FLEXIBILITY THROUGH ELECTRIFICATION

Achieving climate goals means reducing greenhouse gas emissions from all energy sectors. Deep decarbonisation of heating, transport, and industry can be achieved by substituting fossil fuels with emission-free alternatives. Electrification of energy consumption is a particularly promising pathway since the fastest-growing emission-free energy production technologies, wind and solar, generate electricity. At the same time, electrification brings new alternatives for managing the variability of wind and solar in a cost-effective manner.

How to decarbonise final energy demand?

Fossil fuels used in end-use energy sectors can be replaced either directly with electricity or indirectly through synthetic fuels made with electricity (Figure 1). There are also other alternatives, such as nuclear energy, solar thermal energy and bioenergy, but many of them have limitations due to resource, usability or geographical constraints.

Direct electrification technologies include resistance heaters, heat pumps, electric vehicles, and industrial solutions, such as electric arc furnaces.

Indirect electrification usually starts with electrolysers that produce hydrogen from electricity and water. Hydrogen can then be converted to more complicated synthetic fuels and other molecules, such as ammonia. Hydrogen can also be converted back to electricity and/or heat. However, because of losses in the conversion phases, indirect electrification is an expensive route.

Space heating and domestic hot water can utilize both direct and indirect electrification. Heat pumps have the best efficiency and are likely to be the major electrification route, but they can be complemented by resistance heaters, heat storages and synthetic fuels to increase flexibility.

In the transport sector, the bulk of electrification is likely to be through electric vehicles. However, it is not an option in all cases (e.g. aviation) and it is likely to be supplemented by synthetic fuels as well as hydrogen fuel cell vehicles.

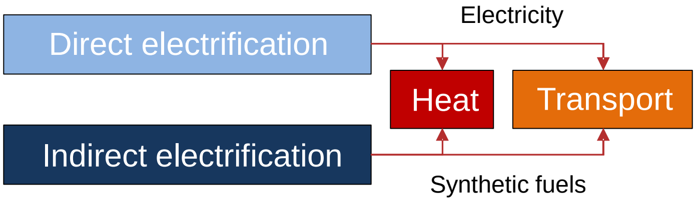

Figure 1. *Direct electrification is defined as replacing fossil-based end-use technologies with electric end-use technologies. Indirect electrification is defined as the substitution of fossil fuels through electricity-based synthetic fuels.*

Emissions from the industrial sector can be divided into energy-related and process-related emissions. Energy related emissions mostly result from the use of heat at different temperature levels. Heat pumps are usually the cheapest option for low temperature levels, but they can be supplemented by resistance heaters and heat storages. High temperature levels can also be achieved with direct conversion from electricity – using resistance heaters, electric arc furnaces, and induction furnaces, for example. When fuel combustion is necessary, indirect electrification has advantages. Finally, the reduction of process-related emissions requires specific solutions (e.g. in cement making and reducing oxygen from metals).

Is there sufficient potential for wind and solar to cover the additional electricity demand?

Decarbonisation through electrification only works if enough emission-free electricity is available. This raises the question whether the potential of wind and solar energy is sufficient to cover the increased electricity consumption due to electrification.

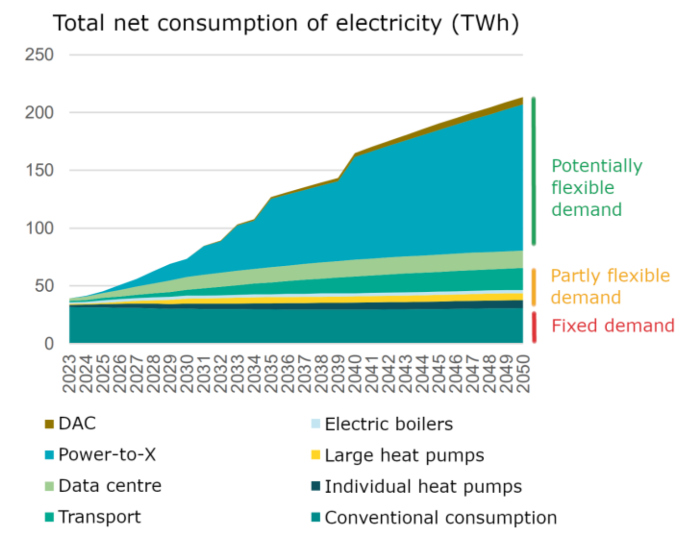

Figure 2. *Future load will be more flexible. DAC: direct air capture (Adapted from: Danish Energy Agency & Energinet).*

In all European countries, for example, the technical potential for wind and solar energy is significantly higher than the required electrical energy consumption after electrification. However, in many regions the realisable potential for wind and solar energy is limited due to land-use and landscape factors. In these cases, energy imports are likely to be important.

Particularly with limited land availability, options also include installing rooftop solar, co-locating wind and solar with agriculture, building offshore wind and installing floating solar panels on waterbodies.

What is the effect of increased electrification on short and long-term flexibility in the energy system?

Adding inflexible electrical loads can increase system costs and impede the integration of larger shares of wind and solar energy. On the other hand, if the new loads are flexible, this will enable more cost-efficient integration of larger wind and solar energy shares. Indirect electrification can often be flexible. For example, hydrogen electrolysers can be shut down at high electricity prices. Furthermore, indirect electrification options pose an opportunity for seasonal (and inter-annual) energy storage.

In the long term, the energy system is likely to adapt to the increasing variability of power generation. Electrification can become an important source of flexibility (Figure 2).

It is important to incentivise flexibility as lifetimes of energy devices are typically long, in the range of 15 to 60 years. Without proper incentives now, a large portion of newly installed electrical devices may be unnecessarily inflexible and cause problems for the system later.

Both flexible and inflexible electrification may require notable grid reinforcements.

How is electrification proceeding?

Electrification is already happening, and the climate targets foresee more electrification.

In the past, low electricity prices in countries such as France, Norway or Sweden resulted in a higher share of electrical appliances in heating and/or transport compared to traditionally fossil-based systems such as Germany or Italy. These examples show that the willingness to electrify depends, amongst others, on the electrification costs.

Cheaper electricity or more expensive fuels can speed up the electrification. Fossil fuels will become more expensive when the cost of emitting CO_2 goes up. This can accelerate electrification especially where the cost of equipment is low like in heating. On the other hand, for electric vehicles, the cost of batteries is more decisive than the cost of fuels.

Associated publications

- Danish Energy Agency (2023), **Analyseforudsætninger til Energinet** (in Danish). https://ens.dk/sites/ens.dk/files/Statistik/af23_-_sammenfatningsnotat.pdf
- ESIG (2019). **Toward 100% Renewable Energy Pathways: Key Research Needs**. https://www.esig.energy/esig-101/
- Guminski, A. et al. (2019). **System effects on high demand-side electrification rates: A scenario analysis for Germany in 2030.** WIREs Energy and Environment, 8, e327. https://doi.org/10.1002/wene.327
- Kiviluoma, J. et al. (2022). **Flexibility From the Electrification of Energy: How Heating, Transport, and Industries Can Support a 100% Sustainable Energy System**. IEEE Power and Energy Magazine, 20(4). https://doi.org/10.1109/MPE.2022.3167576

More information

This Fact Sheet draws from the work of IEA Wind TCP Task 25, a research collaboration among 17 countries. The vision in the start of this network was to provide information to facilitate the highest economically feasible wind energy share within electricity power systems worldwide. IEA Wind TCP Task 25 has since broadened its focus to analyze and further develop the methodology to assess the impact of wind and solar power on power and energy systems.

See our website at

https://iea-wind.org/task25/

See also other fact sheets

Flexibility for Power Systems
Storage for Power Systems
Balancing Power Systems with Large Shares of Wind and Solar Energy
How Do We Ensure Long-Term Reliability of Future Power Systems?
Wind and Solar Integration Issues