact, air pollution from the Chinese manufacturing sector led to 1.85 million premature deaths in China in 2019.[106]

70% of the energy that powers Chinese manufacturing comes directly from fossil sources, while only 24% is from electricity, almost none of which is used for heating. Additionally, 73% of the final energy for manufacturing is used to generate heat and is dominated by fossil sources.[107] However, electrifying heating can create a substantial increase in efficiency, as well as a large drop in excess heat. Consequently, if the electricity is delivered from renewable resources, this not only increases the efficiency but can also make a major dent in the outsized carbon footprint of Chinese manufacturing.

There are many heating technologies driven by electricity. Heat pumps can be used to reach temperatures of over 150°C while other technologies like electric resistance heaters and electric arc furnaces can be used to reach higher temperatures. The existing electric heating technologies can deliver heat up to 1,700°C and can cover two-thirds of China's industrial heating demand.[108]

The competitiveness of electric heating depends on the temperature and process. For temperatures under 100°C, industrial heat pumps are highly competitive with fossil alternatives, such as boilers and heat from combined heat and power plants (CHPs). This is considering investments, maintenance, energy consumption, labor cost, and an expected carbon cost for 2030. Heat between 100°C and 165°C from industrial heat pumps is about 50% more expensive than heat between 80°C and 100°C because high-temperature heat pumps are less efficient. However, it is only 10% and 20% more expensive than heat from natural gas boilers and natural gas-fired CHPs, respectively.[109] High-temperature heat pumps are expected to become both cheaper and more efficient,[110] so it is fair to consider it a competitive heating alternative in the green transition as the technology continues to develop.

26% of all industrial heat in China is below 150°C and can be electrified cost-competitively while at the same time drastically reducing the climate footprint. Take for instance the chemicals sector, the second highest heat demanding sector in the Chinese industry. More than half of the heat is between 80°C and 150°C. Heat pumps can prove one of the most effective levers to decarbonize this industry.[111]

High temperatures up to 1,700°C can be electrified cost-competitively through thermal batteries, but this technology is not applicable for all types of productions. For example, steel and iron production can be electrified in electric arc furnaces or indirectly electrified by using green hydrogen as a fuel.[112] The cost-competitiveness of this will depend on carbon pricing and the cost of carbon capture and storage (CCS) on conventional blast furnaces.

China has ambitions of making the electricity grid free of GHG emissions and conventional air pollutants like particulates and nitrogen oxides by 2050. By electrifying Chinese industrial heating, the sector can achieve the dual goals of increasing public health for local communities while dramatically reducing its industrial carbon emissions globally.[113]

Electrifying industrial process heat

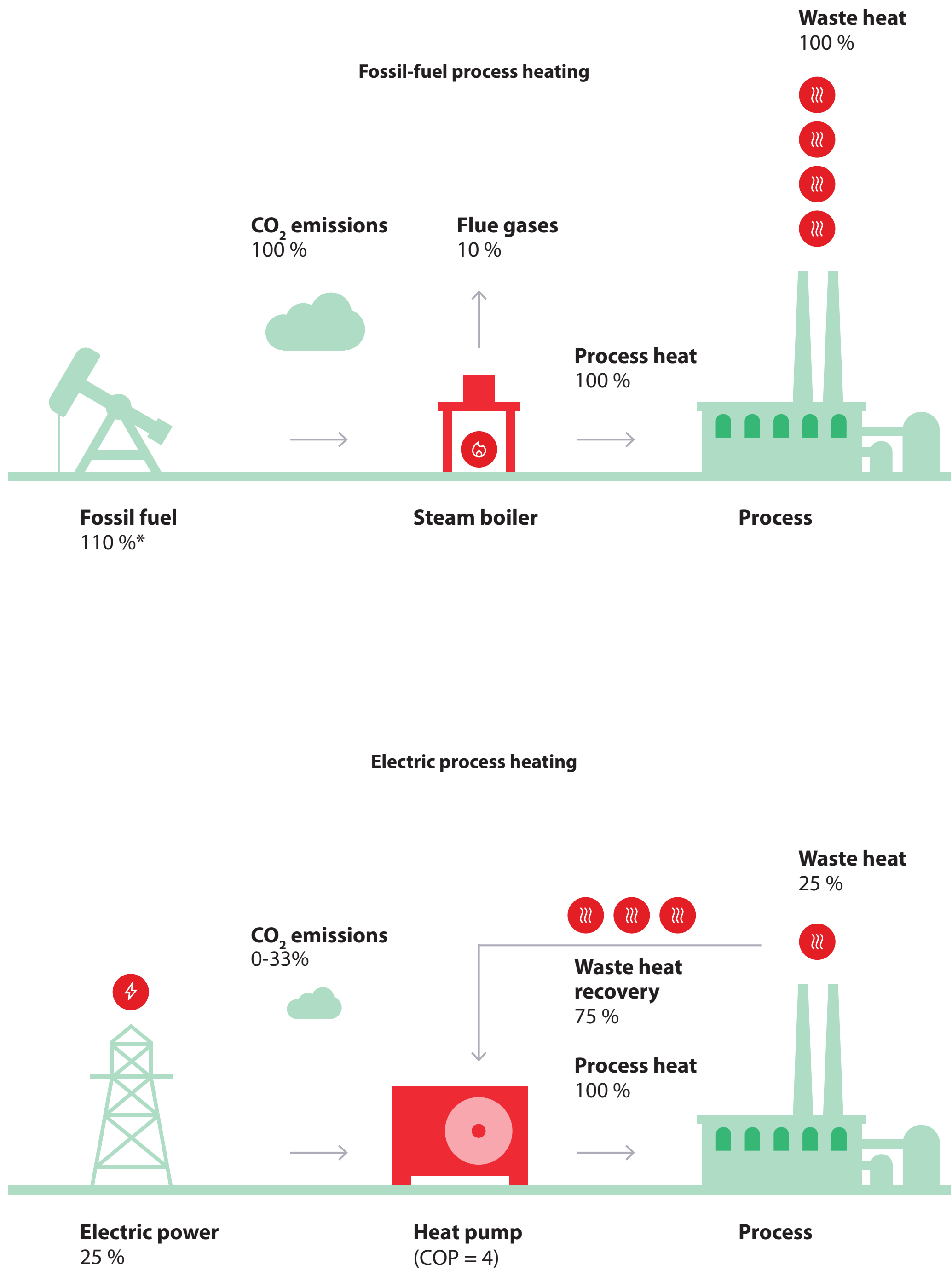


Figure 4: Strengthening Industrial Heat Pump Innovation: Decarbonizing Industrial Heat. In a heat pump scenario, the CO_2 emissions factor will be determined by the proportion of renewables in the electricity mix. Figure adapted from de Boer et al. (2020). *In a fossil-driven system, it is necessary to have a 110% fossil fuel input to produce 100% heat because 10% is lost as flue gases.

Green hydrogen for industry

When we think about electrification, we typically think about converting machinery that is currently directly driven by fossil fuels – such as gas turbines – into something that we can charge, ideally using renewable energy sources. This is what we refer to as direct electrification.

However, there are some end-use sectors that will not be able to be turned into this form of direct or hybrid electric machinery – at least not anytime soon. Here, we often think of sectors such as aviation, long-distance shipping, and cement and steel production. To directly electrify these sectors would require batteries that are too large for the vessel in which they would be used (e.g., aviation) or require tremendous amounts of heat production (e.g., cement and steel). While they are very difficult to directly electrify in an efficient way, these sectors are major GHG emitters and therefore their electrification would contribute greatly to reducing GHG emissions and reaching net-zero goals. This is where *indirect* electrification comes into play.

Indirect electrification primarily comes in the form of hydrogen electrolysis. Using electricity to produce hydrogen, electricity can *indirectly* be stored or used as fuel in hard-to-electrify processes. If the electricity used for electrolysis comes from renewable sources – commonly referred to as *green hydrogen* – these processes and sectors can be decarbonized. In the case below, we demonstrate how green hydrogen can play a central role in indirectly electrifying and decarbonizing one common industrial resource: ammonia. For a more comprehensive overview of the potential of green hydrogen, see Danfoss Impact No. 5, "Green hydrogen: A critical balancing act".[114]

Case: Electrifying ammonia production with green hydrogen

From fertilizer and refrigerants to the production of plastics and synthetic fibers, ammonia is used in a wide range of industrial applications. This makes it a highly versatile compound and critical resource for many industries. However, the production of ammonia currently relies heavily on fossil fuels and accounts for about 1.3% of global CO_2 emissions and 2% of the final energy consumption.[115]

Over the coming decades, demand for ammonia is projected to increase drastically. In fact, according to the IEA's Stated Policies Scenario, ammonia production is set to increase by 40% by 2050,[116] driven in large part by population changes and economic growth. This rapid and major increase in ammonia demand means a corresponding increase in emissions associated with its production – already 3% by 2030.[117] As such, **finding ways to decarbonize ammonia production will be a critical lever in reducing industrial emissions.** On this front, green hydrogen provides great promise.

Today, ammonia is produced by splitting natural gas into hydrogen and CO_2, and then combining the hydrogen with nitrogen from the atmosphere under high pressure and temperature – also known as the Haber-Bosch process.[118] This is a very GHG-intensive process since the CO_2 is released into the atmosphere. Actually, 1.6 to 2.6 tons of CO_2 are emitted for every ton of ammonia produced.[119,120,121] In the future, the hydrogen and electricity for ammonia production can be supplied from renewable sources, drastically lowering the climate footprint from ammonia.[122] According to IEA, about one-third of the GHG reductions in ammonia production must stem from electrolytic hydrogen to reach the Paris goal.[123]

Electrify, at a glance

Chapter summary

Electrify wherever possible.

One of the single most energy-efficient measures we can take is to electrify all possible industrial processes. By transitioning to a fully electrified energy system, we could cut up to 40% of final energy consumption.[124] 78% of industrial energy use can be electrified today, and 99% can be reached with technologies already in development. This widescale electrification would cut GHG emissions by nearly 80% and mitigate almost all energy-related emissions in these industries.[125]

Heat generation is the largest barrier to industrial decarbonization.

In many industrial powerhouses of the world such as the EU and US, less than 5% of process heat is produced with electricity (see page 28). However, by 2030, industrial heat pumps can supply nearly 40% of industrial process heating.[126] This makes it possible to integrate renewables into the industrial energy mix, decarbonizing heating supply and oftentimes saving money at the same time.

Leverage green hydrogen as a clean alternative to direct electrification.

Some process heating still requires too high temperatures and cannot yet be fully electrified. By producing hydrogen with decarbonized electricity, green hydrogen can serve to indirectly decarbonize these high-temperature processes that are difficult to directly electrify today.

40%	**78%**	**40%**
reduction in final energy consumption just by transitioning to a fully electric energy system	of industrial energy use can be electrified today	of industrial process heat can be supplied by industrial heat pumps by 2030

Integrate

What's one of the simplest ways to lower your energy bill and emissions? Reuse energy you've already bought.

The industrial sector consumes a great deal of energy. However, it also produces large amounts of wasted resources, such as water, carbon, and heat. Currently, the lion's share of this waste ends up as exactly that: waste. However, when planned strategically, such resources can be captured from producers and reused by consumers to replace or supplement the consumption of new or "virgin" resources – both within industrial processes themselves and across disparate sectors. A deeper integration of sectors to optimize the use of wasted resources is critical.

What is sector integration?

Sector integration or sector coupling refers to the combination of at least two different sectors of energy demand and production (i.e., electricity, heating, cooling, transport, and industrial processes) to maximize synergies. This can happen within the same factory, within industrial clusters, or even on a larger scale through district energy networks. Urban planning can leverage the potential of sector integration by connecting energy producers with energy consumers through a smart grid, utilizing synergies in infrastructure and between sectors' use of resources.

Large synergies can occur when a producer of excess heat – for instance, a factory – is located close to entities that can buy and use large amounts of the excess heat. This could be another factory or production facility with a high demand for low- to medium-temperature heat, such as greenhouses. Alternatively, industrial excess heat producers could be linked to urban district heating networks to provide heating for local homes, businesses, and water. 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.**[127]

While there is great potential to reuse many – though not all – forms of industrial waste through sector integration, none is more promising a tool to transform our energy system and decarbonize industry than excess heat. As we will see, **excess heat is one of the world's largest untapped sources of energy.**

The global potential of 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 factories, supermarkets, data centers, wastewater treatment plants, metro systems, and hydrogen electrolysis facilities found in cities across the globe. **By 2030, up to 53% of the global energy input will be wasted as excess heat.**[128] Furthermore, the climate can benefit greatly if we recover excess heat. In fact, we can reduce the global emissions by 10-19% if we recover the full theoretical potential of excess heat.[129] Reusing the energy already produced and purchased is one of the simplest ways to reduce energy consumption, emissions, and cost.

Heating is one of the largest energy consumers in the energy system. In Europe, heating accounts for over 50% of the annual final energy consumption, and most European heat is still generated using fossil fuel-based sources, almost half of which is natural gas.[130] At the same time, all urban areas in Europe have access to numerous excess heat resources. There is about 2,860 TWh per year of excess heat accessible in the EU, much of which could be reused.[131] To put this number into perspective, it almost corresponds to the EU's total energy demand for heat and hot water in residential and service sector buildings, which is approximately 3,180 TWh per year in the EU and UK.[132]

In some countries, the excess heat potential even matches the total heat demand.[133] In the Netherlands, for instance, excess heat amounts to 156 TWh per year,[134] while the water and space heating demand is only 152 TWh per year.[135] The picture is similar across the rest of the world as well. Looking at the industrial sector in Northern China, there is around 813 TWh of excess heat during heating season alone.[136] Just imagine what the total amount of excess heat across all sectors in the whole of China looks like.

Pathways for industrial heat recovery

Repurposing heat at the source

The simplest way to use excess heat is on-site by reintegrating the heat into the same processes or other processes at the same location. The temperature of the excess heat will vary depending on the process it results from. For instance, excess heat from heavy industries such as chemicals and cement is a much higher temperature than excess heat from cooling in buildings. Depending on the temperature of the excess heat, the heat can be used for different purposes. In general, high-temperature excess heat can be used for both industrial processes and domestic use, while lower temperatures are suitable for domestic use, such as space and water heating.

One measure to use excess heat internally is by installing a heat recovery unit. A heat recovery unit is worth considering in almost all cases where unused heat energy is produced as a waste product in order to increase the efficiency of the overall plant and lower energy bills. Heat recovery units make excess heat usable for processes at a similar or lower temperature level.

Industrial cluster planning

Companies and industries oftentimes benefit when they operate in close proximity to other companies either within their industry or directly up or down the supply chain. By keeping suppliers, buyers, and other partners close, they can oftentimes reduce costs and scale production more rapidly. When a substantial number of companies begin to operate and plan their operations in this way, they create what is called an "industrial cluster." When companies operate in close proximity, they can also lean on one another as both heavy producers and consumers of waste resources – not least, excess heat. When dealing with the high temperatures often needed to carry out certain industrial processes, excess heat generation is almost certain. However, if this production is taking place within an industrial cluster, the density of nearby off-takers of the heat is much higher, meaning the excess heat generated in one factory could be used to heat the air, water, or lower-temperature industrial processes of another. By identifying the optimal links between all actors within a cluster – not only excess heat but also water and materials – the energy intensity of the cluster as a whole can be reduced.

District energy

District energy is a collective system that supplies the housing and building stock of an entire area with heating or cooling. Such networks tap into heat from a combination of sources – such as renewable sources (e.g., solar, geothermal, and biomass) and fossil sources such as at power plants – and distribute it through pipelines to end users in the form of heated water. Today, district energy networks are prevalent in many cities across the world. However, 90% of global district heating is supplied from fossil fuels, especially in Russia and China.[137] According to the IEA, the CO_2 emissions intensity of district heat production must be at least 20% lower by 2030 compared with 2022.[138]

Industrial actors can play a key role in providing low-emissions heat to local district energy systems. **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 we have already seen, the industrial sector produces large amounts of excess heat, much of which can be integrated into district energy systems. This can serve as an environmental and economic benefit both to industrial producers of heat and to consumers who get their heat via district heating networks.

Not all excess heat is of the same temperature grade. For lower temperature grades (under 200°C) to become suitable for use in district heating networks, the heat must be "boosted" to a higher temperature grade. This can be done in a highly efficient manner by installing heat pumps, which can generate three units of heat with only one unit of electricity. As renewables become cheaper and more widespread, powering these heat pumps with renewable electricity can ensure that the heat sold into district heating networks remains a low-emission heating source.

Case: The greenest and cheapest energy is the energy we don't use

A new Danfoss factory in Grodzisk, Poland was specifically built for a CO_2-neutral future. Here, no machine burns natural gas or oil. Heating, cooling, and ventilation installations, and all production machines run on renewable electricity.

But renewable electricity isn't free. In Poland, it is often more expensive than electricity produced by burning fossil fuels. So, to reduce overall demand for electricity, thereby keeping costs down, the factory has installed more than ten big and small energy efficiency solutions. For example, machines working on the factory floor generate excess heat. The ventilation system catches this heat with heat exchangers and reuses it to warm up the building. Inside the heat exchangers, warm exhaust air on the way out heats up colder air coming in. The result is free heat.

Additionally, the factory's line of heat pumps and chillers are effective at reducing energy consumption. They pull heat or cold from air or water – boost it – and use it to ensure comfortable inside temperatures or to cool down machinery as necessary. Heat pumps are a perfect example of how electric technologies can enable other energy efficient processes such as excess heat capture and sector integration.

The technical team at Danfoss has specified the energy efficiency solutions for the project in compliance with the company's 2030 Strategy on Environmental, Social, and Governance issues and its desire to become CO_2 neutral.

> "It's really simple. The greenest energy is the energy you do not use in the first place. That's also the philosophy behind any use of energy in this factory. We are extremely proud of the result."
>
> Adam Jedrzejczak
> President, Danfoss East Europe Region

Case: Heating China's cities with industrial excess heat

Today, 96% of China's heat is generated from fossil sources. 45% of the heat is generated in coal or gas-fired boilers – directly emitting one billion tons of CO_2 – while 53% of the heat is generated in combined heat and power plants (CHPs) fired by gas or coal.[139] The main purpose of these CHPs is to produce electricity, and leveraging the excess heat generated from electricity production is a wise way to provide heat for buildings and water. However, the unsustainable problem is that the production is based on fossil sources. With proper planning, however, this heat can be delivered from alternative sources, such as excess heat from industrial processes.

The heat from CHPs far exceeds the Chinese demand. However, China is looking into a radical transformation of the electricity production, moving away from fossil sources and towards a much higher share of renewable electricity.[140] This means that China must look at alternative heat sources, and industrial excess heat represents an excellent option. Looking at just the five most wasteful subsectors, the annual excess heat reaches 2,000 TWh[141] – heat that could be repurposed in industrial processes and district heating grids. Today, the industrial excess heat is actually enough to cover about half of China's heating demand for industrial processes, hot water, and district energy in the heating season from October through March. Additionally, it can cover the heating demand for non-process industrial heat and hot water demand outside the heating season.

The future of excess heat in China

An important aspect of China's climate strategy is to increase energy efficiency and ramp up electrification.[142] This strategy will lead to a much more efficient industrial sector, while at the same time nearly cutting excess heat in half from 2,000 TWh to 1,080 TWh by 2050.[143] However, 1,080 TWh is still a substantial amount of heat. By 2050, the excess heat in China will exceed the heating demand from April through December for non-process industries, district heating, and domestic hot water. However, in January, February, and March, the demand is higher than the supply. To accommodate this seasonal gap, long-term planning must consider seasonal storage of excess heat.[144]

Another challenge in putting the excess heat to use is a geographical gap between the supply of and demand for heat – that is, where the excess heat is produced and where there is demand for it. This is a problem that has to be solved and factored into long-term planning.[145] Through strategic industrial cluster planning, facilities can be planned together to use byproducts from one facility in another, as the excess heat from one facility may be the best option for heating in another facility.

Through district energy grids, the excess heat can be distributed over quite some distance and be used to heat large urban areas. District heating is the most efficient way of delivering heat to densely populated areas, and using excess heat in the grid can be one of the greatest levers for phasing out fossil fuels for heating.

The technology already exists

The technology for utilizing excess heat is mature, and it can be repurposed across industrial processes, in district heating grids, and even within industrial clusters, which are relatively commonplace in the Chinese industrial sector. For example, many industries use temperatures below 150°C, something that can be achieved today by using heat pumps and excess heat.

Excess heat is already being recovered from Chinese industry today. At Danfoss' Haiyan Factory, smart monitoring technologies are reducing energy consumption, while heating and cooling technology reuses excess heat from the factory production processes for other on-site heating needs. This delivers substantial energy efficiency gains compared to conventional air conditioning systems. At Danfoss' Wuqing Factory, a central heating station recovers excess heat from air compressors using software to adjust the heat supply according to the outdoor and indoor temperature, lowering the climate footprint of the factory.

The solutions are there, but there is no "one-size fits all". The geographical, industrial, and climatic variations across China mean that industrial cluster planning can be a great solution in one area, and district heating will work in another area. There will even be places where these can be combined to make the most out of the energy sources.

Excess heat is one of the world's largest untapped sources of energy.

Integrate, at a glance

Chapter summary

Excess heat is the world's largest untapped energy source.

By 2030, up to 53% of the global energy input will be wasted as excess heat.[146] Both companies and the climate can benefit greatly if we recover this heat. In fact, global emissions can be reduced by 10-19% if we recover the full theoretical potential of excess heat.[147] Tapping into this potential proves an intelligent and highly cost-efficient way for industrial actors to decarbonize their operations.

There are multiple pathways for integrating industrial excess heat.

Excess heat can be recovered and used to increase the efficiency of the overall system. Industrial facilities can reuse excess heat on-site, reducing their energy bill significantly. If industries are in proximity to other off takers, such as other industries or district energy infrastructure, the excess heat can be commoditized and used to lower heating demand from fossil fuels outside the factory walls. This enables heavy energy consumers to become major energy suppliers.

53%	10-19%	2,860 Twh
of the global energy input will be wasted as excess heat by 2030	of global emissions can be reduced if we recover the full potential of excess heat	of excess heat is accessible per year in the EU

Policy recommendations

Industrial decarbonization is imperative to reach the Paris goals. This paper shows what can be done already today to decarbonize industry and reap the socio-economic benefits from lower emissions and costs. Competitiveness, growth, decarbonization, and energy security are not mutually exclusive terms. On the contrary, they can be interconnected and reciprocally beneficial.

The IEA's Industry Tracker still labels the industrial sector as "*not on track*" for a net-zero scenario.[148] However, the opportunity to take a major leap forward is imminent. Existing policies only provide limited support for electrification and decarbonization, but **by simplifying excessive red-tape regulation and implementing the right policy framework, industrial decarbonization can finally take off.**

Create economic incentives

Tax benefits will go a long way in incentivizing industry's green transition and are oftentimes easier to navigate and require less bureaucracy than subsidy programs. For instance, the US Inflation Reduction Act (IRA) includes a range of tax provisions, which bring down the cost of the green transition for consumers and industry. These tax credits are simple levers to increase the appeal of committing to climate-friendly technologies without compromising profitability. As seen with the US IRA, utilizing tax credits can increase competitiveness, create more jobs, and lower consumer electricity bills.

While many decarbonization solutions require relatively small upfront investment costs, others can be more capital intensive. High investment costs and locally fluctuating electricity prices make some solutions unattainable – despite short payback times. Both tax credits and subsidy programs will allow for more companies and households to make those initial investments, which in turn will become self-sustaining through lower energy consumption.

There are numerous examples of how carbon credit and trading schemes can further the green transition. The Californian Cap-and-Trade Program even distributes some of the collected funds to consumer and small business' electricity bills, and the EU ETS has proven to be a mature system to lower emissions over time. Enabling companies to profit from their sustainable business models and awarding them for creating technologies that lower emissions is imperative to incentivize sustainability and can free up funding for further green investments.

Regulate playing field

A level playing field will allow for more stakeholders to engage in the green transition. Creating a level and competitive market requires that equal opportunities and regulations ensure that market players are held to a certain standard. With the EU Energy Efficiency Directive, the union has regulated the ways in which companies must conduct energy audits and management. Depending on energy use and size of enterprise, companies must carry out an energy audit or implement an energy management system (EMS). However, only the EMS comes with obligatory implementation of energy-saving measures. Mandating more entities at all levels to carry out energy audits and implementing EMS would see companies utilize "low-hanging fruit" measures with short payback times and realize great savings potentials.

Seeing the system in its entirety and ensuring it is fully optimized for energy efficiency is the next step. This requires energy auditing to be standardized and regulated through a shared framework. It also requires demanding *system efficiency* as opposed to solely component efficiency. For example, the international standard ISO 50001 is a standard on energy management, which provides a framework for developing an energy management system that can help manage energy performance and climate impact. Such a standard can provide the much-needed holistic approach to energy efficiency measures.

Set high ambitions and secure supply chains

Political ambitions function as guidelines for the industry to follow, and they are important measures to accelerate and ensure stakeholders' willingness to invest in the green transition. Uncertainty in political resolution and direction will create too many risks for industrial actors. Ever-changing market regulations decrease reliability and prevent stakeholders from long-term planning. Therefore, it is important to set the right, ambitious targets, mitigating the tendency to take on stop-and-go policies. Policymakers must focus on creating certainty, resilience, and security, ensuring diplomatic ties and supply chains are not held up by bottlenecks endangering the progress towards the Paris goals.

Setting system efficiency targets in factories, creating requirements, and making energy performance transparent – much like the Minimum Energy Performance Standards – can be useful in setting milestones for the green transition in the industrial sector. Similarly, an integrated policy framework for electrification in the industrial sector is also necessary to fully unlock the potential of electrification of industrial processes. Targets such as these will create tangible objectives for industry and provide policymakers with knowledge and data useful for setting newer and even more ambitious targets for decarbonization.

Appendix: Implementing VSDs in EU industry

In the following, we estimate the potentials for cost, energy, and emissions reductions by implementing variable speed drives (VSDs) in EU industry. Additionally, the assumptions and methodological approach behind these estimates are described.

Outline of the motors in European industry

A report ordered by the European Commission estimated that the installed base of motors in European industry was 380 million motors in 2020, of which 48 million (13%) had a VSD installed. The estimated load of these 380 million motors was 1,117 TWh output/year, 25% of which (298 TWh output/year) came from motors with VSDs.[149] Typically, motors with variable load profiles can achieve 15-40% savings with a VSD.[150] Looking broadly at the EU – that is, beyond industry alone – about 50-60% of motor applications have some load variation (speed/torque). Of these, 30-35 percentage points have no VSD installed.[151,152] In other words, at least one-third of the motors in the EU can benefit from a VSD. This is without considering oversized motors, meaning the potential arguably is higher. Most motors are small, and looking broadly at motors, 89% are below 0.75 kW and 0.02% are above 375 kW. For AC motors, 78% are smaller than 0.75 kW.[153] One study suggests that globally there are 2.23×10^9 motors. 89.66% are below 0.75 kW, 10.31% are between 0.75-375 kW, and 0.03% are larger than 375 kW. Motors below 75 kW consume 9% of the electricity, while motors between 0.75-375 kW and those above 375 kW use 68% and 23% respectively.[154] Since the global distribution of motor sizes is similar to the EU distribution, we can also assume the corresponding electricity consumption pattern is comparable.

Comparison of the European and the US industrial motor stock

To our knowledge, there are no recent analyses of the potential of VSDs in European industry. In the US, however, a series of motor market assessment reports were prepared for the US Department of Energy by Berkeley in 2022. These reports study, among other topics, the potentials of saving money, emissions, and energy by implementing VSDs wherever applicable in the US industrial sector. In the following, the characteristics of the US and the EU industrial motor stocks are compared to establish if it is fair to apply the US savings potential to the EU motor stock.
In these reports it was found that 45% of the energy consumption from industrial motors[155] and 52% of the industrial motor units[156] were attributed to variably loaded motors. They estimate that 16% of the industrial motor stock[157] and 23% of the consumption[158] is controlled by VSDs. This is very comparable to the installed VSD base in European industry (see table A.1).

To our knowledge there are no analyses of the load profiles of the European industrial motor stock that are comparable to that of the American motor stock. The analysis of the US motor stock and that of the European stock do not consider exactly the same size ranges. The US analysis considers motors above 0.75 kW while the European analysis considers the range 0.12-1000 kW. However, the US motor analysis finds that by far most energy is consumed in the mid-size motors, despite the fact that there are far more small motors between 0.75 and 3.75 kW.[159] All things equal, based on this we find it fair to assume that the US and the European industrial motor stocks are comparable.

Table A.1: Characteristics of the US and the EU industrial motor and VSD stock

	US motor stock	EU motor stock
Share of motor stock with VSDs	16%	13%
Share of load with VSDs	23%	25%

VSD potential in the EU

As we established above, it is fair to compare the European and US industrial sectors in terms of the number of motors and how much of the consumption is controlled by VSDs. It is estimated that a full implementation of VSDs on motors with variable load profiles in US industry will lead to 8% energy, cost, and greenhouse gas (GHG) savings. This is a conservative estimate and does not consider the potential to install VSDs on oversized motors with constant load, where the actual potential very likely is even higher.[160] As such, with similar characteristics for the EU and the US motor and VSD stock, and with the 8% savings potential being a conservative estimate, we assess that it is reasonable to apply the US savings potential to the EU industrial motor stock.

The electricity consumption of the motors in EU industry is between 650[161] and 729[162] TWh/year. As we established, the potential savings from VSDs is 8%. The US analysis only looks at motors above 0.75 kW. Although only constituting about 10% of the motor units globally and in the EU, these motors consume 91% of the electricity consumed by motors. As established above, this is arguably also the case in the EU industry. The 8% savings potential is thus only applied on 91% of the electricity consumption from EU industrial motors, or 593 to 663 TWh/year. 8% of this is 47.3-53.1 TWh/year. This is equivalent to up to 9% of Germany's electricity production (588.3 TWh/year) – the largest producer in the EU.[163]

The weighted average electricity price was €0.2008/kWh including non-recoverable taxes for non-household medium-sized consumers between 500 and 2000 MWh in the second semester of 2023.[164] With this price, the potential cost savings from electricity is €9.5-10.7 billion. In 2020, the GHG intensity of the average EU electricity was 265g CO_2e/kWh.[165] If VSDs were installed across all suitable motors in the EU industry, this could lead to 12.5-14.1 million tons of CO_2e-reductions. In 2022, the average EU citizen emitted 7.009 t CO_2e/year,[166] meaning that implementing VSDs in the EU industry can save equivalent to the footprint of 1.8-2.0 million EU citizens.

The savings potentials from VSDs in the context of the EU climate targets

The EU motor stock in 2030 has been projected with two different scenarios for the European Commission as a part of the work with the Ecodesign Directive: a Business-As-Usual scenario (BAU) and an Ecodesign scenario (ECO), considering the expected effects of the Ecodesign Directive.[167]

It has been projected that the EU motor stock will be 403 million units by 2030, of which 51 million (13%) or 65 million (16%) will have a VSD installed, in the BAU and the ECO scenario respectively. This is compared to 380 million, of which 48 million (13%) have a VSD in 2020.[168] In the BAU scenario, the load of the motors in 2030 will be 1280 TWh output/year, of which 350 TWh output/year (27%) is from motors with VSDs. In the ECO scenario, the load of the motors will be 1212 TWh output/year, of which 452 TWh output/year (37%) is from motors with VSDs, compared to 25% in 2020.

As described earlier, 45% of the energy consumption and 52% of the motor units can be attributed to variably loaded motors, 8% savings can be achieved, and this is applicable to the 91% of the motors above 0.75 kW.

The Regulation 2019/1781 removed the option of supplying the motor with a VSD to achieve the efficiency requirements.[169] Because of this it is fair to discuss if BAU or ECO will be realized. In both scenarios, the 8% savings potential applied earlier can partly be realized. In BAU, 27% of the load has VSDs installed, and in ECO, this share is 37%. In 2020, 25% of the load has VSDs installed. The 8% savings potential equals the 20 percentage points from 25% in 2020 to 45% of the motor consumption that can benefit from VSDs. Thus, 10% and 61% of the savings potential is realized in BAU and ECO respectively by 2030, or the remaining savings potential is respectively 7.2% and 3.1%.

The BAU electricity consumption from motors above 0.75 kW is 725 TWh/year. The savings potential of 7.2% equals 52 TWh/year by 2030. The ECO electricity consumption is 672 TWh/year. The savings potential equals 21 TWh/year. The EU has a binding target of decreasing the energy consumption by 11.7% by 2030 from the 2020 EU Reference Scenario, which projects a final energy consumption of 864 Mtoe (10,048 TWh) in 2030. An 11.7% reduction results in a 763 Mtoe (8,874 TWh) final energy consumption in 2030,[170] or a reduction of 1,174 TWh. The unrealized 21-52 TWh annual saving equals 1.8% to 4.4% of the energy reduction goals by 2030.

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What is Danfoss Impact?

Danfoss Impact is written to share our view on the potential of energy efficiency and electrification to transform our energy system. In the dialogue about the green transition, energy efficiency is often overlooked. One main reason for this is that experts and industrial leaders have inadequately explained its role in accelerating electrification to enable a future powered by renewables.

Drawing on evidence from credible sources, Danfoss Impact presents cases from a broad range of industries, highlighting solutions with great potential to save energy and reduce emissions in a cost-efficient and scalable manner. With this series, we also aim to demonstrate that the technologies we need for a rapid and sustainable green transition already exist today.

The greenest energy is the energy we don’t use.