Renewable Power and Heat for the Decarbonisation

Subjects: Environmental Sciences

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Renewable energy (RE) solutions have been classified into technologies based on the use of renewable electricity and those used to produce heat for multiple industrial processes. Electrification will be key thanks to the gradual decrease in renewable power prices and the conversion of natural-gas-dependent processes. Industrial processes that are not eligible for electrification will still need a form of renewable heat. Among them, the following have been identified: concentrating solar power, heat pumps, and geothermal energy. These can supply a broad range of needed temperatures. Biomass will be a key element not only in the decarbonisation of conventional combustion systems but also as a biofuel feedstock. Biomethane and green hydrogen are considered essential. Biomethane can allow a straightforward transition from fossil-based natural gas to renewable gas. Green hydrogen production technologies will be required to increase their maturity and availability in Europe (EU). Energy Intensive Industries (EIIs)' decarbonisation will occur through the progressive use of an energy mix that allows EU industrial sectors to remain competitive on a global scale. Each industrial sector will require specific renewable energy solutions, especially the top greenhouse gas-emitting industries.

Keywords: energy-intensive industries ; decarbonisation ; renewable energies

1. Introduction

The EU has set ambitious targets for decarbonisation by 2050 [1]. Part of this decarbonisation relies on the implementation of renewable energy (RE) technologies that replace the use of fossil-based energies. The second pillar of this decarbonisation path must be built on avoiding the emission of greenhouse gases (GHG) into the atmosphere by energy-intensive industries (EIIs). It is well known that EIIs were responsible for a third of the total of such emissions (>508 Mt CO2e) in the EU in 2014 [2][3]. In 2020, the European Union consumed around 2685 TWh of energy. The chemical and petrochemical sectors had the highest energy consumption (22%), followed by the non-metallic mineral (14%); paper, pulp, and printing (14%); and food, beverage, and tobacco (12%) sectors.

2. Renewable Electricity

Solar Photovoltaic, Concentrating Solar Power, and On/Offshore Wind

Renewable power can be obtained from different sources: solar photovoltaic, concentrating solar power, and on/offshore wind. The last decade has seen price improvements in these technologies for power production. According to a recent analysis by IRENA [4], the price of these sources of renewable power has steadily decreased. In comparison, fossil-based energy sources such as coal-fired power plants have operating costs that are higher than their renewable counterparts. IRENA's analysis—focused on Europe, North America, and South Asia—indicates that the costs of these renewables vary, in part due to the price imposed on CO_2 emissions.

The main advantage of renewable power is its flexibility in terms of implementation. Grid-connected installations harvest electricity for self-consumption and the surplus can be given to the network. However, off-grid facilities operate in isolation. These are placed in remote locations to meet local electricity demands. Off-grid facilities require the installation of batteries to store surplus electricity. By 2021, the European Union had installed around 26.8 GW of photovoltaic capacity [5]. The largest European market was Germany (21%), followed by Spain (19%), France (14%), the Netherlands (13%), Poland (13%), Greece (4%), and Italy (4%). The current worldwide photovoltaic power capacity is expected to grow from 900 GW (EU share of 25%) to 3000 GW (EU share of 5%) by 2050 according to the IEA Roadmap [6].

There are two main pathways for the implementation of renewable electricity produced either from solar photovoltaic, concentrating solar power, or on/offshore wind. The most straightforward pathway is the direct substitution of fossil-based electricity in current industrial processes. The second pathway involves the electrification of current processes based on a heat supply obtained from the use of non-renewable fuels such as natural gas and coal, among others [7].

Electrically powered technologies cover the broad temperature spectrum required by industries [8]. Applications that require low and medium temperatures, such as electric boilers and heat pumps that supply heat and cooling, are not sector-specific and can thus be implemented transversally.

3. Renewable Heat

3.1. Solar Thermal

Solar thermal heat is the energy produced by converting solar energy into usable heat. Solar thermal collectors are the devices used for this purpose. They absorb the incoming solar radiation, convert it into heat, and transfer this heat to a medium (usually air, water, or oil) flowing through the collector. The solar energy collected is transported by the circulating fluid to be used directly or stored in a thermal energy storage tank [9].

There are two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's radiation on a smaller receiving area, thereby increasing the radiation flux [10].

Non-concentrating solar heaters are already in use on a commercial scale. Parabolic troughs have also reached commercial maturity, with well-documented references concerning their availability and reliability [11]. Linear Fresnel collectors are less mature than troughs, but they are also available on a commercial scale [12]. Parabolic dish and power tower receivers also exist on a commercial scale but they are still at the initial stage of commercialisation in Europe. The total overall production of solar thermal energy in the EU-28 countries in 2016 was around 50 TWh, representing a 2% share of renewable energy [13].

The solar process heat installations applied to industrial sectors are similar to those used in residential buildings, especially for those applications where low (<150 °C) to medium (150 °C–400 °C) temperatures are required. For higher temperatures (>400 °C), more advanced or concentrated solar collectors are required. Almost all industrial processes with a heat demand require temperatures that can be provided by a solar thermal system. Among the EIIs, the chemical sector has a high percentage of low- and medium-temperature heat requirements in its production processes (>50%) and is the most suitable industrial sector (among the EIIs) for the effective use of solar thermal heat. The selection of an appropriate solar collector depends on several factors including operating temperature, thermal efficiency, energy yield, and costs, among others [14].

3.2. Heat Pumps

A heat pump (HP) is a technology that provides heating, cooling, and hot water. There are multiple known applications of heat pumps focused on district heating [15][16]. However, the use of heat pumps for industrial applications is gaining interest due to their potential to aid in the decarbonisation of processes. Heat pumps convert energy from air, ground, and water to useful heat using a refrigerant cycle. Such a cycle runs thanks to a special fluid that undergoes phase transitions and circulates in a closed circuit, which is normally composed of four parts: an evaporator, compressor, condenser, and expansion valve [17].

Air-source heat pumps use the heat of the surrounding ambient air as their primary energy source. These types of heat pumps are considered less expensive compared to other existing heat-pump-based technologies. Air-source heat pumps are installed above ground. Another type of air-source heat pump applied to industrial processes is the so-called exhaust heat pump. It uses the exhaust heat from manufacturing processes. Exhaust heat is typically warmer than the surrounding air. This causes the evaporation-to-condensation process to be more effective. These types of heat pumps are very suitable for the industrial sector due to the available heat streams that could potentially be recovered.

Underwater heat pumps require a water source as the heat-exchange medium, which could be obtained either from the ground, surface, or seawater [18]. These types of heat pumps extract heat from the water source, making the heat available for other applications such as heating, cooling, and the preparation of hot water. Water heat pumps are considered highly efficient due to the excellent temperature characteristics of water as an energy carrier. Additionally, the underwater temperature remains stable throughout the year. This type of heat pump is especially interesting for locations where extreme weather does not cause a drop in performance.

The implementation of heat pumps in EIIs is limited for multiple reasons. There are not enough manufacturers of equipment based on the concept of heat pumps. The available equipment is not able to deliver the broad range of process temperatures typically required by industries. Most commercial manufacturers provide equipment able to supply heat with temperatures up to 90 °C. Above such temperatures, the available options in the market are constrained. Only a few providers offer equipment that is able to deliver heat in the range of 120 to 165 °C. Fortunately, several ongoing projects have demonstrated heat delivery in the range of 160 to 200 °C [19]. EIIs have a large heat demand, requiring temperatures up to 200 °C.

3.3. Geothermal

Geothermal energy is increasingly seen as an energy source that will aid in the decarbonisation of European industries. There are projections that by 2050, around 100 to 210 TWh/year will be available using geothermal energy [20]. The main applications of geothermal energy have been in the residential and commercial sectors in the form of district heating [21][22]. However, applications in the agricultural and industrial sectors are also expected [23]. In industries, geothermal energy can be directly employed to supply heat or steam for processes as diverse as pasteurisation, drying, and evaporation, among others. Geothermal heat and steam could be implemented in industries such as the food-processing industry, chemical production, and material mining. Additionally, the benefits of geothermal energy sources include the provision of local, flexible renewable energy; diversification of the energy mix; reduction in fossil-based fuel imports; and protection against volatile fossil fuel prices [24].

Geothermal energy applications are highly dependent on the below-surface water temperature. According to Dalla Longa and colleagues [24], practically all regions in Europe show an economical potential for geothermal energy applications depending on the depth. Except for Iceland and a few other European regions with clear volcanic activity, the potential to produce electricity from geothermal energy is limited to reservoirs of depths less than 2 km. Direct geothermal applications, such as in agricultural greenhouses or industries, can be developed when reservoirs with depths of less than 2 km are available.

Historically, European countries that have taken advantage of geothermal energy, such as Iceland, Italy, France, and Hungary, among others, have been the first to develop applications based on this energy source. However, applications based on the use of geothermal energy can also be developed in other low- and medium-enthalpy areas [25]. In regions with lower-temperature geothermal sites, applications make use of heat pumps [24].

One challenge concerning the use of geothermal-based energy is related to the financing and development of the infrastructure for a new heat grid [26]. Retrofitting is seen as an alternative to the implementation of geothermal energy not only for its most common application—urban district heating—but also as an energy source for energy-intensive industries.

3.4. Solid Biomass

Solid biomass has been identified as a key fuel for the transition to renewable energies in Europe. It is by far the main feedstock (91%) for bioheat production [27]. There are many conversion processes needed to transform biomass into useful forms of energy, which can be categorised into three main conversion pathways: thermochemical, physicochemical, and biochemical. Renewable heat can be produced using technologies that are characterised as thermochemical conversion processes.

As of 2018, the pulp and paper sector, as well as the wood and wood product industries, used a combined 81% of the biomass used in EU industries for energy consumption. The non-metallic minerals sectors, including glass, ceramics, and cement, are by volume, the third largest industrial users of biomass. Other EII sectors, including the chemical and petrochemical, iron and steel, and non-ferrous metals sectors, use 0.64%, 0.04%, and 0.03% of the biomass for energy consumption, respectively [28].

Biomass combustion to produce heat in combination with electricity is widely applied in several EII sectors. One example is the Polaneic Green Unit in Poland, where the older pulverised coal boiler was replaced with a biomass-fired circulating fluidised bed boiler [29]. Torrefied biomass was applied in the iron and steelmaking industry in existing blast furnaces. Steelmaker ArcelorMittal, Belgium, has started the construction of a new facility called the Torero plant. The produced torrefied biomass will partly substitute pulverised coal and be used as an alternative carbon source [30]. Gasification plants are mainly dedicated to producing heat and electricity from which the heat is used for district heating. There are, however, a few examples of using ‘producer gas’ for pyro-processing systems in cement plants. One such example is in Germany at the Rüdersdorfer Zement GmbH cement plant [31].

Biochar as a by-product of biomass gasification and pyrolysis is of interest to energy-intensive industries as a substitute for fossil coal used in steel production [32]. Biochar in multiple formats has been tested and compared with anthracite reference coals. Melting tests in a pilot electric arc furnace have shown that biochar reacts in a similar way to reference coals. Thus, biochar shows great potential for use in industrial-scale electric arc furnace steelmaking as a substitute for fossil coal. Additionally, biochar obtained from pyrolysis and gasification can be carbon-negative by combining net carbon removal from industrial processes with the production of energy or other added-value products beyond sequestered carbon [33].

3.5. Liquid and Gaseous Biofuels

Biofuels are obtained via the conversion of an organic feedstock either into a liquid (most common), solid, or gaseous form of fuel [34]. Biofuels can be identified depending on the feedstock used for their production in conventional and advanced biofuels [35]. Although conventional biofuels (first-generation biofuels) are known to be produced from edible and land-consuming feedstocks, advanced biofuels (second-generation biofuels) make use of non-food and non-feed organic feedstocks [36]. Although most commercialised biofuels (e.g., biodiesel and bioethanol) are used in the transport sector [37], they are not extensively used in energy-intensive industries within the cement, iron, ceramic, and chemical sectors, to name a few. These sectors still rely on the use of conventional fossil fuels for their processes such as combustion-carbon-based electricity and natural gas for heat production. The former can be substituted more frequently with renewable electricity from variable sources. However, the combustion of natural gas could ideally be substituted by biomethane [38]. Not only is this renewable gas obtained via the anaerobic digestion of multiple renewable organic feedstocks but its use in industries also does not require any modification of current industrial processes.

Independent of the technical feasibility of biomethane, one of its implementation challenges is deeply linked to its availability [39]. It is expected that biomethane will only replace around 8% of the total natural gas consumption in the EU by 2030 [40].

3.6. Green Hydrogen

Hydrogen is an energy carrier that can be produced from fossil fuels and biomass, water, or a mixture of both. At present, roughly 95% of worldwide hydrogen production comes from fossil fuels [41]. Hydrogen is considered renewable or green when the full life-cycle greenhouse gas emissions of the production process are close to zero. The most common method of producing green hydrogen is through the electrolysis of water (in an electrolyser powered by electricity), and with the electricity stemming from renewable sources, it can also be produced through other pathways. FCH JU—The Fuel Cells and Hydrogen Joint Undertaking—investigated 11 different green hydrogen pathways besides electrolysis, and 6 pathways were considered sound for 2030 [42].

Currently, there is no significant hydrogen production from renewable sources; green hydrogen has been limited to demonstration projects [41] but is expected to be developed in the coming years. In low- and medium-grade heat industrial segments, using renewable electricity is the primary way to decarbonise industrial processes according to FCH JU [43]. However, electric heaters, boilers, and furnaces become less efficient when higher temperatures are required, and their use may necessitate major adaptations of existing production processes. For industrial processes in the high-grade heat segment, hydrogen may, therefore, offer benefits due to its ability to generate high temperatures using process setups similar to those used today. As more than 30% of the industries’ CO2 emissions stem from high-grade heat, these uses have an essential role to play in decarbonisation, certainly for as long as CCS or other innovations are not competitive. Besides its use in high-grade heat processes, EIIs can use green hydrogen for chemical and synthetic fuel production and as a reduction agent (steel industries).

The production of green hydrogen is generally not yet carried out on a commercial scale. It can be used directly for heat and/or power generation, for material use (in the chemical and refinery industries), in production processes to avoid the production of CO_2 emissions (in the steel industry), or in CCU processes (in the lime and cement industries). In the steel industry, some companies are exploring the use of hydrogen in their production processes. The three Swedish steel-sector companies, steel manufacturer SSAB, mining company LKAB, and energy company Vattenfall, collectively work on HYBRIT (Hydrogen Breakthrough Ironmaking Technology) and are developing a pilot plant at the SSAB site in Luleå, Sweden. In Germany, the multinational steel production company ArcelorMittal is taking steps to reduce its carbon emissions by retrofitting a production plant to use hydrogen for iron ore reduction. ArcelorMittal partnered with the University of Freiberg to test a hydrogen-based process at its Hamburg steel production plant [44].

Regarding green hydrogen, biological hydrogen production via dark fermentation, photosynthesis, or photofermentation could also be considered [45]. Biohydrogen production is of interest to the scientific community and represents an additional route to green hydrogen production [46]. In the current European context, there exist ambitious goals for green hydrogen produced from electrolysers powered with renewable electricity (6 GW by 2024, 40 GW from 2025 to 2030, and green hydrogen deployment on a large scale by 2030). It seems unlikely that biological hydrogen production processes could cope with such goals [47], especially when biological hydrogen production has only been demonstrated at a low TRL [48].

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