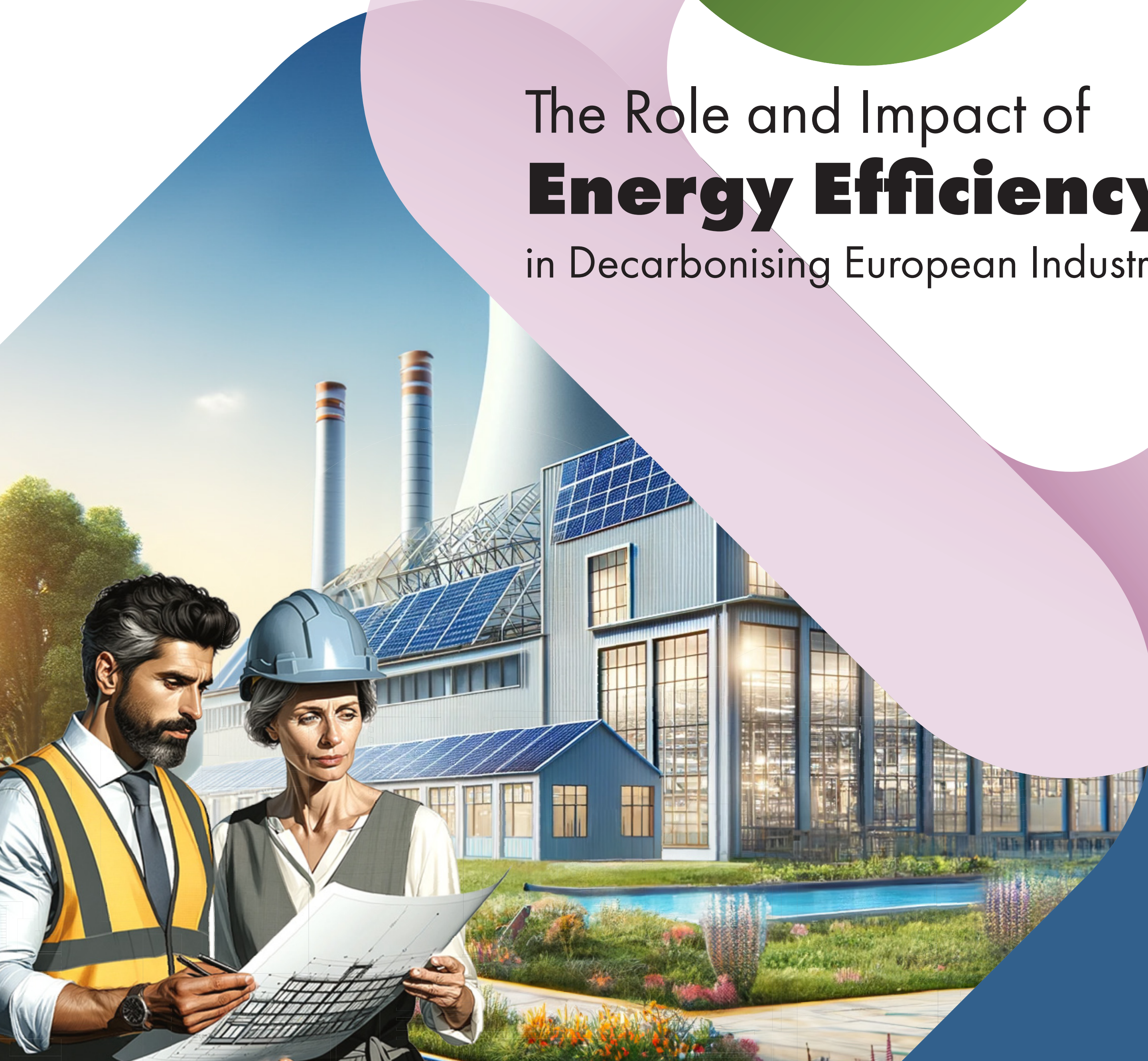
The Role and Impact of **Energy Efficiency** in Decarbonising European Industry



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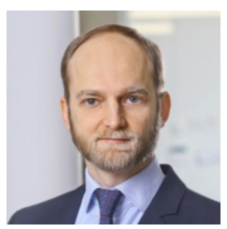

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Executive Summary and Scope of White paper

Energy efficiency - Critical for the green transition

Energy efficiency means using less energy to make the same product. Most industrialised countries will continue to increase their industrial activity with time. This means increased power consumption and an even greater need to reduce industrial greenhouse gas emissions to reach climate goals set for 2030 and 2050. In addition to this comes the current push to develop EU industries for strategic automony (the Critical Raw Materials Act and the Net Zero Industry Act). Industries using fossil fuels must speed up their green transition markedly compared to current efforts. However, a lack of solar and wind capacity, network constraints, as well as a lack of low-carbon fuels, such as hydrogen and fuels from biogenic sources, will be barriers to greenhouse gas emissions cuts in the industry. This makes energy efficiency essential for the green transition, since it reduces future demand for renewable energy and reduces grid constraints, making the transition both more feasible and more affordable.

Within energy circles, it is often said that the energy we don't use is the most sustainable. Increasing energy efficiency may be the easiest and most cost-effective decarbonisation strategy for many industrial sectors and is a critical toolbox of solutions when introducing carbon-free value chains. Implementing energy efficiency measures in industrial sectors can be a low-hanging fruit, in terms of technological maturity, costs and speed, and is also a clean energy pathway without controversies related to nature and biodiversity.

The benefits of maximising energy efficiency in industrial sectors are clear. Implementing energy efficiency measures will reduce the demand for energy, providing more security in our energy supply. It will lead to less grid constraints, lower renewable installed capacity requirements and smaller energy and climate footprints per unit of industrial production. Depending on the energy mix, energy efficiency directly reduces CO_2 emissions and mitigates climate change. Flexible, efficient, and decarbonised energy in Europe will increase Europe's economic competitiveness, boost local economies, and uphold a strong workforce.

There are several strategies to increase energy efficiency in industrial processes. Industries can benefit from utilising recycled feedstocks, which significantly reduces energy demand compared to primary production. Developing more energy-efficient processes, such as those operating at lower temperatures and pressures or with improved catalysts can lead to substantial efficiency gains. Implementing waste heat recovery techniques and process integration methods, involving heat pumps and heat integration, can recover and upgrade heat, reducing energy consumption. Another approach involves heat exchange within industrial clusters and maximising syngergies across industrial sectors, allowing excess heat to be shared with nearby users. Additionally, optimising cooling processes, improving separation and drying techniques, and adopting more efficient mechanical drive can further enhance energy efficiency. Lastly, monitoring energy use and employing digitalisation, can improve informed desision-making on energy efficiency in complex industrial systems.

Despite past efforts in terms of innovative technologies and legislative and regulatory frameworks to enable the transition in the industrial sector, the potential for energy efficiency has yet to be fully realised. Therefore, in an effort to identify opportunities and challenges, this white paper will:

- outline the current state of energy use and energy efficiency in industry,
- present key solutions for improving energy efficiency,
- outline the barriers to implementing these measures,
- provide examples of real-life energy efficiency applications, and
- provide recommendations for increasing energy efficiency in industrial sectors.

1. The state of industrial energy efficiency

Global energy use has increased steadily since the middle of the 20th century, and the lion's share of the energy still comes from fossil fuels as shown in Figure 1. Primary energy is the energy as it is available as resources, before it has been transformed.

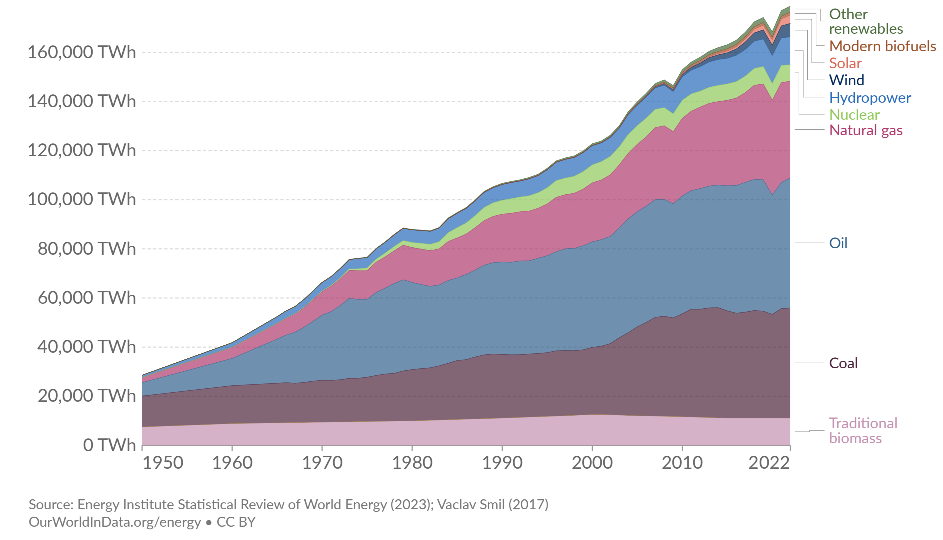


Figure 1:
Global primary energy consumptoin by source. Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

Industrial energy use and GHG emissions in the EU

Reliance on fossil fuels is also high in Europe, despite total energy use declining slowly since the early 1990s, and the share of renewables increasing steadily in the past two decades. Looking at industrial energy use in particular, the share of fossil fuels is also high. Fossil fuels and electricity cover 88% of the industrial energy use in EU-27 Member States. Due to this high reliance on fossil fuels, the share of greenhouse gas emissions from the industry is substantial, accounting for 25% of all European emissions in 2020 [1].

Figure 3 shows the trend in industrial energy use per sector in the period 1991-2021, showing a small decline over time. Together, the chemical industry, iron and steel production and oil refineries account for more than half of Europe's industrial energy demand.

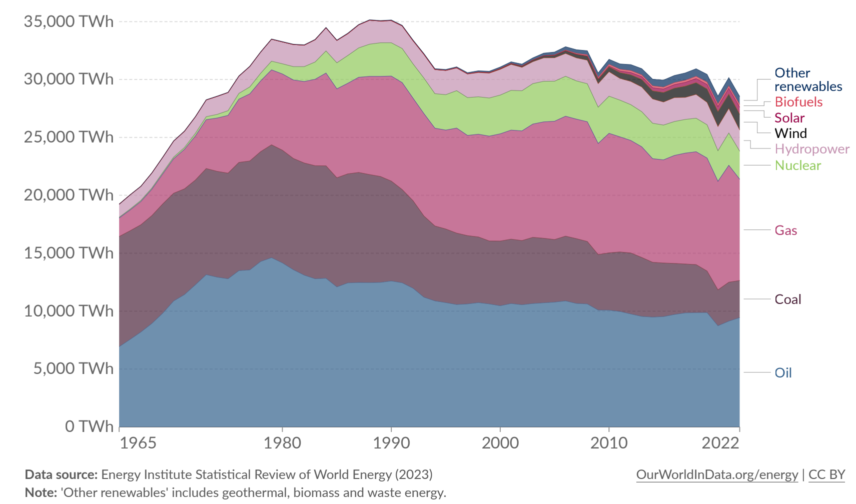


Figure 2:
Total energy consumption by source, Europe Primary energy consumption is measured in terawatt-hours (TWh). It has been calculated using the substitution method, which adjusts non-fossil sources for the inefficiency of fossil fuel equivalents.

What is Energy Efficiency?

Energy efficiency in industry refers to minimising energy use in the production of a product. It can be enhanced by refining processes or by transitioning to alternative energy sources. Additionally, it encompasses the potential recovery and utilisation of excess energy, such as residual heat and other by-products.

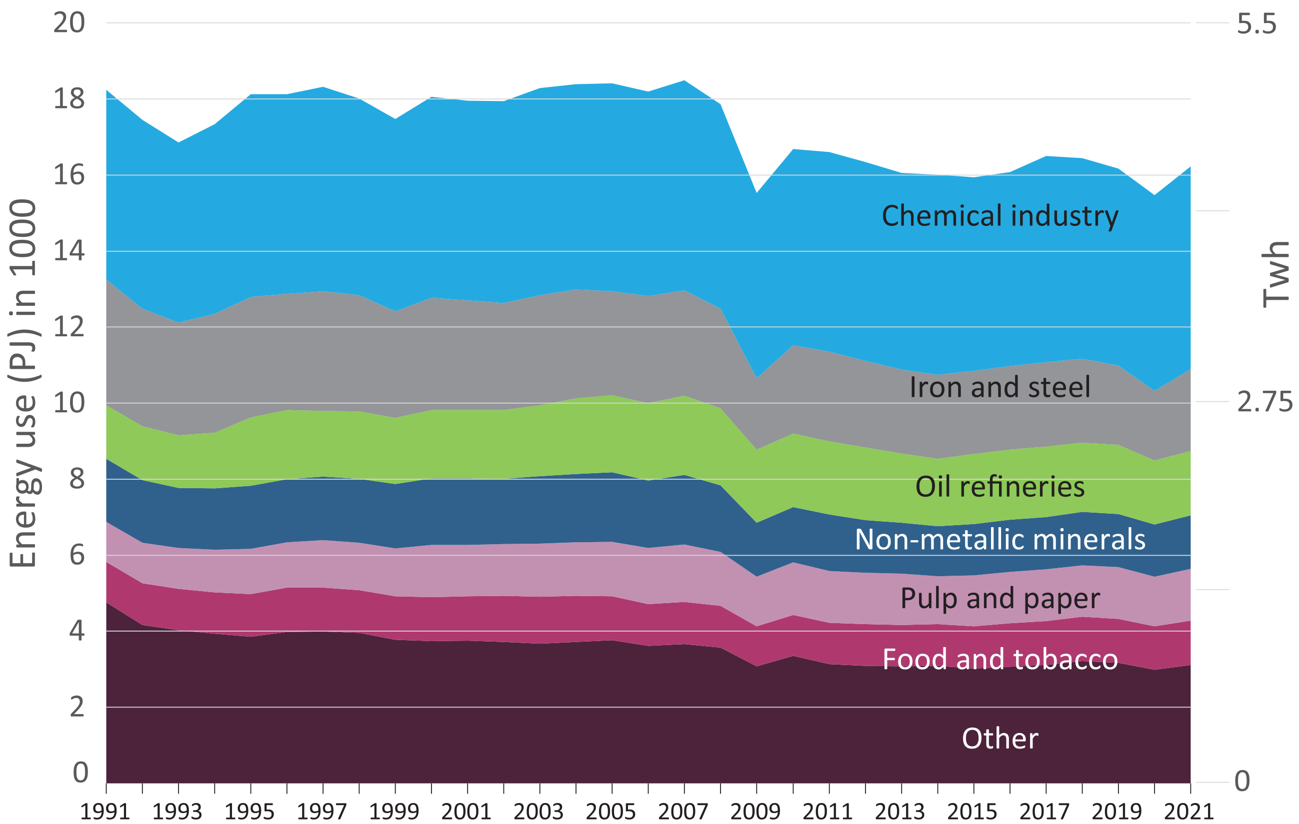


Figure 3
Industrial energy use in Petajoules (PJ) in EU-27 including feedstocks (based on IEA, 2023) [2] . The category "Other" consists of machinery (4%), non-ferrous metals (e.g. aluminium) (3%), construction (3%), transport equipment (2%), wood (2%), mining (1%), textile and leather (1%), and not explicitly included sectors (3%).

Energy use: Main industrial sectors

Chemicals (33%)
The EU chemical industry consumes 33% of all EU industrial energy, with petrochemical feedstocks accounting for most of this usage. The production of key chemicals like ethylene, propylene, benzene, toluene, xylenes, ammonia, and methanol accounts for three quarters of this energy [3]. The steam cracking and steam reforming processes used to produce these chemicals are very energy-intensive. Ammonia, used in fertilisers, and methanol, used as antifreeze and fuel, are both based on natural gas and notably increase energy consumption [4]. The chemical sector is notably large in the Netherlands, Belgium, Estonia, and Lithuania.

Iron and steel (13%)
The second largest industrial energy consuming sector is iron and steel production, accounting for 13% of industrial energy use in 2021 [5]. Steel, essential for infrastructure, is very energy-intensive when made from raw materials. The sector includes integrated mills using blast furnaces, secondary mills with electric arc furnaces, and foundries molding final products [6]. The iron and steel sector is particularly prominent in Luxembourg and Slovakia.

Non-metallic minerals (9%)
Cement production is the most energy-intensive process in this sector. Of the energy used, 90% goes to clinker production (an intermediate product in cement manufacturing) [7]. This step involves burning a mix of limestone and mineral oxides in a kiln [8]. Most energy is sourced from fossil fuels, followed by electricity, which is used mainly for raw material preparation and cement grinding. The energy needed varies with material hardness and additives. Cement production itself also contributes to CO_2 emissions, notably from limestone calcination, representing 11% of industrial greenhouse gas emissions.

Pulp and paper (9%)
The pulp and paper sector consumes significant amounts of biomass. Main energy-intensive processes include chemical and mechanical pulping and paper production, particularly for drying. Most of the energy is used for process heat, and about a quarter for power generation. Integrated mills are more efficient due to better waste heat recovery [9]. Using recovered paper for pulp can cut energy use, varying with the paper and pulping type. Sweden and Finland have a large pulp and paper presence.

Agro-food industry (7%)
The agro-food industry transforms agricultural products into food and beverages. It is one of the largest manufacturing sector in Europe, even though very fragmented, with approximately 291,000 companies, 99% of them being SMEs, and employing 4.6 million people (https://www.fooddrinkeurope.eu). To enhance its competitiveness, EU-27 is fostering measures for sustainable food production ensuring environmental compliance. The industry largely relies on fossil fuels for heating, especially for drying, evaporation and pasteurisation. Most electricity consumptions is associated with the agro-food cold chain, besides other plant operations. As in other sectors, some energy use is embedded in the plastic and aluminum materials used for food packaging.

EU-27 Member States and total energy use

Figure 4 shows the contribution of the individual EU-27 Member States to the total industrial energy use in the EU. The top nine energy consuming countries (33% of countries) account for 81% of industrial energy use in the EU. Germany has the highest consumption accounting for 24% of all EU-27 industrial energy use, followed by France with 11%, Italy, Spain and The Netherlands with 9% each and Poland with 7%. The last 10 countries contribute to only 3% of the total energy use. Fossil fuels and electricity cover a major part of the industrial energy use in 2021 (88%) and the category other includes mainly biomass and waste, followed by purchased steam, and to a lesser extent peat, solar and geothermal energy.

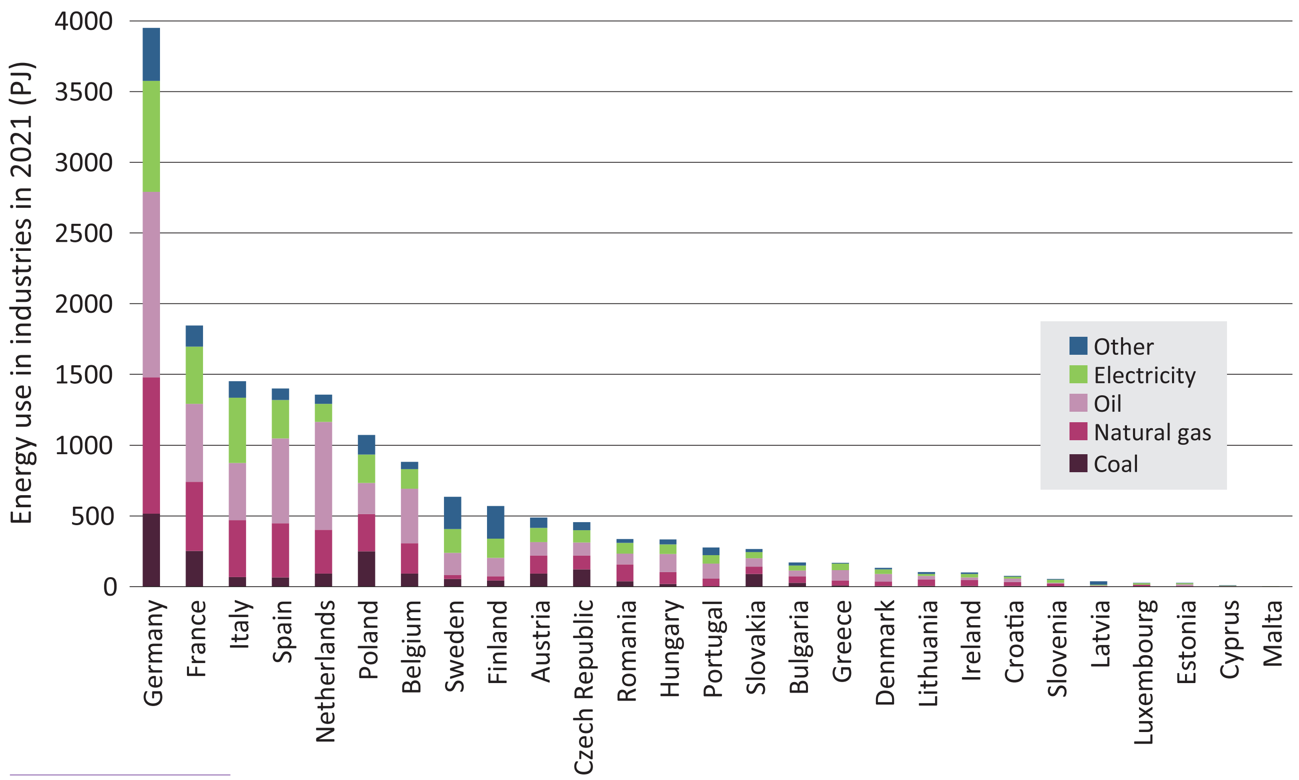


Figure 4 Energy use of industry per country in 2021 (based on IEA, 2023).

Fuel and feedstocks for EU industry

Figure 5 shows the type of energy carriers used in the EU industries in 2021, as share in total energy use, per sector. Pie chart sizes are proportional to each sector's share of the energy use.

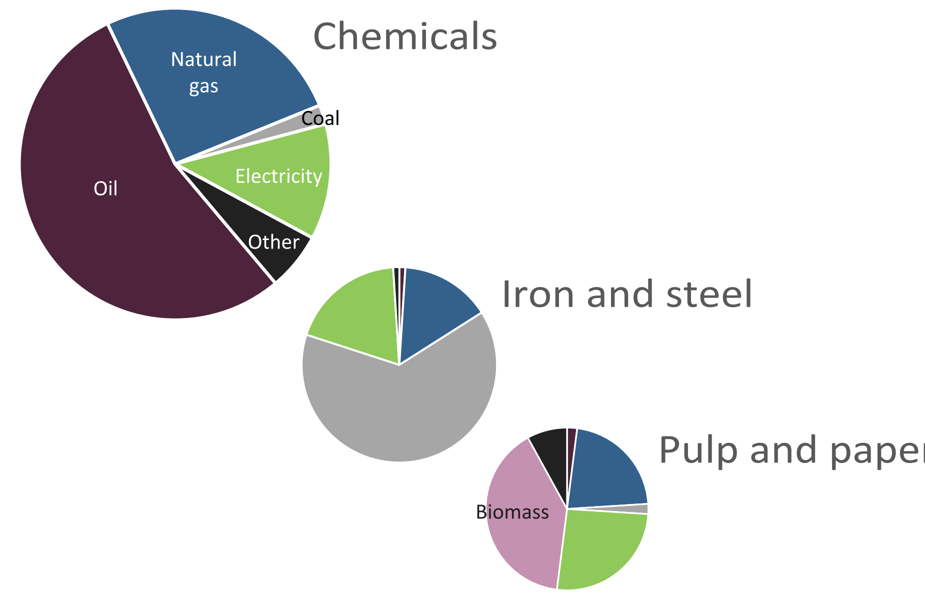


Figure 5 Fuel mix breakdown for the top three industries in terms of energy use in EU-27 in 2021 (including feedstocks) (based on IEA, 2023)

The chemical industry consumes mainly oil and natural gas, while the iron and steel sector has the highest share of coal use. For the pulp and paper sector, biomass accounts for about 40% of the energy use. On average, fossil fuel consumption accounts for 67% of industrial energy use while electricity consumption is at 22%.

Energy Efficiency's impact on CO_2 emissions

Increasing energy efficiency in the industrial sector, where coal, oil, and natural gas play a significant role, is recognised as a pivotal action for reducing greenhouse gas emissions and aligning with the goals set forth in the Paris Agreement.

Fossil energy use causes CO_2 emissions, dependent on the amount of carbon in the feedstock. The combustion of coal causes roughly 90-95 $kton_{CO2}$/PJ, gasoline 72 $kton_{CO2}$/PJ and natural gas 56 $kton_{CO2}$/PJ, related to the amount of carbon in the fuel. To illustrate this, figure 1 shows the rise in annual global CO_2 emissions. The annual global primary energy consumption of fossil fuels in figure 1 is about 146.000 TWh, corresponding to 526.000 PJ, considering an average fuel CO_2 emission of about 73 $kton_{CO2}$/PJ (average of the fuels mentioned above), this would result in a total annual emission of 38 billion tons of CO_2, matching well with the indicated emissions in figure 6.

Significantly reducing the industrial use of fossil fuels and corresponding CO_2 emissions with energy efficiency measures is essential for the green transition, but is also a complex and long-term process that requires commitment from governments, businesses, and individuals. It involves a combination of policy initiatives, implementation of existing energy efficient technology based on dedicated R&D, and behavioural changes to achieve meaningful reductions in CO_2 emissions.

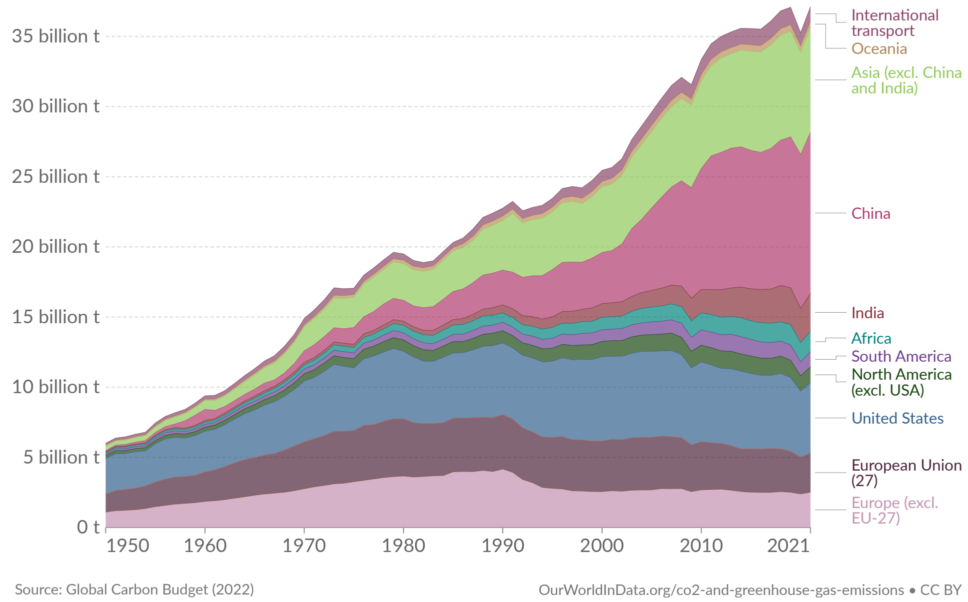
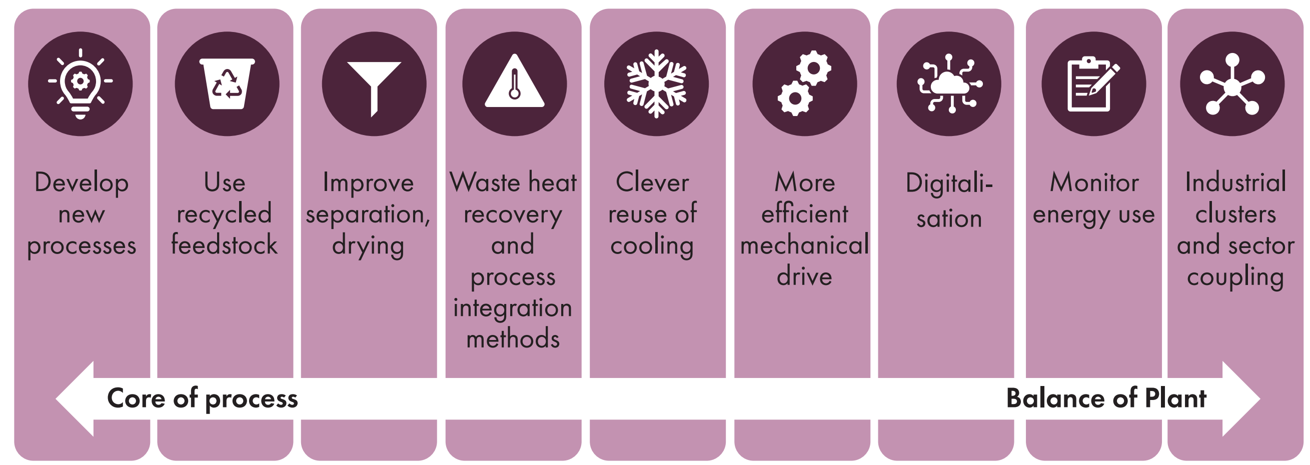


Figure 6: Global emissions [Source: Our world in data].

At the current rate of GDP growth, the EU is on track to have an energy demand of 14.2 EJ in 2050, well above the goal of 10.6 EJ [10]. The result of energy efficiency improvements in industry in the EU and the impact on CO_2 emissions reductions have been modelled in a recent publication [10]. While the study showed that it will be impossible to reach the EU's ambitions for 2050 with current policies and the expected growth in energy demand, it can be used to provide insights on potential pathways to reduce the 2050 energy demand for the industrial sector. One promising example in the publication, and a potential low-hanging fruit for reducing energy demand, estimates that a wide adoption of Best Available Technologies (BAT) for energy efficiency across all industrial sectors and an increased recycling rate can reduce the industrial energy demand in 2050 by up to 23%. [10]

2. Methods and potentials to increase energy efficiency

Energy efficiency improvement in industrial processes is defined as using less energy to generate the same product, both in terms of quality and quantity. Energy-efficient industries use less fuel, heat, cold, steam, etc., thus reducing their energy consumption and associated greenhouse gas emissions, while also saving money on energy costs. This can be achieved through a range of measures, such as optimising processes, upgrading equipment, avoiding or recovering waste heat, improving insulation, recycling, digitalisation, automation, knowledge exchange and training.



Develop new processes: New, more energy efficient processes can be developed, for instance running at lower temperature and lower pressure than the original process or having higher conversion and selectivity to the desired product. Typical examples are processes with improved types of catalyst. Also, low-temperature electrochemical processes can sometimes be more energy efficient than high-temperature thermochemical processes, depending on the overpotential needed to drive the reaction (which should be as low as possible). Currently there is a large effort made to develop processes where CO_2 and other GHG emissions may be eliminated. Some of these processes may however require higher energy input than the original process.

Use recycled feedstock: Depending on the type of feedstock, the use of recycled feedstock may strongly reduce energy demand. This is particularly true for recycling of metals since most of the energy in primary metals production is related to the reduction of the metal oxide in the ore to metal. In case of using recycled metals, these have already been reduced and can therefore be converted to metal product with a much lower energy input.

Improve separation, drying: This is an important category of energy consuming-processes in the chemical industry (distillation), paper industry (paper drying) and food industry (e.g. spray drying of milk powder or starch powder, distillation of vegetable oils). In these processes, evaporation is typically the step that requires the most energy. (Here, it is relevant to realise that the amount of energy to evaporate 1 kg of water is equivalent to the amount of energy required to raise the temperature of 10 kg of water by 53 °C.) New processes that increase product selectivity or non-evaporative separation technologies (e.g. pressing, membrane) are an important step to reduce the heat demand for separation. The heat demand can be reduced further by recovering the heat of evaporation as much as possible. This can be realised by vapour condensation and temperature upgrading by means of a heat pump. Alternatives are vapour upgrading by MVR or multi-step evaporation (as typically used in sugar or salt production).

Waste heat recovery and process integration methods: Heating is the most energy-consuming step in many processes. Typically, heating is done by combusting fossil fuels such as natural gas, which results in both the required heating of the product flow and in a hot exhaust gas flow, embodying a loss. To increase the energy efficiency of the overall process, the heat from the exhaust gas (and preferably also from the product flow or other liquid or solid flows) should be recovered. Heat recovery from the exhaust gas can be realised by steam generation (waste heat boilers) and boiler feedwater preheating (economisers). Another means is to reduce the hot flue gas flow (by regenerative heaters, by oxyfuel combustion or by exhaust gas recycle in flameless oxidation). It is also possible to avoid the hot flue gasses altogether by applying electric heating (preferably by heat pumps, but for high temperatures, other solutions are applied such as resistance heating, inductive heating, microwave-assisted heating or electric arc). To recover the heat from hot product flows, heat integration is typically carried out, recovering heat from a higher temperature process to drive a lower temperature process. This heat integration potential can be enhanced further by applying high-temperature heat pumps. Surplus heat that cannot be utilised internally may be utilised externally, preferably directly or upgraded to a higher usable temperature level by implementing a heat pump, e.g. for district heating, or converted to electricity in a heat-to-power process.

Clever reuse of cooling: The demand for cooling is much lower than for heating. In addition, cooling is typically achieved through electrified vapour compression systems. The main options for increasing energy efficiency are cold integration (reusing cold from product flows), use of the waste heat from the cooling machine or system (i.e. as energy source for a high temperature heat pump) and limiting the temperature lift for cold generation to what is really needed, thereby increasing the efficiency of the cooling machine.

More efficient mechanical drive: In many industries, compressors and fans are driven by steam. However, the efficiency of this process is limited by the corresponding power cycle efficiency. If compressors and fans can be driven electrically, the energy efficiency is highly improved. A point of attention is that the steam used for this mechanical drive is often generated with waste heat. Therefore, to increase the overall process efficiency, new means must be found to reduce or reuse this waste heat.

Digitalisation: Energy demand modelling has developed rapidly in recent years, due to increased availability of data and advanced modelling tools (AI). Automation and digital technologies, including AI, can improve energy efficiency through better fault detection and process control, and enhanced energy demand modelling.

Industrial clusters and sector coupling: If a plant has excess heat that cannot be recovered, this heat can be exported to other nearby users (local use of heat). These users can be nearby industries in an industrial cluster or can be a district heating network for the built environment or for greenhouses. In this way, large amounts of heat that would otherwise be wasted can be put to use. One critical aspect is potential lock-in; the development of a district heating network involves significant costs, and the availability of the heat may dwindle over time, when industries become more energy efficient, make changes in production or even stop production at a certain location. Therefore, typically, energy efficiency should be optimised within the industrial process first, before export of excess heat is considered.

Monitor energy use: a precondition for energy efficiency measures is knowledge of the energy flows and energy losses in the industrial process. To this end, detailed monitoring of heat flows and regular auditing is necessary. With modern automated monitoring measures, the effectiveness and detailedness of monitoring can be greatly enhanced. Analysis of the data can also indicate possible heat integration options (with or without heat pumps) to improve the overall process efficiency.

Best Available Technologies (BATs)

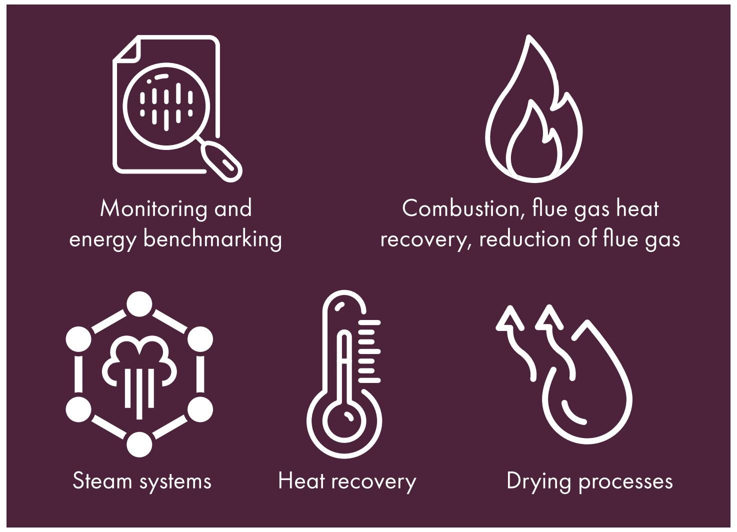
As previously mentioned, implementing the Best Available Technologies (BAT) for energy efficiency has significant potential to reduce energy demand in industrial processes. BAT Reference documents, also called BREF, exist for all industrial sectors. These give recommendations on technologies, processes, methods, and techniques that already exist and have been approved by legislators or regulators for meeting output standards for a particular process, such as pollution abatement. These BREFs should be constantly developing as technology improves and regulations evolve. However, they are not updated as quickly as technology improves and the recommendations can be fragmented when it comes to energy efficiency.

In Appendix 1, an overview is shown of the energy efficiency measures for the main industrial sectors as described in the BAT reference documents (BREF), published on the website of the European IPPC Bureau. While these documents mostly focus on reducing particulate emissions, energy efficiency measures are presented, ranging from general measures related to monitoring and to auditing more process-specific measures.

In addition to sector-specific BREFs, a BREF was published on energy efficiency related to industrial energy supply, with specific measures for combustion, steam systems, heat recovery, cogeneration, power supply etc at European IPPC Bureau.

BAT related to energy efficiency in industrial sectors can be broadly categorised into several key areas. In the general category, strategies involve monitoring and benchmarking energy consumption through online monitoring, reporting tools, and regular audits. Combustion-related measures focus on the recovery of flue gas waste heat, employing techniques such as recuperative and regenerative heaters, economisers, FLOX burners, and combustion air preheating. Reduction of flue gas volume is achieved through methods like minimising excess air, adopting oxyfuel combustion, and implementing burner control. Steam system efficiency is enhanced through back pressure turbines, feedwater preheating, minimising heat exchanger scaling/fouling, optimising boiler blowdown, adjusting deaerator vent rates, and improving condensate return. Heat recovery measures involve the optimal

Figure 7
General categories of Best Available Technologies (BAT) related to improving energy efficiency in industrial sectors. Fore more details, refer to Appendix 1.



use and integration of heat pumps, chillers, and heat exchangers, as well as recovering exothermic heat through low-pressure steam generation. Lastly, in drying processes, efficiency is improved by increasing mechanical dewatering, recovering evaporation heat with heat pumps, and employing techniques such as MVR and superheated steam drying.

Potentials to reduce CO_2 emissions:
An example of the CO_2 reduction potential in the Dutch industry by means of energy efficiency and CO_2 reduction measures with a payback time less than 5 years is provided in the table below (based on Van Lieshout, 2020) [11]. The total emissions reduction of these measures was indicated as 2.8 Mton/year, of which the largest effect results from heat integration options (1.3 Mton/year), followed by ICT (0.9 Mton/year) and improving electromotors and electromotor systems (0.2 Mton/year). Measured against the total Dutch industrial CO_2 emissions of 44 Mton/year, implementing these measures will have a significant effect on the overall emission reductions.

It must be noted that these are only technologies that would in 2025 have a payback time of 5 years or less; if payback would increase to 10 years, another reduction of 1 Mton/year could be realised. Most of this reduction potential was found in the food industry, followed by the chemical industry and refineries. According to the report MIDDEN - Energy efficiency options in the Dutch manufacturing industry (Haque & Lamboo, 2023), the total energy savings related to these CO_2 reductions would add up to over 87 PJ/year for the Dutch industry alone.

Table 1: Feasible economical reduction potentials (kton CO_2/y) in Dutch industry (Project 6-25 Technology Validation, Van Lieshout, 2020)". Note: these numbers apply for the 8 sectors, accounting for 86% of the energy use in the NL [12].

		Industrial Sectors							
		Chemical Industries				Industries			
Technologies		Industrial gasses	Steam crackers	Ammonia & N-fertiliser	Wider chemical industry	Refineries	Iron and Steel	Food	Paper & Board
Motors and drives	Electromechanical system operation	11	29	5	32	20	47	49	39
Heat integration	Flue gas recuperation	5	55	10	59	85	49	67	20
	High temperature heat pumps	0	4	1	52	6	2	165	38
	Mechanical vapour recompression	0	15	2	127	23	8	165	88
	Heat transformer	0	29	0	86	76	0	16	0
ICT	Advanced process control	26	74	49	58	65	46	106	23
	Energy management analytics	14	36	21	25	31	23	63	14
	Asset management analytics	16	39	19	57	29	17	62	14
Separation	Membrane separation of H_2 from hydrocarbons	0	0	3	0	73	0	0	0

3. Policy measures and incentives to boost energy efficiency

How can the industrial energy efficiency potential be fully realised? Industrial actors and authorities must create and enforce action plans that enable efficient investment decisions to reach energy efficiency and decarbonisation goals.

The recently approved Energy Efficiency Directive, officially adopted on July 25, 2023, marks a substantial increase in the European Union's commitment to energy efficiency [13]. It establishes the principle of "energy efficiency first" into EU energy policy [14], granting it legal recognition for the first time. In practical terms, this mandates that EU member states must consider energy efficiency in all relevant policy and investment decisions. The updated legislation build upon a proposal for a revised energy efficiency directive initially introduced by the Commission in July 2021, as part of the EU Green Deal initiative. The 2021 proposal was further strengthened as a component of the REPowerEU strategy, unveiled by the Commission in May 2022, with the aim of reducing the European Union's reliance on fossil fuel imports from Russia [15].

Various economic support mechanisms are available through dedicated funds at the EU and national levels, with a list of sources available here: EU funding possibilities in the energy sector.

European-level policies and incentives

There are a variety of European-level policies and incentives currently in operation to support energy efficiency measures such as the Carbon Border Adjustment Mechanism (CBAM)[1] and the EU Supply Chain Law (17). While these measures are a promising step towards accounting for greenhouse gas emissions and managing social and environmental impacts, these alone will not ensure energy efficiency is maximised, nor do they provide adequate financial incentives to promote the widespread adoption of energy-efficient technologies.

In addition to the EU policy measures, Appendix 2 provides a summary of selected examples of policy instruments from Norway, the Netherlands, Italy, Germany, and Austria, outlining country-specific measures to increase energy efficiency.

4. Barriers

Barriers to energy efficiency implementation

Despite its potential, the adoption of energy efficiency technologies is hampered by different factors. There are several barriers that can impede the successful implementation of energy efficiency measures in industrial settings. These barriers can vary depending on the industry and specific circumstances, but common ones include high upfront costs, reluctance to lock-in investments, limited funding options, regulatory barriers, retrofitting challenges, and lack of information or awareness.

High Upfront Costs and Limited Funding Options

- Many energy efficiency upgrades require significant capital investment, which can be difficult for companies to justify if they don't see immediate returns.
- Even when companies recognise the benefits of energy efficiency, they may not have access to the necessary financing to implement upgrades.

Regulatory and Policy Barriers

- Some regulations or policies may actually discourage energy efficiency, either by imposing additional costs or by creating incentives for companies to continue using traditional, less efficient technologies.
- Also, many times the constant changes in regulation lead to legal insecurity for enterprises, making it difficult to shape consistent business cases for large energy efficiency projects.

Retrofitting Challenges and Lack of Necessary Infrastucture

- Retrofitting older industrial facilities with energy-efficient technologies can be challenging due to compatibility issues and the need for modifications that may cause downtime.
- Companies may be risk-averse when it comes to implementing new technologies or processes, especially if they are uncertain about the potential returns on investment.
- Uncertainties in the development of the future energy system.

Lack of Information and Awareness

- Many companies are not aware of the potential benefits of energy efficiency measures, or they may not know where to start when it comes to identifying opportunities for improvement.
- Organisational barriers can also hinder the implementation of energy efficiency measures. For example, employees may resist changes to their routines or processes, or there may be a lack of communication between different departments or levels of management.
- Lack of technical expertise can hinder progress on energy efficiency measures, and may be addressed through workforce training and development.

Table 2
Categories of energy efficiency measures and their applicability in industrial sector.

Energy efficiency measures (asterisk indicates showcase available, bolded X in sector)		Refineries	Chemicals		Iron & Steel		Non-ferro metals			Non-Metal			Pulp & Paper	Food			Other
			Petrochemical	Inorganic	Steelmaking	Foundries	Aluminium	Copper	Zinc	Cement	Glass	Ceramics		Dairy and starch	Vegetable Oil	Bakeries	
Improved processes	Improved cathodes*						X	X	X								
	Improved catalysts	X	X	X													
	Alternative processes	X	X		X		X										X
	Alternative/recycled feedstock	X	X		X		X	X	X	X	X		X				X
Improved separation and drying	Membranes		X	X											X		X
	Sorption	X	X	X	X												
	Superheated steam drying												X	X			X
	Infrared/microwave-assisted drying												X				X
	Improved mechanical dewatering												X				X
	Heat Integrated Distillation Column (HIDiC)		X												X		
	Pulse-combustion drying*													X	X		X
Improved heat recovery	Mechanical Vapour (Steam) Recompression (MVR)	X	X	X									X	X	X		X
	Electrically driven heat pumps		X	X									X	X	X		X
	Thermally driven heat pumps/transformers (AHT)*	X	X	X									X	X	X		X
	Corrosion-resistant heat exchangers*	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
	Heat storage in batch processes				X	X						X		X	X	X	X
	Economizers	X	X	X									X	X	X		X
	Thermochemical recuperation	X	X		X					X	X						
	Heat to power / Organic Rankine Cycle (ORC)	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
	Industrial clustering / heat networks	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Furnaces and Heating	Direct electric heating (with renewable electricity)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Biomass/biogas/ hydrogen combustion	X	X	X	X	X	X			X	X	X	X	X	X	X	X
	Hybrid steam boilers												X	X	X		
	Hybrid burners	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
	Oxyfuel combustion	X	X	X	X					X	X	X					
	FLOX burners	X	X	X	X					X	X	X				X	
	Infrared/microwave assisted heating		X									X				X	X

5. Showcase examples of energy efficiency

The previous chapter focuses mostly on a general perspective for industrial energy efficiency in Europe, showing the present state of energy use Europe, the potential for energy demand reduction, the importance of realising this and the key barriers. As explained in section 2, many options exist to increase energy efficiency. Now, we will focus on concrete energy efficiency measures that can be implemented and their application in several showcase examples. An overview of the different technologies and sector in which they are more relevant is presented below.

It is important to realise that most of these showcases demonstrate technologies that have a wider application than just the industrial sector for which they are demonstrated here; therefore, the range of application of each energy efficiency technology will be emphasised as well.

Integrated heat pumps and thermal energy storage

Bergen, Norway | **Dairy** | **High-temperature heat pumps, thermal storage**

The TINE plant in Bergen (Norway), in operation since 2019, is the first dairy plant whose thermal demands are 100% covered by heat pumps, in a fully integrated energy system covering cooling and heating demands of the process. The heating demands are met by two heat pumps combined with chillers:

- A conventional ammonia heat pump providing heat at 67°C, and making use of low temperature waste heat at 40°C coming from the ammonia chillers' heat rejection.
- A hybrid absorption/compression heat pump providing heat at 95°C, using as a heat source the heat provided by the ammonia heat pump.

The heat pumps and the chillers are integrated with different buffer tanks at the temperature levels suitable for the associated processes. This way, the plant has process heat available at 40°C, 67°C and 95°C. The plant includes a dry cooler, electric heater, and supply from the district heating network as a backup.


Photo: Hybrid energy/JCI

Potential benefits

The integration of chillers, heat pump systems and thermal heat storage proves to be suitable for meeting cooling and heating demands, with process waste heat recovery rate of over 95%. The use of thermal storage at different temperature levels allows to maximise the potential of the integrated heat upgrading systems (heat pumps) and so, minimise external energy use (from district heating or electricity).

Regarding heat pumps, depending on the upgraded heat temperature level, different technology readiness levels (TRL) apply. Heat pumps upgrading heat until 80°C are well established in the market. When it comes to high temperature heat pumps, the higher the temperature level, the lower the TRL.

Relevant KPIs

38% electricity savings & 40% CO_2 reduction
37% of process heat coming from waste heat
Total system COP = 4.1

[26]

Absorption heat transformer in petrochemical industry for low-temperature waste heat recovery

Izmit, Türkiye | **Petrochemical** | **Absorption heat transformer**

An Absorption Heat Transformer (AHT) was installed, commissioned and monitored at the Tüpras petrochemical refinery in Izmit (Türkiye). The AHT recovers waste heat from a dirty steam condenser tank at 100°C, which is used to activate the AHT at 90-95°C. The AHT provides upgraded heat at 130-135°C. Improved operation modes for adiabatic absorption have been implemented, providing a higher upgraded temperature in the absorber. An innovative purge system for non-condensables is implemented, optimising the unit operation and reducing maintenance cost. An automatic control system allows for efficient part load operation.

This R&D prototype provided around 200 kW of upgraded heat. In future commercial installations with an installed heat capacity of 600 kW, a payback of 3 years could be achieved, and in the case of a 1 MW AHT, a 2 year payback could even be possible.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 680738.

During the project, a user-friendly Assessment tool was developed which allows any potential industrial user to perform a preliminary technical and economical evaluation for the installation of an AHT system in their own industrial process.

Potential benefits

Absorption Heat Transformers (AHT) are designed to recover and upgrade industrial waste heat below 130°C. Simple effect AHTs allow the heat upgrade of approximately 50% of the recovered waste heat, with a temperature lift between 20 and 50 K. The AHT is a version of the absorption cycle designed for the revalorisation of waste heat, comprising a condenser, evaporator, absorber and desorber. Low temperature waste heat is widely available in several industrial sectors. Thus, the implementation of AHT technology in industrial processes can be an important contribution for the future decarbonisation of industry.

Relevant KPIs

Performance: Thermal COP (upgraded heat/recovered waste heat) = 0.5
Taking into account 20 years service life, net savings correspond to:

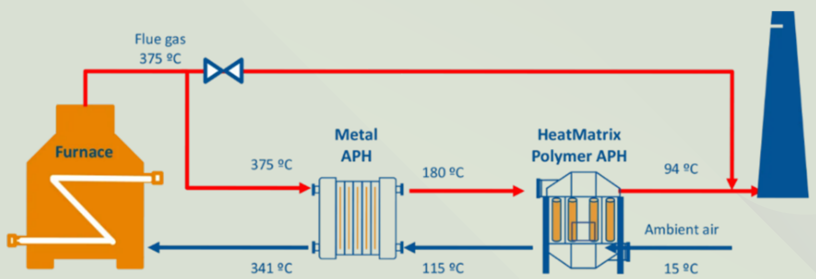
- Primary energy: 45 GWh
- CO_2 emissions: 11900 tn CO_2
- Operation costs savings: 1.4 M€

Corrosion-resistant heat exchangers

Showcase

Eastern Europe | **Refinery** | **Corrosion-resistant polymer heat exchanger**

A corrosion-resistant polymeric heat exchanger (manufacturer: HeatMatrix) is used in series with a metal Air PreHeater (APH) to recover flue gas waste heat from a fired heater, providing heat to the crude distillation unit in a refinery. The waste heat is used for preheating ambient combustion air in the polymeric heat exchanger from 15°C to 115°C, followed by further heating the air to 341°C in the metal APH. These flue gases include highly corrosive components, such as sulfur oxides and other corrosive components, and the polymeric heat exchanger makes it possible to recover the heat in the flue gas below the H_2SO_4 acid dew point temperature without corrosion. The flue gas flow is 103,000 kg/hr and the total heat exchange system has a capacity of 9 MW, of which 3.2 MW is realised by the polymer heat exchanger.



Source: HeatMatrix - Customer Reference (heatmatrixgroup.com)

Potential benefits

The polymer heat exchanger makes it possible to recover heat from highly corrosive flue gases below the acid dew point. With corrosion-resistant heat exchangers, additional economisers and preheating solutions can be implemented, for instance for preheating of combustion or drying air.

Relevant KPIs

After the HeatMatrix polymer air preheater was installed, furnace efficiency increased by 4%. Corrosion rates downstream of the heat recovery system remained below 0.1 mm/year. Payback time was less than 5 years.

[20]

New Cu electrolysis technology

Showcase

Kristiansand, Norway | **Non-ferro metals production** | **Innovations in Cu electrolysis**

Several innovations have been implemented in a nickel, copper and cobalt production plant, specifically in the Cu electrolysis process. The innovations include a new steel cathode (which leads to fewer process steps), a new titanium anode with a catalytic coating (IrO_2-Ta_2O_5), larger cell vessels (which lead to higher area utilization), better process control, cleaning of exhaust gas improved environment in closed cells and robotization of the extraction of Cu from the cathode.

Potential benefits

The combination of all the innovations and operational improvements lead to a very significant specific consumption reduction in the Cu production process.

Relevant KPIs

- Lower specific consumption (1.56 kWh/kg from 2.3 kWh/kg)
- 22.2 GWh/year energy consumption reduction

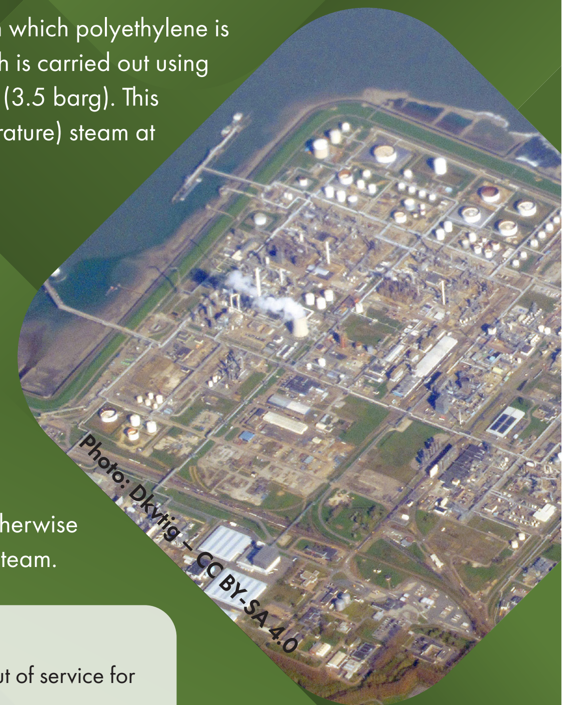
Steam compression heat pump for hydrocarbon processing plants

Showcase

Terneuzen, Netherlands | **Chemical industry** | **Mechanical vapour recompression**

Dow Chemical has a large plant in Terneuzen (NL), in which polyethylene is produced. This process requires reactor cooling, which is carried out using water that thereby is converted to low pressure steam (3.5 barg). This steam can be upgraded to high pressure (high temperature) steam at 12 barg by means of vapour recompression.

Whereas Mechanical Vapour Recompression (MVR) is a well-established technology at lower steam pressures using blowers, these higher pressures required a different compressor technology, for which Atlas Copco was selected as compressor supplier.



Potential benefits

By using MVR, excess low-pressure steam that was otherwise condensed, can now be upgraded to useful process steam.

Relevant KPIs

- Running without significant problems; only briefly out of service for steam network maintenance.
- Average COP of 7.5
- 10 million Nm³ of natural gas was saved over 12 months
- 17.8 kton of CO_2 emissions were avoided over 12 months

Enhancement of process efficiency in the cement industry using an optimisation tool for decision making

Italy | **Cement industry** | **Descriptive tool monitoring decision making**

The cement sector is a highly energy intensive process, therefore an enhancement in the process efficiency in terms of energy consumption is crucial. The aim of the raw mill rig is to grind raw materials (clay and limestone) to obtain a powder that in the rotary kiln furnace is sintered to clinker, the main component to make cement. This is a key process in a cement manufacturing company with an important energy consumption that has to be minimised without impacting productivity.

The enhancement of process efficiency (minimisation of the ratio energy consumption/ton manufactured) started with a descriptive analysis, process models of relevant indicators and the prescription of process parameters. Data-driven models based on process data establish a causal relationship between process parameters (dosages of raw material, temperatures, and pressures at different points in the process) and the KPI (ratio between energy consumption and clinker production). To develop the optimisation, data-driven models have been built based on historical data.

The enhancement of process efficiency has been carried out by the optimisation tool. However, a descriptive tool has been used to analyse the historical data before constructing the data-driven models. In the figure, the dashboard of the descriptive tool is shown. In the upper part, current values of some indicators such as material dosage per feeder, total mill load, instantaneous medium and low voltage power and the ratio of energy consumption per ton manufactured, can be seen. In addition, a small Gantt is included to know the load status of the mill (load-in production, low load, no load-stopped) in the last period. At the bottom, 4-time plots with hourly grouped data are displayed. The upper right graph shows the evolution of the target KPI to be optimized, which is the ratio consumption/ton manufactured. This ratio depends on the variables shown in the rest of the 3 graphs.

Dashboard of the descriptive tool to monitor the process.

The optimisation tool for decision making has been used to solve the posed optimisation problem by minimising the KPI and considering the constraints. The results were validated in three scenarios designed by experts of Rossi. The results show that the KPI values obtained from the process parameters suggested by the decision-making tool were lower than the ones used by the company.

Potential benefits

The developed methodology for improving the efficiency of the process helps the company to determine the values for parameters such as dosages of raw material, pressures and temperatures, while minimising the energy consumption within the constraints set by production requirements. In addition, the previous step carried out by the descriptive tool helps to control the process indicators (material dosage per feeder, total mill load, instantaneous medium and low voltage power and the KPI).

Relevant KPIs

Energy consumption reduction of 15%.

[22]

Showcase

Pervaporation for dehydration of bioethanol

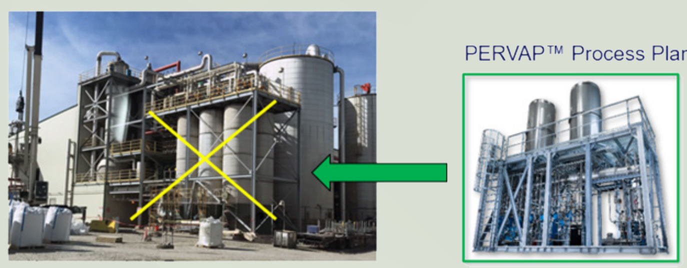
Europe

Bioethanol production

Pervaporation

Bioethanol is produced by fermentation. It is then subsequently purified by distillation to produce an ethanol water mixture which contains about 6% water. Pervaporation is then used to produce 99.9% pure ethanol for pharma use, processing 1600 kg/h.

A compact pervaporation membrane plant continuously dehydrates the wet ethanol producing the final dry ethanol. The wet ethanol is heated and flows through a series of PERVAP™ membrane module in series. Water permeates selectively through the membrane under vacuum. The aqueous permeate is condensed. The residual ethanol in the permeate is recycled and recovered. The result is a continual dry ethanol stream at almost 100% recovery. The plant has been running for over 15 years.



Potential benefits

The plant has a small footprint and is simple and fast to start up and switch into operation. Upstream distillation equipment is smaller. Compared with alternatives like molecular sieves or azeotropic distillation, pervaporation has low operating costs and saves significant energy. Compared to zeolite drying, the risk of product contamination with zeolite dust is eliminated and no sorbent regeneration is needed, while compared to azeotropic distillation, no additives (entrainers) are needed to suppress side streams.

Relevant KPIs

- Improved energy efficiency
- 15 years running so far

[23]

EERA European Energy Research Alliance

Showcase

Direct electrification

Uttendorf, Austria

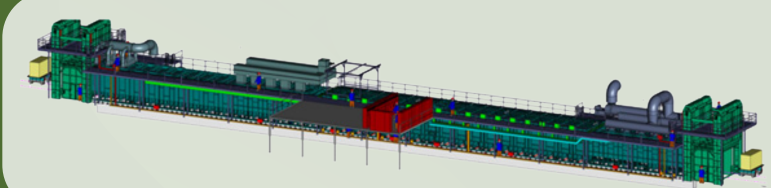
Brick production

Direct electrification and high-temperature heat pump

The GreenBricks project will decarbonise a brick manufacturing facility by implementing electric kilns powered by renewable energy. Traditionally, the industry has relied on high-temperature tunnel kilns fired by natural gas, resulting in significant energy-related CO_2 emissions. This is compounded by process-related CO_2 emissions from the release of carbonates in the clay and the burning of additives.

The existing gas-fired burner will be replaced with an innovative electrically-fired high-temperature kiln. The new kiln will be commissioned in phases, culminating in an evaluation at a production capacity of 300 tons of bricks per day.

In addition, the project is investigating viable carbon-neutral alternatives for porosifying agents. These agents are critical to ensure effective thermal and acoustic insulation in bricks, but their effectiveness in large-scale applications remains to be tested and validated.



Novel kiln design by Wienerberger

A comprehensive analysis and modification of the tunnel dryer is underway to improve the overall energy efficiency of the dryer-burner-heat pump system. This includes both internal and external heat recovery mechanisms, with a particular focus on integrating a heat pump into the system.

Potential benefits

The primary energy demand should be reduced by about 30%. With the new clay mixtures, using renewable electricity and the use of heat pumps in the drying process, the overall CO_2-emissions will be reduced by 88%.

Relevant KPIs

- 30% primary energy demand reduction
- 88% CO_2 reduction

[24]

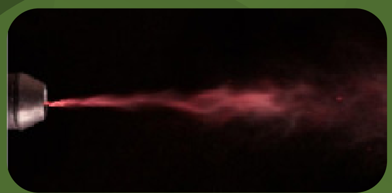
Pulse spray drying for brewer's yeast
(or other high-viscosity products)

Showcase

Poland | **Food/brewing industry** | **Pulse combustion spray dryer**

Pulse Spray Drying (PSD) is a spray drying technique where the product is atomised by using shock waves or pulses generated by a generator or pulse combustion burner. The pulse generator is a gas burner where the combustion air flow enters the combustion chamber through a rotary valve that opens and closes more than 100 times per second, generating a pulsating combustion with more than 100 pressure oscillations or pulses per second. The combustion processes generate heat which is used to dehydrate the wet product. The wet product is injected through an injection pipe, in the middle of a hot stream. The heat pulses generated by the combustion break the wet product into droplets. Acceleration of the droplets within the hot stream creates a narrow and long spray, and thus, the energy and mass transfer are significantly increased, and with that also the drying rate.

The installed PSD system has a 3,000 kW capacity to dry concentrated brewer's yeast with dry matter of more than 30%.



The dryer has 3 PC (pulse combustion) burners of 1,000 kW thermal each. Each burner has two blowers, one for combustion air and one for quench air, which controls the combustion temperature and the drying air, respectively.

Potential benefits

Since the pulse generator both provides pulses for atomisation of the wet product and the heat for evaporation, there is no need for nozzles or discs to atomise the product and the energy efficiency in the drying process is very good. The pulses can atomise high viscosity pastes which is not possible in a conventional spray dryer, and there is no need of high pumping pressure due to the combustion technology. The pumping pressure range from 0.5 to 4 bar, which is low.

Since the dryer can cope with more concentrated products, energy can be saved in the drying process. Heat damage of dried product is avoided due to higher drying rates that produce a quicker evaporative cooling within the spray. In addition, waste heat recovery systems can be applied and make the system even more efficient.

Relevant KPIs

- Specific energy use: 0.71-0.96 kWh/kg H_2O evaporated
- Energy efficiency: 20-30% compared to conventional drying technologies
- Drying chamber outlet temperature 105° C
- Natural gas flow in the tree burners: 115-154 kg/h
- Total air flow (leaving the drying chamber): 29.5-39.2 kg/h

[25]

6. Current RD&D and gaps on industrial energy efficiency

This white paper has shown that there is a large application potential for energy efficiency in industry, but also a variety of processes and boundary conditions into which energy efficient technologies must be integrated. Achieving optimal performance (e.g. technical, economic, environmental) across a broad range of applications in industrial processes requires the development of a range of technologies to cover the market. One of the challenges of the current research and development in energy efficiency in industry is the broad scale of energy efficient technologies and the different solutions for each industrial sector and even each industrial site. For these reasons, the development of new and dedicated energy efficient technologies for industrial applications needs to be advanced in national and international RD&D projects.

Important specific technology developments that can reduce specific energy consumption in industrial processes are:

Process improvements:

- new reactor design concepts and equipment,
- new catalyst development for resource and energy efficiency,
- development of electrochemical processes,
- increased use of sustainable feedstock.

Efficient separation technologies:

- energy efficient distillation with heat recovery,
- membrane separation,
- sorbent separation,
- energy-efficient solutions for drying & dewatering;

Efficient heating & heat recovery technologies:

- industrial heat pumps,
- heat-to-power technologies,
- improved heat integration,
- efficient renewable hybrid heating technologies (el/H_2/bio),
- thermal energy storage solutions for peak shaving and better utilisation of fluctuating heat losses (establishing waste heat supply).

In addition to technology development at low and medium TRL, involvement of R&D is important for implementation of new technologies at high TRL:

- Techno-economic studies and integration studies to find effective applications for new energy saving technology;
- Demonstration projects on innovative efficiency measures together with industry, and be involved in monitoring and dissemination of the results;
- Development of training courses for industry to get acquainted with new energy saving options;
- Development of standardised solutions for new energy saving technology.

In order to be able to carry out this task properly, support for R&D on energy efficiency measures should be strongly increased and provided in a consistent and structured way, not only addressing the low hanging fruit, but keeping in mind long-term targets that must be met. Current R&D on energy efficient technologies is driven by scattered national initiatives which are very much targeted towards local industrial sectors. The main motivation for these development projects is typically focused on reducing operational costs through saving energy. On a European level, the low priority of energy efficiency technologies on the research agenda means that only a limited number of projects (FP7, Horizon2020) containing technology developments have been undertaken in recent years.

Whilst the current approach to R&D on energy efficient technologies has led to impressive individual results, it is limited in its ability to ensure the technologies reach a level of maturity to achieve meaningful CO_2 reductions, which would otherwise be possible. Undertaking energy efficient technology developments on a project by project basis, mainly through nationally funded incentives, prevents coordination of essential development activities, the sharing of critical knowledge and continuity of development. A more programmatic approach on a European level is needed to address these issues.

7. Recommendations to maximise the potential of energy efficiency in industrial sectors

Energy efficiency is a means to keep industrial production in Europe competitive, considering that towards 2050, Europe is going to have a shortage of cheap renewable energy. Considering that for strategic reasons, Europe needs a certain level of basic industrial production to reduce dependencies on volatile external markets, energy efficiency is a means to realise this in a cost-effective way. To increase energy efficiency in industrial production, the following recommendations are proposed.

1. Energy use should be better monitored and audit recommendations should be implemented;
2. Best available practices regarding energy efficiency need to be updated, shared and implemented.
3. The implementation of new energy-efficient innovations, related to energy-efficient feedstock, processing and waste heat reuse/reduction, should be supported by regulations and financial incentives;
4. A level playing field should be ensured for low-emission industries;
5. The development of new energy-efficient technologies should be stimulated.
6. Long-term decarbonisation plans should be made and aligned among policy makers, energy network companies and the industry;
7. The recommendations above need to be supported by regulatory measures and financial incentives, suitable for their level of maturity, as indicated in the table below.

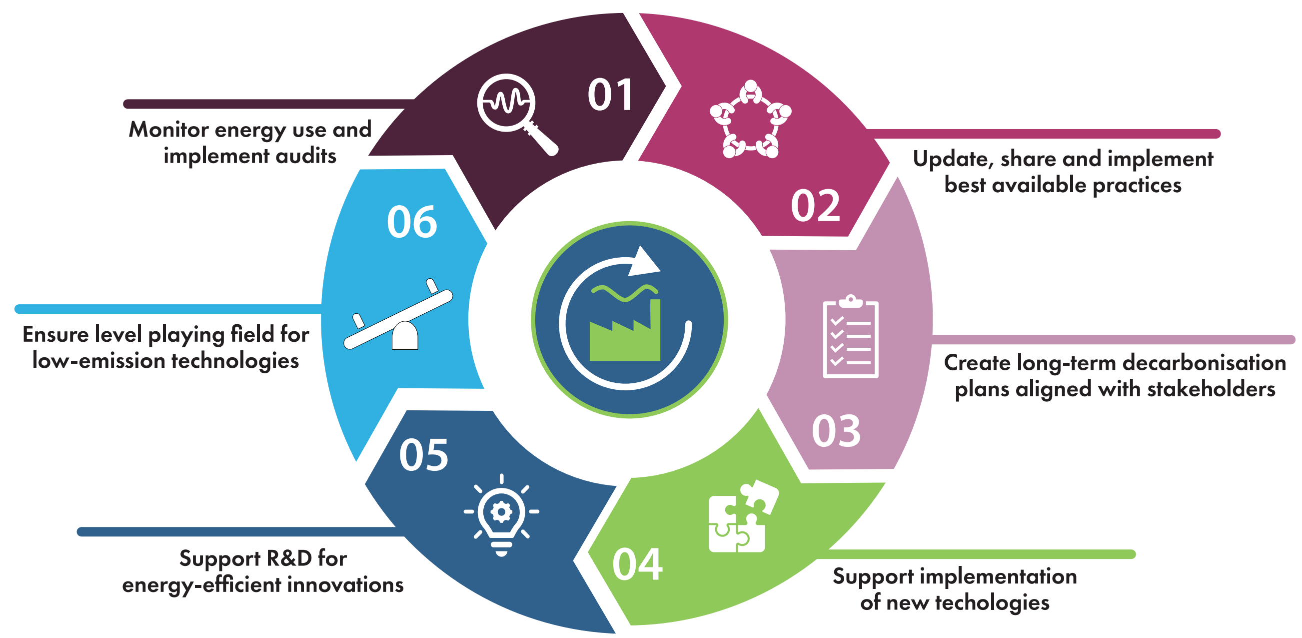


Figure 8
Recommendations to increase energy efficiency in industrial production.

Table 3
Potential energy efficiency support measures as a function of technology maturity.

Maturity		Support measures
TRL 9	Best available practices BAT https://eippcb.jrc.ec.europa.eu/reference/	These need to be implemented as soon as possible. Limited support required, related to market development and certification. De-risking can be facilitated by new financial constructions, e.g. ESCO type [19].
TRL 7-8	Technologies at the brink of introduction – demo and pilot projects	Should receive support from EU, national and regional governments to realise demonstration projects to gain confidence in technology potential. Dissemination is essential, e.g. via branch organisations.
TRL 1-6	Technologies in earlier stage of research	Should receive R&D support.

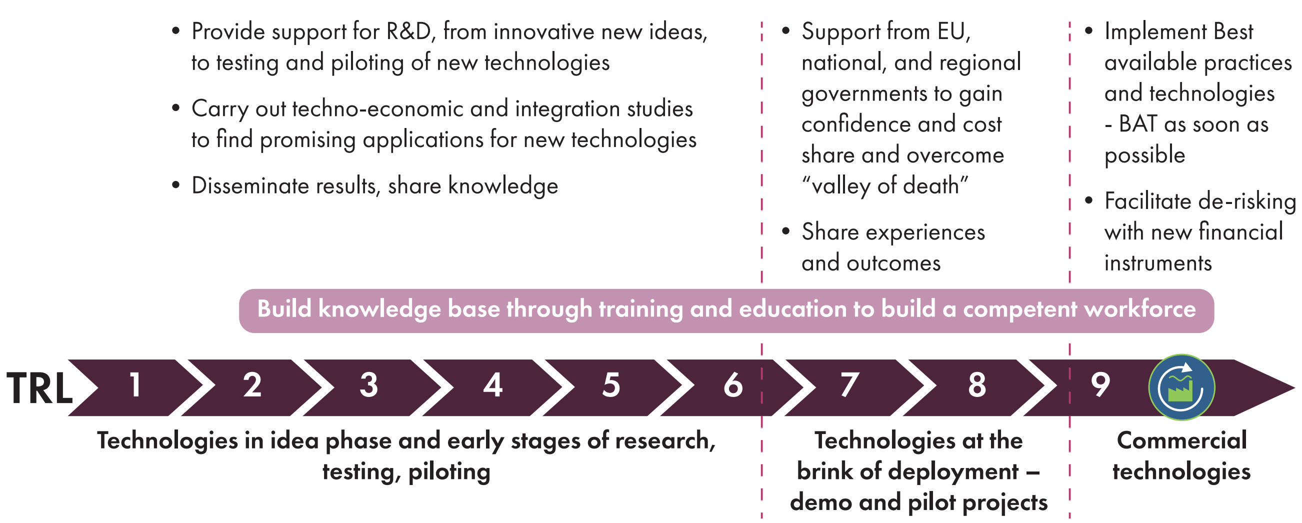


Figure 9
TRL-specific recommendations for promising energy efficiency technologies leading to widespread implementation.

Recommendations to stakeholders
to increase energy efficiency in industry

Industry
- Install/improve energy management systems and energy **monitoring**
- **Implement** current Best Available Technology (**BAT**) recommendations
- **Reduce/reuse waste heat:**
  - Focus internal reuse
  - Export if needed
- Develop long-term **decarbonization plans**
- Carry out **demonstration projects** on innovative energy efficiency measures
- Increase share of **recycled feedstock**, as well as recyclable products
- Allow for **time-flexibility** in production process

Policy
- **Require implementation**
- **Support demonstrations & development BAT** (Best Available Technology)
- **Provide outlook:**
  - Clear vision & targets
  - Require clear infrastructure plan
  - Require decarbonization plans
  - Energy efficiency first policy
- **Support R&D** for new technology development

Finance
- Develop new **business models** to reduce risk and to free up assets for innovating industries
- Give **priority to energy efficiency investments**

Energy grid companies
- Develop clear **long-term planning for realization of future energy infrastructure and communicate these** with policy and industry:
  - Electricity
  - Hydrogen
  - Biogas
  - Heating networks (district heating or industrial heat clustering)

R&D
- **Develop new energy efficiency technology** in cooperation with industry:
  - Sustainable feedstock
  - Energy-efficient production
  - Efficient heating and waste heat recovery and upgrade
- Develop **training courses** for industry to get acquainted with new energy saving options
- Carry out **techno-economic studies and integration studies** to find good applications for new energy saving technology
- **Develop standardized solutions** for new energy saving technology

Appendices

Appendix 1

Available technologies (BAT) for the main industrial sectors to increase energy efficiency. These technologies are described in the BAT reference documents (BREF), published on the website of the European IPCC Bureau (ref. listed in section 2).

Chemical

BAT technologies:

- Use of combined heat and power (CHP): Co-production of electricity and steam for use in the process;
- Use of a combined cycle gas turbine: A technique to generate electricity at a higher efficiency than conventional steam boilers;
- Heat integration & application of pinch technology: A structured design methodology for optimising the overall level of heat integration that can be achieved on a site-wide basis;
- Heat pump integrated or energetically coupled distillation;
- Recovery of energy from waste gas streams, recompression of vented gas to recover energy, recovering energy from liquid and solid residues by using them as fuel;
- Use of energy recovery devices, such as a waste heat boiler, to provide space heating or district heating;
- Process optimisation using control and maintenance techniques;
- Management and reduction of steam consumption.

Steel & ferro

BAT technologies:

- Optimise process gas utilisation;
- Heat recovery:
    - o Heat exchangers and re-distribution within steelworks or to district heating;
    - o Use of steam boilers or reheating furnaces;
    - o Preheating combustion air;
    - o Insulation of steam and water pipes;
    - o Recovery of heat from products, e.g. sinter;
    - o Use of flue gas boilers;
    - o Oxygen evaporation and compressor cooling;
    - o Top recovery turbines to convert gas kinetic energy from blast furnace into electric power.
- Lower coking temperatures;
- Use of high-quality ores, sinter or pellets with high iron content and low gangue content;
- Highly controlled blast furnaces;
- Recovery and use of blast furnace gas;
- Oxy-oil injection to reduce raceway temperature;
- Computer-aided hot stove operation;
- Use of suitable burners to improve combustion;
- Preheating of the fuel or combustion air in conjunction with insulation of the cold blast line and waste gas flue;
- Rapid oxygen measurement and subsequent adaptation of combustion conditions;
- Steel shop automatisation (the automatic ladle lid system and automated BOF tapping practice);
- Electric arc furnace process optimisation, including of oxy-fuel burners.

Non-ferro

BAT technologies:

- Heat recovery, e.g. by use of regenerative burners, recuperative burners, heat exchangers, e.g. for preheating of combustion air, feed and the fuel gas, and waste heat boilers;
- Oxygen enrichment of combustion air for smelting;
- Use of appropriate furnace lining and insulation at installations using high temperatures;
- Use circulating fluidised bed calciners instead of rotary kilns (alumina);
- Cover feedstocks from rain and pre-dry feedstock at low temperature;
- Gases from anode furnaces can be used in drying or other process stages;
- The insulation and covering of electrolysis furnaces decrease heat losses and the consumption of heat necessary to maintain the temperature;
- Recover chemical heat in waste gas streams containing CO or SOx;
- Increase share of recycled material;
- Do not use more slag than necessary given the level of contamination of the feedstock.

Non-metallic minerals (cement, glass, ceramics, etc)

- Supply the liquid metal for direct moldingthermal and electric energy use – factors that influence specific energy consumption:
    - o Number of cyclone stages, calciner, tertiary air, compound operation of the mill, aspect ratio of the kiln, type of clinker cooler, moisture content of materials and fuels, calorific fuel value, process control, bypass rate;
    - o Electricity use – mills and exhaust fans.
- Reduce thermal energy use:
    - o Kilns: High capacity utilisation, optimised length, optimised to fuel, uniform and stable operation, optimised process controls, reduce air-in leakage. vertical kilns in general and the parallel flow regenerative kilns (PFRK) are best;
    - o The installation of heat exchangers for long rotary kilns to recover surplus heat from fluegases or to permit the use of a wider range of fuels;
    - o The use of surplus heat from rotary kilns to dry limestone for other processes such as limestone milling;
    - o In some cases, where shaft kilns have ceased to be economically viable, it has been feasible to convert them to modern designs, for example by converting a simple shaft kiln to the annular shaft design or by linking a pair of shaft kilns to create a parallel flow regenerative kiln. Conversion extends the life of expensive items of equipment, such as the kiln structure, the stone feed system and the lime handling/ storage plant in exceptional cases, it may be economic to shorten long rotary kilns and to fit a preheater, thus reducing fuel use;
    - o Electrical energy use can be minimised through the utilisation of energy efficient equipment;
    - o Calciner – low pressure drop, unform meal in the riser, extensive precalcination of the raw meal;
    - o Preheater – low pressure drop and high heat recuperation, high cyclone collection rate, uniformity.
- Grate preheater for kilns;
- Using waste fuels (with appropriate calorific values);
- Metering and proportioning of the mill feed;
- Appropriate grinding systems.

Pulp & paper

- Efficient drying and dewatering.
    - o Reducing the consumption of heat or steam, or lower consumption of electrical energy and for higher power production especially by use of highly energy-efficient recovery boilers.
- Effective secondary heating systems, for example the most effective mills possess;
- Various clean hot water temperature levels, and several secondary condensate heat levels where the condensate temperature equals the usage temperature;
- Well closed water system that leads to reduced water consumption:
    - o Relatively well closed bleaching plant;
    - o High pulp concentration (middle or high consistency technique);
    - o Highly effective evaporation plants with an increased number of effects (which may also save power depending on the type of evaporator); the evaporation plant has the highest development potential;
    - o Recovery of heat from dissolving tanks, e.g. by vent scrubbers;
    - o Management of secondary heat balance with optimised water and secondary condensate utilisation;
    - o Use of available low temperature waste heat sources (secondary heat) to heat buildings, boiler feedwater and process water;
    - o Heat recovery from the flue-gas from the recovery boiler between the ESP and the fan;
    - o Monitoring and control of processes by advanced control systems;
    - o Optimise integrated heat exchanger network;
    - o Energy management system.

- II. Measures for low consumption of electrical power:
    - o As high a pulp consistency as possible in screening and cleaning;
    - o Speed control of various large motors;
    - o Efficient vacuum pumps;
    - o Proper sizing of pipes, pumps and fans;
    - o Optimised tank levels.

Agro-food

For an energy efficient and sustainable food Processing, BATs may incorporate renewable energy, waste heat management, solar energy solar energy, and efficient heat pump, ice storage heat pump, thermal energy storage heat pump, drying with heat recovery and dehumidification. Some main examples of BATs in the agro-industrial sector are given specifically for the case of Fruit and Vegetables (F&V) processing plants.

Cooling and freezing (cooling storage represents the main electricity demanding process in F&V processing plants)

- Efficient cooling systems:
  - o Uncoupling cooling production and cooling demand by using a coupling storage system;
  - o Efficient cooling machine components;
- Insulation improvement in cooling chambers.

Heating (thermal processes involving heating require high thermal energy consumption)

- Use of energy recovery devices.

Thermal Drying (significant thermal energy must be transferred to the solids to increase temperature in the drying process)

- Innovative 2thermal-drying system able to drastically reduce the amount of waste to be disposed of;
- Heat pump-assisted drying with multimode and time-varying heat input;
- Low and atmospheric pressure superheated steam drying;
- Modified atmosphere drying;
- Intermittent batch drying;
- Osmotic pretreatments;
- Microwave-vacuum drying, etc.

Non Thermal Drying

- High pressure processing (HPP);
- Ultrasonication;
- Cold plasma technology;
- Supercritical technology;
- Irradiation;
- Pulsed electric field;
- Pulsed ultraviolet technology;
- Ozone.

Efficient motors (they may substantially reduce electricity consumption)

- Increasing the energy efficiency of electric motor (calculated as the ratio of the mechanical output power to the electrical input power). The energy efficiency level is expressed in International Energy efficiency classes (IE), IE1 being the lower class and IE5 the highest;
- Proper motor sizing;
- Motor controls.

Compressed air systems (CASs) for press machines, cooling systems, compressors, conveyors, etc.

- Optimising system design;
- Variable speed drives and storage volume;
- Reducing CAS leaks;
- Feeding the compressor with outside cool air;
- Optimising the pressure level;
- Pipes and valves insulation.

Heating water and/or air

- Solar thermal for heating water;
- Heat recovery systems (from air compressors, by economisers or condensers.

Capacitor batteries to decrease reactive energy

Lighting

High efficiency in power transformers

Appendix 2

Selected examples of national policy instruments

Norway's mechanisms to increase energy efficiency

Norwegian Energy Act: Regulates production, conversion etc. of energy.
Energi21 is a Norwegian national strategy for research and innovation within new climate friendly energy technology.

Norwegian Action plan for energy efficiency: A national goal and guiding efforts for energy efficiency. The government will follow up on the status of goal achievement by:

- Strengthening efforts to achieve the target of a 30% improvement in energy intensity from 2015 to 2030;
- Investigating the consequences of a goal to reduce electricity consumption by 10 TWh in the entire building sector from 2015 to 2030;
- Regularly reporting on the status, with particular attention to energy usage in buildings and industry;
- Identifying potentials and possible measures for energy efficiency in various sectors.

Specifically for the industrial sector, the government has implemented special requirements for industries with the highest energy consumption, closer monitoring of industrial consumption, and closer collaboration with Enova to develop and implement energy efficient and flexibke solutions in industrial applications.

ENOVA (www.enova.no): Provides subsidies for new energy-and climate technology to be developed and adapted by the industry. They cover additional costs for implementing novel technology.

R&D: The Norwegian government continues the commitment to research, development, and innovation to contribute to realising the potential for energy efficiency in the Norwegian energy system and in petroleum activities.

Centres for Environment-friendly Energy Research are grants from the Norwegian Research Council. These Centres carry out long-term research targeted towards renewable energy, energy efficiency, CCS and social science aspects of energy research, in close collaboration between R&D, universities, trade and industry. Project period of 8 years. FME HighEFF (www.higheff.no) focuses on technologies and processes with potential for large reduction in specific energy use, e.g., development of industrial heat pumps. Total budget of approx. 40 M€.
Handlingsplan for energieffektivisering i alle deler av norsk økonomi

Support for industrial energy efficiency measures: Examples from the Netherlands

The DEI+ subsidy is a grant for to help realise innovations in the field of energy and CO_2 reduction in the form of a pilot or demonstration project. Demonstratie Energie- en Klimaatinnovatie (DEI+).

The SDE++ subsidy is an exploitation subsidy; once granted, it runs for 12-15 years, financing the 'additional cost' of using innovative technologies to reduce CO2 emissions, as compared to the cost of using the conventional reference technology. This additional cost estimate is updated annually.
Stimulering Duurzame Energieproductie en Klimaattransitie (SDE++).

Incentives for energy efficiency: Examples from Italy

In Italy, various incentive tools are available to promote energy efficiency.

Tax deductions: For carrying out energy requalification interventions on buildings there is a benefit from tax deductions of up to 75%.

Thermal Account 2.0: The Thermal Account (Conto Termico 2.0) promotes the increase in energy efficiency and the production of renewable energy for public administrations, businesses and private individuals.

White Certificate System: White certificates are qualifications relating to the achievement of energy savings. The system is linked to the achievement of annual objectives by electricity and natural gas distributors.

National Energy Efficiency Fund: The Fund supports energy efficiency interventions carried out by companies and the Public Administration on properties, plants and production processes.

Ecobonus and Superbonus: The Bonus supports the energy efficiency measures of buildings envisaged by the Relaunch decree (Decreto Rilancio). Currently, Ecobonus refunds the 65% of the energy saving costs, while the Superbonus refunds up to 110%. This last has been recently revised and the deduction will remain valid until 2025 with decreasing rates, in particular: 110% for expenses incurred by 31 December 2023; 70% for those supported in 2024; 65% for those supported in 2025.

Policies and Incentives for energy efficiency: Germany

Energy Efficiency Act: The German government recently adopted a new law on energy efficiency measures in all branches and sectors of the society, in particular households and industry. It came into force on Nov. 18, 2023. The main goal specified in this law consists in a total energy demand reduction of annually 2% to which, for the first time, all sectors must contribute. And, obviously, all activities in terms of energy efficiency must agree with the German objectives related to the substantial reduction of greenhouse gas emissions.
Gesetz zur Steigerung der Energieeffizienz in Deutschland

R&D: In October 2023 the German Federal Ministry of Economy Affairs and Climate Action published the new Energy Research Program on applied Energy Research. It formulates five missions, from which the first one focuses on research addressing a resilient and energy efficient energy system. It addresses all aspects of the energy system transition, including electricity, the heating and cooling supply, the transition to renewable energy sources, the substantial increase in use of hydrogen, and in particular the combination of energy and resource efficiency measures. This new Energy Research Program is designed as a learning program with a continuous monitoring of all measures in order to indicate necessary adjustments to detailed goals and research activities at an early stage.
Energieforschungsprogramm zur angewandten Energieforschung – Forschungsmissionen für die Energiewende

Policies and Incentives for energy efficiency: Austria

In Austria there is a mixture of energy efficiency reduction demands, banning of some technologies and funding of efficiency measures.

Transformation of Industry - Funding Scheme: Up to 80% of CAPEX funding for investments that reduce carbon emissions by 60%. If companies choose carbon neutral energy carriers and best available efficient technologies, that higher cost can partly funded. Example: High temperature heat pump could yield higher energy costs, while at the same time be much more efficient in operation

Transformation der Industrie (bmk.gv.at)

Energy Efficiency Act – Reduction of End Energy Demand
Energieeffizienzgesetz passiert abgespeckt das Parlament – BMK INFOTHEK

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