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# ECONOMIC AND FINANCIAL ANALYSIS OF PLANTS FOR OBTAINING ENERGY FROM HYDROGEN*

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## Abstract

To meet the needs of decarbonisation of the economy and the implementation of the Italian PNRR, hydrogen appears to be a current and convenient source for obtaining energy. The paper tries to evaluate some pilot projects located in the Sicily region from an economic and environmental point of view. After analyzing the Sicilian energy plan, the project carried out by a collaboration with two companies is described, of which a technical and economic analysis is carried out, highlighting the economic and environmental advantages of the pilot plant. This experimental project can allow cooperating companies to test the idea on an industrial scale, to enhance the Sicilian competitive environment and make technological innovations for the generation, storage and transport of green hydrogen in the Sicilian region, a hub for hydrogen clean consists of a regional network consisting of the production, the end use and the connection infrastructure necessary to produce and transport clean hydrogen in a functional regional market.

*Keywords:* circular economy, hydrogen energy, industrial area, sustainability

## 1. Introduction

According to the Integrated National Energy and Climate Plan ("INECP"), published in December 2019 by the Ministry of Economic Development together with the Ministry of the Environment and the Ministry of Infrastructure and Transport, one of the primary objectives that Italy aims to achieve by 2030 is the reduction of about 30% of national

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greenhouse gas emissions. With this in mind, hydrogen plays a key role in achieving this goal due to its unique chemical and physical characteristics (Crabtree and Dresselhaus, 2008).

The Italian legal framework governing the production, operation and connection of hydrogen is quite fragmented and this has often proved to be an obstacle to the development of new projects. For example, although the authorization process for hydrogen production and storage is set at national level, local public authorities may have different requirements regarding land use. This divergence can lead to uncertainties in terms of project funding and timing.

Another relevant aspect is the lack of a clear distinction, in terms of authorization procedures, between:

- the production of hydrogen for industrial use obtained by the reforming process;
- the production of green hydrogen obtained through the electrolysis process.

The Italian environmental authorities do not distinguish between these two processes with the result of imposing the same level of restrictions, even if electrolysis is an extremely more sustainable production process, almost zero impact, compared to steam reforming, which generates $CO_2$ emissions. Therefore, it is desirable to introduce different authorization regulations based on the dimensional scale of the plants and which distinguish hydrogen production processes that involve greenhouse gas emissions from those with low or zero emission levels (Barisano, 2021).

On 23 October 2018, the Ministry of the Interior, in agreement with the Ministry of Infrastructure and Transport, issued a Ministerial Decree containing "Fire prevention technical standards for the design, construction and operation of hydrogen distribution systems for motor vehicles ". The objectives of the technical regulation are to minimize the causes of fire and explosion; limiting damage to people and buildings in the event of an event and allowing rescue to be carried out safely. The “Energy efficiency, mobility, hydrogen decree” (not yet issued) for the launch of the ecological transition is being drafted. It is considered optimal to transfer all the Mise competences on renewables, decarbonisation, energy efficiency, research, sustainable mobility, hydrogen plan and sector strategies, etc to Mite (Capozza et al., 2021).

It is necessary to differentiate hydrogen based on the production process through which it is obtained:

- Gray hydrogen: it is the most polluting, as its production generates emissions of $CO_2$. It represents the majority of hydrogen produced today (about 95%)
- Blue hydrogen: with low $CO_2$ emissions. It is carried out through the steam reforming of methane, but associated with a process of capturing and storing the greenhouse gases produced through this process, or, carried out with electrolysis, but powered by low-emission electricity sources (such as nuclear power plants) or in turn associated with a capture & storage method.
- Green hydrogen: zero or close to zero emissions. It includes: o that produced by electrolysis in electrolysers powered by energy from renewable sources; o clean hydrogen from bioenergy;
- Turquoise (or circular) hydrogen: it is produced from waste, by pyrolysis and subsequent purification. Green hydrogen seems to be the only viable alternative capable of generating an important reduction in emissions of $CO_2$.

The objective of this PAPER is to verify the effective applicability and functionality that hydrogen can have in the process of decarbonization of the economy. To achieve this goal, the analysis of a case study was carried out concerning the project implemented, in collaboration with two companies in the sector, aimed at the creation of a hypothetical innovative Hydrogen Hub in the Catania hub.

## 2. Materials and methods

Hydrogen is a very important molecule with an enormous range of applications and uses. The main uses are: oil refining, ammonia production, methanol production, steel production through the direct reduction of iron ore, fertilizer production and food processing (Zhang et al., 2021). The uses of hydrogen can be roughly divided into the following categories:

- As a reagent in hydrogenation processes;
- As a $CO_2$ "scavenger";
- As a fuel;
- As a refrigerant in electric generators.

In most applications of hydrogen as a reagent, hydrogenation takes place to insert hydrogen in order to saturate the molecules or to split them in order to remove atoms such as sulfur or nitrogen (Popa et al., 2015). Hydrogen as a reagent is used above all in the chemical and petroleum industry: among the most frequent uses we find: Ammonia production (almost 50%), petroleum refining (37%) and methanol production (8%). A sudden increase in the use of hydrogen within oil refining is expected due to changes in environmental regulations, which have become more stringent (Ramachadran and Menon, 1998). The primary application of hydrogen as a fuel occurs in the aerospace industry. The combination of liquid hydrogen and oxygen has been used as a propellant for numerous applications for several years. A mixture of $H_2$ and $O_2$ is able to release the highest value of energy per unit weight of propellant, a property that is fundamental in aerospace applications (Aline, 2008). Hydrogen can then be used inside fuel cells, devices that convert hydrogen and oxygen into electricity, they represent a valid alternative to fossil fuels for their efficiency, versatility and environmental sustainability.

Different types, of different sizes, of fuel cells are available for various applications: small cells can power laptops or mobile phones, large cells instead can supply power to electric grids, emergency energy systems and allow to supply electricity to places not connected to a eletricity grid. Carbon Capture, Usage and Storage (CCUS) technology can be applied to both SMR and ATR hydrogen production. The use of CCUS with SMR plants can lead to a reduction in carbon emissions of up to 90%, when applied to both process and energy emission streams. There are several ways in which $CO_2$ capture can take place in an SMR facility. $CO_2$ can be separated from the high pressure synthesis gas stream, reducing emissions by up to 60%. $CO_2$ can also be captured by the more diluted furnace fumes. This can increase the level of overall emissions reductions by up to 90% or more, but it also increases costs. ATR is an alternative technology in which the required heat is produced in the reformer itself. This means that all $CO_2$ is produced inside the reactor, which allows for higher $CO_2$ recovery rates than those achievable with SMR. The splitting of methane offers a potential new way to produce hydrogen from natural gas. Several technologies have been developed since the 1990s. The main technology is based on three-phase AC plasma and uses methane as a raw material and electricity as an energy source.

Splitting methane requires high-temperature plasma and significant thermal losses reduce its efficiency advantage, but it uses three to five times less electricity than electrolysis for the same amount of hydrogen produced. It produces a small amount of $CO_2$ and creates solid carbon in the form of carbon black. It requires more natural gas than electrolysis, but could create additional revenue streams from the sale of carbon black for use in rubber, tires, printers and plastics.

Water electrolysis is an electrochemical process that divides water into hydrogen and oxygen. Today, there are three main electrolysis technologies: alkaline electrolysis, proton exchange membrane electrolysis (PEM), and solid oxide electrolysis cells (SOEC):

- Alkaline electrolysis: it is the method with greater maturity and greater commercial diffusion. The system consists of a pair of electrodes immersed in an alkaline solution, usually potassium hydroxide (KOH) at a concentration of 25 to 30% and separated by a diaphragm. In the cathode the water is split to form H2 and release hydroxide anions which pass through the diaphragm and recombine at the anode to form $O_2$.
- Proton Exchange Membrane Electrolysis (PEM): PEM electrolyser systems were first introduced in the 1960s by General Electric to overcome some of the operational drawbacks of alkaline electrolysers. They use pure water as an electrolyte solution, thus avoiding the recovery and recycling of the potassium hydroxide electrolyte solution needed with alkaline electrolyzers.

They are relatively small, which makes them potentially more attractive than alkaline electrolysers in dense urban areas. They are capable of producing highly compressed hydrogen for decentralized production and storage at filling stations. In the face of this, however, they need expensive catalysts for electrodes (platinum, iridium) and materials for membranes, and their lifespan is currently less than that of alkaline electrolysers. Their overall costs are currently higher than those of alkaline electrolysers and are less common. Solid oxide electrolysis cells (SOEC): they are the least developed electrolysis technology; they have not yet been commercialized.

## 3. Case study

Sicily can be an excellent starting area for the implementation of a transition to a hydrogen economy, in fact, this region has the following characteristics that make it an excellent starting zone:

- its good availability of renewable resources at competitive costs given the high solar radiation in the region and the potential for imports from North Africa at even lower costs;
- limited interconnection with the rest of the Italian electricity grid due to physical constraints to be connected via submarine cables;
- an existing capillary natural gas network: the area has a transmission network of 1,100 km of national pipelines and 1,500 km of regional pipelines, as well as a large network that covers all cities
- good mix of final applications on the demand side, the region has 1.6 million gas-powered residential and commercial companies, the transport sector has 80,000 medium and heavy trucks and buses, as well as 578 km of diesel railways, and Sicily also includes refineries with a current production volume of 0.7 Mbbl per day.

The Environmental Energy Plan of the Sicilian Region (Pears), is the programmatic document which, in line with the European objectives of the 'Green Deal', defines the evolution of the regional energy system up to 2030, through useful actions for the energy transition and decarbonisation (Matarazzo et al., 2022). The plan envisages two main objectives: the reduction of energy consumption in end uses, with particular reference to the civil-agricultural sector and to the transport sector (smart mobility); the increase in the share of renewable energy, with an estimated incidence of 68% by 2030 on the total regional energy production, compared to 33% in 2019. The plan also focuses on the modernization of existing photovoltaic and wind systems and on the installation of new plants in suitable areas, which are primarily disused quarries and landfills, unproductive agricultural land, industrial sites.

All the professionals involved in the hydrogen supply chain will participate in the observatory, from renewable energy producers to academic professors involved in research.

The project will be developed in collaboration with two companies in the sector and will aim to accelerate the full commercial maturity of all those technologies that make it possible to produce green hydrogen in a sustainable and competitive way. Enel manages a large part of the country's electricity distribution network and offers integrated solutions for products and services for electricity and gas. In total, the group in question has a net installed capacity of over 84 GW and distributes electricity and gas to approximately 69 million customers thanks to a network of approximately 2.2 million kilometers (Di Leo et al., 2020). The production of electricity is made from various energy sources including geothermal, wind, photovoltaic, hydroelectric, thermoelectric, nuclear, biomass and solar thermodynamic. In the year 2021, the Enel group produced a total of 232 billion kWh of electricity, distributed 510.3 billion kWh on its networks and sold 309.4 billion Kwh.

## 4. Results and discussion

A clean hydrogen hub is a regional network consisting of the production, end use and connection infrastructure needed to produce, transport, store and use clean hydrogen in a functional regional market. These potentially large demonstration projects aim to test and demonstrate the technologies needed to minimize the greenhouse gas (GHG) emission intensity of hydrogen production, use it in new applications to aid decarbonization and store it and transport it in new ways to meet the demands of a newly formed national hydrogen market.

The development of a Hydrogen Hub in Sicily is at the very heart of the collaboration between these two companies, which intends to activate a supply of green hydrogen produced from renewable energy from the Carlentini wind farm in eastern Sicily (Saccani et al., 2020). The more than 200 tons of estimated production capacity of the Sicilian hub are the subject of the annual supply provided for in the agreement.

Once fully operational, green hydrogen will be produced primarily by a 4 MW electrolyser, powered exclusively by renewable energy from the existing wind farm, and to a lesser extent by state-of-the-art platform-tested electrolysis systems. Launched by one of these companies in the sector in September 2021, NextHy's Hydrogen Industrial Lab is a unique example of an industrial laboratory where production is constantly accompanied by technological research. In addition to the sectors reserved for large-scale production, there are also areas dedicated to the experimentation of new electrolysers, components such as valves and compressors, and innovative liquid and solid storage systems. This is an ambitious project that focuses on a sustainable energy source that will develop at every link in the supply chain: in NextHy green hydrogen will not only be produced, stored and moved to an industrial scale, but also purchased and used by companies that have understood that green hydrogen is the solution to decarbonize their production processes.

One of the two groups, founded in 1922 and based in Monza, operates in the industrial and medical gas sectors and in home care throughout Italy and abroad in France, Germany, Slovenia, Turkey and Spain. With a turnover of over 700 million euros and 2,250 employees, it produces, develops and markets gas, innovative technologies and integrated services for the industrial sector. To carry out a satisfactory technical and economic analysis, it is appropriate to implement the 3S (Source, System, Service) analysis method. In terms of energy source (Source), a company has chosen to exploit the Carlentini wind plant, a plant built by the same company, inaugurated in December 2001. The structure consists of two wind farms: Carlentini 1, consisting of 11 wind turbines and Carlentini 2, consisting of 17 wind turbines of 850 kW.

The total power of the two parks is 21.7 MW and the expected production of approximately 38 million kilowatt hours. The exploitation of this wind farm will allow one of the two companies to make significant savings in terms of costs, as the company will be able to count on its own structure, of which, as regards the Carlentini 1 park, it has already amortized the costs of construction, which amount to approximately 6.2 million euros, over 20 years, while for Carlentini 2 it was possible to amortize the costs for approximately 14 years (Billi et al., 1986).

As for the second S (System), reference can be made to the operational arm of the Nexthy project, namely the Hydrogen Live Industrial Platform located between Carlentini and Sortino. This plant will leverage a 4 mw electrolyser with a production capacity of 245 t/year and will also act as a yardstick for the test platform, located alongside it, which will be able to test new technologies for hydrogen: electrolyzers up to three MW, innovative stacks or storage systems and components necessary for the production of hydrogen can be tested.

Finally, as regards the last S (Service), the analysis can be divided into two dimensions: o Marketing service in collaboration with one of the two companies; o Research and innovation service in collaboration with partners, stakeholders and innovative startups.

The transport of the product will be carried out through a network of hydrogen pipelines and cylinder wagons already available to the company that has set itself several goals:

- Being able to reliably and safely satisfy both production and energy efficiency industrial needs;
- Contribute to the creation of the demand for green hydrogen, collaborating with public services such as, for example, public transport;
- Building the largest green hydrogen hub in Southern Italy.

What the company is looking for are new solutions, based on both new technologies and existing technologies, but revisited to reduce costs and increase efficiency and sustainability, looking at both electrolysers and storage systems (Rubin et al., 2013). The proposals received are evaluated and selected on the basis of expected performance, maturity and sustainability.

## 5. Concluding remarks

The project developed by one of the two companies, in collaboration with another in the sector, can give unprecedented impetus to the economy of the Italian island, generating a significant amount of environmental benefits, allowing to avoid the emission of tot kg of $CO_2$ per year, giving the possibility to offer a balancing service to renewable energies, managing to accumulate the energy produced in excess, and at an economic level, leading to the development of the work chain and consequently to the formation of new jobs.

Work, attracting foreign investments, reducing the costs of the various energy-intensive industrial chains and contributing to the increase of the region's tourist attractiveness by improving its image from a green point of view. The advantages of using green hydrogen in various application fields are undoubted: using it as an energy source, in terms of environmental impact, both $CO_2$ and particulate emissions are drastically reduced, which would derive alternatively from the use of fossil fuels. ; as an energy carrier it allows greater efficiency in the production of renewable energy sources by allowing the storage of excess energy during peak production hours.

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