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Decarbonization strategies for large industrial users

Direct electrification potential and technology needs

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Outline

Energy and carbon footprint of industry	Global industrial sector demonstrates steady energy demand growth, while its electrification rate stands still Enhancements in energy efficiency and transition to cleaner energy sources are stabilizing carbon emissions Fossil-based heat supply accounts for almost all industrial emissions
Direct electrification potential	Replacing a large share of fossil fuels in process heat supply with low-carbon electricity is the most efficient decarbonization strategy Today's technologies allow direct electrification of up to 75% of industrial heat resulting in 57% carbon emission reduction.
Technology innovation trends	Electrification of industrial demand requires stronger and dynamically controllable T&D grids Electrified industrial demand can contribute to system flexibility at different time scales Alternatives to direct electrification include synthetic clean fuels and solar thermal energy
Modeling in energy system scenarios	Represent industrial demand by thermal energy profiles which can be supplied by different energy vectors Define potential flexibility of industrial demand be setting maximum shifted percentage and time

Global final energy consumption in the industry sector

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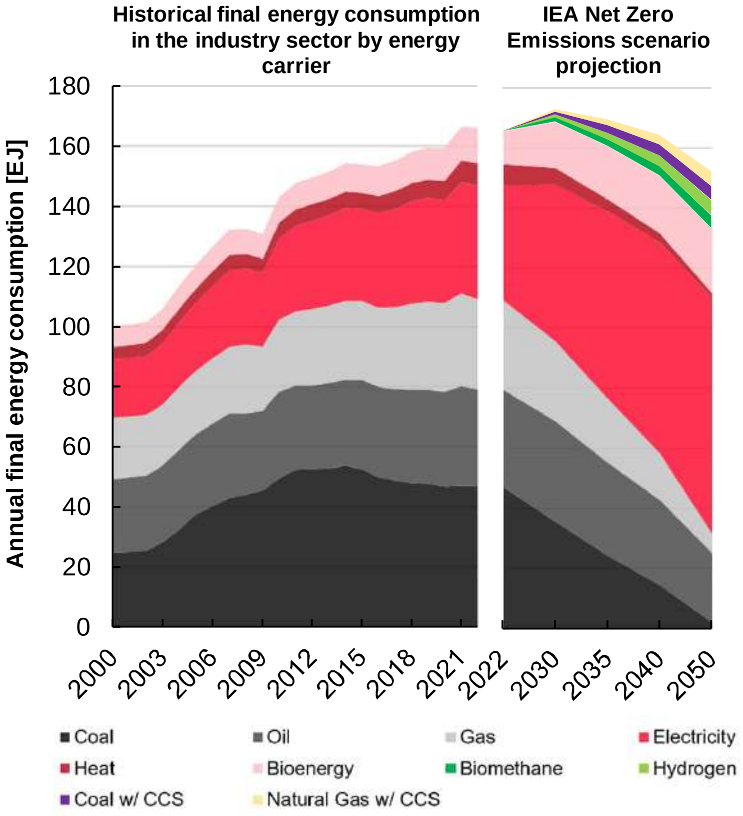
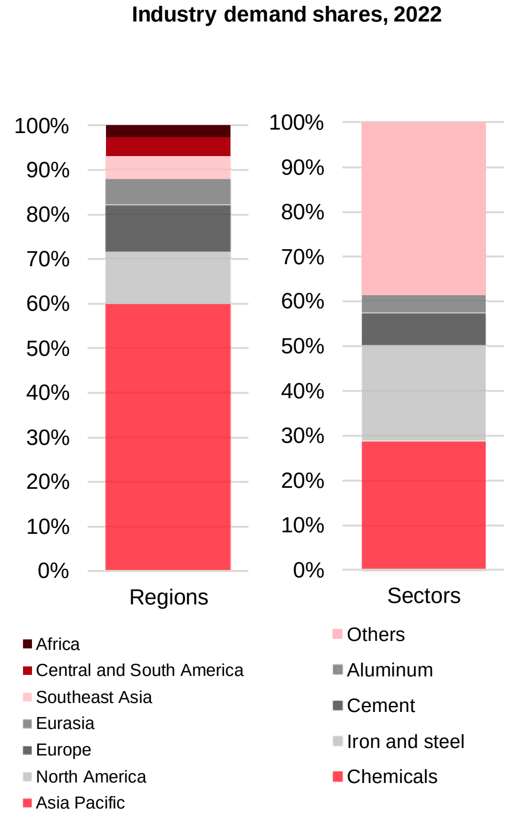
Slow progress of electrification

– In the last two decades the global final energy consumption of the industry sector has increased by 65% from 100 EJ in 2000 to 166 EJ in 2022.
– The electrification rate of the sector has only increased by 3.4% from 19.3% in 2000 to 22.7% in 2022.
– The share of bioenergy and district heat has remained constant over the past two decades. Hence, the slight increase in the electrification rate is the only cause of a small decline in the fossil fuel share from 69.4% in 2000 to 65.7% in 2022.
– In 2022, the final energy consumption of some of the principal industry sectors were are follows:
  - o chemicals (48 EJ),
  - o iron & steel (35 EJ),
  - o cement (12 EJ),
  - o aluminum (7 EJ).





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Source: IEA

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Carbon emissions in the industry sector

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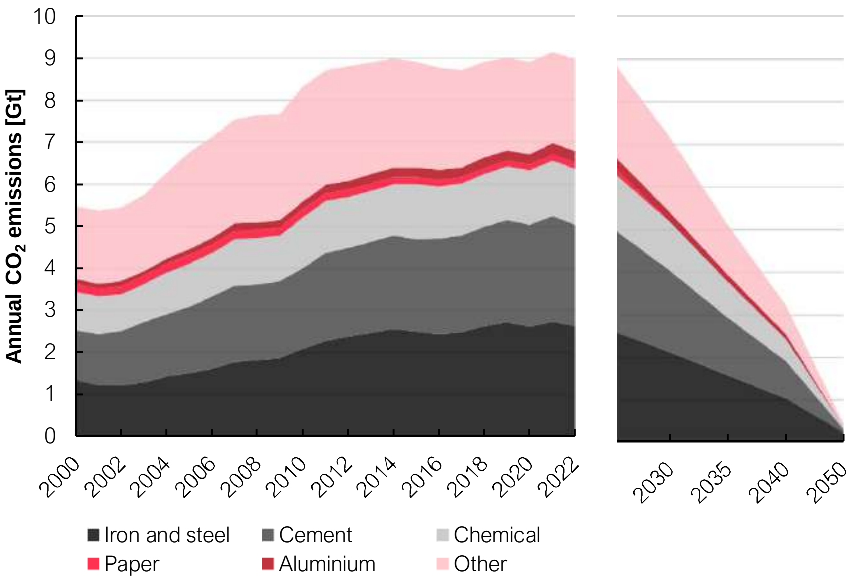
Global industrial carbon emissions could peak soon

The global annual CO_2 emissions in the industry sector increased by 60% from 5.48 Gt in 2000 to 8.72 Gt in 2011. Since then, it has been staying in a narrow range 8.8 – 9.1 Gt.

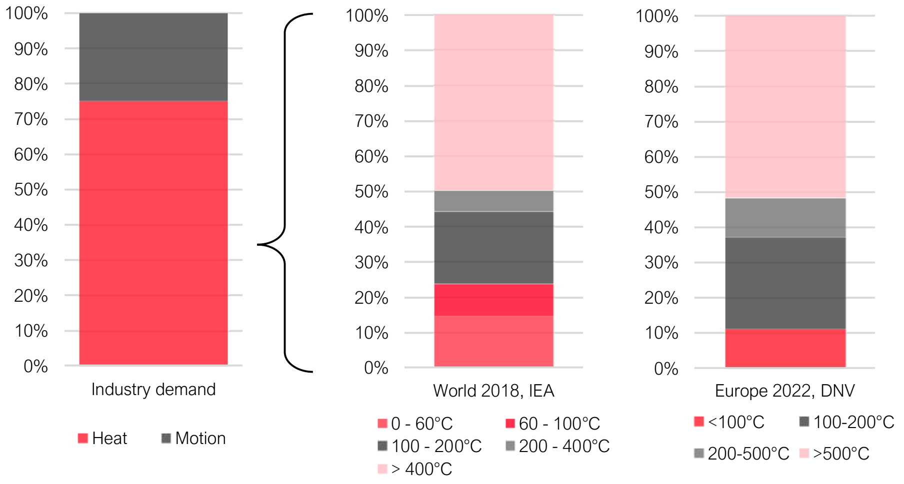
Historical CO_2 emissions in the industry sector by subsector | **IEA Net Zero Emissions scenario projection**



Composition of industry demand

- From the final useful energy demand of the industry sector, 75% is required in the form of heat and the other 25% in form of motion from electric motors.
- From the heat component of the demand in 2022, 85% of the heat was supplied by processes involving combustion of fuels (boilers, furnaces, etc.), while the remaining 15% was shared by heat exchangers and electric heaters.

Industry energy demand | **Heat demand in the industry sector by temperature range**



Source: IEA, DNV

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Heat supply needs and technologies

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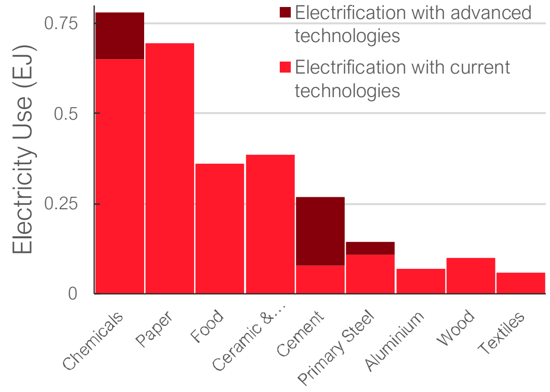
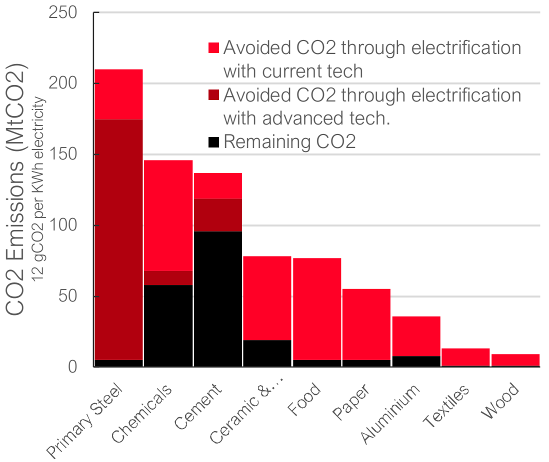
<100C	100-400C	400-1000C	>1000C
(cooling, drying)	Chemicals (steam, extruders)	(crackers, reformers)	Primary steel (blast furnace)
(space heating)	Pulp & paper (steam, extruders)	(limekilns)	
	Ceramic & glass (drying)		Ceramic & glass (firing, melting)
(space heating, cooling, drying)	Food (steam, ovens)	(pre-heating)	Cement (clinker burning)
(space heating)	Wood (steam)	Secondary steel (re-heating furnace, smelters)	
	Aluminum (steam, re-heating, melting)		
(space heating, drying)	Textile (steam)		

- Heat Pumps
- Mechanical Vapor Recompression
- Electric Arc Furnace
- Electric Boilers
- Induction and resistance welding
- Chillers
- Resistance Furnace
- Microwave & Radio Frequency Heaters
- Induction Furnace
- Infrared Heaters
- Plasma Arc Furnaces
- Thermo-electric cooling
- Resistance Kiln
- Electric Calciner
- Electric Annealing Furnace
- Plasma arc welding
- Thermal Plasma
- Crackers and reformers





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Source: S. Madeddu et al 2020 Environ. Res. Lett. 15 124004

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Technology innovation for industrial heat processes

Electrowinning

RotoDynamic Heater

Electrocracking

Concentrated Solar Power

Biomass Boilers

Carbon Capture, Utilization and Storage

Public

Electric Arc Furnaces (EAF) to clean-up metals

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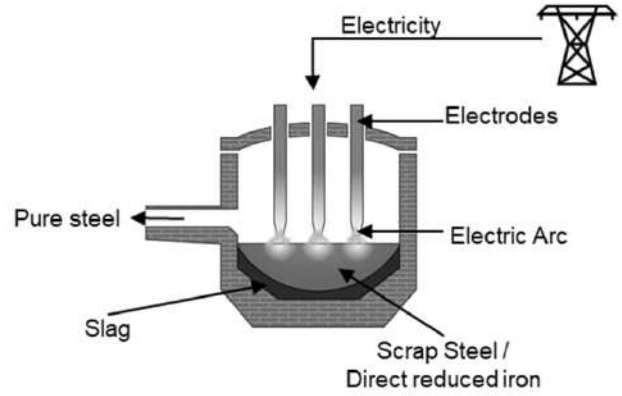
Overview

EAF heats metallic materials by an electric arc.

– Primarily used in secondary steel production from scrap as well as in primary steel production following the BF or DRI processes.

– Typical power consumption range is 50-300 MVA.



EAFs have almost instant startup and shutdown time (tap-to-tap time 30-40 mins), and operate in batches, hence can contribute to the system flexibility.

Decarbonization Potential

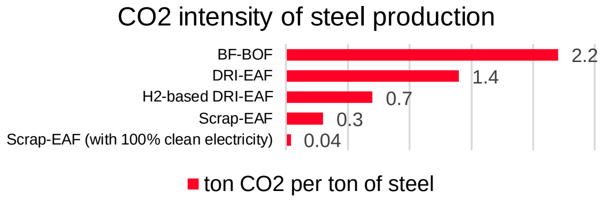
Routes to producing low-carbon steel using EAF:

– Increase share of scrap in input (scrap share of input expected to increase to 46% in 2050 in IEA Net Zero Emissions scenario)

– Replace coke/natural gas with H2 as reduction agent in DRI-EAF

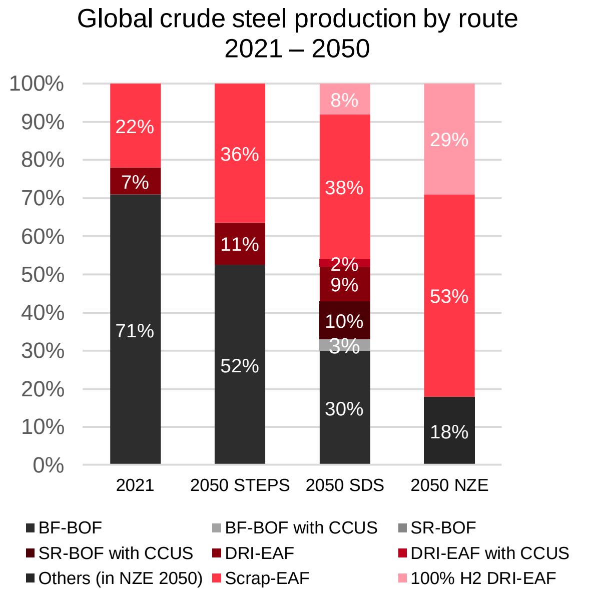
– Increase share of renewable electricity in EAF input

With increased share of renewable powered EAF and H2-based DRI along with addition of CCUS, CO2 emissions in iron and steel industry can be reduced from 2.6 Gt CO2/year in 2022 to 0.2 Gt CO2/ year in 2050 as per IEA Net Zero Emissions scenario.



*The CO2 emission numbers are taken from IEA methodology which includes both direct and indirect emissions. Direct emissions generate from fuel combustion in iron and steel sector, whereas indirect emissions attribute to global average CO2 intensity of electricity generated and imported from grid. Scrap-EAF with 100% clean electricity account for only direct emissions (assuming no indirect emissions from 100% renewable electricity)

EAF technology in steel Industry



SDS: Sustainable Development Scenario
STEPS: Stated Policies Scenario
NZE: Net Zero Emissions Scenario
BF-BOF: Blast Furnace-Basic Oxygen Furnace
SR-BOF: Smelting Reduction – Basic Oxygen Furnace
DRI-EAF: Direct Reduction of Iron in Electric Arc Furnace
CCUS: Carbon Capture, Utilization and Storage
Others (in NZE 2050): All other routes excluding Scrap EAF and H2 based DRI in IEA NZE scenario

Source: IEA: Iron and Steel technology Roadmap; IEA: Net Zero by 2050

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Power quality solutions for EAF

EAF used for steel scrap melting and refining may create a range of power quality issues in the connected transmission system.

Power electronics-based devices such as SVCs and STATCOMs can stabilize the arc furnace bus voltage during the melting phase, achieving important benefits for the user:

- Increase in available melting power which gives shorter melt down time and thereby higher productivity
- Decrease of specific electrode consumption due to more stable arcs
- Decrease of specific energy consumption due to lower radiation losses per melt
- Decrease of plant losses due to the decreased flow of reactive power
- Mitigate flicker seen by other consumers in the region
- Lower specific power billing due to a higher power factor at the point of common coupling.

EAF has quick startup and shutdown time, and operate in batches, hence can be scheduled to operate at specific time

Modeling industrial demand in capacity expansion analysis

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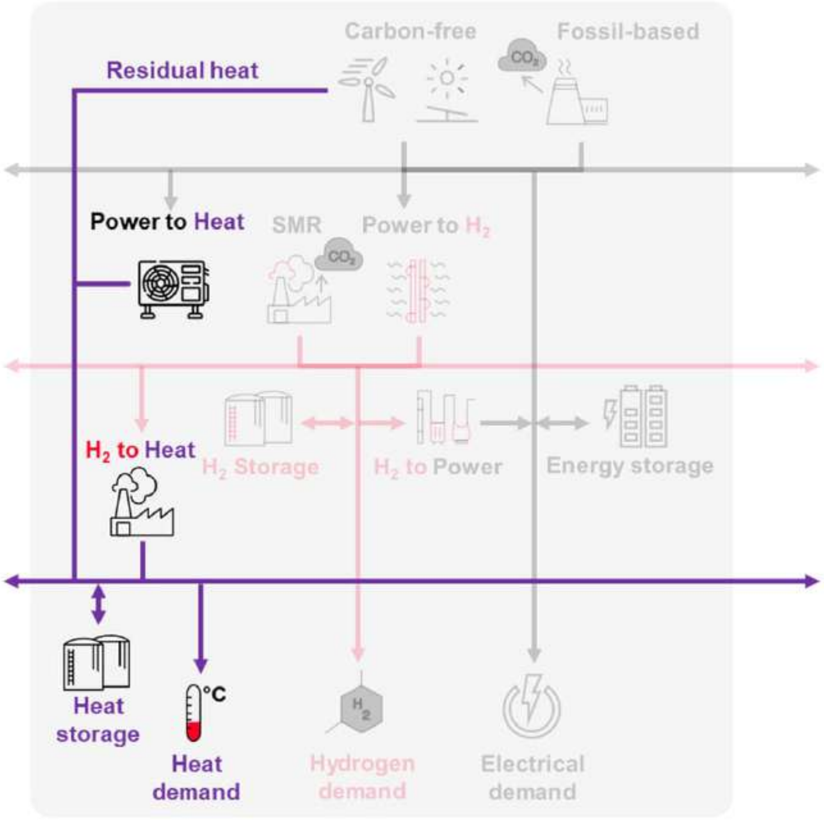
Capacity Expansion Modeling Framework

– Multi-zonal and multi-period capacity expansion modelling framework is applied.

– Investments in assets for production, conversion, transport and storage of electricity, hydrogen and heat are co-optimized as a single objective.

– End use demand of heat, electricity and hydrogen is provided and the generation, storage, conversion technologies are chosen by the optimizer based on the technology costs, efficiencies and emissions over the optimization duration.

– Undertakes a holistic energy system planning approach to leverage complementarities and flexibilities between different energy vectors.



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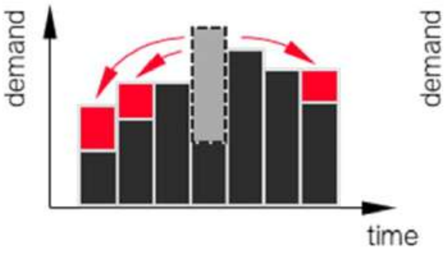
Energy time shift

Hourly demand can be optimally shifted forward or backward within a predefined maximum percentage and time (symmetric or non-symmetric)

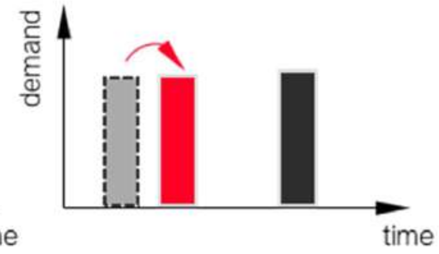
It is triggered by a variability of variable renewables or grid conditions with the objective to minimize total system cost (investments and operation).

Different technologies have specific flexibility capabilities.

Heat pumps example



EAF example



Problem formulation

Change in demand: $P_t = P_t^0 - P_t^- + \sum_t P_{t,\tau}^+$

$P_t^- = \sum_\tau P_{t,\tau}^+$ reduced demand should be compensated within time delay

P_t: modified demand after demand shift

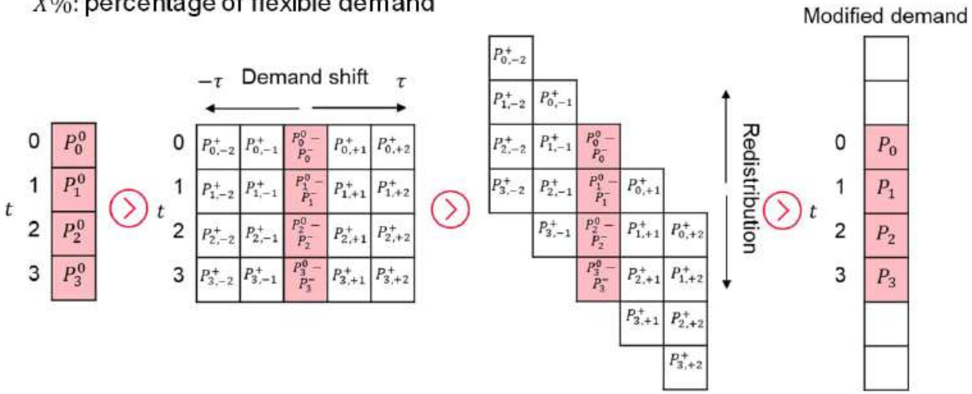
P_t^0: initial demand

P_t^-: reduction of demand

$P_{t,\tau}^+$: compensation of reduced demand

$X\%$: percentage of flexible demand

$P_t^- \leq X\%$ limit for change of demand



Demand management plays a crucial role in balancing variable renewables while maintaining affordable cost

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What does the electrification of the industry sector imply?

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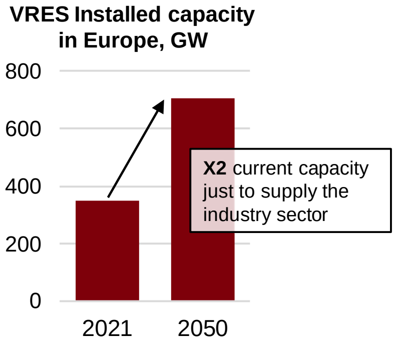
Increased electricity consumption

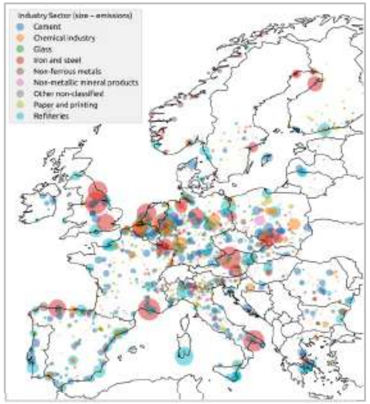
The European electricity consumption of the industry sector is expected to increase from 930 TWh in 2021 to 1,538 TWh by 2050 according to the most ambitious scenario by Fraunhofer institute.

This represents an increase of 608 TWh, equivalent to 65% of the current consumption, requiring additional ~355 GW of installed capacity of VRES just to supply the industry sector's electrification.

In order to meet the new electricity demand using VRES sources, the installed capacity of solar and wind in 2021 would need to be doubled.

The industry demand geographical location is concentrated in specific regions in the continent, most of which are densely populated areas. Therefore, a robust and upgraded electric grid infrastructure will play a significant role in the efficient and reliable delivery of the new capacity supplied for the newly electrified processes.





Country	Steel industry energy demand, TWh/a
Germany	115
France	53
Italy	44
UK	42
Poland	32

Country	Chemical industry energy demand, TWh/a
Germany	198
France	79
Netherlands	76
Belgium	44
UK	40

Country	Cement industry energy demand, TWh/a
Germany	27
Poland	22
Italy	16
France	14
UK	9

Sources: Eurostat, Fraunhofer

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