UNIVERSITY OF PIRAEUS
Department of International & European Studies
MSc in Energy: Strategy, Law and Economics

THESIS

The viability of green hydrogen factory in Greece: Case of Hellenic Hydrogen

VODENIOTIS ANASTASIOS CHRISTOS

Piraeus, January 2025

The intellectual work fulfilled and submitted based on the delivered master thesis is exclusive property of mine personally. Appropriate credit has been given in this diploma thesis regarding any information and material included in it that have been derived from other sources. I am also fully aware that any misrepresentation in connection with this declaration may at any time result in immediate revocation of the degree title.

Vodeniotis Anastasios Christos

The viability of green hydrogen factory in Greece: Case of Hellenic Hydrogen

Vodeniotis Anastasios Christos

Supervisor: Dr. Galanos George

Examiners: Dr. Kotios Angelos, Dr. Roukanas Spyridon

Tables of Contents

1. Abstract

The subject of my work emphasizes the importance of renewable energy sources (RES) in Greece, particularly focusing on the production and sustainability of green hydrogen. It highlights how green hydrogen, produced using renewable energy sources, represents a significant advancement in clean energy technologies. The study describes the various forms of RES, including solar, wind, geothermal, biomass, and hydropower, as well as their respective roles in generating electricity with minimal environmental impact. Solar energy, recognized as a key contributor, involves photovoltaic panels that convert sunlight into electricity, while wind energy harnesses kinetic energy from the wind through wind turbines.

Hydropower utilizes the potential energy of water to generate electricity, making it a stable energy source. However, the installation of RES projects can affect local ecosystems and requires large land areas, underscoring the need for environmental management strategies. The case of Hellenic Hydrogen is then introduced, a joint venture aiming to produce green hydrogen by 2027 through a facility in Amyntaio, Florina. This initiative seeks to significantly reduce CO2 emissions, create jobs, and promote economic development in the region while ensuring low environmental impacts. The four main targets are guiding the project's development focus on energy transition, market development, quality assurance, and support for innovation, highlighting Greece's commitment to sustainable energy solutions. Overall, the text encapsulates the importance of integrating green hydrogen into the energy landscape for a cleaner future.

2. My warmest thanks

At this point, I would like to express my gratitude to Mr. Georgios Galanos, whose guidance and advice helped me compile this thesis. I sincerely thank him for the time he dedicated to me. Additionally, I would like to thank my supervising professors, Mr. Kottios Aggelos and Mr. Dagoumas Athanasios , for the time they spent reviewing my work.

3. Renewable Energy

The deeper stimulus of my work should be sought in a phenomenon of our times that will not leave anyone with social, economic, and political concerns indifferent. I am specifically referring to the production and distribution of green hydrogen in our country, as well as the viability of this grand project. Thus, it is very important to define what green hydrogen is. And since renewable energy sources play the most crucial role in its production, it would be reasonable to analyze the initial steps of its production, which are none other than the renewable energy sources themselves.

The first part of the study will therefore be devoted exclusively to Renewable Energy Sources. The term RES refers to the renewable energy sources currently available on the planet. These forms of energy are called renewable because they tend to be fully replenished with their use, in contrast, of course, to non-renewable energy sources, which either do not replenish their reserves or their replenishment occurs at a very slow rate. According to the Ministry of Energy of Greece, renewable energy sources are categorized as follows:

Solar Energy

Wind Energy

Geothermal Energy

Energy from the Sea

Biomass

Osmotic Energy

Hydropower

Among the seven categories mentioned above, solar, wind, and hydropower account for almost the entirety of the produced amount of electrical energy from renewable energy sources that are used for both commercial and industrial applications.

Solar energy

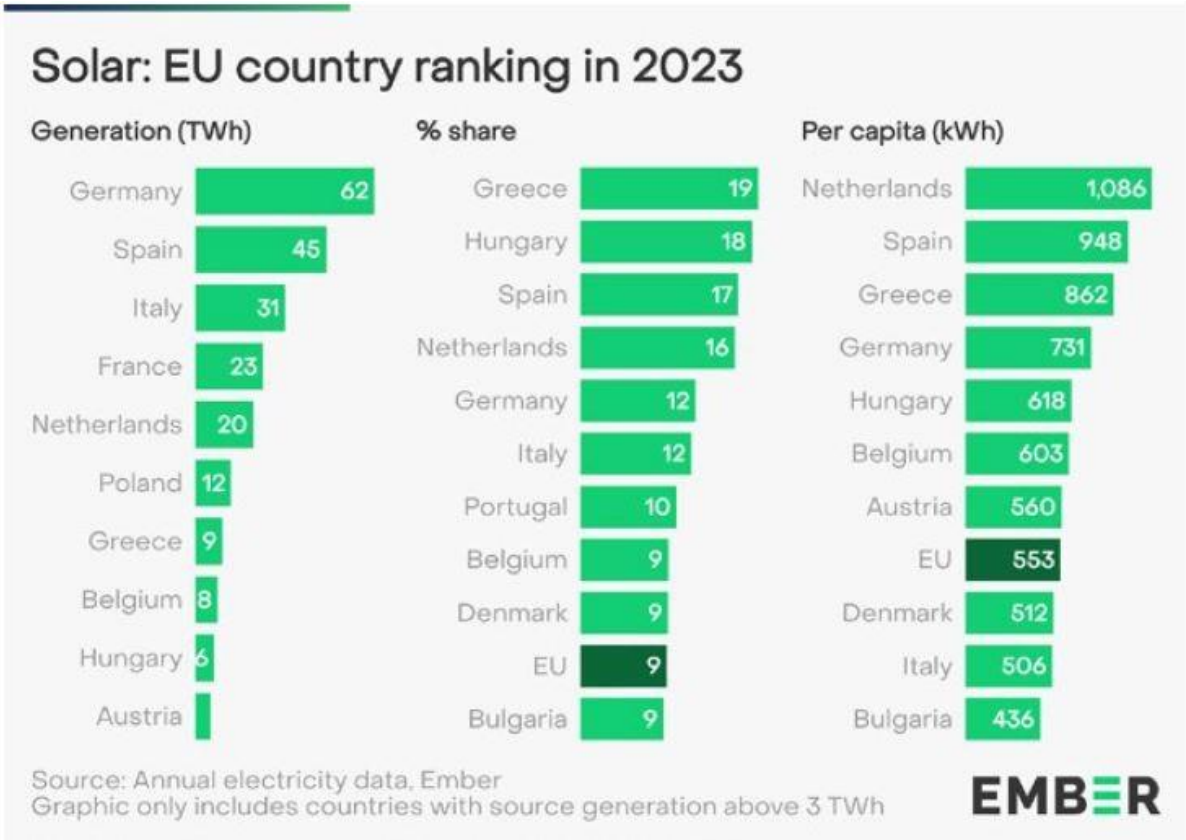
It is the form of energy that, compared to the others, has the greatest technological advancement and the highest production. Primarily, it is generated through the use of photovoltaic panels that are installed either in large solar parks in the countryside, producing electrical energy depending on their efficiency, or on rooftops and terraces of homes, businesses, and even factories to meet the needs of households, businesses, and industries. This is the form of energy in which enormous amounts have been invested in research and development to increase the efficiency of the panels, as well as their lifespan, while at the same time, it is also particularly friendly to the environment, as their installation requires minimal environmental impact.

According to Sotiris Kalogirou, professor and chairman of the Department of Mechanical Engineers and Materials Science and Engineering, the production of energy through photovoltaic panels relies on the beam of light that enters the panel from the sun. The sunlight is absorbed by solar collectors, which consist of hundreds of solar cells. Thus, the solar cells have layers of semiconductors, and at the moment the sunlight strikes these semiconductors, electrons are immediately released. The free flow of electrons ultimately creates electric current. The electric current is collected through the substation installed near the park and is then transmitted through the high and extra-high voltage network to households, businesses, and industries to meet their needs.

Initially, it would be important to mention the benefits derived from electricity production through solar energy. This is a form of energy with low maintenance costs. Solar parks have very low maintenance costs compared to other energy sources. The solar panels are of high technology and durability, capable of withstanding time and various weather conditions. Additionally, their lifespan and efficiency have increased, now approaching 25 to 30 years before being replaced with new ones. All of these factors lead to a sustainable cost of installing photovoltaic parks for the production of electrical energy from the sun. Furthermore, the most significant benefit of solar energy production is the dependence reduction on conventional energy sources, namely non-renewable energy sources. By harnessing solar energy, the production of electricity from the burning of fossil fuels, which are harmful to the environment, such as oil, coal, or natural gas, is significantly reduced. This, in turn, drastically decreases greenhouse gas emissions, which are detrimental to humanity and continuously increase the planet's temperature.

At the same time, another method of energy production through solar radiation is thermal solar systems. These systems play an important role in the economy of each country. According to Christos Michalopoulos, vice president of the Association of Solar Energy Industries, more than 1,500,000 households annually save over 500,000,000. The solar water heaters that make up these thermal solar systems are devices installed on the rooftops of homes or in sunny locations, providing abundant hot water to households, depending on the periods of sunshine. At the same time, the annual reduction in carbon dioxide (CO2) emissions is equivalent to the amount of CO2 emitted by a family car annually. Therefore,

they almost entirely replace the use of electric water heaters, which consume enormous amounts of energy during their operation. According to Ember's data, the percentage of electric energy produced in the country through solar energy is around 19%. This literally represents a huge leap for our country in the field of renewable sources. Only in 2022, 1.4 GW were added to the country's energy portfolio, and 1.7 GW in 2023. These figures show our country’s shift towards renewable energy sources, whereas the European average for electricity production from renewable sources is at 9.1%.



Wind energy

Wind energy is one of the primary renewable energy sources globally. Along with solar energy, it stands at the forefront of renewable sources, offering substantial amounts of energy by harnessing a single element of nature: the air. Wind energy is defined as the energy produced from the kinetic energy of the wind, which is then converted into electrical energy through wind turbines. Thus, it is clear that this type of energy is particularly environmentally friendly, as it uses the inexhaustible resource of wind as its fuel.

According to the Greek Scientific Association of Wind Energy, one of the main advantages of creating wind farms is that they require a short construction time. This happens because neither mining nor energy conversions are necessary. At the same time, it is considered a low-cost form of energy with relatively stable prices. This allows it to compete in terms of pricing and profitability with traditional forms of energy. Additionally, its installation is accessible everywhere, especially in areas like deserts that are unsuitable for other business activities such as agriculture; at the same time, it can coexist with other commercial and industrial activities as well as agricultural and livestock practices.

On the contrary, wind energy also presents certain disadvantages that require particular attention to minimize. More specifically, high-voltage lines are needed to transmit electricity to the energy market without problems. However, in our country, high and extra-high voltage lines are not evenly distributed throughout the territory, but follow specific routes to connect the regions of the country. This results in additional costs for transporting energy through the creation of these high-voltage lines. Additionally, there are limitations related to wind speed. High-intensity winds can create problems for the rotor and generally affect the smooth operation of the park; for this reason, certain cut-off measures are applied to prevent such physical damages. Also, there are unpredictable weather conditions that affect the overall production of wind farms. I specifically refer to the absence of winds of at least moderate intensity for reasonable periods, perhaps even for days. This disrupts the steady energy production, ultimately reducing the efficiency of the park. Of course, with the energy storage systems and batteries currently being installed, this problem tends to be resolved. Finally, wind farms also create certain environmental impacts. I specifically refer to the populations of birds that interact with the ecosystems in which the wind farms are constructed. At the

same time, the establishment of wind farms negatively affects the aesthetics of the landscapes where they are built, while their construction requires vast areas of land.

The process of producing kinetic energy from the wind relies entirely on wind turbines. The wind, depending on its intensity, sets the blades of the wind turbine in motion. During their rotation, the blades, in turn, rotate the generator's shaft. Thus, the generator converts the produced kinetic energy into electrical energy through electromagnetic induction. At the same time, the generated electric current is transferred via cables and through substations to be used for industrial, residential, or any other needs. Locations where more than one wind turbine is set up are called wind farms. Wind farms are constructed in locations that favor moderate to high-intensity winds. For this reason, these farms are usually installed in areas of high elevation, such as hills and mountains. Additionally, in recent years, with advancements in technology surrounding renewable sources, the construction of farms in marine and lake zones has been proposed. Platforms are built on the seabed or lakebed, and the farms are then installed on these platforms. These wind farms are called offshore farms. The reason for this is that, unlike the continental land where winds weaken for certain hours of the day and night, in the sea, winds are constant. As a result, the wind turbines installed there provide a continuous flow of electrical energy. Thus, offshore farms, as opposed to other forms of renewable energy sources, provide a continuous and abundant production of electric current.

In our country, the map of wind farms has expanded rapidly in recent years. According to the Greek Scientific Association of Wind Energy, 23.5% of the total electricity generation in our country came from wind farms. At the same time, wind power reached 5,226 MW in 2023. In total, this year, 153 new wind turbines with a total power of 542.8 MW were connected, marking an annual increase of 11.6% in wind energy production compared to 2022. The geographical distribution of the country's wind farms is spread across almost all regions. The region at the top of wind production is Central Greece, with a production share of 44% and 2,293 MW, followed by the Peloponnese with a production share of 12% and 639 MW, while Eastern Macedonia and Thrace rank third with 534 MW and a share of 10%.

From the above, it is clear that wind energy is and will continue to play a leading role in electricity generation in the coming years.

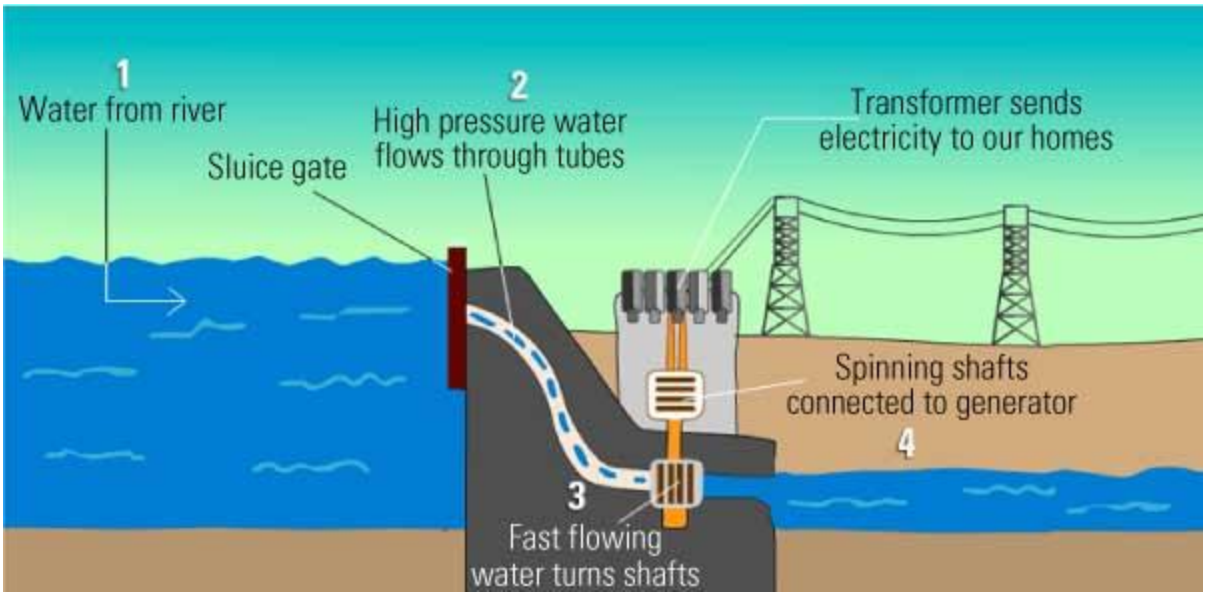
Hydroelectric energy

Among the renewable energy sources used in Greece as well as in many other countries, hydropower cannot be overlooked. It stands out as one of the most important sources of green energy with a zero carbon footprint, delivering substantial amounts of energy. It is the only renewable energy source that utilizes potential energy and converts it into electricity. Practically, it represents an inexhaustible source of energy that exploits rivers, streams, and both artificial and natural dams to produce electrical energy. The operation of a hydropower plant is very simple. Artificial or natural dams hold vast quantities of water, which are then violently released from a significant height. At the base of the dam is the hydropower plant, which receives these quantities of water. At that point, large turbines move due to the pressure exerted by the water and rotate at high speeds. As with wind turbines, generators are installed within the turbines that convert the kinetic energy of the turbine directly into electricity. Thus, the potential energy of the water, which is manifested as the water rushes down from a great height, is transformed into kinetic energy with the help of the turbines and subsequently into electrical energy through the generator inside the turbine. For this reason, it is the only energy source that utilizes the potential energy of a substance (water) for electricity production.

There are two types of hydropower plants: small hydropower plants, which do not require large installations and barriers, and are typically located along river flows. This type of plant serves rural areas since their capacity is smaller compared to large hydropower plants that are constructed at dams. Nevertheless, they have the advantage of low environmental impact since they do not require extensive projects for their construction and do not significantly alter or pollute the ecosystems of these areas. In contrast, large hydropower plants require the construction of large technical barriers. The environmental impacts are greater because embankments must be created, and there is alteration of the land required for their construction. However, these plants can meet the energy needs of industrial parks that require substantial and continuous power, as well as cities.

Among the advantages of hydropower plants is the continuous production of electricity. Utilizing vast water reserves, hydropower plants are the only ones capable of producing continuous current without interruptions, unlike the aforementioned renewable energy sources. Furthermore, hydropower plants can not only determine the continuous production of power but also control the quantity of production. In contrast to the other renewable sources we mentioned, hydropower plants have the ability to decide how much electricity they will produce depending on the demands of the Electricity Grid Operator to whom they supply the electricity. They achieve this very easily by using the gates of the dams they are

located on. Thus, during periods of high electricity demand, such as the summer months or during severe winters, the plants open their sluice gates, allowing for a greater flow of water. Consequently, the amount of potential energy spinning the turbines increases, which in turn increases the amount of electricity produced. Conversely, during periods of low demand, the plant closes the sluice gates, reducing the volume of water released for the movement of the hydro turbines, thereby decreasing electricity production. This is the main advantage of hydropower in relation to other renewable energy sources.



As mentioned, Greece, due to its geographical location and irregular topography, is ideal for the exploitation of hydropower. Currently, there are 110 small hydropower plants operating or under construction in the country, with a total capacity of 228 MW. Furthermore, the most significant large hydropower plants with artificial dams are located at Aliakmonas, with an annual energy production of 220 GWh, as well as at Nestos, near Drama, where the Thesaurus produces 507 GWh annually and Platano-vrysi with an annual production of 278 GWh. We should not forget the artificial dam at Iliarionas, with an annual energy production of 270 GWh, as well as the Achelous River dams STRATOS 1 & 2, with a total production of 156 GWh and the dam at Mesochora with a total production of 160 GWh.

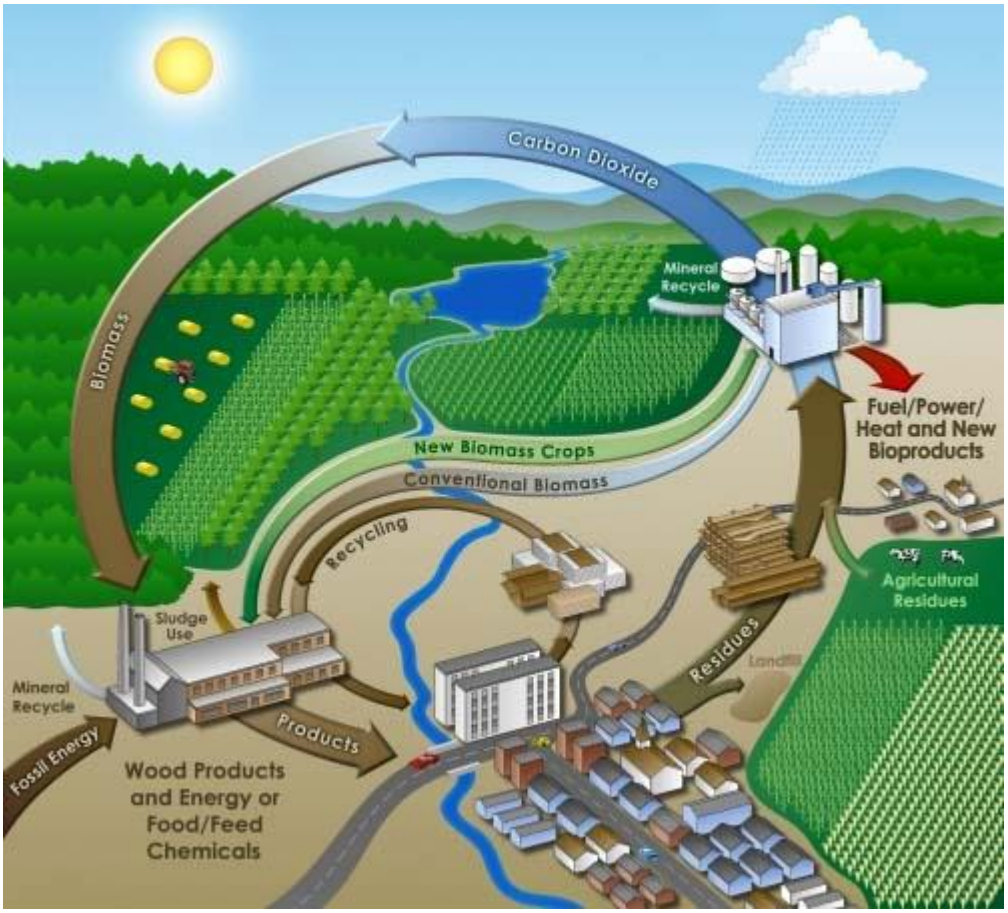
From the above, the importance of hydropower in the balance of renewable sources and in the overall energy balance of our country becomes clear.

Geothermal energy

Geothermal energy is a mild and renewable form of energy that utilizes underground geothermal potential. According to the Ministry of Environment, it has zero or minimal environmental impact with no emissions, as with the rapid increase in technology, geothermal energy can now also produce electricity. To extract the underground fluid, it must exceed a temperature of 30 degrees Celsius. In most countries, geothermal energy is primarily used to meet the needs of desalination units to provide water supply and irrigation to the local population, as well as for greenhouse heating and aquaculture. In Greece, the existence of 30 geothermal fields has been identified that could, in turn, meet the electricity needs for desalination, especially in islands, heating greenhouses, and providing energy for aquaculture with a zero environmental footprint. All these activities require low amounts of energy compared to industrial fields that waste enormous amounts of electric current and energy in general.

BIOMASS

Biomass consists of organic compounds that have either a direct or indirect origin from the plant kingdom. It belongs to renewable energy sources since it is used as an environmentally friendly form of energy. Plants, through the process of photosynthesis, absorb solar energy from the sun and convert it into chemical energy. Humans, in turn, convert this chemical energy into electricity through combustion. Additionally, animals feed on plants, so the chemical energy is transferred to them, meaning biomass is also produced from animals in the form of waste (manure). Furthermore, all agricultural and forestry residues, such as branches from pruning, straw, and wood shavings like pellets, as well as seeds like olive pits, can be used for biomass production through combustion. Biomass is the oldest source of energy used by humans. However, in today's world, due to the shift of most countries towards renewable energy sources to reduce fossil fuel consumption and decrease carbon emissions, which in turn contribute to the greenhouse effect, biomass plays a significant role in the energy balance of most countries, especially those with developed primary agricultural and livestock sectors.



Therefore, the usable biomass for energy production has various forms, as we have seen above. In addition to agricultural, forestry, and livestock residues and waste, we have energy crops, such as sunflowers and canola, whose oils are used as biofuels, representing a green form of energy with zero emissions. At the same time, biodiesel is produced from vegetable oils as well as animal fats and oils. Biodiesel is now used as an alternative fuel, mainly in boilers instead of oil.

Additionally, a portion of biomass for electricity production consists of urban waste. Municipal wastewater contains organic compounds that, with the appropriate treatment, are converted into biogas, which produces electricity when burned. Particularly at wastewater treatment plants, the production of biogas is significant and can help supply part of the city and its infrastructure with electricity.

Consequently, biomass is a form of energy that can be used for the production of large quantities of electricity as well as a mild form of energy, such as geothermal energy. It can thus meet the energy needs of crafts, desalination plants, greenhouses, and fish farms. On the other hand, the production and combustion of biogas can electrify large cities, industrial

units, and urban infrastructures. Furthermore, it can be used by households as a heating medium through pellet and biogas boilers, as well as for district heating, which essentially involves the transfer of hot water through pipelines spanning many kilometers to households.

Additionally, in the residential sector, biomass is commonly used in rural towns, municipalities, and villages as a means of heating through the combustion of firewood in stoves and fireplaces. Finally, processed biomass such as wood chips and pellets are used in specialized boilers. Processed biomass, unlike firewood, has the advantage of easy storage.

4. Green Hydrogen

Green hydrogen refers to hydrogen produced using clean, renewable energy sources, representing a significant and promising technology in the field of clean energy and sustainable development. To fully understand the technology behind green hydrogen, it is important to examine in detail the steps involved in its production and its relative position in the energy landscape. The primary process for producing green hydrogen is water electrolysis. Electrolysis is a chemical process that uses electric current to split water (H_2O) into two elements: hydrogen (H_2) and oxygen (O_2). In the case of green hydrogen, the electricity required for electrolysis comes from renewable energy sources such as solar, wind, hydroelectric, or geothermal energy. The use of renewable energy sources is the critical element that makes hydrogen "green." Unlike other methods of hydrogen production, such as "gray" or "blue" production, which rely on fossil fuels, green hydrogen emits no CO_2 or other greenhouse gases during its production process. This feature makes it a crucial solution for combating climate change and reducing the environmental impact of energy.

The production of gray hydrogen involves the use of fossil fuels. Natural gas, through the steam methane reforming (SMR) process, reacts with water to produce a significant amount of hydrogen, accompanied by substantial CO_2 emissions. "Blue" hydrogen production also uses natural gas but incorporates carbon capture and storage (CCS) to reduce CO_2 emissions. While this approach significantly lowers environmental pollution on the one hand, it still relies entirely on fossil fuels, and therefore, it is not considered green or fully environmentally friendly. Nevertheless, as a transitional form of hydrogen production, it is regarded as an excellent intermediate solution. However, the production of green hydrogen using renewable energy sources is the most environmentally friendly option, as it dramatically reduces CO_2 emissions. The technology of electrolysis, combined with renewable energy, can decisively contribute to the sustainability of the energy system of the future. Challenges remain, such as the high cost of electrolysis and the need to develop infrastructure for hydrogen distribution and storage. Despite these challenges, green hydrogen has immense potential as a fuel and energy source. It can be utilized in various applications, including transportation (in hydrogen-powered vehicles), electricity generation and heating, and industry, replacing conventional polluting burners. In summary, green hydrogen is a critical technology for the transition to a sustainable energy economy, offering a clean and renewable alternative to reduce greenhouse gas emissions and promote energy independence.

Applications of Green Hydrogen

Transportation

The transportation sector is one of the most significant areas where green hydrogen can deliver substantial benefits. Fuel cell vehicles use hydrogen as a fuel to generate electricity through an electrochemical reaction in fuel cells, with the only byproduct being water. These vehicles, such as hydrogen-powered cars and buses, have the potential to cover long distances with rapid refueling, offering a sustainable alternative to conventional gasoline and diesel vehicles. It is well known that the transportation sector is one of the largest sources of environmental pollution and contamination. Since the advent of transportation powered by internal combustion engines, fuels like diesel and gasoline have been used for vehicles, heavy fuel oil for ships, and kerosene for airplanes. It is evident that the transition to an era with reduced emissions and pollution depends largely on the green transition within the transportation sector, which is key to addressing the climate crisis. This transition has already begun with the development and use of hybrid and, primarily, electric vehicles. Indeed, electric vehicles do not produce CO_2 or other greenhouse gases during operation. However,

the electricity used to recharge these vehicles is not entirely generated from renewable energy sources. Additionally, the batteries in electric vehicles are manufactured using per- and polyfluoroalkyl substances (PFAS), which make the batteries less flammable while enhancing their electrical conductivity. These substances are particularly harmful when they come into contact with the environment and ecosystems and have been linked to a range of adverse health conditions for humans. In light of these challenges, hydrogen-powered vehicles present an environmentally friendlier alternative, with green hydrogen offering a sustainable path to cleaner transportation and significant progress toward mitigating climate change.

Therefore, it is crucial that the transition of the transportation sector to the green era is closely linked to the production of vehicles that use green hydrogen as fuel. This is particularly recommended for commercial vehicles such as buses and small or large trucks, as it is considered the optimal solution. Beyond being entirely environmentally friendly, hydrogen-powered vehicles offer several advantages over electric vehicle (EV) technology. Firstly, refueling vehicles that use hydrogen fuel cells—known as Fuel Cell Electric Vehicles (FCEVs)—is comparable in time to refueling conventional trucks, taking approximately 5–10 minutes. This eliminates the need for the nearly hour-long battery recharge required by fully electric vehicles, also known as Battery Electric Vehicles (BEVs). Additionally, the range of green hydrogen vehicles matches that of conventional vehicles. This is in stark contrast to the range provided by electric vehicles, which is significantly lower. These benefits make hydrogen-powered vehicles a practical and efficient choice for transitioning the transportation sector toward a more sustainable future.

Industry

Industrial production is another critical sector where green hydrogen can play a significant role. In steel production, hydrogen can replace coal as a fuel, thereby reducing CO_2 emissions associated with the manufacturing process. Additionally, green hydrogen can be used for synthesizing chemicals such as ammonia, which is a key component in fertilizer production. In chemical processing and manufacturing, green hydrogen can substitute fossil fuels, significantly reducing the ecological footprint of industrial operations. This transition to

hydrogen-powered industrial processes represents a pivotal step toward achieving sustainability and minimizing environmental impact in the sector.

Electricity generation

Green hydrogen can also play a central role in electricity generation through fuel cells or in combination with other technologies, such as thermal power plants. Its ability to store energy in the form of hydrogen and utilize it during periods of high demand or when renewable energy sources are less available can contribute to grid stability and the achievement of energy security goals.

Energy Storage

Green hydrogen can serve as an energy storage medium during periods of high production from renewable sources. When energy production from solar or wind farms exceeds demand, the excess energy can be used to produce hydrogen via electrolysis. The stored hydrogen can later be utilized to generate electricity or for other applications, helping to balance fluctuations in renewable energy production.

Advantages of Green Hydrogen

A. Environmental Benefits

The environmental benefits of green hydrogen are very significant. On one hand, green hydrogen is produced from electrical energy, thus having zero carbon dioxide emissions. On the other hand, the only waste it produces (by-product) is water, and it is completely environmentally friendly. Consequently, its production helps in reducing greenhouse gas emissions, while at the same time, the use of green hydrogen in industry as well as in transportation will enhance air quality, as until now, to meet their energy needs, almost entirely fossil fuels harmful to the atmosphere have been used.

B. Energy Security

With the full production and distribution of units of green hydrogen, it will be another step toward the green transition. Green hydrogen can contribute to achieving the energy security

of states, as its use in the transportation sector, which constitutes one of the main sources of pollution with greenhouse gases, becomes fully compatible. It stands in stark contrast to electric vehicle technologies, which so far have faced issues with battery autonomy, as well as the lack of heavy electric vehicles. The engines running on green hydrogen can compete with internal combustion engines (diesel, gas, and gasoline) and, in fact, with a lower fuel consumption cost.

C. Flexibility

Green hydrogen is highly versatile and can be utilized in a wide range of applications and sectors, from transportation to industry and energy storage, providing a flexible solution to diverse energy needs.

Challenges and Limitations

A. Production Costs

The production of green hydrogen remains expensive compared to traditional hydrogen production methods (such as grey or blue hydrogen). Electrolysis technology is costly, and the price of renewable energy sources can affect its economic viability.

B. Infrastructure

The storage, transportation, and distribution of hydrogen require specialized infrastructure, which is not yet widely developed. This includes pipeline networks, storage facilities, and fueling stations, all of which demand significant investment. Current costs for developing such infrastructure remain notably high.

C. Efficiency and Performance

The efficiency of fuel cells and electrolysis systems can be affected by technological limitations and the need for optimization. Additionally, hydrogen storage presents challenges, as the energy required for compression or liquefaction can limit overall efficiency.

Future Prospects

The technology of green hydrogen is continuously evolving and improving. Researchers and engineers are working to reduce production costs, enhance technological efficiency, and develop the necessary infrastructure. Strengthening the hydrogen distribution and storage infrastructure, along with supportive policies and subsidies, will be critical for its widespread adoption. Support for research and development in this field, as well as collaboration between governments, industries, and research institutions, is essential to successfully transition to an economy based on green hydrogen. Green hydrogen holds significant potential to create a sustainable energy system, contributing to global goals for combating climate change and transitioning to renewable energy. Strategically promoting the technology and overcoming existing challenges will be key to establishing green hydrogen as a central component of the future energy landscape.

Production Method: Water Electrolysis

Green hydrogen production is an advanced technology that utilizes renewable energy sources to generate clean hydrogen without CO_2 emissions. The primary method for producing green hydrogen is water electrolysis, a process that uses electric current to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). This method involves applying electrical energy to break the bonds between hydrogen and oxygen atoms in a water molecule. Electrolysis is carried out through an electrolyte, typically a liquid or solid substance , that facilitates the transfer of ions between the two electrodes in the solution. The two electrodes (cathode and anode) are placed within an electrolysis cell, and when an electric current passes through the solution, ions migrate towards the electrodes. At the cathode, hydrogen gas is released, while at the anode, oxygen gas is produced. This process forms the backbone of green hydrogen production, leveraging renewable electricity to ensure zero-emission energy generation.

Through Renewable Energy Sources

For hydrogen to be considered "green," the electricity used in the electrolysis process must come entirely from renewable sources. In practice, this means that the energy must come

either from solar and wind stations or from hydroelectric or geothermal power plants. The use of renewable energy sources ensures that hydrogen production has no CO_2 emissions and therefore creates a green environmental footprint, making green hydrogen a clean alternative to previous hydrogen production methods based on non-renewable energy sources.

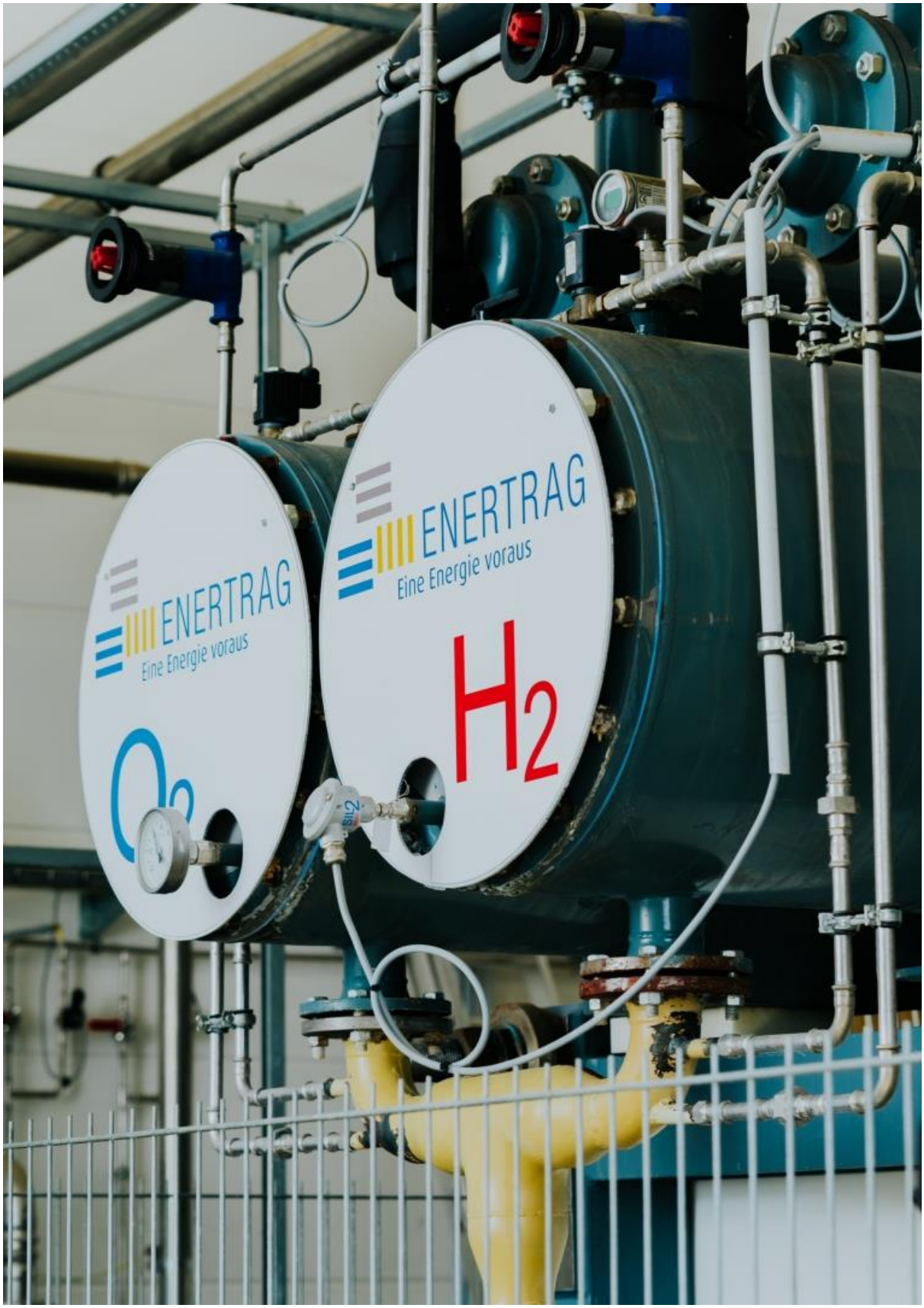
Types of Electrolysis

There are three different types of electrolysis used in electrolysis cells, which are as follows:

Alkaline Electrolysis: They use an alkaline solution, which is often either sodium hydroxide or potassium hydroxide, and are the most common electrolysis technology. Alkaline electrolysis are widely considered reliable and recognized, but they are characterized by particularly low efficiency compared to other technologies.

Proton Exchange Membrane (PEM): They use a solid polymer membrane as the electrolyte. PEM cells, while providing high current density and quick response, have a very high cost in the production process.

Solid Oxide Electrolysis (SOEC): The characteristic of this type is that it operates at high temperatures and is currently the most efficient type of technology compared to other technologies. The potential weakness of this type of electrolysis is that it requires special production conditions and specialized technology in order to provide maximum performance.


ENERTRAG
Eine Energie voraus
O2
ENERTRAG
Eine Energie voraus
H2

Storage and Distribution

After the production of green hydrogen, the next stage is storage and distribution. Storing hydrogen requires high pressure, either in liquid form or through chemical processes such as hydrogen storage. The infrastructure for hydrogen storage and distribution includes tanks, pipelines, and refueling stations, and is essential to avoid issues with its availability for consumption. Despite this, the storage and distribution of green hydrogen is not considered more expensive compared to the corresponding options for other forms of energy, mainly renewable energy sources.

Exports

The sustainability of an energy form in its initial stage depends on internal consumption and distribution, as well as on the reduction of costs incurred throughout its production and distribution. However, for an energy form to become competitive with others and establish itself in the energy landscape, it must pursue the direction of exports. In the previous chapter, we examined renewable energy sources such as biomass and geothermal energy. Although these forms of energy are very environmentally friendly due to their low efficiency and productivity (they are mild forms of energy), they will not, under any circumstances, be able to compete with the investments being made to increase their productivity. This is also the reason why countries do not invest large sums into these forms of energy. Furthermore, their exports are negligible, especially in geothermal energy. Hence, it becomes clear that if our country truly wishes to introduce green hydrogen into its energy portfolio, it must invest in exporting it to third countries. Only in this way can it become a competitive form of energy within the country. The production of green hydrogen requires electricity from renewable sources. Each year, our country increases its electricity production from renewable sources. Therefore, it appears that our country is achieving its energy goals, which are also the goals of the European Union. The surplus that will arise in the energy balance of renewable sources could be used for the production of green hydrogen. Thus, the question arises as to whether this process is feasible, either economically or in practical terms.

From the above, it is clear that Greece, with the leaps it is making in the field of renewable energy sources, will manage to have an energy surplus. At the same time, our country is

currently a significant liquefied natural gas (LNG) hub in the Eastern Mediterranean. Therefore, there is a similarity, although by no means to the same extent as in the example of Australia. Along with the renewable energy units that will supply the green hydrogen production plant with electricity, a portion of the surplus electricity could be made available through renewable sources at the national level created during periods of supersized efficiency. This would lead to the production of even larger quantities of green hydrogen at low cost and potential through LNG storage units, bringing us a step closer to achieving the goal of exporting green hydrogen to the Balkan and European energy markets.

Disadvantages of Green Hydrogen Production in Greece

After analyzing the method and benefits of green hydrogen production, it is very important to examine the disadvantages of this specific investment in our country. First of all, green hydrogen is currently in a transitional production phase in most countries around the globe. This is due to the fact that high technology is required to achieve water electrolysis in order to produce significant quantities of green hydrogen that are economically viable. Additionally, the consumption of green hydrogen requires car, truck, ship, and airplane manufacturers to spend huge amounts on research and development to produce engines compatible with this specific form of energy. Consequently, industries specializing in the creation and production of such engines require not only large capital investments but also a highly specialized workforce. Thus, the costs so far for most of these industries are prohibitive. All of this indicates that investment in our country will already face difficulties for which solutions do not depend on it. On the other hand, there are also internal difficulties. Initially, the facilities for producing green hydrogen and storing these quantities require enormous investment capital with high risk, as global production is currently in an experimental-transitional phase. In addition to the high investment costs, we also face high costs in the area of human resources. It is clear that significant amounts will need to be spent on the jobs that will be created, which must be filled by specialized workers. Additional problems may arise in the process of distributing green hydrogen. As mentioned above, one method of distribution could be the use of natural gas pipelines. It is understandable that such a solution is not feasible at this time, when most households in the country use these pipelines to meet their needs. Therefore, a transportation and distribution network with modern facilities, as well as storage facilities, must be created. This is of utmost importance, as

hydrogen is an extremely flammable gas and particularly dangerous for the human body. In addition to transportation and storage, facilities must be established at refueling stations to ensure safe refueling of vehicles that use green hydrogen. There is an additional cost associated with the transportation and storage of the produced quantities of green hydrogen for market supply.

5. Sustainability

Sustainability, as a concept today, concerns all sectors related to humans as entities. It is intrinsically linked to any activity that takes place, whether economic-productive, political, or social. The notion of sustainability first appeared in 1987 as sustainable development by the BRUNDTLAND Commission of the United Nations (OUR COMMON FUTURE). Thus, sustainability is defined as the ability of a system, activity, or organization to develop and improve in such a way that it meets today's needs without jeopardizing the ability to meet future needs in the long term. This means that current productivity should not, under any circumstances, put future reserves at risk in order to satisfy the needs of future generations.

In this context, sustainability is divided into three main pillars, each of which is of utmost importance and should not, under any circumstances, be undermined or marginalized for the sake of improving the other two. Consequently, these areas are economic sustainability, social sustainability, and environmental sustainability.

Economic sustainability

Initially, economic viability is the backbone of a productive process aimed at producing goods and services to meet the needs of the economy and society. Economies must be characterized by high productivity and efficiency in order to remain competitive. Productivity and efficiency help maximize the production of goods at the lowest possible cost. This cost represents one of the greatest challenges in the production process. Industries, crafts, and businesses often suffer from rising unit production costs and struggle to be economically profitable. This may be due to a variety of factors, both endogenous, such as limited access to technology aimed at improving production methods and consequently increasing production costs, and exogenous, such as restrictions on raw materials that directly lead to price increases, thereby increasing unit production costs. Thus, practices that are deemed economically sustainable target the proper use of resources, the efficient use of capital, and the maintenance of stability to ensure that natural resources are not jeopardized in the future.

Social sustainability

The next fundamental pillar of sustainable development concerns its impact on society. I am specifically referring to social sustainability, which plays a decisive role in society overall. Social sustainability pertains to both the creation and preservation of societies. Humanity, in order to survive and evolve over time, has been compelled, one way or another, to create its own society, whether slowly or rapidly. Society is a collective of individuals who interact with one another or with other groups of people with the ultimate goal of improving their quality of life. Therefore, social sustainability ensures the welfare of people across society as a whole. Its objectives are achieving equality, justice, and generally ensuring basic human rights. Thus, the sustainability of society is intrinsically connected to the democratic system that citizens of countries have sought in recent years. Democracy represents the only mechanism capable of ensuring human rights as well as a series of critically important provisions for individuals, such as the right to education, health, and participation in decision-making processes. Based on the principle of democracy, it is possible to achieve equality among all citizens, regardless of religion, ethnicity, political belief, or gender.

Environmental sustainability

Environmental sustainability has become a major concern in recent years for states, companies, and individuals alike. There are two primary factors that constitute the concept of environmental sustainability.

The first and most significant is the protection of the environment as well as ecosystems. Protecting the environment is of utmost importance for governments worldwide in order to avoid climate change and the ongoing increase in global temperatures, along with the catastrophic consequences that will follow. The methods for protecting the environment primarily involve reducing air pollution mainly through decreasing carbon emissions from burning fossil fuels and shifting to renewable energy sources, as well as conserving biodiversity. The protection of forests and flora, which serve as the lungs of the Earth by producing oxygen and absorbing carbon dioxide from the atmosphere, also plays a significant role.

The second factor concerns the rational use of natural resources. Every industrial activity requires raw materials and energy to produce goods. On one hand, it is essential that the resources used for production are utilized rationally to avoid future shortages. On the other

hand, the resources used for energy production, which in turn will meet the needs of large industrial units and subsequently consumers, must be replenished and not depleted. For this reason, there has been a significant shift towards Renewable Energy Sources, which, as indicated by the very term, are inexhaustible as they are continuously renewed, and are ‘green’, meaning they are environmentally friendly since their production and consumption do not generate so-called greenhouse gases.

Thus, environmental sustainability is of utmost importance for every business and other activities. States worldwide are investing substantial amounts in research and development to secure more future options that are low-cost and high-efficiency, aiming to ensure environmental protection. Meanwhile, large industrial units are taking measures independently in their production to ensure that the use of resources in the production process will be rational and will not exceed the planet's capacity to renew them.

SUSTAINABILITY OF RENEWABLE ENERGY SOURCES

Sustainability, as has become clear from the above, represents the necessary condition for the achievement of economic activity. Renewable Energy Sources must be sustainable in order to establish themselves as the primary form of energy used by societies both now and in the future. As previously stated, sustainability is based on three main pillars: economic, social, and environmental. Their sustainability, therefore, relies entirely on the simultaneous achievement of all three pillars. It is a global challenge to ensure their sustainability, as the use of Renewable Energy Sources can enable green development and the green transition.

ECONOMIC SUSTAINABILITY OF RENEWABLE ENERGY SOURCES

Firstly, the economic sustainability of Renewable Energy Sources is a topic that concerns both electricity producers and consumers. In contrast to environmental and social sustainability, which while important for producers, mainly occupies the concerns of consumers, the economic sustainability of Renewable Energy Sources is a significant concern for both parties. The goals of the Ministry of Energy of Greece are the rapid increase of energy derived from renewable sources. Therefore, increasing from 12.5 GW in May 2024 to 22.4 GW by 2030 requires not only new investments in new renewable energy units (solar photovoltaic and wind farms) but also additional investments to replace a portion of the

renewable energy units operating since before 2010 by 2030. Similar targets are set until 2050, as by that time, the total number of units producing electrical energy from renewables will need to be replaced since they will have completed their life cycle. At the same time, significant importance is also placed on investments for storing the energy produced from renewable sources. These batteries have a lifespan of up to 20 years, and those that are built and operated until 2030 will need to be replaced in the 2040-2050 decade. It is therefore crucial to increase the funds allocated to research and development for companies operating in the renewable energy sector, as well as for the construction and operation of energy storage batteries, in order to ensure a smooth green transition and a continuously reduced use of fossil fuels for electricity generation. Because of advances in technology, it is possible to reduce the construction costs of all energy production and storage units, allowing them to become economically sustainable over time. Nevertheless, focusing on the development of solar and wind farms, which utilize the wind and sun characteristic of the Mediterranean climate, achieves economies of scale that lower costs with the increasing production of green energy, enabling them to compete with nearby countries and potentially lead in this sector. Moreover, investing in these energy production areas may be the only viable option, as our country lacks nuclear reactors for electricity generation, and indications suggest it will continue to do so for the coming years. Despite not being renewable, nuclear energy is considered green and has been adopted by many countries that previously invested in this form of energy. Storing green energy through batteries and supplying it to the market during low production periods will not only ensure energy security but also stabilize electricity market prices. Recent events, such as the war in Ukraine and the reduction or complete ban on gas supplies from Russia to European Union countries, as well as the crisis in the Middle East with the increasing attacks by Houthi rebels in Yemen on commercial ships and tankers in the Red Sea and the Gulf of Aden, have driven prices of imported fossil fuels up for EU countries, including our own. Consequently, energy security is key to price stability over time, as renewable energy production units cannot always produce the same amount of electricity daily due to weather conditions. Therefore, it is very important to store excess electricity during high production periods to direct it to the grid and meet the needs during low energy production periods, avoiding the need to supplement with conventional energy sources. In conclusion, economic sustainability is crucial for continuing the path toward the green transition in the coming years and ensuring that the energy security of the country is not disrupted.

SOCIAL SUSTAINABILITY OF RENEWABLE ENERGY SOURCES

On the other hand, social sustainability is a significant pillar for achieving sustainability and the sustainable development of Renewable Energy Sources. This term encompasses social equality, meritocracy, transparency, and the processes that, in turn, will lead to social well-being. Social well-being is the highest priority for people and workers, all of whom seek a high standard of living and social prosperity. At the same time, social well-being emphasizes various sectors and services, such as health, education, social cohesion, and economic stability. Initially, health leads to increased life expectancy and improves people's quality of life. The use of Renewable Energy Sources reduces pollution rates in the environment, which directly impacts public health. On the other hand, education encourages people to invest in training and specialization to increase their productivity through knowledge and experience, as well as to choose the ideal job for themselves from various educational institutions such as schools, colleges, and universities. Education is one of the most important tools for achieving the development of Renewable Energy Sources, as it will expand the technology for creating and producing green energy, directly affecting low costs and high productivity. Consequently, specialized personnel will achieve better working conditions, including higher wages. Simultaneously, economic stability is closely related to social well-being and, by extension, to social sustainability. Renewable energy sources can offer stable employment compared to conventional forms of energy, as they rely on the continuous availability of renewable energy without depleting natural resources. This allows for the creation of high wages, combined with health insurance systems and retirement plans, ensuring dignified living standards and social solidarity. Finally, a fundamental aspect of social well-being is human rights and their protection. Equality and respect among different social groups and genders, as well as religious tolerance, freedom of speech, and the defense of democracy, contribute to enhancing social prosperity among people and the societies that interact with one another.

On the other hand, social cohesion is included among the fundamental pillars through which social sustainability can be achieved. Humans organized into societies already during the Neolithic period, specifically before 3000 BC. Over the years, societies became increasingly organized, creating specialized job positions, and through technological progress, they increased their productivity in agricultural and livestock sectors, and later in artisanal and industrial sectors. Hence, they created cohesive relationships among themselves. These relationships led them to collaborate and interact harmoniously with one another and to

progress. Thus, most countries over the years have shed authoritarian regimes that ruled them and turned to democracy and the establishment of constitutions. This created trust between citizens as well as between citizens and democratic institutions, thereby solidifying social cohesion. Institutions increasingly warn about the consequences of the climate crisis and urgently seek a transition to green energy, encouraging citizens to reduce pollution by choosing clean forms of energy to meet their needs. It thus becomes clear that social cohesion is an important tool for achieving the social sustainability of Renewable Energy Sources. Additionally, the preservation of cultural heritage and intercultural understanding are the foundations of social sustainability. Through the creation and development of traditions and customs, individuals socialize, organize into groups, and enhance their prosperity. Furthermore, through interaction with other cultures and societies, people broaden their social and professional horizons, leading to a better understanding of other cultures and respectful behaviour towards individuals with different ideologies, mentalities, and lifestyles. In this way, the spread of Renewable Energy Sources is encouraged in both high-growth countries, such as those in Europe, as well as in countries with lower growth rates, such as those in Africa. Thus, intercultural understanding and the cultural heritage of people and societies foster the assurance of the social sustainability of Renewable Energy Sources in general.

ENVIRONMENTAL SUSTAINABILITY OF RENEWABLE ENERGY SOURCES

The third and final pillar concerning the sustainability of Renewable Energy Sources relates to their environmental sustainability. Specifically, it refers to the ability of Renewable Energy Sources to contribute to sustainability and sustainable development in order to reduce the negative environmental impacts stemming from the burning of fossil fuels to meet the energy needs of countries and citizens. Perhaps the most important role played by the use of Renewable Energy Sources is the reduction of carbon dioxide emissions, that is, greenhouse gases that result from burning fossil fuels and conventional forms of energy. Each of the Renewable Energy Sources, such as solar energy, wind energy, hydroelectric energy, biomass, geothermal energy, and ocean energy, is considered a green form of energy. This designation arises from the fact that during the generation of electricity from these energy sources, there are no CO2 emissions produced. It is therefore clear that the preference for and use of such forms of energy over conventional ones, which involve the burning of fossil fuels, lead to environmental protection and primarily to a reduction in climate change.

Additionally, Renewable Energy Sources contribute to the preservation of the planet's natural resources. Conventional energy forms, such as coal, oil, and natural gas, although relatively inexpensive forms of energy, are certainly not sustainable. This is because the reserves of these energy sources are limited and concentrated in specific areas of the planet. Even if environmental pollution decreased dramatically with the rapid advancement of technology, and the burning of conventional energy sources no longer polluted the environment at the same rate as it has until now, the reserves would last for several years, but certainly not for the entirety of humanity's future. This is due to the fact that these resources either do not renew or they renew at a very slow rate. Consequently, the situation regarding reserves naturally leads to the search for other forms of energy. Furthermore, the most significant aspect of the sustainability of Renewable Energy Sources concerning the environment relies on their low environmental impact. Renewable Energy Sources have always been characterized by their minimal environmental impact, both during their production and their consumption. These specific forms of energy produce only electricity, the consumption of which does not create additional atmospheric burdens, as occurs with the burning of fossil fuels. At the same time, energy production through Renewable Energy Sources has a very low environmental impact, and the difference between electricity production through Renewable and energy production through conventional forms, such as the extraction and burning of fossil fuels, is enormous. The extraction and refining of fossil fuels is a process that has burdened the environment for decades, completely destroying the ecosystems in which it takes place. For example, coal mines, oil and natural gas drilling on land and at sea via offshore platforms constitute massive sources of pollution. Moreover, although refining methods have reduced atmospheric pollution over the decades due to rapid technological advancements, they continue to pollute and degrade the areas where they occur through refineries. Ultimately, pollution and environmental contamination from burning fuel for energy production to meet societal needs ranks at the top of the pyramid of causes of greenhouse gas emissions and the enhancement of climate change to this day. Therefore, the environmental sustainability of Renewable Energy Sources is achieved to a great extent, particularly in contrast to conventional energy forms, as their environmental impact cannot be compared in any way.

On the other hand, there are several issues that can certainly raise concerns about the production and operation of electricity generation units that use Renewable Energy Sources. The challenges are significant and should not be ignored in any way to improve their

efficiency and maximize environmental protection. Firstly, the biggest challenge involves the construction of the facilities that will host the renewable energy production units. These units are considerably more environmentally friendly compared to fossil fuel production units; however, they also create serious problems for ecosystems. For instance, the establishment of wind farms in high altitudes, such as mountains and hills, significantly disturbs the local fauna, primarily threatening bird populations. Additionally, their construction requires vast areas of land to be expropriated, as well as extensive earthworks for building road networks to transport the materials and machinery needed for their foundation. All of these activities result in the destruction of existing flora, further harming the already burdened natural environment. Similarly, the establishment of photovoltaic parks, which serves as the main source of green energy for many countries, requires vast areas, mainly in flat and semi-hilly regions. These areas are predominantly private land, which previously consisted of agricultural land. Therefore, while the establishment of photovoltaic parks may not directly impact the local fauna, it does affect both flora and fauna since it occupies extensive land that could either be reforested or used for agricultural production, which is already declining. Furthermore, the management of the materials and raw materials used for constructing these units must be comprehensive. Solar panels consist of solar collectors and batteries, the disposal of which can be particularly polluting for the environment, especially for groundwater. Consequently, an organized regulatory framework for the immediate recycling of these hazardous materials is required to protect the natural environment from this waste.

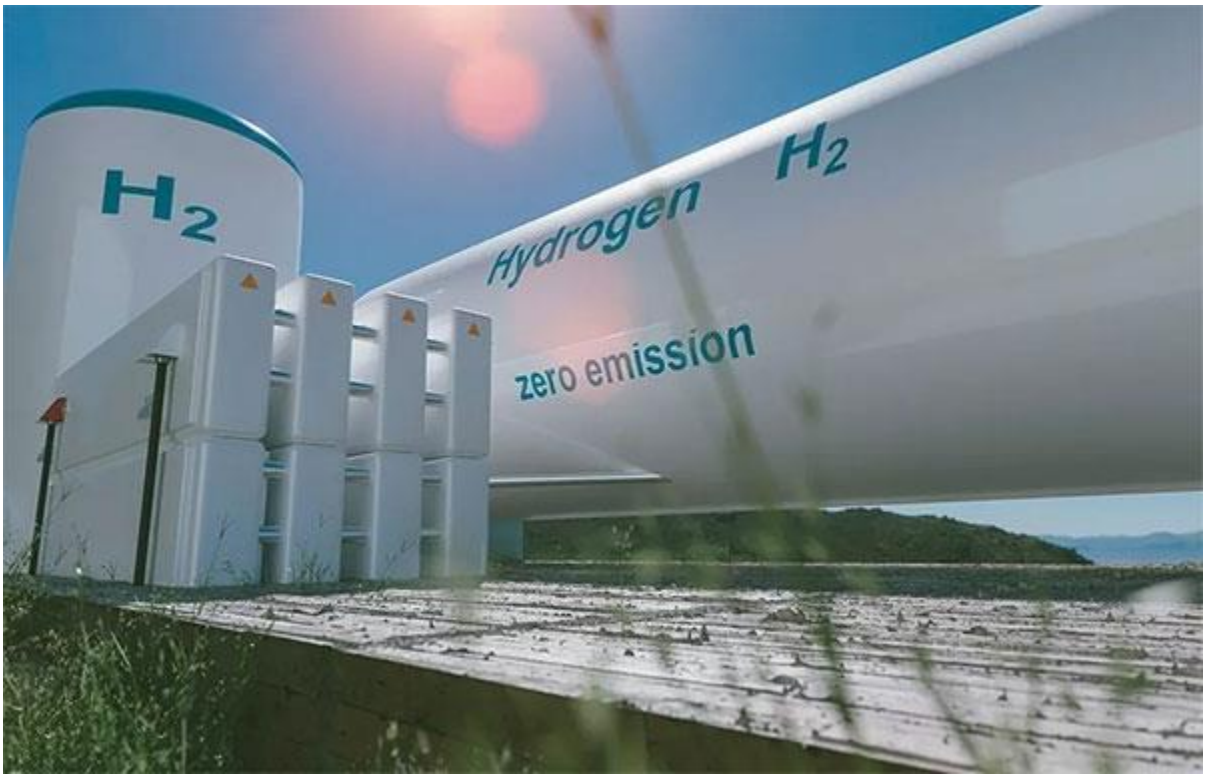
6. Green hydrogen in Greece

Greece's policy in recent years has shifted towards renewable energy sources, as it has invested significantly in solar and wind energy to lead the green transition. However, there are fields where decoupling from coal cannot be achieved through renewable energy sources, such as certain industrial sectors and, primarily, the transportation and shipping sectors. These fields cannot currently adopt the electric energy produced from renewable sources to meet their substantial and extensive needs. This is where the role of hydrogen comes into play, which, with its dynamics and excellent performance, can provide solutions for the previously polluting sectors of transportation and shipping, as outlined in Chapter 2. According to Mr. Georgios Chatzimarkakis, CEO of HYDROGEN EUROPE, who is a significant factor in promoting green hydrogen in the industrial sector in Europe and worldwide, Greece has set an ambitious plan for the integration of green hydrogen into its energy strategy. The use of green hydrogen is expected to reduce CO2 emissions by up to 750,000 tons annually, and through the development of the production chain, it is feasible to create up to 2,000 jobs in Western Macedonia, as well as enhance the GDP by €1.1 billion annually. Mr. Chatzimarkakis emphasizes that in the future, there will be three types of countries in the hydrogen economy: countries that produce, countries that distribute, and those that consume. In order to attract both domestic and foreign investors, the country must have a coherent and stable strategy towards green hydrogen, directly reducing bureaucratic obstacles and supporting, by any means possible, the creation of production units to fulfill its goals.

CASE OF HELLENIC HYDROGEN

Hellenic Hydrogen is the first company expected to start the production of green hydrogen through the North Project 1 production unit. Hellenic Hydrogen is a joint venture of Motor Oil and the Public Power Corporation (ΔΕΗ). The company's goal is to lead and excel in the production of green hydrogen by utilizing the most advanced technologies and innovative approaches, as well as to gradually decouple from fossil fuels in order to spearhead sustainable green development. Additionally, it aims to lead the effort towards the decarbonisation of critical sectors of the Greek industry and transportation, such as road traffic and shipping. To achieve these ambitious goals, significant investments are required. This company will operate the first industrial-scale renewable hydrogen production unit in 2027, located in Amyntaio, Florina, specifically on the site of the old coal-fired power plant in Amyntaio. According to Mr. Dimitrios Triantafyllopoulos, CEO of Hellenic Hydrogen, one of the main objectives of the company is to export green hydrogen to the energy markets of Central and Northern Europe. The name of the investment is North Project 1, and its estimated cost is €120 million, aiming to achieve initial production of 25-50 MW depending on the market demand at that time. Moreover, the local community and the local workforce of the specific area will greatly benefit, as it is estimated that the benefit to the local community will be around €100 million, while simultaneously, 40 to 50 direct jobs will be created, along with 500 indirect jobs. Consequently, the balance for this particular area is clearly positive, both due to economic development and because this investment will have a very low environmental footprint, especially in a region that has been suffering for decades

from continuous harmful pollution and contamination of the environment, as well as health issues for both workers and residents caused by lignite units and the operation of coal-fired power plants.



Thus, Hellenic Hydrogen has established four key pillars to develop and lay the foundation for achieving its goals. The four areas are as follows:

1. Energy Transition and Sufficiency of Greece: The energy transition arises from the construction and operation of electrolysis facilities, both small and large scale, to produce green hydrogen using electricity entirely from renewable energy sources. Greece's energy autonomy is derived from the country's domestic resources, utilizing water and renewable energy sources.
2. Development of the Hydrogen Market: The development of the hydrogen market is based on the study and development of the potential supply of green hydrogen to sectors that account for the largest share of carbon emissions, such as refineries, electricity generation, heavy-duty transportation, the steel industry, and shipping.
3. Quality and Safety Assurance: Guarantees regarding the supply of top-quality green hydrogen, as well as commitments and assurances to ensure the safe production and distribution of hydrogen through specialized studies compliant with international safety standards and best practices.

4. Contribution to Innovation and Research: Investments in research and development around green hydrogen technology. Initially, the company promotes investments in innovative technologies related to the production, storage, and distribution of green hydrogen to consumers. Subsequently, it fosters investments in research programs aimed at the continuous improvement of green hydrogen production technology. Finally, it invests in human capital through ongoing investments in specialized workforce development, which is a fundamental prerequisite to help the company excel in the production and innovation of green hydrogen.

Analyzing the financial statements of 2023, the following becomes clear:

The Company maintains significant cash balances and equivalents, which protects it from fluctuations in exchange rates, as its transactions are primarily conducted in euros and are limited to the Greek market. It focuses on managing its capital to ensure its long-term sustainability. At the same time, it continues to develop large electrolysis units for the production of renewable hydrogen, placing them in areas with abundant natural resources—renewable energy sources. The goal is to exploit economies of scale and leverage the strategic position of its shareholders in key regions of Greece, such as Western Macedonia, the Peloponnese, Thrace, and Crete. These units are expected to enhance the country's energy

security by utilizing domestic raw materials. Additionally, the Company has developed a program that includes grants and funding to strengthen research and expertise in hydrogen technology through partnerships with universities and research centers. At the same time, it supports education through scholarships and grants, enhances the specialization of its executives, and promotes innovative software in the hydrogen sector. A priority for the Company is the development of a 50 MW electrolysis facility in Amyntaio, using renewable energy sources and leveraging existing resources of shareholders in the area to create synergies for hydrogen in Western Macedonia. The management believes that the Company has the necessary resources to ensure the sustainable continuation of its activities in the foreseeable future, and there are no conditions that pose a risk to its continued operation.

7. Conclusion

The emphasis of the work is on green hydrogen production and its role in the transition to renewable energy in Greece. Green hydrogen is identified as a crucial clean energy solution that can significantly reduce carbon emissions, particularly in sectors difficult to decarbonise, such as transportation and heavy industry. Greece's active engagement in renewable energy, especially through solar, wind, and hydropower, establishes a solid foundation for green hydrogen production.

The Hellenic Hydrogen initiative exemplifies this commitment, aiming to produce green hydrogen by 2027 with a significant investment and development strategy in Amyntaio, Florina. The project is designed to not only curb CO2 emissions but also create jobs and stimulate economic growth in the region. The four pillars guiding Hellenic Hydrogen's efforts include energy transition, development of the hydrogen market, quality assurance, and contributions to innovation and research, emphasizing a holistic approach to green hydrogen deployment.

Despite the promising benefits of green hydrogen, various challenges remain, including high production costs, the need for specialized infrastructure, and potential operational limitations regarding technology and market acceptance. However, the proactive development of renewable resources and strategic investments in hydrogen technology are paramount for overcoming these barriers. Overall, vigorous efforts towards green hydrogen and renewable energy integration signify Greece's path toward a sustainable energy future, ensuring energy security and contributing to climate change mitigation. The commitment to developing a robust hydrogen economy reflects not only local aspirations but also aligns with broader European sustainability goals.

8. References

1. Ball, M. and Wietschel, M., 2019, *The Hydrogen Economy: Opportunities and Challenges*, Springer
2. DIANEOSIS Research and Policy Institute, 2021, *The Consequences of Climate Change in Greece*, DIANEOSIS Research and Policy Institute
3. International Trade Administration, 2024. *Greece energy hydrogen technology market updates.* [online] Available at: https://www.trade.gov/market-intelligence/greece-energy-hydrogen-technology-market-updates
4. Halkos, G.**,** 2014, *An analysis of long-term scenarios for the transition to renewable energy in Greece,* University of Thessaly Press
5. MacKay, D.J.C., 2008, *Sustainable energy – without the hot air*, Cambridge: UIT Cambridge
6. Intergovernmental Panel on Climate Change (IPCC), n.d. *Synthesis report.* [online] Available at: https://www.ipcc.ch/synthesis-report/
7. Mustafa, E., Shinji, K. and Yukio, H., 2019, Hydrogen production technologies overview, *Open Journal of Energy Efficiency*, 7(1), pp.1–15. [online] Available at: https://www.scirp.org/journal/paperinformation?paperid=90227
8. OT.gr, 2022, *Northern Greece becomes an energy hub with 8 key projects.* [online] Available at: https://www.ot.gr/2022/02/06/english-edition/northern-greece-becomes-an-energy-hub-with-8-key-projects/
9. Papandreou, A. and Pantelis, C.K., 2024, Perspective chapter: Renewable energy for resilience and sustainable development after the global energy crisis – The case of Greece. In: Renewable Energy for Resilience and Sustainable Development, Athens: Green Energy Press.
10. REN21, n.d. Global status report: Renewable energy. Renewable Energy Policy Network for the 21st Century.
11. Tom, S. and Henry, B., 2022. The history of water electrolysis from its beginnings to the present. Hydrogen energy: What are its benefits for the EU? [online] Available at: https://water-waste.gr/site/
12. World Energy News, 2023. Renewable & sustainable development. [online] Available at: https://www.worldenergynews.gr/