THE ROAD TO EU CARBON NEUTRALITY

INCENTIVE

Overview

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Executive summary

The energy system is responsible for 75% of global CO_2 emissions, so meeting the Paris Agreement objectives requires fundamental changes to the energy system.

In this study, we examine three challenges in the green transition of the energy system: maintaining electricity security of supply, phase-out of coal-fired power plants and transforming industrial energy consumption.

Maintaining electricity security of supply
In the long run, a combination of batteries and hydrogen-fired power plants may be a solution, but in the short run, gas-fired power plants deliver production flexibility necessary to balance an electricity system with a rapidly growing share of solar and wind power generation.

Phase-out of coal-fired power plants
Most countries in the EU have plans for phasing out the coal-fired power plants; however, these plans may not be fast enough to meet the Paris Agreement. Furthermore, in the short run, CO_2 emissions reductions may be achieved by making sure that gas-fired power plants are competitive relative to coal-fired power plants.

Transforming industrial energy demand
Industrial energy demand accounts for more than 1/3 of total EU energy consumption and includes hard-to-abate industries such as steel, chemical and cement. Meeting the objectives of the Paris Agreement requires major technical developments and support systems are probably necessary to avoid risking a major carbon leakage problem. A transition to electricity and hydrogen-based technologies is needed in the long run, but short-term CO_2 reduction may be achieved in some industries from switching from oil and coal to natural gas as a stepping stone in the green transition.

1: The Paris Agreement, signed in 2016 by all 196 members of the United Nations Framework Convention on Climate Change (UNFCCC).

Introduction

In this section, we outline the scope of changes to the energy system that are required to meet the Paris Agreement.

The main findings are the following:

- Renewables are still only a fraction of the energy mix today. Hydro, bioenergy and other renewables made up 16% of total primary demand and 37% of electricity production in Europe in 2019.
- Decarbonisation of the EU energy system requires more than decarbonising electricity generation. Electricity is only 21% of energy consumption, and fossil fuels dominate transport, heating of buildings and industrial energy use.
- EU electricity generation today is far from renewable. In the International Energy Agency's (IEA) Sustainable Development Scenario (SDS), the renewable generation capacity needs to increase by almost 300%.
- Although the energy system has changed several times during history, for the first time decarbonising means that existing energy forms have to be replaced by carbon-neutral alternatives.
- Even though the global energy-related CO_2 emission fell by almost 5% due to the COVID-19 pandemic, there is still a need for substantial changes to meet the Paris Agreement, as energy demand is expected to pick up and even surpass pre-COVID levels in the coming years.
- Hydrogen and power-to-X are playing a larger role in the IEA's SDS than previously.

1: In 2021 the IEA published the report Net Zero by 2050 (IEA 2021b) which outlines the changes required in order to reach global net zero emissions by 2050.

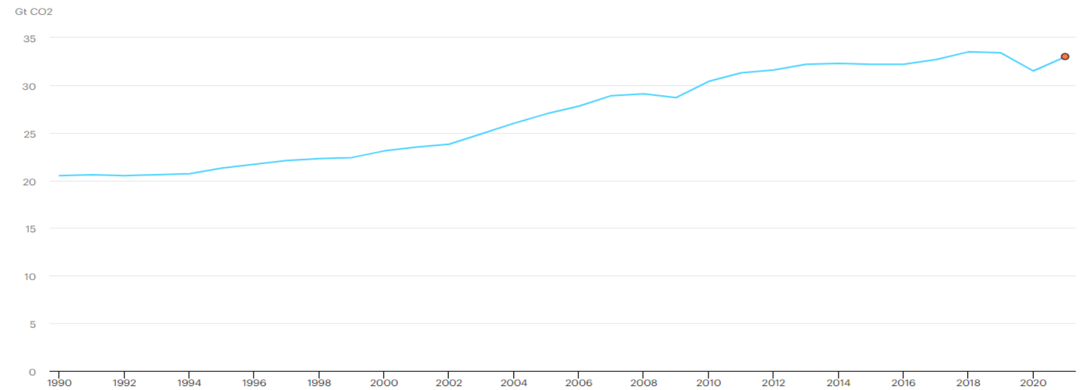
Meeting the objectives of the Paris Agreement still requires fundamental changes to the energy system

Total energy-related greenhouse gas emissions equalled 31.5 billion tons of CO_2 in 2020, after the COVID-19 pandemic lead to the largest decline in emissions ever. However, emissions are projected to rebound and increase by around 1.5 Gt CO_2 in 2021, leaving the emissions at a level 1.2% below the 2019 level.

The aim of the Paris Agreement is to keep the increase in the global average temperature well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.

The IEA's World Energy Outlook 2020 shows a Sustainable Development Scenario which illustrates the dramatic changes to energy-related CO_2 emissions that are necessary to achieve the objectives of the Paris Agreement. Dramatic changes are especially needed for the developing countries in Asia and Africa, who are currently on an increasing trend with regards to CO_2 emissions.

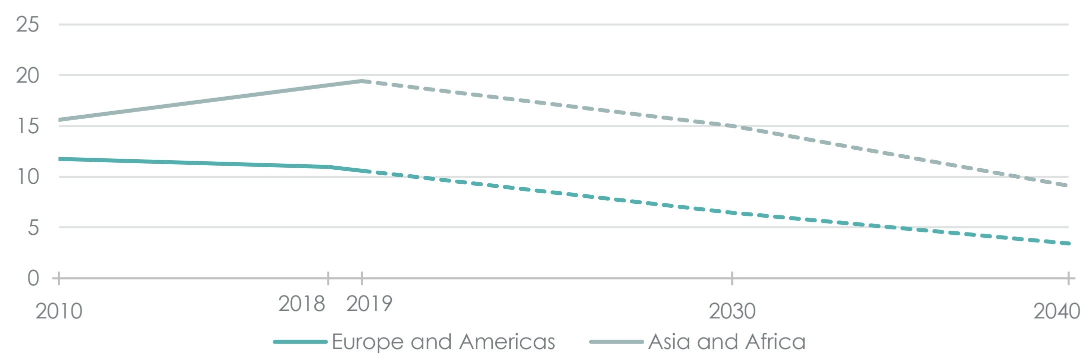
After a decline of almost 2 Gt CO_2 in 2020, emissions are projected to increase by around 1.5 Gt CO_2 in 2021



Source: IEA (2021a).

The IEA: Dramatic emission-reduction is required to meet the targets of the Paris Agreement

SDS: Illustrative trajectory of energy-related CO_2 emissions



Source: IEA (2020a). **Note:** Asia includes the Middle East and Russia.

Maintaining the decline in CO_2 emissions that the COVID-19 crisis started in 2020 requires action now

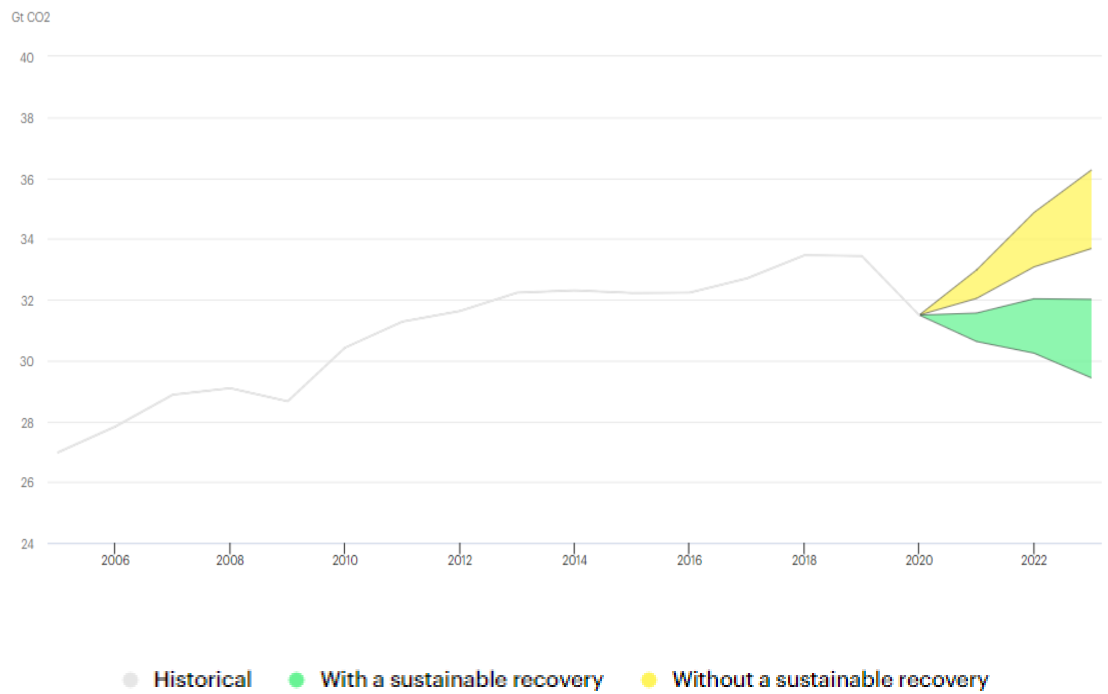
Crises have a significant impact on CO_2 emissions, as was seen in 2008-2009, when the financial crisis hit, and again in 2020, when the COVID-19 crisis hit.

However, the increase in CO_2 emissions following the financial crisis showed that these declines are only temporary and changes are required to maintain them.

In collaboration with the International Monetary Fund, the IEA has developed a Sustainable Recovery Plan that outlines policies and investments necessary to stay on a declining trend instead of returning to an increasing trend. The plan includes the following, among other things:

1. Accelerate the conversion of using renewable sources in electricity generation
2. Increase the share of cleaner transport such as electric vehicles
3. Improve the energy efficiency of buildings
4. Boost innovation of crucial technology areas including hydrogen, batteries, and carbon capture utilisation and storage.

The development in CO_2 emissions depends on whether action is taken now
Total energy-related CO_2 emissions with and without a sustainable recovery



Source: IEA (2020b).

Today, the majority of the EU energy consumption is based on fossil fuels

The total energy demand in the EU amounted to approx. 11,700 TWh in 2019.

In recent years, the growth in renewable electricity generation from wind, solar and biomass has attracted significant attention. However, electricity only accounts for around 21% of all energy consumption.

The EU energy consumption continues to be heavily dominated by fossil fuels. Therefore, reducing energy-related CO_2 emissions is a challenge across both consumption sectors and fuel types.

Today, the EU energy consumption is dominated by fossil fuels
EU27 energy demand, TWh (2019)[1]

	Industry	Transport	Buildings
Bio energy	314	204	517
Heat	175		353
Electricity	932	58	1.409
Natural gas	926		1.366
Oil	300	3.027	466
Coal	195		97

Source: IEA (2020a).

1: "Other sector" (1.720 TWh) is excluded because it is not split on fuel types. Coal/oil/gas does not include use in power generation.

The EU electricity sector is still a long way from running 100% on renewables

EU electricity generation mainly uses nuclear energy, natural gas and coal as fuels.

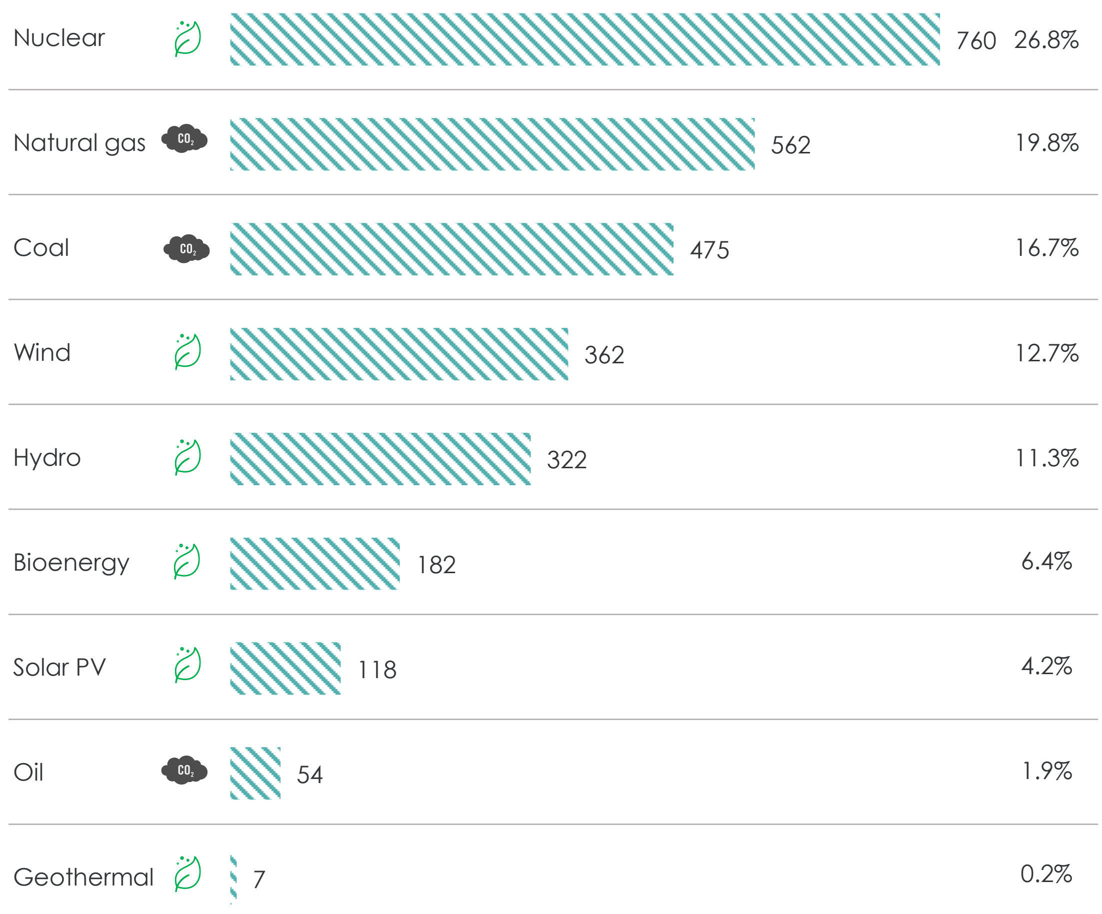
The focus on offshore wind, onshore wind and solar PV in the past two decades has resulted in solar and wind generating 17% of the total electricity volume in 2019.

In 2019, the IEA released a study that showed that the EU has a very large potential for offshore wind generation. Provided that the EU finds ways to secure balance between consumption and demand, there is a large potential for solar and wind to replace coal and natural gas at the power stations later.

The IEA also highlights that the quickest way to reduce CO_2 emissions from electricity generation is to use capacity on existing gas-fired powerplants to phase out coal-fired powerplants. This is already happening in the EU, as coal's share of electricity generation fell from 22% in 2018 to 17% in 2019, and natural gas' share rose from 17% in 2018 to 20% in 2019.

Coal and natural gas remain the main sources of electricity generation today

EU27 electricity generation, TWh



Source: IEA (2020a).

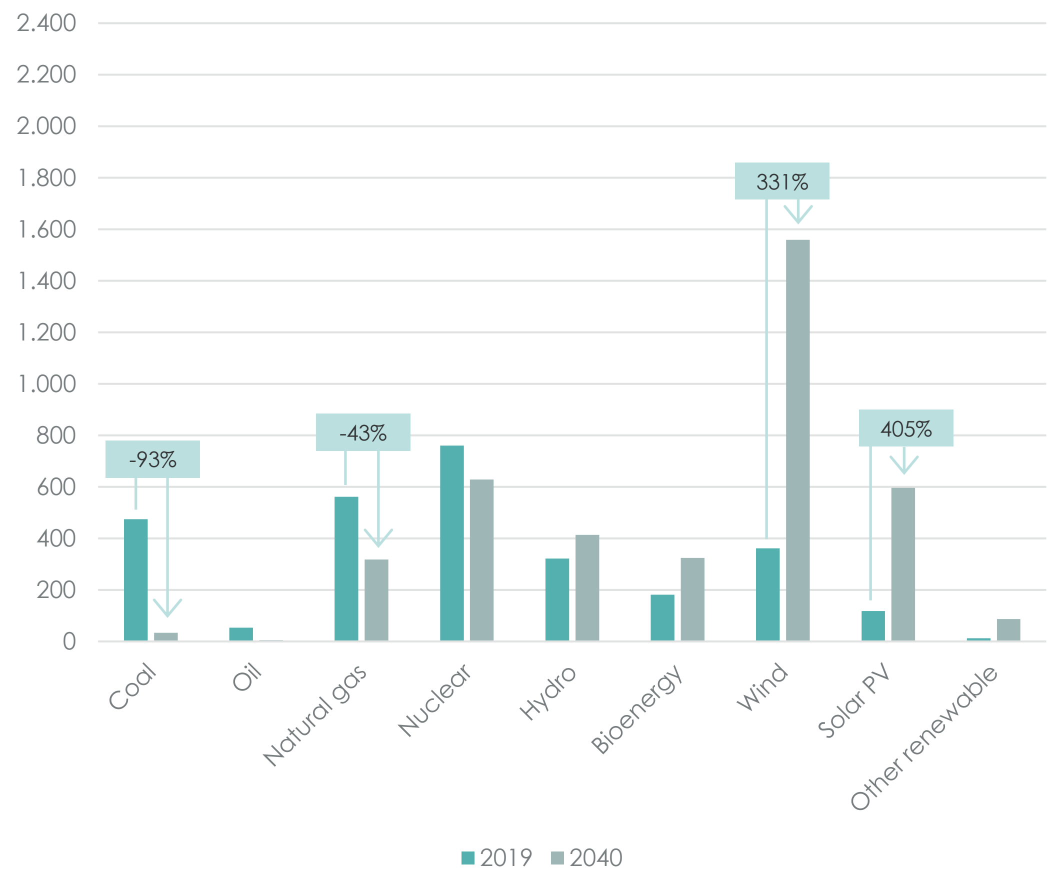
Large changes to the electricity generation in the EU are required

The IEA's Sustainable Development Scenario (SDS) includes very large changes to the electricity generation system:

- Coal is almost completely phased out.
- Wind power generation grows by more than 300% and becomes the main source of electricity.
- Solar PV grows by 400% but comes from a lower starting point.
- Natural gas consumption declines. This reflects that in the IEA's SDS, gas-fired power plants mainly serve as peak load and reserve load capacity.

Overall, the SDS entails that the renewable share of electricity generation increases to 75% in 2040 from 36% in 2019.

The IEA's SDS: Fundamental changes in electricity generation
Changes in electricity generation in EU27 in the IEA's Sustainable Development Scenario



Source: IEA (2020a).

Changes to many parts of the energy system are necessary: In the following, we look at a few of the challenges on the way

The IEA's Sustainable Development Scenario (SDS) outlines a transformation of the energy system aligned with the Paris Agreement.

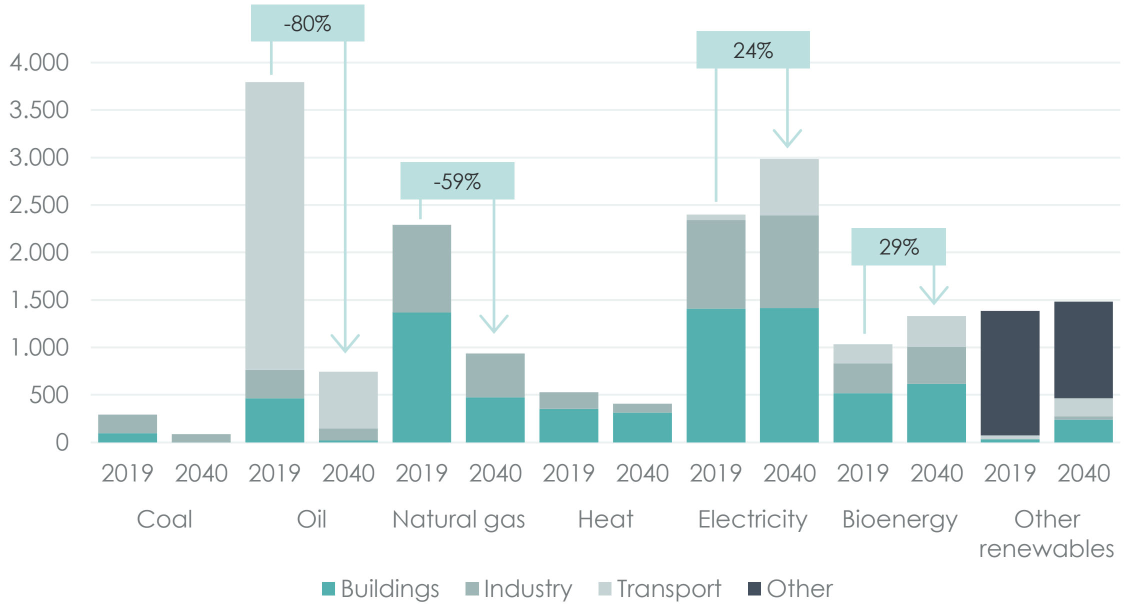
Getting there will require dedication, investments and innovation on an unprecedented scale.

In order to provide a more detailed insight into the required changes, we will dive into these three challenges in the following:

- Security of supply
- Phase-out of coal-fired power plants
- Industrial energy consumption

The IEA's SDS: Changes in consumption pattern reduces fossil fuel use[1]

Changes in energy consumption in EU27 in the IEA's SDS, TWh



Several elements of the energy consumption must change:

- Transportation must convert from oil to bioenergy and electricity on a large scale.
- Natural gas consumption for building heating must decline because of improved energy efficiency.
- Electricity consumption must increase because of electrification of transport and building heating.
- Bioenergy must increase but is limited by the availability of renewable resources.
- Hydrogen and power-to-X must play a larger part in the SDS than previously, reflecting a growing international interest in power-to-X technologies.

Source: IEA (2020a) and Incentive.

1: The IEA does not split gas consumption, natural gas and low-carbon gasses for Europe. They note that "over 15% of total gas supply in China and the European Union is low-carbon gas in 2040".

Security of supply

Summary
Security of supply is crucial for modern societies. One of the challenges in a greener future is that a large part of energy consumption will be covered by electricity produced with inflexible renewables such as wind and solar. This is a challenge when it is cold and there is no wind or sun, a phenomena the Germans call kalte Dunkelflaute. Here, an inflexible supply meets an inflexible demand, and this creates a need to be able to store large amounts of electricity.

In the long run, a combination of batteries and hydrogen-fired power plants can constitute security of supply, but in the short run, a shift from coal- and oil-fired power plant to gas-fired power plants may be the most feasible option to maintain security of supply while also reducing CO_2 emissions, as the carbon footprint is lower for gas.

Security of supply

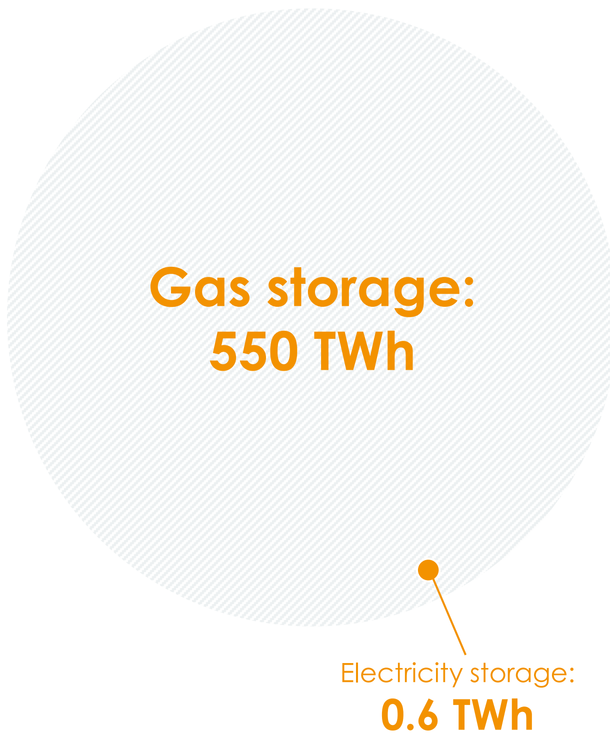
Security of supply is a core policy element
Energy is a basic commodity in modern societies. For many years, security of supply has been a core element in national energy policies.
Depending on the source of energy, security of supply has been provided by a combination of having flexible, excess production capacity and storage of fossil fuels.

Flexible, excess electricity capacities
A future electricity-based energy system also needs security of supply. In principle, batteries can provide security of supply, but battery capacity today does not have the anywhere near the necessary capacity to store large amounts of electricity.

Conversely, traditional fossil fuels such as coal, oil and gas can be stored and used for electricity generation in situations where electricity demand exceeds renewable electricity generation.

In this section, we look at the need for flexible electricity capacities.

Electricity storage is scarce and insufficient to cover demand volatility
Storage capacity (TWh)



Source: Frontier (2019).
Note: Covering Sweden, Denmark, Germany, the Netherlands, Belgium, France, Switzerland and the Czech Republic.

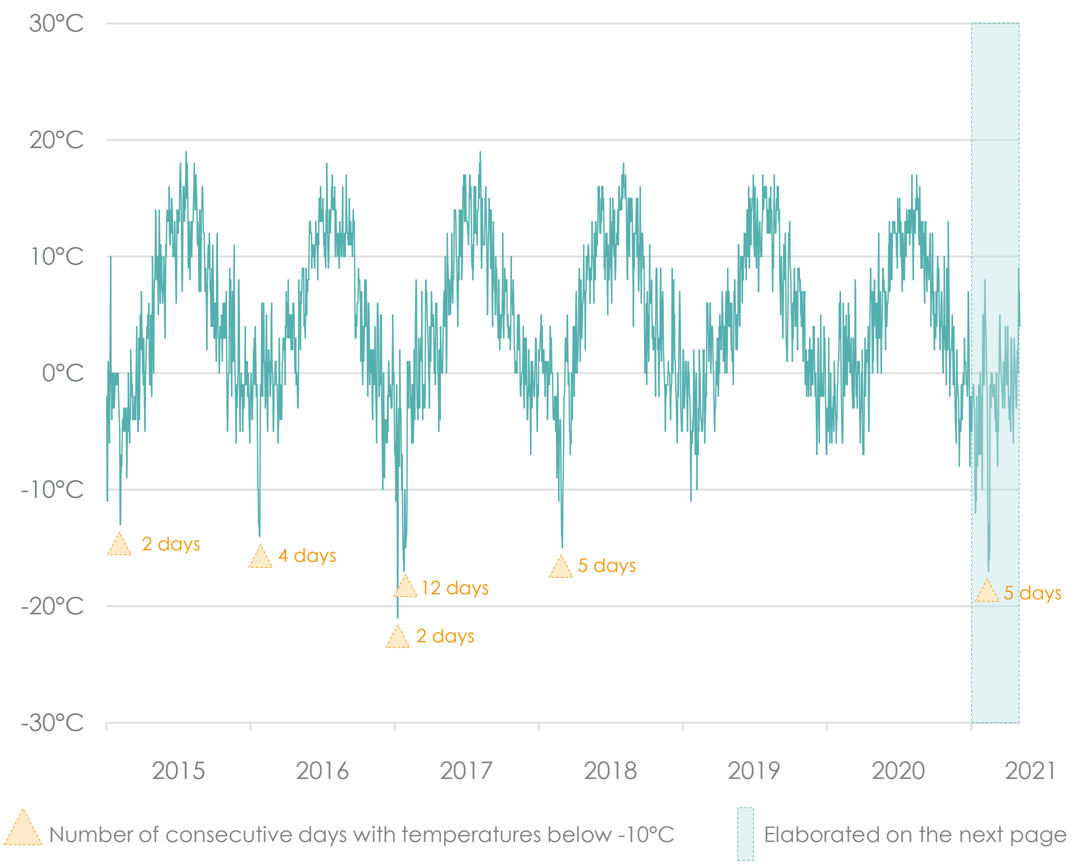
Cold spells occur on a regular basis

Cold spells occur regularly
Periods of very cold weather occur around once per year on average. Those periods often constitute peak energy demand because of additional need for heating.

Like energy demand, production from solar and wind power depend on the weather
Traditionally, electricity systems have been designed with flexible power-plant production capacity to meet fluctuations in demand. Solar and wind electricity production adds a new element of volatility to the electricity system that must be handled to avoid electricity shortages.

On the next pages, we consider how energy was produced to cover the increased demand during the cold spell of 2021.

Cold spells occur almost yearly and often last 4-5 days
Lowest daily temperature measured in Munich



Source: weather.com.

Cold spells are also known as kalte Dunkelflaute

Kalte Dunkelflaute
Cold spells often occur simultaneously with:

- Low windspeeds, as temperature and wind speed are inversely related.
- Little sunshine, as they mostly occur during winter.

Germans refer to these periods with coldness, darkness and little wind as "kalte Dunkelflaute".

In times of a kalte Dunkelflaute, gas-fired and coal-fired power plants deliver flexibility

The largest kalte Dunkelflaute in recent years led to increased production from gas and coal

From 11-15 February 2021, Northwestern Europe[1] was struck by extreme coldness. In Munich, around the centre of Northwestern Europe, the temperatures were as low as -17°C.

During this period, the wind speed was 35% lower than the average yearly level.[2]

In Northwestern Europe, overall demand for energy increased 14%. Despite increased demand, production from solar and wind sources declined 20% and 18% during the cold spell compared to one week before and after.

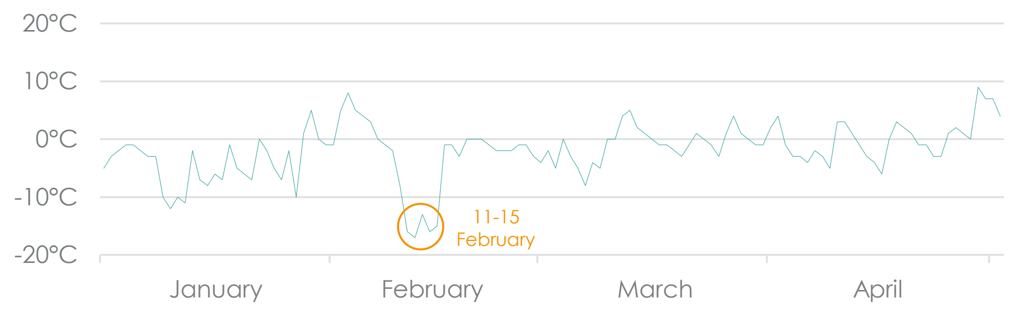
To compensate, gas and coal production increased 51% and 45%, respectively.

Demand cannot be covered by imported renewables

As the weather correlates highly in Northwestern Europe, import of renewable energy from surrounding countries is rarely possible. The countries must be able to produce energy from a flexible source.

A cold spell struck Northwestern Europe[1] in February 2021

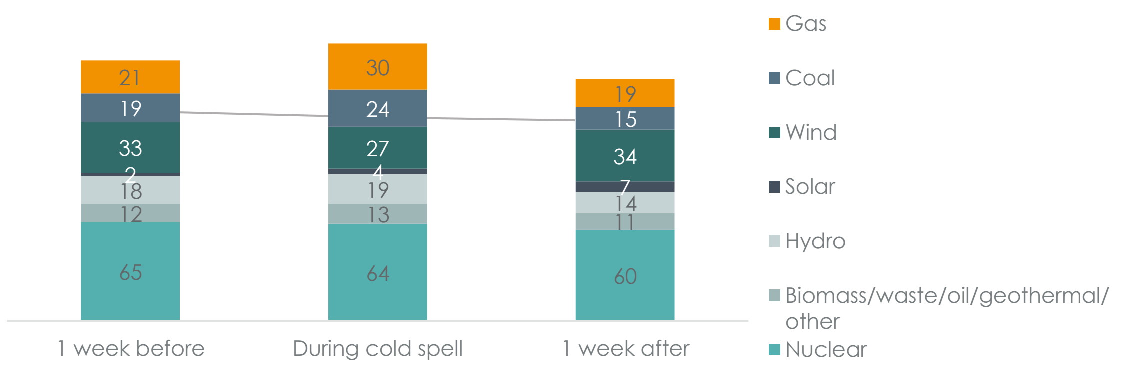
Lowest daily temperature measured in Munich, 2021



Source: weather.com.

During cold spells, gas and coal ensure that the energy demand is satisfied

Energy production (GW) in Northwestern Europe[1] around the cold spell in February 2021



Source: entsoe.eu. 1 week before: February 4th to 8th. 1 week after: February 18th to 22nd.

Notes: [1] Northwestern Europe is defined as: Denmark, Germany, Austria, Switzerland, France, Belgium and the Netherlands. [2] Source: weather.com. Basis for average yearly level is 2020.

Transition to solar and wind power increases the need for flexible production sources

Solar and wind production is volatile

Contrary to gas-fired and coal-fired power plants, solar and wind production supply does not necessarily respond to electricity demand. Rather, it reflects how much production weather conditions allow.

Solar production is higher in the middle of the year when consumption is low. Wind production follows the same pattern as demand over the year, but with a high degree of volatility. There are days with low wind speed and high demand, making wind unsuited to consistently accommodate peak demand.

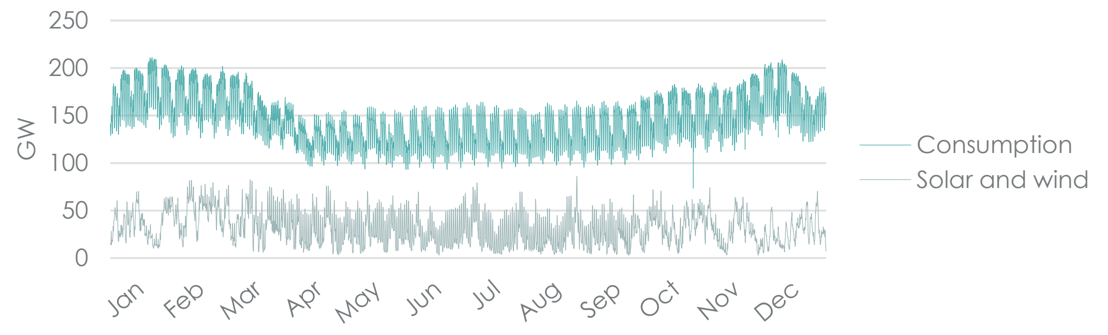
Production from solar and wind enhances the need for a flexible source

Because overall consumption is volatile, some of the energy production must be flexible.

Since solar and wind production is weakly related to demand, usage of them enhances the need for a flexible production source. In 2020, hourly consumption varied from 74 to 211 GW, creating a production need that varies by 138 GW. When accounting for solar and wind production, the residual production need varies by 163 GW. And if solar and wind production is doubled, the residual production need varies by 202 GW.

Production from solar and wind varies significantly within days and over the year

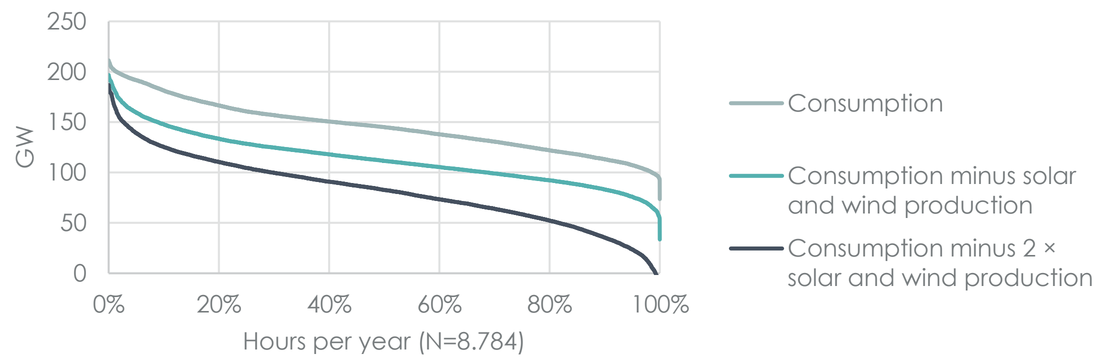
Daily production in Northwestern Europe (GW), 2020



Source: entsoe.eu.

The volatile solar and wind production enhances the need for volatile residual production

Duration curves: GW in Northwestern Europe, 2020



Source: entsoe.eu.

Variable Renewable Energy's volatility makes it unfit to secure flexible production capacity

Solar and wind production do not increase in the most demanding hours

Since solar and wind production depend on the weather, production cannot simply be increased in times of higher demand.

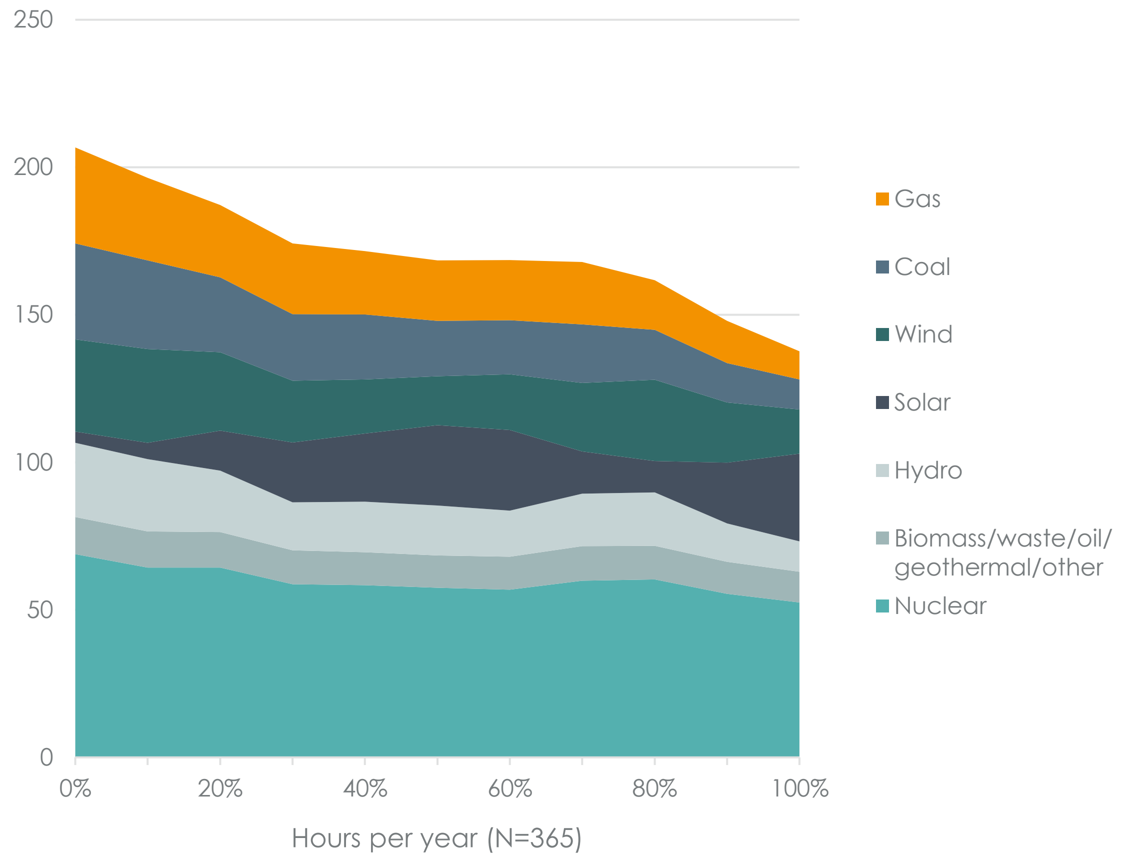
Looking at the daily peak hours in 2020, production from wind and solar energy is not related to the total consumption. In the 10% most demanding daily peak hours, wind and solar production amounted to 35 GW. In the 10% least demanding daily peak hours, they produced 45 GW.

Flexible sources ensure security of supply

In the most demanding hours, more flexible sources – gas and coal – accommodate needs.

Solar production is lower when demand is higher, and wind production is somewhat random

Consumption duration curve: Energy production (GW) in the daily peak hour in Northwestern Europe, 2019



Source: entsoe.eu.

Battery and electricity storage may compensate for volatile consumption and production but will require massive investments

As a simple though experiment, let us consider a situation where all electricity consumption is produced from solar and wind. What scale of electricity storage capacity would this require?

1. Solar and wind production needs to be upscaled by a factor 4.5

In 2020, solar and wind production covers 22% of the Northwestern European electricity consumption of 1,270 TWh. If they were to produce energy corresponding to the consumption over the year, they would need to upscale 4.5-fold.

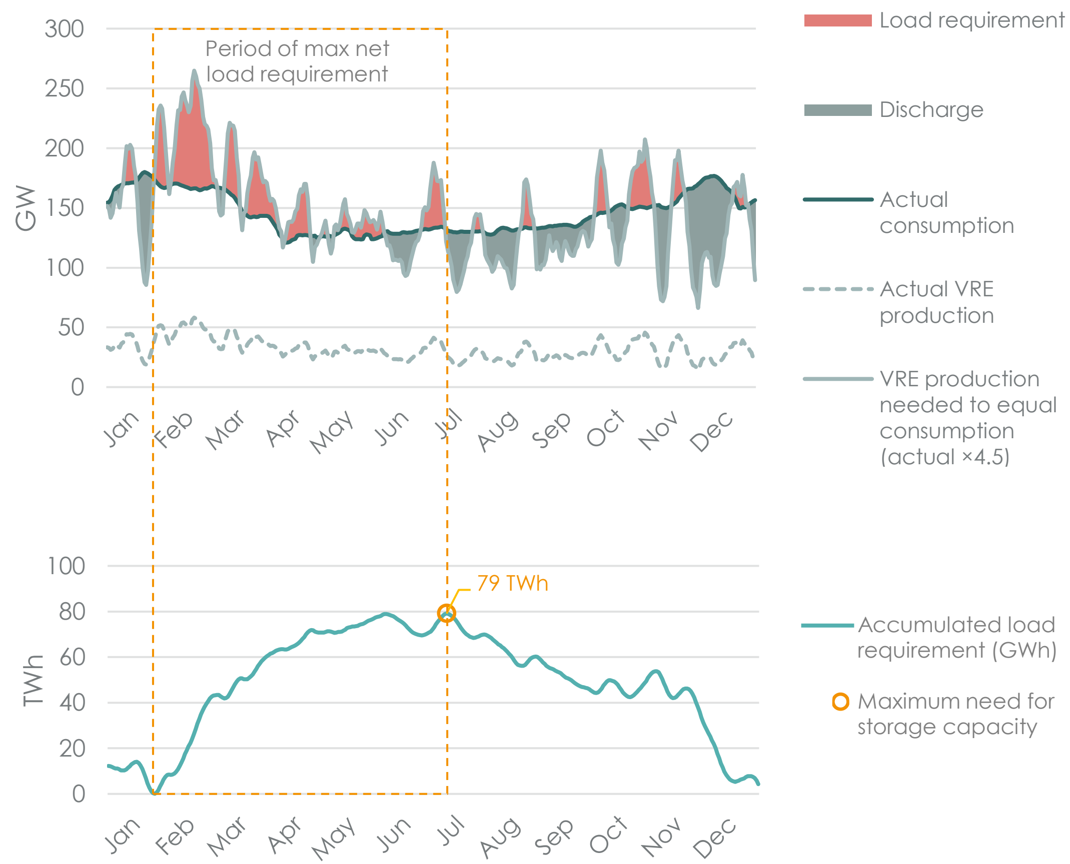
2. Electricity storage capacity of around 79 TWh would be required

Both electricity consumption and solar and wind production vary over the day and over the year.

Let's assume that there is a storage capacity so that excess production is stored and excess consumption is discharged. To make ends meet, the storage capacity would have to be in excess of 79 TWh. In principle, this could be practicably possible, but utility-scale batteries are still less that 500 MWh, so a long way away from 79 TWh.

If solar and wind were the only production sources, Northwestern Europe would need some 80 TWh of storage or overproduce energy

Consumption and renewable production (GW) in Northwestern Europe, 2020



Source: entsoe.eu and Incentive.
Note: 7-day moving averages for visual purposes. VRE production: Solar and wind.

In the short term, gas is the most feasible option to maintain security of supply

Flexible consumption is difficult to implement
In theory, one way of maintaining security of supply is to make consumption match production. However, experience shows that this is difficult to implement, especially once the production is transitioned to the volatile Variable Renewable Energy. While it may be a part of the long-term solution, it is not likely to solve the issues on its own.

In the long term, a combination of batteries and hydrogen-fired power plants may constitute security of supply
Batteries may be part of the solution due to their fast-increasing power capacity. Likewise, carbon-free hydrogen-fired power plants will likely be a part of the solution. Neither of the technologies are developed enough to sufficiently solve the problem in the short term.

In the short term, peak demand should be covered by gas
Until the technology of batteries and hydrogen-fired power plants is sufficient, peak demand must be met by dispatchable energy types. Using capacity at existing gas-fired power plants may be the best short-term option.

Role of electricity production types in Northwestern Europe

Production type	Today	Short-term future	Long-term future
Solar and wind			
Wind	Made up 17% of Northwestern Europe's production in 2020. Gradually increasing.	Main production sources, but dependent on other types during kalte Dunkelflaute and peak demand.	With high-capacity batteries, renewables can increasingly produce energy to accommodate peak demand.
Solar	Still a minor production type, but gradually increasing.		
Fossil fuels and hydrogen			
Gas	Made up 14% of Northwestern Europe's production in 2020.	Produced in periods when renewables cannot cover demand.	Phased out.
Oil	Almost no production today.	Phase out as quickly as possible.	Phased out.
Coal	Gradual phase-out.		
Hydrogen	-	-	May replace gas as the production type ensuring that peak demand is met.

Carbon footprint: Low – High

For gas-fired power plants to ensure security of supply, their profitability must be sustained

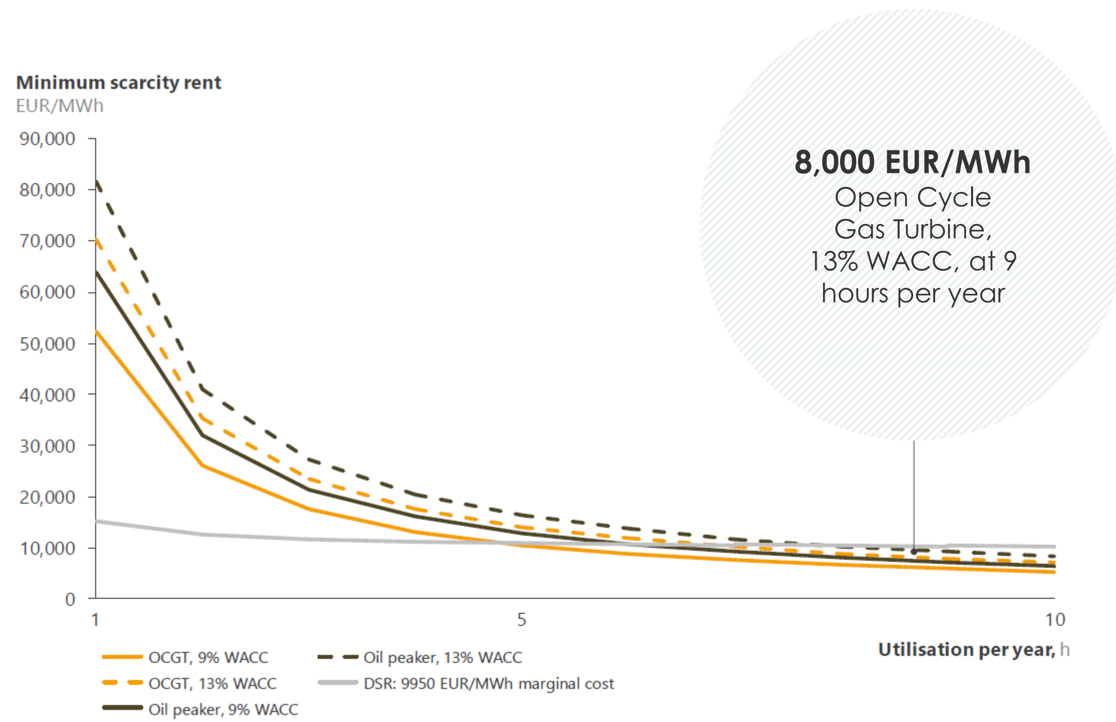
The gas price must increase when operating hours decrease
In the short-term future, gas-fired power plants will continue to ensure flexible electricity production.

As solar and wind gradually increase their production share, gas will gradually be needed for fewer production hours.

To keep gas-fired power plants profitable when they have less production, the price of each produced MWh must increase.

A study by Aurora (2021) illustrates the problem by calculating that an Open Cycle Gas Turbine (OCGT) with an average dispatch of 9 hours per year could require prices of 8,000 EUR/MWh to sustain commercial viability.

The price must increase as the gas-fired power plants are gradually used less



Source: Aurora (2021).

Phase-out of coal-fired power plants

Summary

Coal-fired power plants have historically played a major role in the EU, but their large carbon footprint makes is necessary to phase them out.

Most countries in the EU have already made plans for phasing out coal-fired power plants, but as time is running out for fast reductions in CO_2 emissions, gas-fired power plants can be a part of the transition to a greener future.

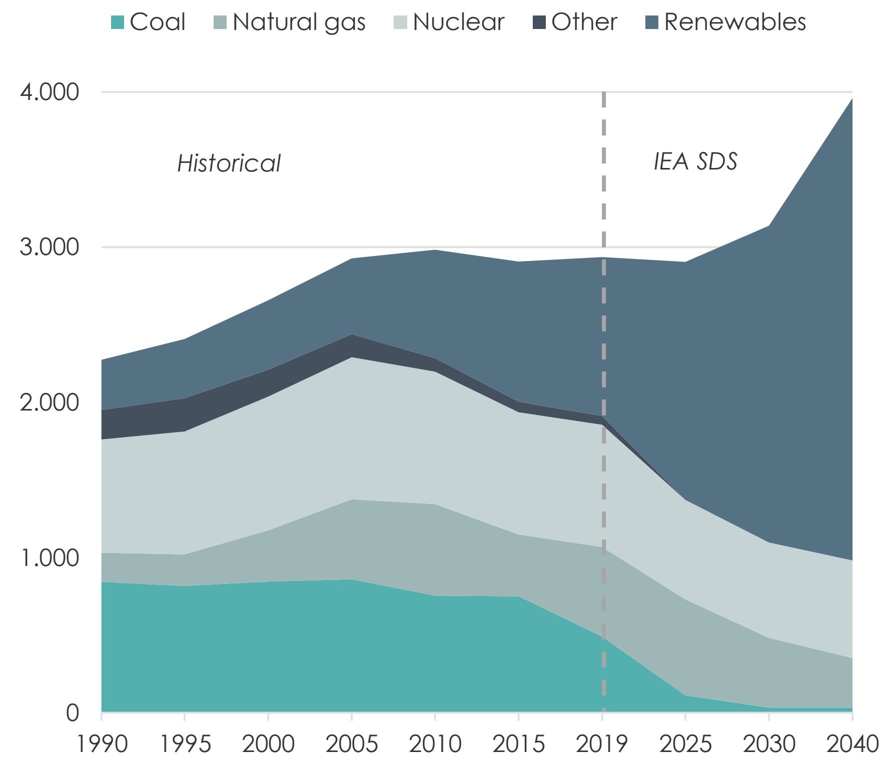
The market for CO_2 emission certificates play a role in the shift towards gas-fired power plants, as higher prices incentivises the market to shift to gas-fired power plants, as these become relatively cheaper when the prices increase.

Phase-out of coal-fired power plants

Phasing out coal-fired power plants is a key part of fulfilling the Paris Agreement
Historically, coal-fired power production has been important in the EU. However, the large carbon footprint from coal makes it crucial to phase out coal from EU power production to reach the goals in the Paris Agreement.

In this section, we look at the plans for phasing out coal-fired power plants and the possibility of using gas as an accelerator for phasing out coal-fired power plants in the EU.

The IEA's Sustainable Development Scenario (SDS) requires that coal is phased out from electricity production by 2030
Power generation in the EU27 by type, TWh



Source: https://www.iea.org/data-and-statistics.

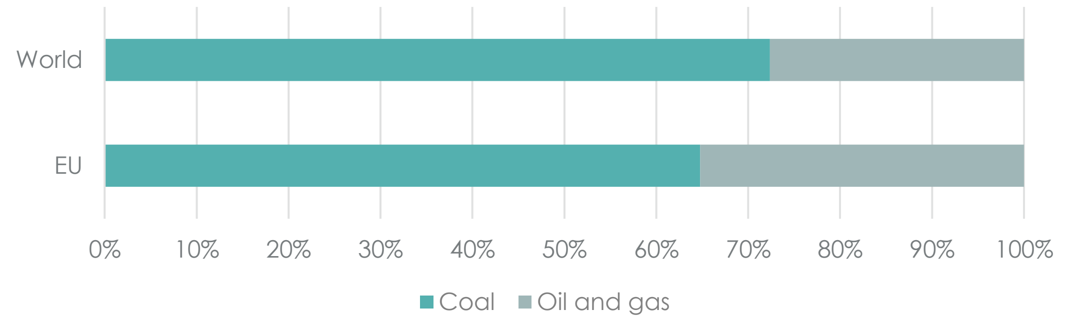
Coal-fired power plants account for a large part of global CO_2 emissions

Coal-fired power plants are a large global CO_2 emitter

In 2019, around 75% of the world's CO_2 emissions was from the energy sector, and 65% of the emissions from the electricity sector in the EU was from coal-fired power plants.

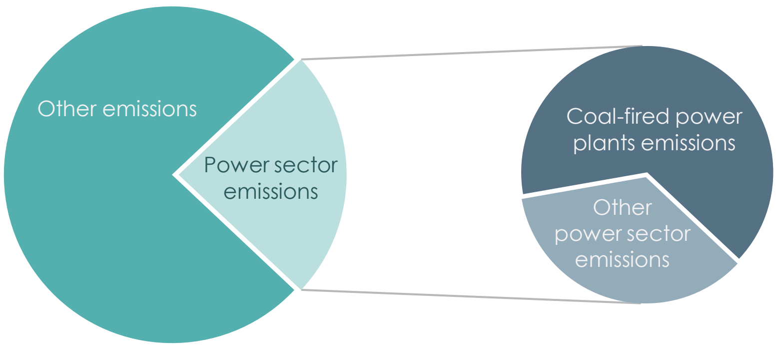
In the EU, the coal-fired power plants account for 20% of total emissions. This makes coal-fired power production the second largest CO_2 emitter in the EU, only surpassed by the emissions from transport.

Coal accounts for more than 70% of global CO_2 emissions from the electricity sector
CO_2 emissions from coal in the electricity sector, 2019



Source: IEA (2020a). The EU is excluding the UK.

In the EU, coal-fired power plants account for 20% of total CO_2 emissions
CO_2 emissions from the power sector by type, EU27, 2019.



Source: IEA (2020a). The EU is excluding the UK.

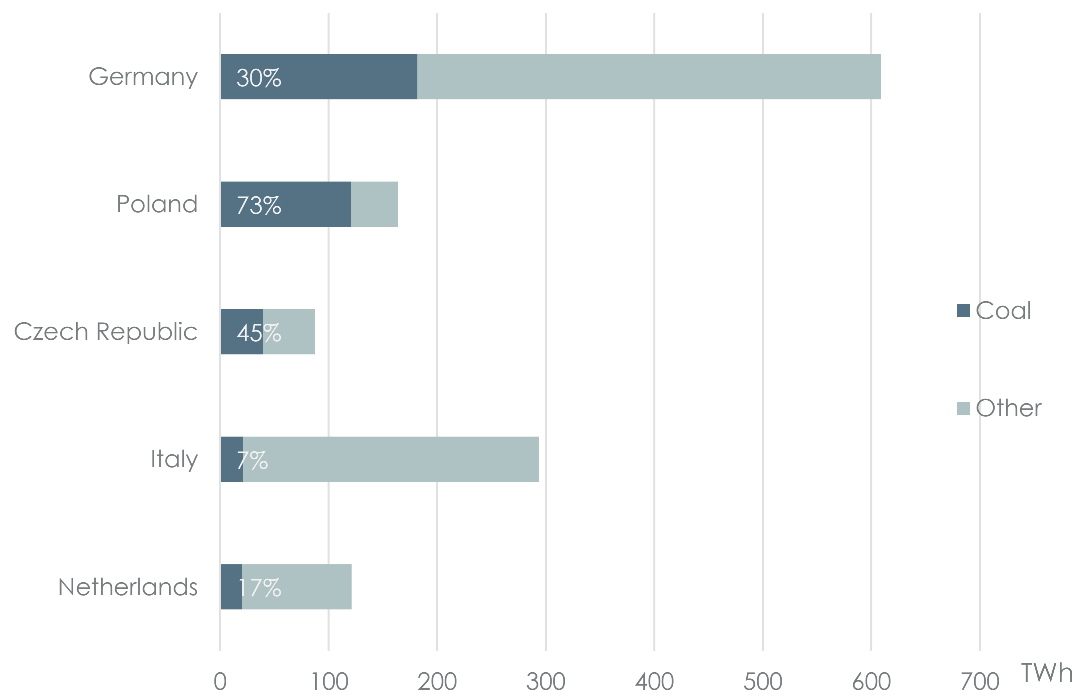
Reaching the Paris Agreement objectives requires phase-out of coal-fired power plants

Historically, coal has been important in power generation in the EU
In the recent years the share of coal in power production has decreased, while the share of gas and renewables has increased. Since its peak production around 2005, coal-fired power production in the EU has fallen by 43%.

However, coal still accounts for 17% of the power production in the EU in 2019. The IEA's Sustainable Development Scenario shows that to reach the Paris Agreement, coal must be effectively phased out from the EU power production in 2030 by reducing coal-fired power production by 96% compared to 2005.

Phasing out coal within 10 years is a significant challenge in some EU countries
Germany and Poland alone produces two thirds of the power generated from coal in the EU. Furthermore, in some eastern European countries such as Czech Republic and Bulgaria coal continues to play a large role in power generation.

Phasing out coal requires changes in the EU – especially in Germany and Poland
Power generation in the five EU countries using the most coal, 2019



Source: https://www.oecd-ilibrary.org/energy/data/iea-electricity-information-statistics_elect-data-en. Excluding non-OECD EU countries.

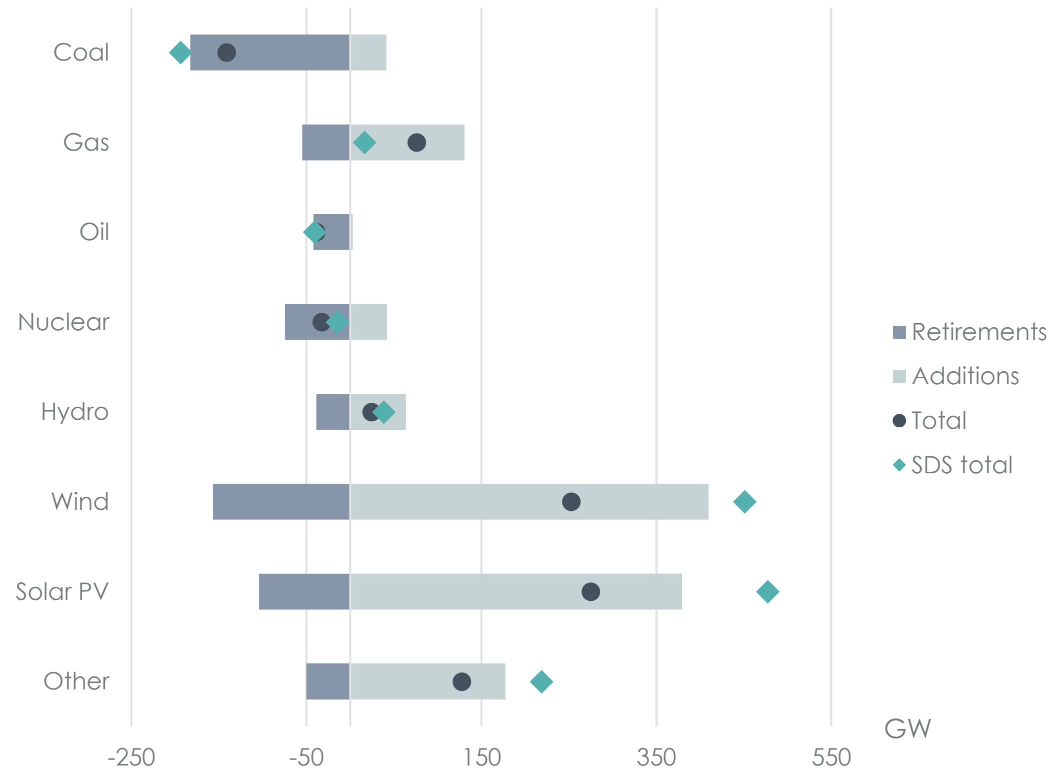
Most European countries have plans to phase out coal

23 out of 27 EU countries have set a date to phase out coal
In 2021, nine EU countries have no coal in their electricity mix. If plans hold, only six countries will generate power by coal after 2030.

In the IEA's Sustainable Development Scenario (SDS), coal-fired power production is phased out. In the SDS, EU27 are required to phase out coal by 2030 – faster than the current plans.

Currently, the two largest operators of coal-fired power-plants – Germany and Poland – plan to have phased out coal by 2038 (potentially 2035) and 2049, respectively.

European countries plan to invest in renewables and phase out fossil fuels in power production
Retirements and additions of power plants in Europe, 2020-2040



Source: IEA (2020a). The figure also includes European countries outside EU27.

In the short term, switching to gas can accelerate the coal phase-out

The potential from switching from coal- to gas-fired power plants is large

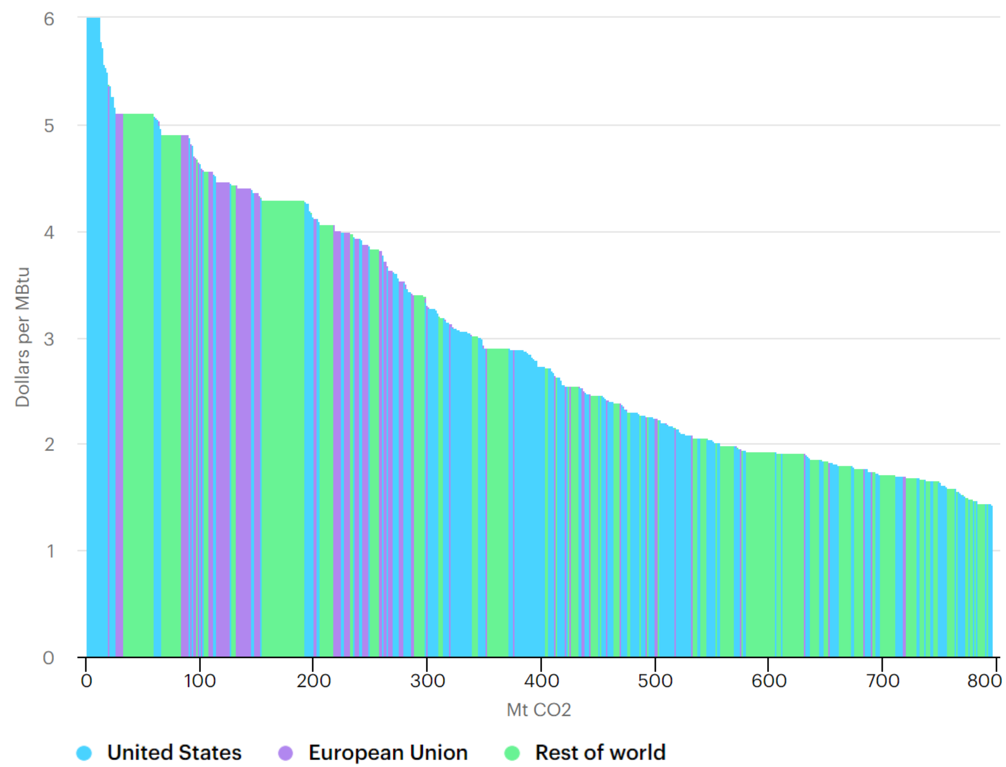
In the EU, there is potential to use capacity on existing gas-fired power plants to phase out coal-fired power production.

The IEA shows that there is a large potential to switch from coal to gas even with relatively high gas prices.

In total, the IEA estimates that at 2020 price level of gas prices, it is possible to cost-effectively save 147 Mt CO_2 by switching from coal to gas.

European countries plan to invest in renewables and phase out fossil fuels in power production

CO_2 emissions savings possible from coal-to-gas switching at different gas prices, 2020



Source: IEA (2020c).

The market can drive switching if gas-fired power plants remain more cost-competitive than coal-fired power plants

The increase in CO_2 prices have made gas-fired power plants cost-competitive

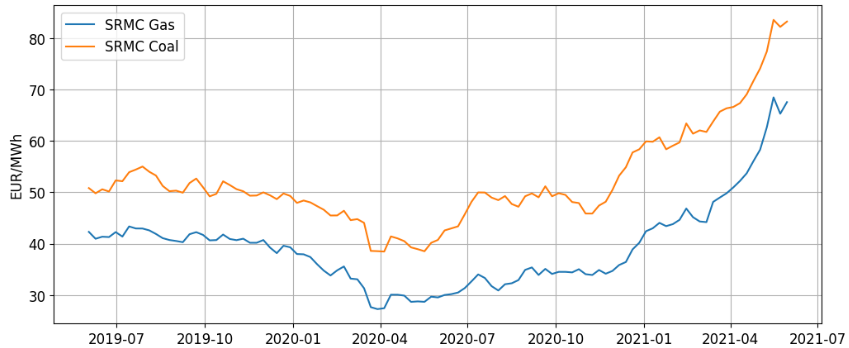
The change in the EU CO_2 quota regulation in 2017 has led to increasing prices on CO_2 emission certificates. And this in turn means that coal-fired power production has become more expensive than gas-fired power generation.

Keeping the CO_2 quota price high and gas prices low relative to coal creates a market impetus to switch from coal-fired power plants to gas-fired power plants.

A shift towards gas-fired power generation will help the transition towards greener power production, as gas-fired power generation emits 50% less CO_2 than coal-fired power generation.

In recent years, coal has become more expensive than gas

Marginal costs of coal and gas electricity generation



Source: Businessinsiider.com and theice.com

As carbon prices rise, the marginal costs of coal power production will increase

Prices on EU Emission Trading System's carbon emissions futures

Source: https://markets.businessinsider.com/.

Industrial energy consumption

Summary

Industrial energy demand accounts for more than 1/3 of the total EU energy consumption.

Meeting the Paris Agreement targets requires that industrial energy consumption is reduced by 20% over the next two decades. And given that industrial energy consumption has been very stable over the past 10 years, this requires a major change in this trend.

Industrial energy consumption includes a number of hard-to-abate industries such as steel, chemical and cement, and although technologies are on the horizon, major technical developments and probably support systems are necessary to meet the objectives without risking a major carbon leakage problem.

Long-term, the transition to electricity and hydrogen-based technologies is envisaged as forming a basic pillar of the industrial energy supply.

In the short term, CO_2 reduction benefits may in some industries be achieved by switching from oil and coal to natural gas as a stepping stone in the green transition.

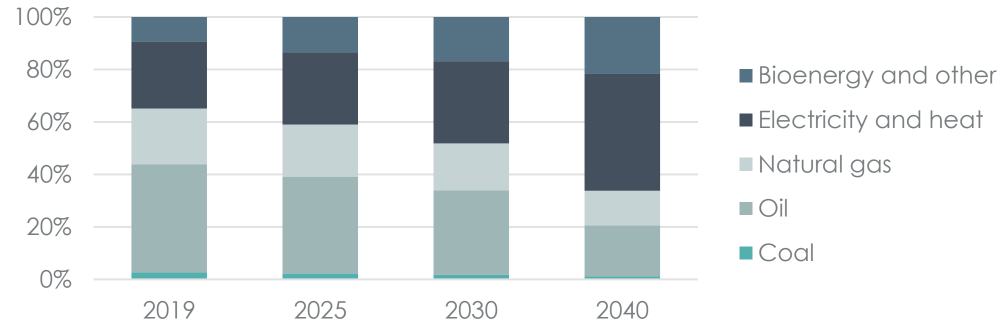
Meeting the Paris Agreement requires fundamental changes to energy consumption in all sectors

Meeting the Paris Agreement requires fundamental changes to both energy production and energy consumption.

Energy consumption has to change from the current reliance on fossil fuels to renewable electricity, hydrogen and bioenergy.

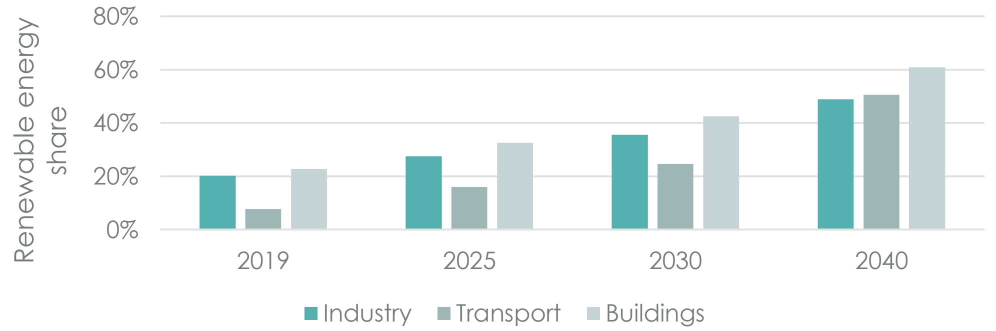
The required changes impact all sectors. However, it is most pronounced in transportation, where the share of renewable energy has to increase by a factor 6.

In the IEA's Sustainable Development Scenario (SDS), EU energy consumption is required to fundamentally change over the next few decades



Source: IEA (2020a) and Incentive.

The SDS implies that all sectors decarbonise and increase the share of renewable energy consumption dramatically



Source: IEA (2020a).

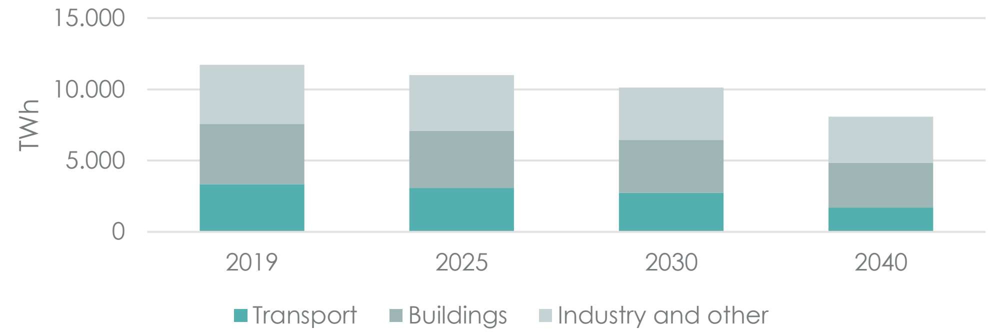
Decarbonising EU industrial energy consumption requires effort in all sectors

Industrial energy consumption accounts for more than 1/3 of EU energy consumption.

To meet the Paris Agreement, the IEA predicts that energy consumption overall has to be reduced by some 30%. The predicted decline in industrial energy consumption is around 22%, reflecting that industrial energy consumption may be harder to decarbonise than transportation and building heating.

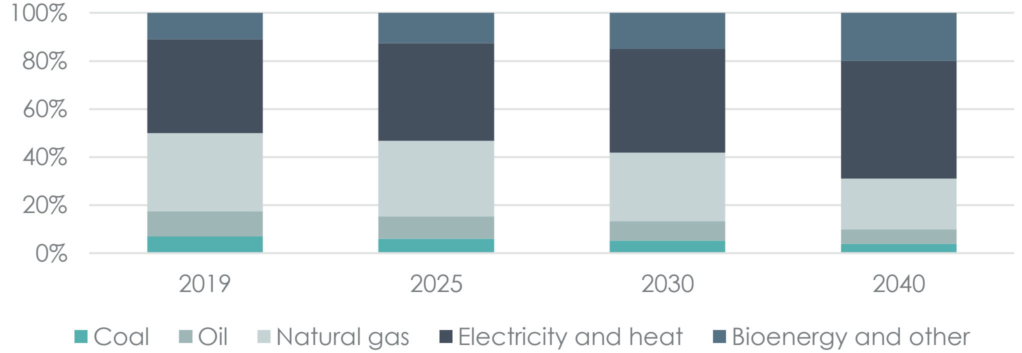
Furthermore, the industrial energy consumption has to reduce oil and coal share to less than 10% and reduce the natural gas consumption by 50%.

Today, EU industrial energy consumption accounts for more than 1/3 of all EU energy consumption, and improving energy efficiency is first line of defence



Source: IEA (2020a) and Incentive.

Industrial energy consumption has to transition from 50% coal, oil and gas to more than 50% electricity and heat



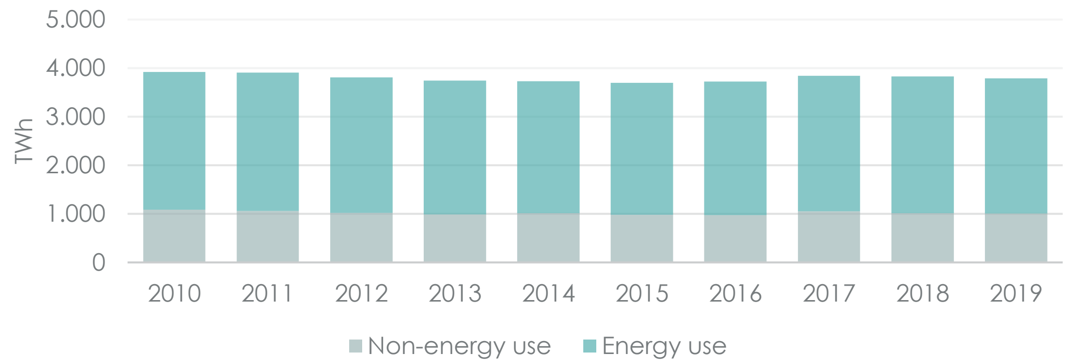
Source: IEA (2020a) and Incentive.

Decarbonising the EU requires a change in the trend for the industrial energy use in the EU

The EU* Industrial energy consumption is a combination energy use (fuels) and non-energy use (primarily petrochemical feed stock).

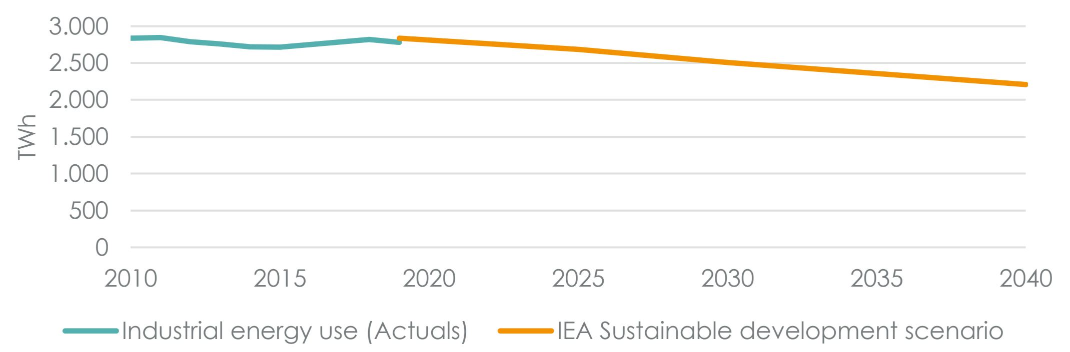
Since 2010, the industrial energy consumption has been relatively stable; however, industrial production volumes has increased by 10%, so the energy intensity has declined at a similar rate.

The EU industrial energy consumption has been very stable for the past 10 years



Source: Eurostat.

The IEA's Sustainable Development Scenario requires industrial energy use to break with a flat trend and reduce energy use



Source: Eurostat and IEA (2020a).

* The EU covers the current EU27 countries.

Decarbonising industrial energy consumption requires investments in new technologies and high CO_2 prices to enable the change

Agora Energiwende (2019) reviews industrial energy consumption and the potential for decarbonising.

The study concludes that:

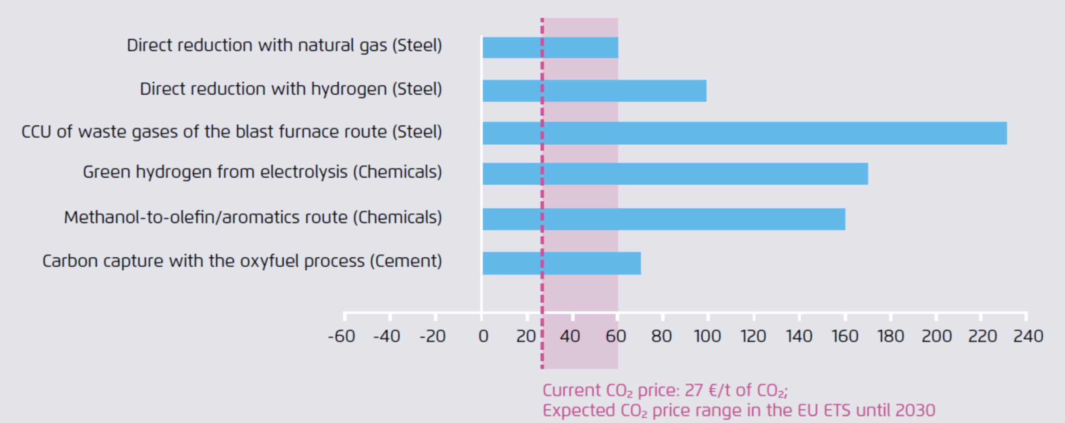
- Industrial emissions to some degree can be reduced by improved efficiency and fuel switching.
- Long-term, the largest impact comes from investments in new technologies and between 30% and 53% of industrial installations are due for reinvestments within the next decade.
- New technologies require high CO_2 prices to make investments in new technologies viable.
- CO_2 contracts-for-difference could be considered as a support tool for zero-carbon investments.

Since the release of the Agora study, the CO_2 price has increased to more than 50 EUR/t, reducing the gap to viability for some of the technology options.

Agora Energiwende has made a study of the industry zero-carbon technologies and the CO_2 price necessary to facilitate investments in new technologies

Estimated CO_2 abatement costs of selected key technologies versus today's conventional reference process for 2030

Figure 4



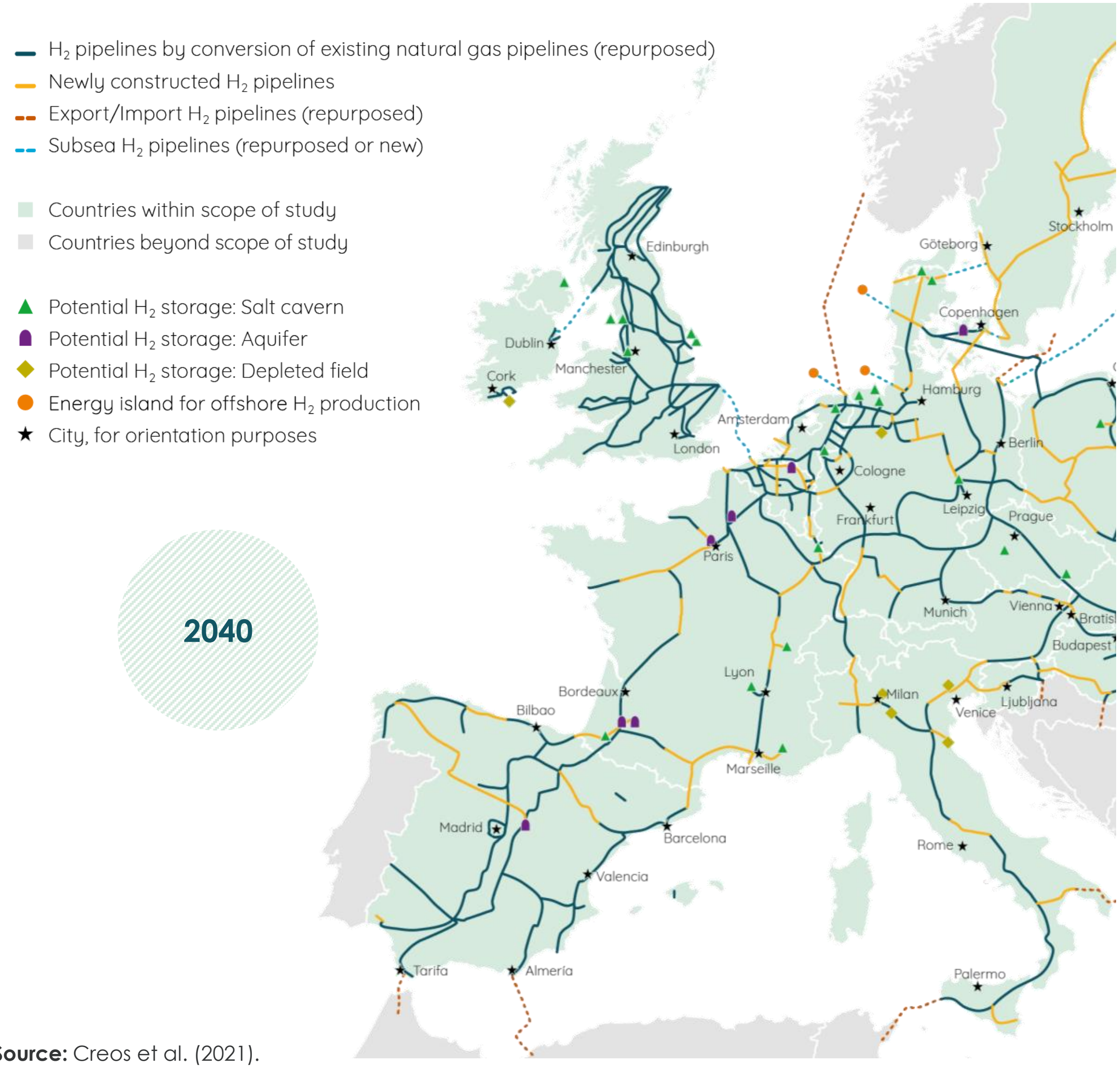
Source: Agora Energiwende (2020)

Hydrogen infrastructure is likely to be part of a zero-carbon future but will have to be built from scratch

A group of 21 gas Transmission System Operators and gas stakeholders have made a study of how a hydrogen backbone grid can be established in Europe.

The study finds that it is possible to build a new hydrogen backbone network on the basis of large-scale reuse of existing natural gas grid.

The grid is envisaged as being established in stages, with the initial grid covering industrial clusters and later extending to an EU-wide scale.



Source: Creos et al. (2021).

Deep dive: Decarbonising the steel industry: "A hard-to-abate industry"

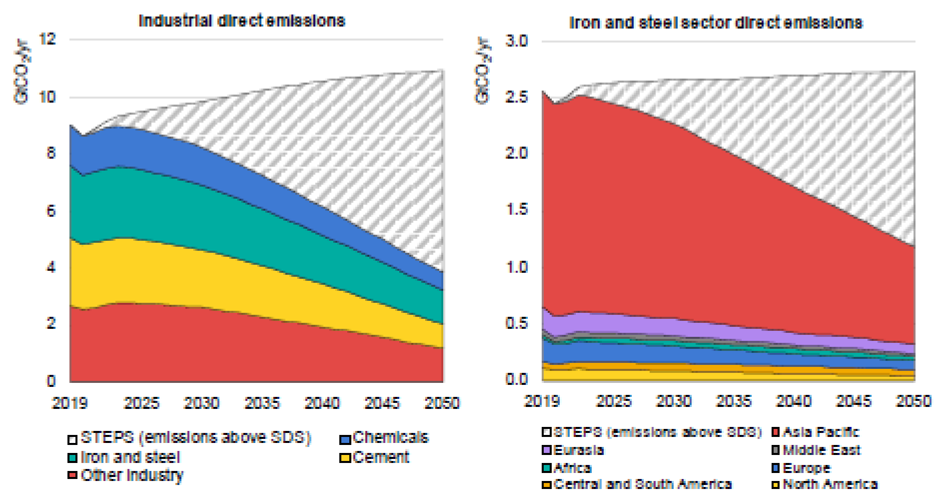
Some industries are considered hard to abate. In this section, we look more deeply into the steel industry and the options for decarbonisation.

In 2020, the IEA published a detailed roadmap for the path towards a sustainable steel industry. The IEA identified three factors making the steel industry hard to abate:

"The primary high reliance on coal in current steel production, long-lived capital assets and the sector's exposure to international trade and competitiveness make this transition towards near-zero emissions challenging."

The global steel and iron industry accounts for around 2,500 mill. Tonnes of CO_2 emissions per year. To meet the Paris agreement, the IEA's SDS envisages that the emissions must be reduced by 50% by 2050 and to zero by 2070

Figure 2.1 The contribution of the iron and steel sector to direct industrial CO_2 emissions by scenario



Notes: Gt CO_2/yr = gigatonnes carbon dioxide per year. STEPS = Stated Policies Scenario. SDS = Sustainable Development Scenario. "Other industry" includes emissions from the remainder of industry total final consumption in the IEA Energy Balances, including for example aluminium, pulp and paper, food and beverage, machinery, mining and textiles.

Source: IEA (2019).

Decarbonising the steel industry: Zero-emissions technologies are on the horizon

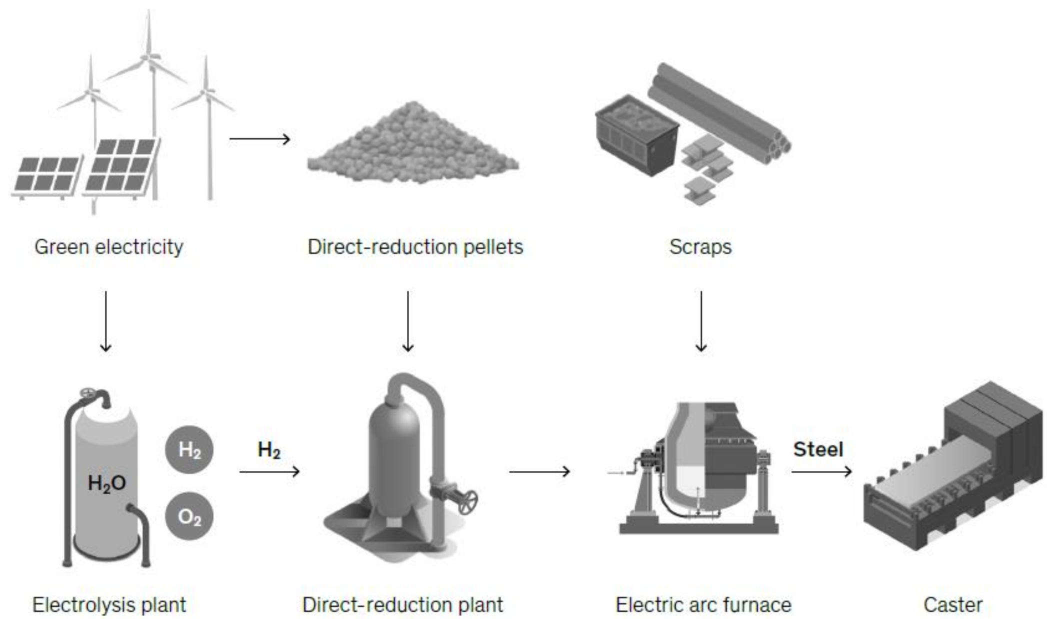
A number of studies in recent years have evaluated options for decarbonising steel manufacturing.

McKinsey (2020) and (2021) evaluates different options for reducing CO_2 emissions or full decarbonisation.

The conclusion is that hydrogen-based steel production is technically possible but currently not commercially viable due to high hydrogen prices.

McKinsey estimates that hydrogen-based technologies will become cost-effective by 2050, but this very much depends on the carbon price.

Zero-carbon steel production based on hydrogen: Renewable electricity is used to produce hydrogen, which in turn is used in direct reduction plants



Source: McKinsey (2021).

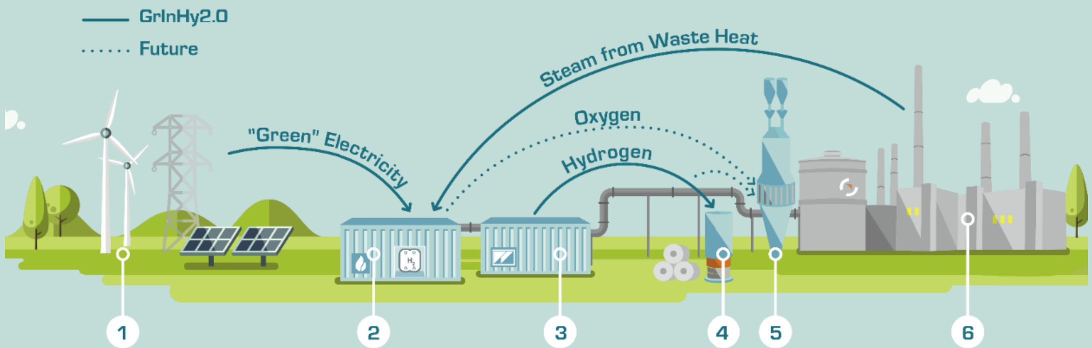
Decarbonising the steel industry: The GrInHy project is a current example of zero-carbon technology

Salzgitter AG is a German steel major with activities across the entire steel value chain.

Together with a number of technology partners, Salzgitter have started projects to investigate how hydrogen can be used in a transition to zero-carbon steel-making. A number of studies in recent years have evaluated options for decarbonising steel and iron manufacturing.

GrInHy 2.0 is an EU-supported demonstration project.

The GrInHy project is a live demonstration of how renewable electricity, green hydrogen and direct reduction plant can be combined to produce zero-carbon steel



1	**Renewable Energies**	Usage of renewable electricity
2	**Steam-Electrolyser**	Electrochemical hydrogen production based on steam from waste heat
3	**Hydrogen Processing**	Compression, drying and injection of hydrogen into existing infrastructure
4	**Annealing Processes**	Hydrogen for reducing atmosphere during annealing of cold-rolled steel
5	**Direct Reduction Plant**	Core aggregate of hydrogen-based, low CO_2 steelmaking of the future
6	**Integrated Iron-and-Steel Works**	Integration into existing infrastructure and provision of steam from waste heat sources

Source: Salzgitter (2021).

Decarbonising the steel industry: The framework must support the change

Decarbonising the EU steel and iron industry requires supporting framework conditions.

Germany is the largest steel manufacturer in the EU, and more than 80,000 people work in the industry.

As the steel and iron industry is a very global industry, the problem of carbon leakage is very real. This issue must be solved in order to support a decarbonisation of the EU steel and iron industry.

Eurofer recommends that the EU:

- secures access to green electricity: A full decarbonisation is estimated to require 400 TWh electricity, of which 60% would be used for production of 5.5 mill. tonnes of hydrogen;
- creates a stable regulatory framework;
- builds electricity and hydrogen infrastructure; and
- supports Research and Development to make hydrogen-based steel cost-competitive.

The Steel Action Concept includes a number of recommendations for creating a level playing field for the German and EU steel industry necessary to support decarbonisation

> "Until a level global playing field with all the key steel-making countries is also attained here, further effective measures will need to be taken to prevent the relocation of energy-intensive industries to countries with less stringent standards."

Source: The German Federal Government (2020).

The European Steel Association (Eurofer) has identified two main pathways for CO_2 reductions in the steel industry

	Circular Economy: Enhancing the recycling of steel (e.g. scrap in BOF/EAF*) and its by-products, Resource efficiency. *BOF= Basic Oxygen Furnace, EAF= Electric Arc Furnace			
Pathways/ Groups	Smart Carbon Usage (SCU): Process Integration with reduced use of carbon (+CCS)	Smart Carbon Usage (SCU): Carbon Valorisation/ Carbon Capture and Usage (CCU) (+CCS)	Carbon Direct Avoidance (CDA): Hydrogen	Carbon Direct Avoidance (CDA): Electricity
Description	Integration of process steps and internal use of process gases	Using CO/CO_2 from steel mill as raw material (Chemical conversion of CO/CO_2)	Use of renewable electricity in basic steelmaking, e.g. production of H_2 to replace carbon	
Projects/ Initiatives	HISARNA, TGR-BF-Plasma (IGAR), PEM, STEPWISE, Torero	Steelanol, Carbon2Chem, FReSMe, Everest, Carbon2Value	HYBRIT, H2Steel (H2Future, SuSteel, Hybrid Steel Making), tkH$_2$Steel, GrInHy, SALCOS, Hydrogen Hamburg, SIDERWIN	

Source: Eurofer (2019).

Decarbonising the steel industry: 50% reduction in CO_2 emissions from a large number of changes

In the 2019 steel industry report, the IEA outlined a roadmap for how the global steel industry can support the Paris agreement and the SDS.

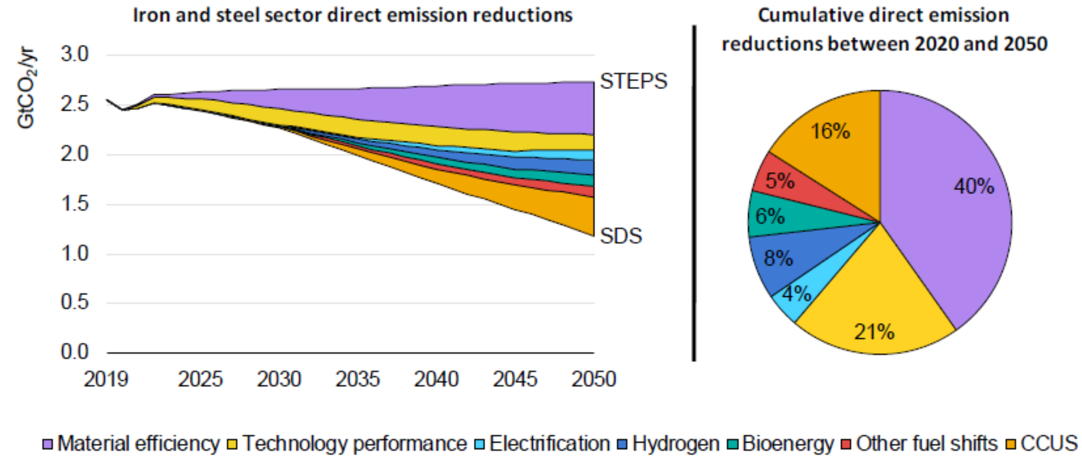
In the short term most reductions arise from improved technology and material efficiencies.

Long-term, a more fundamental change to the industry is required to reach the Paris Agreement objectives:

- Hydrogen-based technologies has a commercial breakthrough
- Carbon-capture technologies are widely deployed
- Fuel switching from coal to natural gas and from natural gas to hydrogen

In particular, the commercial viability of hydrogen-based technologies and fuel switching from coal to natural gas will depend on the CO_2 price.

In the period until 2030, the IEA envisages that reductions in global steel sector CO_2 emissions mainly derives from improvements in current technologies. Long-term, the focus is on hydrogen, electrification, fuel switching and carbon capture



Source: IEA (2020a).

Decarbonising the steel industry: Long investment cycles calls for early action and possibly interim solutions

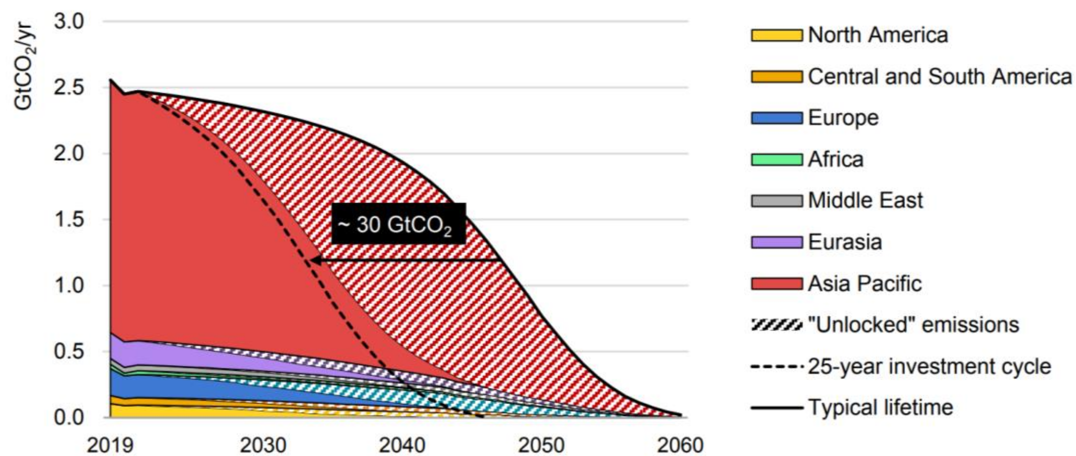
Steel factories typically have long expected lifespans of 40 years or more. The IEA (2019) notes that typically, steel production facilities have major overhauls or refurbishments after 25 years of production. This could be an opportune moment to adapt to new technologies.

Furthermore, to accelerate the phase-out of fossil fuels in steel-making, the IEA recommends investigating:

- Early retirement or interim underutilisation of assets
- Refurbishment and retrofitting of Carbon Capture Utilization and Usage
- A change in material inputs, for example a higher share of scrap use
- Fuel switching and incremental blending

Switching from coal to gas may be a way to accelerate CO_2 emissions reductions on steel units with a long remaining lifespan.

Investments in the steel industry have an average lifetime of 25 years. The IEA has calculated a substantial CO_2 reduction potential if new technologies are adopted after 25 years rather than 40 years



Source: IEA (2019).

Decarbonising the steel industry: In conclusion

The steel industry is hard to abate, and major changes must be facilitated.

The steel industry accounts for 7% of global energy system CO_2 emissions.

The new technologies for a zero-carbon steel industry is on the horizon, but the road to carbon neutrality is long and requires many efforts to support the transition:

- Securing availability of very large volumes of inexpensive, renewable energy
- Sufficient electricity and hydrogen infrastructure
- High carbon prices to make hydrogen-based steel-making cost-competitive and gas competitive relative to coal

Although the use of natural gas long-term is in decline, natural gas can play a role as a stepping stone while new hydrogen-based technologies are matured and developed.

In some industries, fuel switching to natural gas could be a stepping stone to carbon neutrality: The case of Nordic Sugar

Today, Nordic Sugar in Denmark uses coal and oil as energy sources for the sugar production on the Danish island of Lolland.

Regulatory requirements mean that Nordic Sugar must replace their fuel sources from oil and coal with alternatives with lower emission within the next few years.

Long-term, the solution could be high-temperature heat pumps, biogas or hydrogen, but today, Nordic Sugar's analysis shows that the best alternative is to switch to natural gas.

Shifting to natural gas can reduce Nordic Sugar's CO_2 emissions by up to 40% compared to today.

The NZE illustrates that some of the industrial sectors are hard to abate and that carbon capture of coal and gas can be a necessary stepping stone

New gas pipeline in Denmark

At the beginning of 2021 in Denmark, it has been decided to build a 115 km long pipeline to connect Nordic Sugar's two sites on Lolland and Falster with the existing gas network.

Switch to natural gas and biogas

The new pipeline will allow Nordic Sugar to switch to natural gas in the short run.

The new pipeline also introduces the possibility of establishing biogas production on Lolland and Falster from residues from the sugar production, among other things, to supply Nordic Sugar and the rest of the country with biogas.

Source: IEA (2021).

In some industries, fuel switching to natural gas could be a stepping stone to carbon neutrality: The case of Aalborg Portland

Cement manufacturer Aalborg Portland is one of the largest CO_2 emitters in Denmark. The company has committed to reducing its CO_2 emissions by 30% by 2030, equivalent to 660,000 tonnes of CO_2.

To achieve the 2030 objective, Aalborg Portland has signed an agreement and committed to an investment of 40 MDKK in order to be connected to the Danish gas grid in 2022. This enables the company to shift to natural gas in the short run and serves as a stepping stone towards shifting to biogas in the long run.

The NZE illustrates that some of the industrial sectors are hard to abate and that carbon capture of coal and gas can be a necessary stepping stone

SUSTAINABILITY

26 February 2021

Aalborg Portland will invest in natural gas to ensure significant carbon reduction in Denmark

Get connected to the gas grid in Denmark	Switch to natural gas and biogas

Source: Aalborg Portland.

Conclusions

1	**Security of supply is a core element in national energy policies** • Today, gas-fired power-plants are used to meet fluctuations in demand. • An increasing share of solar and wind electricity production adds volatility to the electricity system. • Renewable alternatives such as batteries and hydrogen-fired power plants will require large investments. • Using the capacity of existing gas-fired power plants may be the best short-term option.
2	**Phasing out coal-fired power plants is a key part of fulfilling the Paris Agreement** • Coal-fired power production in the EU has decreased by 43% since 2005, but still accounts for 17% of the power production in 2019. • The IEA estimates that it is possible to cost-effectively save 147 Mt CO_2 by switching from coal to gas-fired power production.
3	**Meeting the Paris Agreement requires fundamental changes in industrial energy consumption** • Industrial energy consumption accounts for more than 1/3 of EU energy consumption and must decrease by around 22% in order to meet the Paris Agreement. • Three elements can help the decarbonisation of hard-to-abate industries: hydrogen-based technologies, fuel switching from coal to natural gas and later to hydrogen, and carbon-capture technologies.

Recommendations

1	**Use natural gas as part of the transition** Natural gas can work as an accelerator and stepping stone in the green transition. In many sectors, the long-term carbon-neutral solution may be switching to electricity and hydrogen. However, in the short term, technologies may be unavailable, and a reduction in CO_2 emissions could be achieved in the short term by shifting to natural gas.
2	**High CO_2 prices will aid the transition** High CO_2 prices will ensure that gas-fired power plants are more attractive than coal-fired power plants and thereby incentivise the market to shift from coal to gas in the short run.
3	**Support R&D in clean energy and secure supply of electricity** Electricity produced with renewable sources and hydrogen are essential parts of a greener future. Therefore, it is crucial to support the R&D in hydrogen to drive prices down. When electricity is produced with inflexible sources as solar and wind, it is also important to ensure security of electricity supply with power plants and storage capacity.

References

Publications

Aurora (2021)
Aurora Energy Research. *The impact of weather in a high renewables power system*. 2021.

Creos et al. (2021)
23 European gas infrastructure companies. *Extending the European Hydrogen Backbone*. 2021.

Eurofer (2019)
The European Steel Association. *Low carbon roadmap – Pathways to a CO_2-neutral European steel industry*. 2019.

Frontier (2019)
Frontier Economics. *The value of gas infrastructure in a climate-neutral Europe*. 2019.

IEA (2019)
International Energy Agency. *Iron and Steel Technology Roadmap*. 2019.

IEA (2020a)
International Energy Agency. *World Energy Outlook 2020*. 2020.

IEA (2020b)
International Energy Agency. *Global Energy Review: CO_2 Emissions in 2020*. 2020.

IEA (2020c)
International Energy Agency. *Sustainable Recovery*. 2020.

IEA (2021a)
International Energy Agency. *Global Energy Review 2021*. 2021.

IEA (2021b)
International Energy Agency. *Net Zero by 2050 – A Roadmap for the Global Energy Sector*. 2021.

McKinsey (2020)
McKinsey & Company. *Decarbonization challenge for steel*. 2020.

McKinsey (2021)
McKinsey & Company. *Tackling the challenge of decarbonizing steelmaking*. 2021.

Salzgitter (2021)
Salzgitter Mannesmann Forschung GmbH. *GrInHy2.0 and future hydrogen-based steelmaking*. 2021.

The German Federal Government (2020)
Federal Ministry for Economic Affairs and Energy (BMWi). *For a strong steel industry in Germany and Europe*. 2021.

INCENTIVE