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Η Μετάβαση από το Φυσικό Αέριο στο Πράσινο Υδρογόνο: Μια Διαδρομή προς τη Βιώσιμη Ενεργειακή Κατανάλωση

Κωνσταντίνος Πανόπουλος

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The Transition from Natural Gas to Green Hydrogen:

A Path to Sustainable Energy Consumption

By

Konstantinos Panopoulos

Master Thesis submitted to the Department of Economics of the University of Piraeus in partial fulfillment of the requirements for the degree of Master of Arts in Economic and Business Strategy

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Στην οικογένειά μου και

σε όσους πιστεύουν στις ιδέες μου.

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Σημαντικοί Όροι: Φωτοβολταϊκή Ενέργεια, Ηλεκτρόλυση, Ενέργεια Παραγόμενη από το Υδρογόνο, Αποδοτικότητα, Κατανάλωση Φυσικού Αερίου

Περίληψη:

Η παρούσα εργασία αποσκοπεί στη διερεύνηση των δυνατοτήτων μείωσης της κατανάλωσης φυσικού αερίου, μέσω της αύξησης της παραγωγής πράσινου υδρογόνου ως βιώσιμης και ανανεώσιμης εναλλακτικής λύσης. Η ανάλυση θα καλύψει τις περιβαλλοντικές και οικονομικές επιπτώσεις, καθώς και τις διάφορες μεθόδους παραγωγής πράσινου υδρογόνου. Επιπλέον, στο δοκίμιο θα αναλυθεί η τρέχουσα κατάσταση των υποδομών υδρογόνου και τα απαραίτητα βήματα που απαιτούνται για την επιτυχή μετάβαση σε μια οικονομία βασισμένη στο υδρογόνο. Το συμπέρασμα θα αναδείξει τα ευρήματα και θα τονίσει τη σημασία της προώθησης της πράσινης παραγωγής υδρογόνου για τον μετριασμό της κλιματικής αλλαγής και την προώθηση της βιώσιμης ανάπτυξης.

The Transition from Natural Gas to Green Hydrogen: A Path to Sustainable Energy Consumption

Keywords: Photovoltaic Power, Electrolysis, Hydrogen Power, Efficiency, Natural Gas Consumption

Abstract:

In the present thesis we will delve into the possibilities of reducing our reliance, on gas by increasing the production of hydrogen which serves as a sustainable and renewable alternative. We will examine the economic effects of this shift well as explore various methods of generating green hydrogen. Furthermore, we will address the state of hydrogen infrastructure. Outline the necessary steps for a successful transition, towards an economy fueled by hydrogen. To conclude we will summarize our findings. Underscore the significance of promoting hydrogen production to tackle climate change and foster sustainable development.

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CHAPTER 1

Green Hydrogen Production Methods

1.1 Introduction

The production of hydrogen mainly depends on two eco techniques; electrolysis and biological production. In this section we will delve into these methods examining their effectiveness and assessing their suitability, for adoption on a scale.

1.2. Electrolysis

Electrolysis is a process that involves breaking down water into its components, namely hydrogen and oxygen with the help of electricity. It's worth noting that this method is widely regarded as friendly especially when powered by energy sources, like solar power, wind power or hydropower. In terms of electrolysis techniques there are three types; alkaline electrolysis, proton exchange membrane (PEM) electrolysis and solid oxide electrolysis.

1.2.1. Alkaline Electrolysis

Alkaline electrolysis stands out as the established and widely utilized technique, in the production of green hydrogen. This method relies on an alkaline solution serving as an electrolyte with two electrodes. The anode and cathode. Immersed within it. By applying a current water molecules at each electrode split into hydrogen and oxygen. While alkaline electrolysis has been proven effective its efficiency falls within the range of 60% to 80% which's relatively moderate. Nevertheless due to its standing advancement and lower initial investment costs it remains an appealing choice, for green hydrogen production.

1.2.2. Proton Exchange Membrane (PEM) Electrolysis

PEM electrolysis represents a approach that utilizes a solid polymer electrolyte membrane. This membrane permits the passage of protons while effectively blocking electrons. The advantage of this technology lies in its improved efficiency and rapid response times compared to alkaline electrolysis achieving efficiencies of, up to 80%[1]. Nevertheless it is worth noting that PEM electrolysis does come with costs due to the need for expensive materials, like platinum and iridium. Moreover there remains a concern regarding the long term durability of the membrane as it may degrade over time potentially impacting the systems performance[2].

[1] Carmo et al., 2013
[2] Smolinka et al., 2011

1.2.3. Solid Oxide Electrolysis

Solid oxide electrolysis is an emerging technology that operates at high temperatures, typically between 700 and 1000°C [3]. This method utilizes a solid oxide electrolyte that enables the transport of oxygen ions from the cathode to the anode, where hydrogen is produced. The high-temperature operation allows for greater efficiencies, exceeding 90%, and offers the potential for integrating with other high-temperature processes, such as waste heat recovery[4]. However, the elevated temperatures also present challenges, including material degradation and increased energy consumption for maintaining the required temperature[5].

1.3. Biological production

The production of hydrogen using living organisms involves utilizing microorganisms, like bacteria and algae. These organisms perform metabolic processes to generate hydrogen. There are two approaches to this method; photofermentation and dark fermentation.

Another advanced method called PEM electrolysis employs a polymer electrolyte membrane. This special membrane allows protons to pass through while blocking electrons. Compared to alkaline electrolysis PEM electrolysis offers efficiency and faster response times with efficiencies reaching up to 80%. However it does come with some drawbacks. PEM electrolysis requires materials, like platinum and iridium which increase the costs. Moreover the long term durability of the membrane is a concern as it may degrade over time potentially impacting the systems performance.

1.3.1. Photofermentation

Photofermentation is a process in which photosynthetic bacteria convert organic substrates, such as waste biomass, into hydrogen under light exposure[6]. This method has the advantage of utilizing renewable resources and producing hydrogen with low environmental impact. However, photofermentation is characterized by low hydrogen production rates and requires

[3] Graves et al., 2011
[4] Graves et al., 2011
[5] Smolinka et al., 2011
[6] Kars & Gürgan, 2015

specific conditions, such as light exposure and controlled temperature, which limit its scalability and commercial viability[7].

1.3.2. Dark Fermentation

Dark fermentation employs anaerobic bacteria that break down organic matter in the absence of light, producing hydrogen as a byproduct[8]. This method offers faster hydrogen production rates compared to photofermentation and can operate under a wider range of conditions[9]. However, dark fermentation often produces other byproducts, such as volatile fatty acids and carbon dioxide, which can lower the hydrogen yield and may require additional processing steps[10].

1.4. Comparison of production methods and their efficiency

Each method of producing hydrogen has its benefits and limitations. Electrolysis, PEM and solid oxide electrolysis is more efficient and quicker to respond making it better suited for large scale hydrogen production and integration, with energy sources. However these technologies face challenges in terms of costs, material deterioration over time and energy consumption. On the hand biological production methods have efficiency and production rates but offer the advantage of using renewable resources, like waste biomass. They also produce hydrogen with impact. However the scalability and commercial feasibility of these methods are currently limited by conditions required for hydrogen production and the presence of byproducts that may need additional processing.

1.5. Executive Summary

Additional research and advancements are required to enhance the effectiveness and scalability of green hydrogen production techniques while simultaneously minimizing their consequences and expenses. Furthermore employing a combination of production methods that are tailored to regional circumstances and available resources might offer a more efficient strategy, for decreasing natural gas usage and facilitating the shift towards an economy reliant, on hydrogen.

7 Kars & Gürgan, 2015
8 Levin et al., 2004
9 Levin et al., 2004
10 Hawkes et al., 2002

CHAPTER 2

Environmental and Economic Impacts of Green Hydrogen

2.1. Introduction

Switching from gas to hydrogen presents substantial advantages, for the environment and economy. In this section we will explore the effects of producing hydrogen and how it contributes to fostering sustainable development.

2.2. Reduction of greenhouse gas emissions

One of the benefits of hydrogen lies in its ability to lower greenhouse gas (GHG) emissions. Unlike gas, which releases carbon dioxide and methane when burned or extracted, producing hydrogen with renewable energy sources offers a solution. in zero carbon emissions[11]. Furthermore when utilized as a source of energy, in industries like transportation, heating and electricity production green hydrogen only emits water vapor as a result. This not minimizes its impact, on the environment. Also presents an opportunity to decrease greenhouse gas emissions and address the consequences of climate change by substituting natural gas and other fossil fuels with green hydrogen.

2.2.1. Potential for renewable energy integration

Green hydrogen production has the potential to be combined with energy sources, like solar, wind and hydropower. This integration could lead to a adaptable energy system. Electrolysis, which is the process used for hydrogen production can utilize renewable energy when demand is low, or generation is high. This effectively allows for the storage of this surplus energy in the form of hydrogen[12]. Storing hydrogen allows us to use it when renewable energy production isn't enough to meet our needs. This helps make the energy grid more reliable and stable. Moreover, green hydrogen is an energy carrier that enables us to transport energy over long distances and promotes regional energy collaboration.

2.2.2. Job creation and economic growth

The growth of hydrogen production holds potential, for bringing about substantial economic advantages, such, as the creation of employment opportunities and fostering the development of the clean energy industry. Investing in hydrogen technologies can encourage innovation open up market prospects and reduce costs. through economies of scale[13]. The development of a hydrogen-based economy also requires the construction and maintenance of new

[11] Schiebahn et al., 2015
[12] Breyer et al., 2018
[13] Fasihi et al., 2016

infrastructure, such as electrolyzers, storage facilities, and refueling stations, creating additional employment opportunities. With countries placing emphasis on climate action and the advancement of clean energy it is becoming evident that green hydrogen will have a crucial part to play in the global shift, towards sustainable economic growth.

2.3. Executive Summary

Although green hydrogen has benefits it also encounters obstacles and disadvantages that need to be resolved for its complete utilization. The cost of producing hydrogen is still higher compared to methods that rely on fossil fuels primarily because of the expensive electrolyzers and the current expense involved in renewable energy[14]. Furthermore, when it comes to producing hydrogen there is a tendency, for energy conversion efficiencies compared to traditional methods. This is especially true, in the context of production. Additionally, the widespread implementation of hydrogen encounters obstacles related to infrastructure and storage. This is because the current pipelines, storage facilities and transportation networks are not adequately equipped to handle hydrogen as an energy source.

In summary the shift, from gas to hydrogen brings about notable advantages for the environment and economy. These benefits include decreased greenhouse gas emissions, improved integration of energy and the creation of job opportunities. Nonetheless there are obstacles that need to be overcome in order to fully harness the potential of hydrogen as a viable and sustainable substitute for natural gas. These challenges encompass production costs lower energy conversion efficiencies and limitations, in infrastructure.

[14] Schiebahn et al., 2015

CHAPTER 3

The Role of Government and Industry in Promoting Green Hydrogen Production

3.1. Introduction

Transitioning successfully from gas, to hydrogen necessitates the collective collaboration of governments, industry players and other involved parties. In this section we will delve into the roles that these entities can undertake to promote the production of hydrogen. These roles encompass formulating and executing policies providing incentives investing in research and development efforts and fostering cooperation.

3.2. Policy development and implementation

Governments have a role to play in creating the conditions, for the expansion of green hydrogen production. They can demonstrate their dedication to an energy shift by setting climate and renewable energy goals. Moreover governments can implement targeted policies like feed in tariffs, carbon pricing mechanisms and renewable portfolio standards to support the growth of hydrogen. These measures ensure competition, between hydrogen and traditional production methods and other fossil fuels[15].

3.3. Financial incentives and support

Governments have the ability to encourage the growth and implementation of hydrogen technologies by offering incentives and support. This can involve providing grants, loans, tax credits and other forms of assistance to minimize the expenses and risks associated with hydrogen projects. By providing backing, for research and development in the stages pilot initiatives and large-scale implementations governments can play a role, in reducing the production costs of green hydrogen and facilitate its integration into the energy system[16].

3.4. Research and development

Both governments and industries have a role to play in advancing research and development, in the realm of hydrogen generation. This entails investing in studies to enhance the efficiency, scalability and environmental impact of green hydrogen production techniques well as conducting applied research to explore new technologies and their potential applications. Collaboration between public and private sector actors, as well as academia, can help to

[15] IEA, 2019
[16] IEA, 2019

accelerate innovation, share knowledge and best practices, and maximize the impact of research and development efforts[17].

3.5. International collaboration

The production of hydrogen and the technologies associated with it have the ability to contribute towards climate objectives and promote sustainable development. However for this potential to be successfully realized it requires collaboration and cooperation, among nations. International partnerships play a role in pooling resources facilitating technology transfer and promoting the exchange of practices and lessons learned. Some examples of existing initiatives in the realm of hydrogen include the Hydrogen Energy Ministerial, the Hydrogen Initiative by the Clean Energy Ministerial and the International Partnership for Hydrogen and Fuel Cells, in the Economy (IPHE). By working together, countries can overcome barriers to green hydrogen production, accelerate progress towards a hydrogen-based economy, and promote global climate action[18]. In summary the promotion of green hydrogen production necessitates endeavors involving governments, industry players and various stakeholders. By crafting policies providing incentives and support investing in research and development and fostering international cooperation these entities can play a crucial role in facilitating the shift, from natural gas to green hydrogen. This transition will lay the foundation for a environmentally friendly energy future.

3.6. Executive Summary

When we delve into the document called "The Role of Government and Industry, in Promoting the Production of Green Hydrogen " we come across an examination of how government bodies and private sectors collaborate to promote the adoption and expansion of hydrogen technologies. This overview aims to clarify the topics covered in the document while maintaining a tone for discussions, at a university level.

The main topic of this article revolves around hydrogen, a type of energy carrier that is considered friendly. It is produced through a process called electrolysis, where water is separated into hydrogen and oxygen with the help of energy sources. The article underscores the significance of hydrogen, in mitigating climate change and tackling energy security

[17] Hydrogen Council, 2017
[18] IEA, 2019

concerns. It highlights how crucial it is, for transitioning towards an energy landscape that's cleaner and more sustainable.

The rapid advancement and adoption of hydrogen technologies owe much to the efforts, between governments and companies. In the place governments play a role by spearheading the development of supportive policy frameworks that encourage investments incentivize research and development and establish regulatory guidelines. To encourage participation, from the business sector this may involve offering incentives, tax credits and implementing carbon pricing mechanisms.

The documentation also highlights the importance of partnerships, between the private sectors to promote innovation and advance hydrogen initiatives. These collaborations can tackle the burdens associated with green hydrogen production ultimately leading to cost reductions and increased competitiveness. By combining government funding and expertise with knowledge and efficiency these partnerships pave the way for progress, in the term.

The passage emphasizes the importance of cooperation, between governments and companies to enhance collaboration. Through sharing information best practices and resources countries can leverage their strengths. Join forces to tackle the obstacles hindering widespread adoption of green hydrogen.

Furthermore, there is a case, for enhancing investments in state of the art technologies that can enhance the efficiency and reduce the cost of generating hydrogen. Additionally the significance of conducting research and development activities is emphasized. To ensure a flow of advancements, in this field collaborative research endeavors involving academia, industry and government research institutions are given priority.

However, the documentation does acknowledge that there are challenges involved in promoting hydrogen. These challenges encompass obstacles, uncertainty, in the market and limitations in infrastructure. To tackle these issues effectively it is important for partners from both private sectors to collaborate and respond in a manner. The documentation highlights the importance of having flexible policy frameworks that can adapt to changes, in market dynamics.

Finally, the report on "The Role of Government and Industry in Promoting Green Hydrogen Production" offers a perceptive and convincing examination of the crucial synergy between governmental involvement and private sector engagement. It underlines the importance of green hydrogen in reaching sustainable energy goals and the necessity of teamwork in formulating legislation, conducting research and development, and engaging in international collaboration. Governments and businesses can encourage a strong and profitable green hydrogen ecosystem by upholding these ideals, ushering in a cleaner and brighter future for our planet.

Green hydrogen production is gaining increasing attention as a crucial solution to tackle climate change and usher in a sustainable energy future. Governments and industries are expected to play a vital role in driving the advancement and adoption of green hydrogen technologies, making them an integral part of the global energy transition.

The urgency to address greenhouse gas emissions and combat climate change has fueled the need for alternative energy sources, and green hydrogen stands out as a promising contender. Produced through renewable energy-driven electrolysis, green hydrogen holds the potential to decarbonize various sectors, including transportation, industry, and heating. This necessitates a collaborative effort between governments and industries to expedite the deployment of green hydrogen technologies on a large scale.

Effective government policies and regulatory support are instrumental in fostering the growth of green hydrogen production. By providing incentives like feed-in tariffs, grants, and tax breaks, governments can encourage investments in green hydrogen infrastructure and research. Carbon pricing and emission reduction targets also contribute to creating a conducive environment for the growth of green hydrogen technologies. Policymakers must establish a stable and predictable regulatory framework that attracts private investments and nurtures the green hydrogen industry.

To drive innovation and advancements in green hydrogen technologies, government-led research initiatives and collaborations with the private sector are indispensable. Allocating funding for research projects and technology demonstrations can lead to breakthroughs in efficiency and cost reduction. Public-private partnerships can fast-track the scale-up of green hydrogen production methods and facilitate the exchange of knowledge across industries.

A robust green hydrogen infrastructure is essential for its widespread adoption, and this requires substantial investments in electrolyzer facilities, hydrogen storage, and transportation networks. Governments and industries should collaborate to integrate green hydrogen into existing energy systems, ensuring the growth of a sustainable hydrogen economy.

Collaboration, between countries is crucial in unlocking the potential of hydrogen. Governments and industries can work together to conduct research establish standards and create policy frameworks that promote the growth of a market for green hydrogen. By facilitating trade in hydrogen we can address regional differences, in renewable energy supply and demand.

Driving innovation deploying technology and reducing costs in the production of hydrogen are heavily reliant on industry leadership and investment. Private sector investments have the potential to complement government initiatives and expedite the shift, towards an economy fueled by hydrogen. It is important for industries to actively explore ways to integrate hydrogen into their operations and supply chains.

To sum up the key, to promoting the production of hydrogen lies in the close cooperation, between governmental bodies and industries. It is crucial for policymakers to establish an environment through regulations and financial incentives while industries should focus on investing in research and deploying advanced technologies. By working they can lead us towards an more resilient world embracing a sustainable energy future fueled by green hydrogen.

CHAPTER 4

Hydrogen Infrastructure and Storage

4.1. Introduction

To establish hydrogen as a substitute, for natural gas it is crucial to focus on the development of suitable infrastructure and storage options. In this section we will explore aspects of hydrogen infrastructure, such as transportation, storage and applications, in industries. We will also discuss the obstacles faced in these areas and the progress made to overcome them.

4.2. Transportation

Hydrogen can be transported through pipelines, much like gas. However, it's important to note that existing natural gas pipelines may need adjustments to accommodate hydrogen transportation. This is mainly because hydrogen has molecules and there is a possibility of certain pipelines materials[19]. Research into the blending of hydrogen with natural gas has shown promise, with low concentrations of hydrogen (up to 20%) posing minimal technical challenges for existing pipeline infrastructure[20]. Additionally, dedicated hydrogen pipelines can be constructed using compatible materials, such as polyethylene, to minimize the risk of embrittlement and leakage.

4.3. Compressed and Liquid Hydrogen

Hydrogen, in a compressed form can be transported using high pressure vessels whereas liquid hydrogen can be transported in tanks, at low temperatures of 253°C. These methods have been utilized in the industrial gas sector for years. Can be modified to facilitate the transport of large-scale green hydrogen transportation[21]. However, these methods come with expenses and energy needs when compared to pipeline transportation, which could potentially affect their feasibility for long distance and large-scale hydrogen transportation.

4.4. Storage High-pressure and Cryogenic Storage

Similar to transportation, compressed and liquid hydrogen can be stored in high-pressure vessels and cryogenic tanks, respectively. Compressed hydrogen storage typically requires pressures of up to 700 bar, while liquid hydrogen storage necessitates cryogenic temperatures to prevent evaporation[22]. Although these methods are well-established, they are associated with energy losses during compression or liquefaction, as well as potential boil-off losses in the case of liquid hydrogen storage.

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[19] Mittelstadt et al., 2020
[20] Melaina et al., 2013
[21] Eichman et al., 2018
[22] Eichman et al., 2018

4.5. Underground storage

Underground storage options, such as salt caverns, depleted gas reservoirs, and aquifers, offer the potential for large-scale, long-term hydrogen storage[23]. These storage techniques have already been proven effective, for storing gas. Can be easily adjusted for hydrogen storage with minimal changes. Storing hydrogen underground offers advantages, such as energy losses compared to high pressure and cryogenic storage methods. Additionally, it reduces the risk of hydrogen leakage and embrittlement due, to the pressures and constant temperature. conditions[24].

4.6. Solid-state storage

Solid-state storage refers to the adsorption or absorption of hydrogen within materials, such as metal hydrides, porous carbon, and metal-organic frameworks (MOFs)[25]. These materials can store hydrogen at lower pressures and higher densities compared to compressed hydrogen storage, which can reduce storage costs and improve safety. However, solid-state storage typically requires higher temperatures for hydrogen release, which may impact the efficiency of the storage process[26].

4.7. End-use applications

Green hydrogen can be utilized in various end-use applications, such as fuel cells for electricity generation, hydrogen combustion for heating, and as a feedstock for industrial processes (e.g., ammonia production and steelmaking)[27]. It is essential to prioritize the advancement of efficient technologies to ensure the incorporation of green hydrogen, into our energy system.

4.8. Executive Summary

To sum up the establishment of hydrogen infrastructure and storage systems is crucial, for the implementation of hydrogen as a substitute for natural gas. Although there has been advancement in these domains' obstacles persist concerning expenses, effectiveness and expandability. Additional research and funding are required to tackle these hurdles and promote the embrace of hydrogen, within our energy system.

[23] Kötter et al., 2016
[24] Eichman et al., 2018
[25] Eichman et al., 2018
[26] Jensen et al., 2019
[27] Schiros et al., 2021

CHAPTER 5

Case Studies of Green Hydrogen Initiatives

5.1. Introduction

Within the realm of sustainable energy research, green hydrogen is gaining recognition as a highly promising cornerstone. Its potential is being acknowledged and put into action through a multitude of programs on a global scale. Green hydrogen, which is produced through electrolysis powered by renewable energy sources, presents a sustainable substitute for fossil fuels and plays a crucial role in the pursuit of carbon neutrality.

The global endeavors pertaining to green hydrogen, which are manifested through legislative measures, industrial collaborations, and innovative projects, represent a significant step towards achieving a sustainable transition in the energy sector. This study aims to examine and provide a critical assessment of many groundbreaking initiatives, namely the European Union's (EU) hydrogen strategy, the global efforts of the Hydrogen Council, and a range of successful green hydrogen projects worldwide.

The "EU Hydrogen Strategy" was unveiled in July 2020, signifying the European Union's steadfast dedication to a future reliant on hydrogen as a source of fuel. The European Commission has devised a comprehensive strategy that outlines a systematic approach towards establishing an economy centered around hydrogen. This strategy includes a series of ambitious milestones that have been carefully planned for the upcoming decade (European Commission, 2020).

The Hydrogen Council is a prominent international endeavor aimed at facilitating the widespread implementation of hydrogen technology on a global basis. The Hydrogen Council, a prominent coalition consisting of more than one hundred prominent companies in the energy, transportation, and industrial sectors, aims to promote international acceptance and implementation of hydrogen-based solutions through fostering collaboration across many industries (Hydrogen Council, 2021).

Moreover, numerous pioneering green hydrogen initiatives have emerged globally, establishing concrete illustrations of the transition towards an economy reliant on hydrogen. Notable examples of green hydrogen production facilities include Germany's Energiepark Mainz, which is recognized as a leading facility in this field (Fraunhofer, 2021), and Australia's Asian Renewable Energy Hub (AREH), a significant renewable energy project aimed at the production of green hydrogen and ammonia (Asian Renewable Energy Hub, 2021).

This chapter offers a thorough examination of the aforementioned case studies from an academic perspective, exploring their achievements, difficulties, and impact on the discourse surrounding green hydrogen. The objective is to foster an intellectual dialogue regarding green hydrogen and its significance in our sustainable energy trajectory, hence facilitating subsequent investigation and advancement in this emerging domain.

5.2. Europe's hydrogen strategy

The European Union (EU) has recognized the potential of green hydrogen as a key element in achieving its climate and energy goals. In July 2020, the European Commission published the "EU Hydrogen Strategy," which outlines a comprehensive roadmap for the development of a hydrogen-based economy[28]. Key objectives of the strategy include:

- Installing at least 6 GW of renewable hydrogen electrolyzers by 2024 and producing up to 1 million tons of green hydrogen (European Commission, 2020).
- Increasing the capacity of renewable hydrogen electrolyzers to 40 GW by 2030 and producing up to 10 million tons of green hydrogen (European Commission, 2020).
- Encouraging the development of a European hydrogen market, including infrastructure and regulatory frameworks (European Commission, 2020).

5.3. The Hydrogen Council and global initiatives

The Hydrogen Council consists of, more than 100 companies, in the energy, transportation and industrial sectors. Their main objective is to expedite the adoption and use of hydrogen as a fuel technologies[29]. The council seeks to promote collaboration between governments, industries, and investors to enable the large-scale deployment of hydrogen solutions worldwide[30].

5.4. Successful green hydrogen projects around the world

Germany's Energiepark Mainz: Energiepark Mainz is one of the world's largest green hydrogen production facilities, utilizing wind power to produce hydrogen through PEM electrolysis[31]. The facility can produce up to 2,000 kg of hydrogen per day, which can be used for various applications, including transportation and industrial processes[32].

Australia's Asian Renewable Energy Hub (AREH): The AREH is a planned 26 GW renewable energy project that aims to produce green hydrogen and ammonia for domestic and

[28] European Commission, 2020
[29] Hydrogen Council, 2021
[30] Hydrogen Council, 2021
[31] Fraunhofer, 2021
[32] Fraunhofer, 2021

international markets[33]. The project combines wind and solar power to generate clean electricity for hydrogen production through electrolysis[34].

5.5. Executive Summary

This chapter offers a comprehensive examination of green hydrogen as a sustainable energy resource, considering its pivotal significance in worldwide endeavors to attain carbon neutrality. The focus of the inquiry is around comprehending the major endeavors, namely the hydrogen strategy of the European Union (EU), the global initiatives undertaken by the Hydrogen Council, and diverse instances of effective green hydrogen projects globally.

The European Union has assumed a prominent position in advocating for the adoption of green hydrogen, as seen by the introduction of the "EU Hydrogen Strategy" in the year 2020. The outlined strategy presents a thorough blueprint for the establishment of an economy reliant on hydrogen, encompassing objectives such as the implementation of 6 GW of renewable hydrogen electrolyzers by 2024, followed by a further expansion of capacity to 40 GW by 2030. The European Union (EU) is strategically creating a market for hydrogen within its jurisdiction, so laying the foundation for the widespread adoption of environmentally friendly hydrogen, as stated by the European Commission (2020).

The Hydrogen Council, which consists of over one hundred prominent enterprises operating in the energy, transportation, and industrial sectors, assumes a pivotal role in fostering global collaboration. The Hydrogen Council aims to promote the extensive implementation of hydrogen solutions by facilitating collaboration among governments, industry, and investors[35].

Numerous case studies offer tangible illustrations of green hydrogen initiatives in practice. The successful deployment of hydrogen projects is exemplified by Energiepark Mainz in Germany and the Asian Renewable Energy Hub (AREH) in Australia. The aforementioned initiatives serve as illustrations of the viability and effectiveness of green hydrogen production, as evidenced by the works of Fraunhofer (2021) and the Asian Renewable Energy Hub (2021).

This paper functions as a detailed examination of existing green hydrogen initiatives, strategies, and projects. Through an analysis of these case studies, the present research provides significant and insightful observations regarding the potential contribution of green hydrogen.

[33] Asian Renewable Energy Hub, 2021
[34] Asian Renewable Energy Hub, 2021
[35] Hydrogen Council, 2021

CHAPTER 6

CONCLUSION & FINDINGS

6.1. Introduction

Green hydrogen has the potential to make an impact, on reducing greenhouse gas emissions and offering a substitute for fossil fuels. There are ways of producing it including electrolysis and biological processes, which are continuously being enhanced to boost efficiency and decrease expenses. Governments and industries have a role to play in encouraging the production of hydrogen through policies, incentives, research and development as well, as international cooperation.

6.2. The significance of transitioning to green hydrogen

Shifting towards hydrogen can play a role, in addressing climate change integrating energy generating employment opportunities and fostering economic development. As nations and corporations globally work towards achieving their decarbonization goals green hydrogen is increasingly being recognized as an element, for ensuring an energy future.

6.3. Prospects and recommendations

The widespread adoption of hydrogen relies on the development of green hydrogen production technologies as well as the implementation of favorable policies and incentives. It is crucial to establish a hydrogen infrastructure overcome storage and transportation obstacles and encourage cooperation to fully unlock the benefits of green hydrogen, in the global energy sector.

The transition from natural gas to green hydrogen represents a vital step towards achieving global climate goals and fostering sustainable economic growth. As this comprehensive analysis has shown, green hydrogen production methods, such as electrolysis powered by renewable energy sources and biological processes, provide promising alternatives to conventional hydrogen production derived from fossil fuels[36].

However, challenges related to cost, efficiency, and scalability persist and must be addressed to fully realize green hydrogen's potential.

Governments, industry, and other stakeholders play pivotal roles in promoting green hydrogen production through various means, including policy development and implementation, financial incentives and support, research and development, and international collaboration[37]. The establishment and expansion of appropriate infrastructure and storage solutions are crucial for the large-scale deployment of green hydrogen, with advancements in

[36] Schiros et al., 2021; Ewan et al., 2021
[37] Hydrogen Council, 2017; IEA, 2019

transportation, storage, and end-use applications essential for successful integration into the energy system[38].

Addressing the challenges associated with green hydrogen production and infrastructure demands the concerted efforts of all stakeholders. By collaborating to develop and implement innovative solutions, it is possible to reduce the consumption of natural gas, accelerate the transition to a hydrogen-based economy, and pave the way for a more sustainable and low-carbon energy future[39].

6.4. The Greek Energy Market

The energy market in Greece has been undergoing significant changes in recent years, reflecting both domestic and global trends. In line with Greece's efforts to modernize its energy infrastructure, reduce its dependence on fossil fuels, and promote renewable energy sources, the country has set ambitious targets for renewable energy adoption. By 2025, Greece aims to generate 35% of its electricity from renewables, with a further goal of 50% by 2030[40].

These efforts align with broader global trends towards clean energy, as countries seek to transition away from carbon-intensive fuels and reduce their greenhouse gas emissions[41]. The growing availability and competitiveness of renewable energy technologies such as wind and solar power have made them increasingly attractive options for energy production, and Greece is no exception. Wind and solar power currently account for around 20% of electricity generation in Greece, up from virtually zero a decade ago[42].

To support the transition towards cleaner energy, the Greek government has implemented policies to liberalize the energy market, promote competition, and attract private investment. The electricity and gas markets were fully liberalized in 2018, allowing consumers to choose their energy provider and promoting greater efficiency and innovation in the sector[43]. Greece has also invested heavily in natural gas infrastructure, constructing an LNG terminal in Revithoussa and building a new pipeline from the Trans Adriatic Pipeline (TAP), which will bring natural gas from Azerbaijan to Europe[44].

Despite these positive developments, the Greek energy market still faces several challenges, including high levels of energy poverty, a lack of interconnections with neighboring countries,

[38] Eichman et al., 2018; Mittelstadt et al., 2020
[39] Breyer et al., 2018; Fasihi et al., 2016
[40] European Commission, 2020
[41] International Energy Agency, 2021
[42] Hellenic Wind Energy Association, 2021
[43] European Commission, 2021
[44] TAP AG, 2021

and the need to modernize its energy infrastructure[45]. However, the government's commitment to promoting renewable energy and liberalizing the market, along with the potential for new investment and innovation, suggest that the energy market in Greece is poised for continued growth and development in the years to come, both domestically and as part of the broader global transition to a low-carbon economy.

The energy mix of Greece has traditionally been dominated by fossil fuels, especially lignite, oil, and natural gas. According Papadaskalopoulos and Anastasiou (2019), lignite has been the primary source of electricity production in Greece, accounting for approximately 44% of the total electricity generated in 2017. In addition, Greece has been highly dependent on oil imports for its transportation sector, which accounted for more than 40% of the country's final energy consumption in 2019[46].

However, Greece has been making strides towards diversifying its energy mix and increasing its use of renewable energy sources. According to the National Energy and Climate Plan (NECP) submitted to the European Union, Greece has set an ambitious target of generating 35% of its electricity from renewable energy sources by 2025, and 50% by 2030[47]. In recent years, there has been significant growth in the use of wind and solar power in Greece. As of 2020, Greece has a total installed wind power capacity of 3,923 MW and solar power capacity of 3,032 MW[48].

Natural gas has also become an increasingly important source of energy in Greece. According to the Hellenic Statistical Authority (2021), natural gas consumption has been steadily increasing over the years, accounting for around 9.5% of the country's final energy consumption in 2019. Greece has invested in natural gas infrastructure, including the construction of an LNG terminal in Revithoussa and a new pipeline from the Trans Adriatic Pipeline (TAP), which brings natural gas from Azerbaijan to Europe[49].

Despite the efforts to diversify the energy mix, Greece still heavily relies on fossil fuels for its energy needs. To address this, the Greek government has set policies to phase out the use of lignite and invest in renewable energy sources, as outlined in the NECP[50]. However, there are still challenges to overcome, such as the need for significant investments in infrastructure and addressing energy poverty in the country[51].

[45] European Commission, 2020
[46] Hellenic Statistical Authority, 2021
[47] European Commission, 2020
[48] Hellenic Wind Energy Association, 2021
[49] TAP AG, 2021
[50] European Commission, 2020
[51] Papadaskalopoulos and Anastasiou, 2019

Reducing the consumption of natural gas in Greece would require a combination of measures aimed at promoting energy efficiency, increasing the use of renewable energy sources, and phasing out the use of natural gas in certain sectors. Here are some possible ways for Greece to reduce its consumption of natural gas:

Promote energy efficiency: One of the most effective ways to reduce natural gas consumption is to promote energy efficiency. This can be achieved through a variety of measures, such as improving building insulation, upgrading heating systems, and promoting energy-efficient appliances. The Greek government has already implemented several programs to promote energy efficiency, such as the "Saving at Home" program which provides financial incentives to households for energy-saving measures[52].

One effective method of decreasing the consumption of gas is, by boosting the production of energy. Greece has already witnessed growth in wind and solar power. There is still potential for further expansion especially in offshore wind and energy storage. By increasing the generation of energy, we can reduce reliance on gas, for electricity production and other sectors.

Develop alternative fuels: Greece could also explore the use of alternative fuels in place of natural gas, particularly in the transport sector. For example, electric vehicles and biofuels could help to reduce the dependence on natural gas for transportation. In addition, hydrogen fuel cells could provide a clean alternative to natural gas for heating and industrial processes.

Phase out natural gas in certain sectors: Finally, Greece could consider phasing out the use of natural gas in certain sectors where feasible. For example, in the building sector, renewable heating technologies such as heat pumps and solar thermal systems could be used to replace natural gas boilers. In the industrial sector, energy-efficient technologies and renewable energy could help to reduce natural gas consumption in manufacturing processes.

Overall, reducing the consumption of natural gas in Greece would require a comprehensive and coordinated approach, involving a range of measures aimed at promoting energy efficiency, increasing the use of renewable energy, and phasing out the use of natural gas in certain sectors.

One example of an EU country that has already made significant progress in reducing its reliance on natural gas is Sweden. Sweden has set an ambitious target to be fossil fuel-free by 2045 and has made significant progress in phasing out the use of natural gas in recent years.

[52] Greek Ministry of Environment and Energy, 2020

One of the main reasons for Sweden's success in reducing natural gas consumption is its investment in renewable energy. According to the Swedish Energy Agency, Sweden's electricity generation was 49% renewable in 2019, with the majority coming from hydro and wind power[53]. In addition, Sweden has invested heavily in district heating systems, which use waste heat from industrial processes and other sources to provide heating to buildings. District heating has helped to reduce the need for natural gas for heating purposes.

Another factor that has contributed to Sweden's success in reducing natural gas consumption is its focus on energy efficiency. Sweden has implemented strict building codes and standards that require new buildings to be highly energy-efficient and has also implemented several energy efficiency programs aimed at retrofitting existing buildings[54].

Sweden has managed to decrease its dependence, on gas by implementing strategies. These include promoting energy improving energy efficiency and gradually eliminating the use of fuels. Although Sweden’s approach may not be directly transferable to nations it serves as an example of how a well-coordinated and comprehensive strategy can effectively reduce reliance, on natural gas.

While Greece's current electricity generation mix is dominated by fossil fuels, particularly lignite and natural gas, there is significant potential for Greece to increase its use of renewable energy sources such as hydro power.

Greece has a number of suitable sites for hydro power generation, particularly in mountainous areas, and already has a number of hydro power plants in operation. According to the Hellenic Association of Photovoltaic Companies (HELAPCO), Greece had a total installed hydro power capacity of approximately 2,390 MW in 2020, accounting for around 12% of the country's total electricity generation[55].

Increasing the production of hydro power could help to reduce Greece's dependence on natural gas for electricity generation. Hydro power is a renewable energy source that produces electricity without producing greenhouse gas emissions or air pollution. Unlike solar and wind power, which are intermittent sources of energy, hydro power can provide a reliable source of electricity, particularly in areas with high rainfall or snowmelt.

However, it's important to mention that the ability to generate hydro power in Greece is restricted by factors, like geography, water availability and environmental concerns.

[53] Swedish Energy Agency, 2021
[54] European Environment Agency, 2020
[55] HELAPCO, 2021

Furthermore, establishing hydro power plants can be costly. Have substantial impacts, on the environment.

In general, although generating power, in Greece could contribute to decreasing the reliance on gas for electricity generation it is doubtful if it can be considered as the only solution. It would require a well-coordinated strategy that involves encouraging types of renewable energy sources implementing energy efficiency measures and gradually eliminating the use of fossil fuels in specific industries. This multi-faceted approach is essential to achieve reductions, in natural gas consumption.

Greece's dependence on natural gas from Russia and Turkey does pose some potential risks and challenges. As of 2020, Russia supplies approximately 65% of Greece's natural gas, while Turkey supplies the remainder through a pipeline from Azerbaijan[56].

One potential risk is the vulnerability of Greece's natural gas supply to geopolitical tensions and disruptions. For example, the ongoing conflict between Russia and Ukraine has in the past led to disruptions in natural gas supplies to Europe. In addition, political tensions between Greece and Turkey could potentially impact the supply of natural gas through the Trans-Anatolian Natural Gas Pipeline (TANAP).

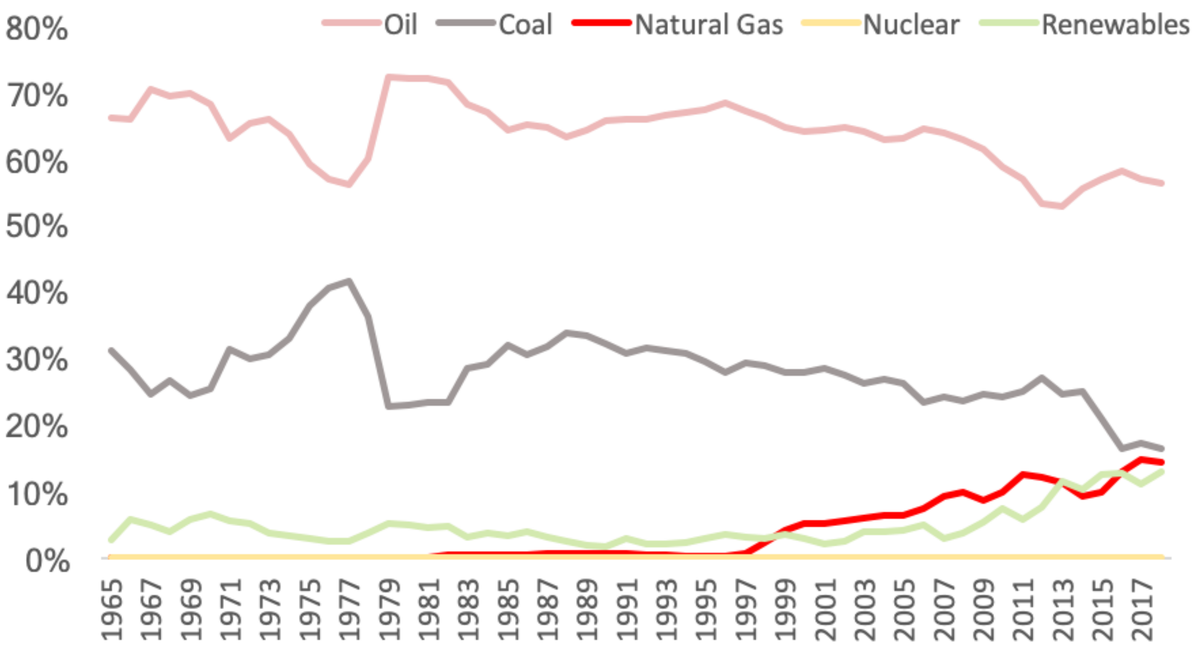
Another risk is the potential for price volatility. Greece's natural gas prices are linked to the price of oil, which can be subject to significant fluctuations. This can make it difficult for Greece to predict and manage its energy costs over the long term.

To address these risks, Greece has been making efforts to diversify its natural gas supply and reduce its dependence on Russia and Turkey. One way it has done this is by investing in liquefied natural gas (LNG) infrastructure, which allows for the import of natural gas from a range of sources. Greece has also been exploring the development of its own natural gas resources, particularly in the eastern Mediterranean.

Overall, while Greece's dependence on natural gas from Russia and Turkey does pose some potential risks, the country has been taking steps to address these risks and increase its energy security.

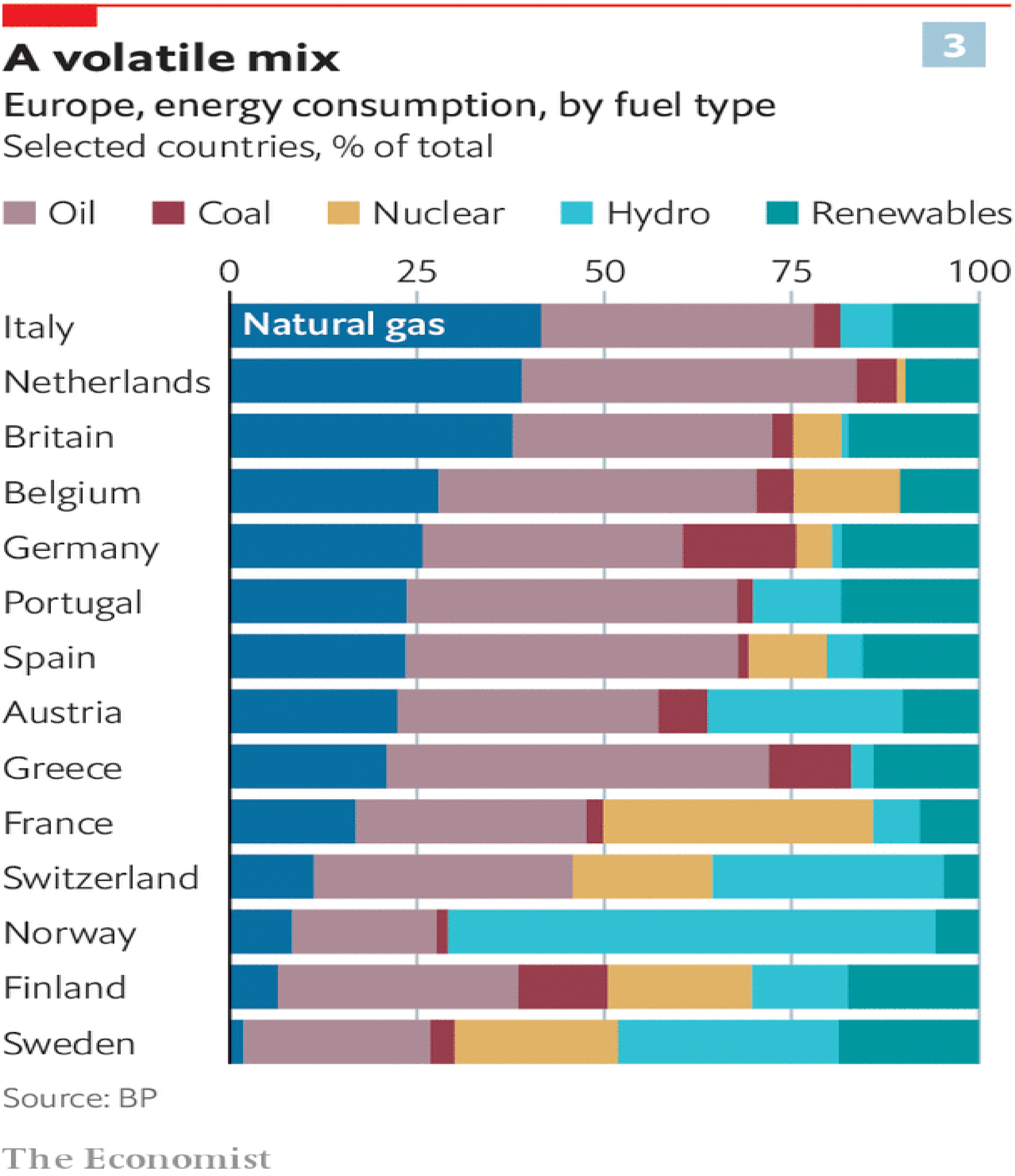
[56] Eurostat, 2021

Chart 6.1
Energy Consumption by Fuel Source in Greece, 1965-2018 BP STATISTICAL REVIEW



Reference: https://energypress.eu/natural-gas-in-greece-the-bridge-to-decarbonization/

Chart 6.2
Europe Energy Consumption by Fuel Type



Reference: https://www.economist.com/graphic-detail/2021/09/20/what-is-behind-rocketing-natural-gas-prices

6.5. Outline in the energy market in Greece

Greece imports natural gas from several countries, including Russia and Turkey. Russia is the primary supplier of natural gas to Greece, accounting for approximately 40% of Greece's natural gas imports in 2020[57]. Turkey, on the other hand, is not a major supplier of natural gas to Greece but acts as a transit country for the Trans Adriatic Pipeline (TAP), which brings natural gas from Azerbaijan to Greece and other European countries. In this context, Turkey's role is more related to the transportation of natural gas rather than being a significant supplier itself.

In terms of fossil gas flows from the country’s four entry points, in December 2022, LNG arriving at Agia Triada was 35% more compared to December 2021 and was by far the main source of gas for the country with 3.9 TWh and a 72% share of total fossil gas flows imported in December. In contrast, Russian gas imports from Sidirokastro covering domestic consumption were down by more than 2/3 (-67.3%)[1]. They amounted to just 0.73 TWh, but increased compared to the previous three months when they were practically zero. Imports from TAP via Nea Mesimvria (-52.7%) decreased significantly, contributing only 0.59 TWh, while imports from Turkey via Kipoi (0.22 TWh) decreased by 8.9%.

Cumulatively for the whole of 2022, Russian gas imports covering domestic consumption decreased by 68.3% compared to the same period in 2021. Thus, with 8.85 TWh and a share of 14.3% among the four entry gates, Russian gas used for domestic consumption fell to third place from the first place in which it stood in 2021 with a share of 39.7%. In contrast, LNG imports through the Agia Triada gate moved into first place reaching 38.08 TWh, an increase of 54% compared to 2021, thus gaining a 61.5% share. Azerbaijani gas imports via TAP decreased by 7.5% to 12.6 TWh (20.3% share), moving to second place for 2022. Finally, there was a large (-39.7%) decrease in cumulative gas imports from the quantitatively smallest gas source, Kipoi, which amounted to just 2.43 TWh (3.9% share).

Based on the latest available Eurostat data on monthly gas consumption in the EU-27 Member States from January to November 2022[2], Greece reduced its consumption by 18. 7% compared to the same period in 2021 and moved up two places in the relevant ranking compared to the previous month, to reach the 11th position, 6 places higher than the EU-27 average (-12.8%). There was also an improvement compared to the 5-year average where Greece in November showed for the first time in 2022 a decrease in consumption (-3.2%).

[57] U.S. EIA, 2021

However, this performance is still one of the worst in the EU-27 (5th from the bottom behind Slovakia, Malta, Spain and Ireland).

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6.6. Outline of ESG and economic impact in the energy market in Greece

Investments in photovoltaic systems (PVs), batteries, and green hydrogen production by the Greek government, investors, and retail clients can increase the Environmental, Social, and Governance (ESG) impact and stimulate economic growth in several ways:

6.6.1. Environmental Impact

Investing in PVs, batteries, and green hydrogen production can contribute to reducing greenhouse gas emissions, increasing renewable energy penetration, and promoting energy independence. These investments can aid in meeting climate change mitigation targets under the Paris Agreement and the European Green Deal[58].

[58] European Commission, 2019; UNFCCC, 2015

6.6.2. Social Impact

Increased investments in clean energy technologies can lead to job creation, especially in the PV installation and maintenance, battery manufacturing, and green hydrogen production sectors[59]. This can result in improved living standards and a more equitable distribution of wealth. Furthermore, it can enhance energy security by reducing dependence on imported fossil fuels, which can have positive social implications[60].

6.6.3. Governance Impact

Strategic investments in PVs, batteries, and green hydrogen production can signal strong government commitment to sustainable development and responsible governance. Effective policies, incentives, and regulatory frameworks can encourage private sector investments, foster innovation, and drive the transition towards a low-carbon economy[61].

6.6.4. Economic Impact

Investing in PVs, batteries, and green hydrogen production can stimulate economic growth by fostering the development of new industries and value chains. It can also improve energy efficiency and reduce energy costs for consumers and businesses, further contributing to economic competitiveness[62].

6.7 Outline of PV investments in the energy market in Greece

A typical investor who has already invested in photovoltaic (PV) systems may be interested in further expanding their clean energy portfolio by investing in batteries and green hydrogen production. Here's how it is possible, the associated costs, and the potential role of the Greek government in supporting such investments:

6.7.1. Investment possibilities

An investor with existing PV systems can consider investing in battery storage systems to optimize their energy usage, increase self-consumption, and potentially sell stored energy back to the grid during peak demand periods. Additionally, the investor can explore green hydrogen production using excess electricity generated by the PV systems, especially during periods of

[59] ILO, 2018
[60] IEA, 2019
[61] IRENA, 2020
[62] EC, 2021

low demand or high solar energy production. This green hydrogen can then be stored, transported, or used in various applications, such as fuel cell vehicles or industrial processes.

6.7.2. Costs

The costs associated with battery storage and green hydrogen production can vary based on the specific technologies, system sizes, and market conditions. Battery storage costs have been decreasing over the years, with lithium-ion batteries being the most popular choice due to their efficiency and declining prices[63]. The cost of green hydrogen production, primarily through water electrolysis, has also been reducing, and further cost reductions are expected with increased deployment and advancements in electrolyzer technologies[64].

6.7.3. Role of the Greek government

To support investments in batteries and green hydrogen production, the Greek government can play a vital role by:

a. Implementing supportive policies and regulations, such as incentives for battery storage systems, feed-in tariffs, or tax credits to encourage private investment.

b. Developing a national hydrogen strategy to promote green hydrogen production, infrastructure development, and market growth.

c. Facilitating access to financing and grants for clean energy projects through national or EU funding programs, such as the European Investment Bank (EIB) or the European Regional Development Fund (ERDF).

d. Encouraging research and development in batteries and green hydrogen production technologies by partnering with universities, research institutions, and the private sector.

e. Collaborating with other EU member states to develop cross-border hydrogen projects and infrastructure, in line with the EU's hydrogen strategy[65].

6.8. Outline of investments in the energy market in Greece with storage and green hydro

Greece can benefit from investments in photovoltaic (PV) systems, battery storage, and green hydrogen production in several ways, aligned with the EU's climate and energy goals:

[63] IRENA, 2020
[64] Ewan et al., 2021
[65] EC, 2020

6.8.1. Achieving EU Climate Targets

Investments in clean energy technologies can help Greece meet its obligations under the EU's climate and energy framework, which includes a 40% reduction in greenhouse gas emissions, a 32% share of renewable energy, and a 32.5% improvement in energy efficiency by 2030 compared to 1990 levels (EC, 2018).

6.8.2. Accelerating the Energy Transition

By investing in PVs, batteries, and green hydrogen production, Greece can accelerate its transition towards a low-carbon, sustainable energy system. This aligns with the European Green Deal, which aims to make the EU climate-neutral by 2050 (EC, 2019).

6.8.3. Enhancing Energy Security and Independence

Investments in renewable energy and green hydrogen production can help Greece reduce its reliance on imported fossil fuels, enhancing energy security and independence, while also supporting the EU's goal of diversifying energy sources (EEA, 2021).

6.8.4. Economic Growth and Job Creation

Investments in clean energy technologies can foster economic growth, create jobs in the renewable energy sector, and develop new industries and value chains. This aligns with the EU's objective of promoting sustainable and inclusive growth, as outlined in the Europe 2020 strategy (EC, 2010).

6.8.5. Access to EU Funding and Support

By aligning its energy investments with the EU's climate and energy goals, Greece can potentially access EU funding and support programs, such as the European Regional Development Fund (ERDF), the Just Transition Fund, and the Horizon Europe research and innovation program (EC, 2021).

6.9. Financial analysis and counterpart of investments PVs and green Hydro

The cost of battery storage for a 1 MW solar PV system and the cost of green hydrogen production can vary depending on several factors, including technology, capacity, and market conditions. Here's a rough estimate of these costs:

6.9.1. Battery Storage

For a 1 MW solar PV system, the battery storage capacity required will depend on the specific energy needs and the intended duration of storage. Lithium-ion batteries are the most popular choice for grid-scale energy storage due to their efficiency and declining prices. The cost of lithium-ion battery storage systems ranges between $150 to $200 per kWh as of 2021[66]. For example, if a 1 MW solar PV system requires 4 hours of storage (i.e., 4 MWh), the total cost would be between $600,000 and $800,000. It is essential to note that battery storage costs continue to decrease, and more recent data should be considered for accurate estimates.

6.9.2. Green Hydrogen Production

Green hydrogen production primarily relies on water electrolysis, where excess electricity from renewable sources, such as solar PV, is used to split water into hydrogen and oxygen. The cost of green hydrogen production depends on the electrolyzer technology (e.g., alkaline, proton exchange membrane, or solid oxide), system size, and electricity costs. As of 2021, the cost of green hydrogen ranges between $2.50 to $6.80per kg[67]. It is expected that the cost will decrease with the increased deployment of electrolyzers and advancements in technology.

To estimate the cost of green hydrogen production for a 1 MW solar PV system, consider the following example: Assume the PV system operates at a 20% capacity factor, generating an average of 200 kW of power throughout the day. If the excess electricity is dedicated to green hydrogen production for 8 hours a day, the total energy used for electrolysis would be 1.6 MWh per day.

To calculate the amount of green hydrogen produced, the energy-to-hydrogen conversion efficiency must be considered. Electrolyzers typically have an efficiency between 60% and 80%[68]. Assuming a 70% efficiency, the daily hydrogen production would be according to 6.1:

$$1.6\ \text{MWh/day} * (1{,}000\ \text{kWh/MWh}) * (70\%\ \text{efficiency}) / (33.33\ \text{kWh/kg}) \approx 33.44\ \text{kg/day} \quad (6.1)$$

The cost of green hydrogen production can be estimated by multiplying the daily hydrogen production by the cost per kg (6.2):

$$33.44\ \text{kg/day} * (\$2.50\ \text{to}\ \$6.80\ \text{per kg}) \approx \$83.60\ \text{to}\ \$227.39\ \text{per day} \quad (6.2)$$

Keep in mind that these calculations are rough estimates and may vary based on specific project requirements, local conditions, and market factors[69].

[66] Lazard, 2021
[67] IRENA, 2021
[68] FCH JU, 2019
[69] Fuel Cells and Hydrogen Joint Undertaking (FCH JU), 2019

6.10. Potential ways to sell green hydrogen

Transportation sector: Green hydrogen can be sold to fuel cell vehicle owners through hydrogen refueling stations. Fuel cell vehicles, such as buses, trucks, and cars, are gaining popularity as they produce zero emissions and offer a longer range and faster refueling times compared to battery-electric vehicles. Establishing partnerships with local governments, public transportation agencies, or logistics companies that operate fuel cell vehicles can create a consistent demand for green hydrogen.

Industrial sector: Industries such as steel production, chemical manufacturing, and fertilizer production can use green hydrogen as a feedstock or to replace fossil fuels in their processes. Partnering with local industries committed to reducing their carbon footprint can help create a market for green hydrogen.

Power sector: Green hydrogen can be sold to power plants that use hydrogen to generate electricity through fuel cells, gas turbines, or hydrogen combustion. This option might be more viable if the local grid has a high penetration of renewable energy sources and experiences periods of excess electricity generation.

Energy storage and grid services: Green hydrogen can be stored and later converted back to electricity using fuel cells, providing grid services such as peak shaving, frequency regulation, or backup power. Selling green hydrogen as a grid service may require partnerships with grid operators or utility companies.

Export: If local demand is insufficient or the hydrogen market is more favorable in other regions, exporting green hydrogen to countries with higher demand could be a viable option. This, however, would require access to hydrogen transportation infrastructure such as pipelines or shipping facilities that can handle compressed or liquefied hydrogen, as well as adherence to international trade regulations.

6.11. Essential factors in order to successfully sell green hydrogen

Market development: Understand the local and regional market dynamics, including demand, competition, and regulations. This will help identify the most promising sectors and customers to target.

Infrastructure: Assess the available hydrogen infrastructure, such as refueling stations, pipelines, or transportation facilities, to ensure that the produced hydrogen can be efficiently delivered to customers.

Partnerships: Establish strong partnerships with customers, industry stakeholders, and government agencies to facilitate market access, secure long-term contracts, and navigate regulatory hurdles.

Certifications and standards: Ensure that the produced green hydrogen meets the required quality standards and certifications, such as purity levels and environmental impact, to be accepted by customers and comply with regulations.

Pricing strategy: Develop a competitive pricing strategy that takes into account production costs, market prices, and the potential premium associated with green hydrogen compared to conventional hydrogen or fossil fuels.

By considering these factors and tailoring your approach to the specific context, you can create a successful strategy to sell 33.44 kg/day of green hydrogen and capitalize on the growing demand for clean, sustainable energy sources.

6.12 Executive Summary

This chapter investigates the involvement of governments and companies in advancing the development of green hydrogen as an environmentally viable substitute for fossil fuels. The utilization of green hydrogen has surfaced as a prospective remedy for mitigating greenhouse gas emissions and facilitating the shift towards a low-carbon energy paradigm. Multiple production methods, including as electrolysis and biological processes, are now being researched and refined with the aim of increasing efficiency and decreasing expenses.

The importance of adopting green hydrogen as a means of addressing climate change, integrating renewable energy sources, fostering job opportunities, and promoting economic development is underscored. The promotion of green hydrogen generation is significantly facilitated by the active involvement of governments and companies, which undertake crucial responsibilities such as policy execution, provision of financial incentives, initiation of research and development endeavors, and engagement in international partnerships.

The chapter underscores the significance of ongoing progress in green hydrogen production technology and the necessity of supportive policies and incentives to facilitate widespread implementation. The establishment of a resilient hydrogen infrastructure, the resolution of storage and transportation obstacles, and the promotion of international cooperation are seen as essential measures for fully harnessing the potential of green hydrogen in the worldwide energy domain.

It examines the endeavors of Greece within its energy market to modernize its energy infrastructure, diminish reliance on fossil fuels, and advance the utilization of renewable energy sources. The renewable energy adoption goals set by Greece are in accordance with the prevailing global shift towards clean energy. Nevertheless, it is important to recognise the existence of certain obstacles, like energy poverty, limited interconnectivity with neighboring nations, and the imperative to upgrade existing infrastructure.

The reduction of natural gas use in Greece necessitates the implementation of a comprehensive strategy, encompassing various measures such as the promotion of energy efficiency, the augmentation of renewable energy generation, the exploration of alternative fuel sources, and the gradual elimination of natural gas usage in specific sectors. The paper emphasizes the significance of diversifying the supply of natural gas and effectively managing potential risks associated with geopolitical tensions and price volatility.

This chapter emphasizes the importance of green hydrogen in the pursuit of sustainable energy objectives and advocates for collaborative endeavors among governments, companies, and stakeholders to facilitate its generation and incorporation into the worldwide energy framework. Furthermore, it underscores the necessity of using customized approaches to tackle the unique obstacles encountered by nations such as Greece during their endeavors towards energy transformation.

Total statement:

Briefly, the production of electricity through renewable energy sources such as photovoltaics is a direct solution for Greece's independence from the import of natural gas. Greece's strategy in the coming years should be oriented towards self-sufficiency and the primary sector, so as not to be vulnerable to external risks and non-ferrous countries - allied suppliers.

Alignment with the European targets for reducing carbon dioxide production and self-production and electricity consumption through renewable energy projects should be aligned with warm support for investment through both direct funding through subsidies and indirect funding through competitive guaranteed production compensation prices for renewable energy projects.

In addition, Greece's and Europe's support for this sustainable model of green RE project development will be further developed if existing and future investments incorporate 24/7 energy storage systems, minimizing energy losses and part of the produced energy is transformed into green hydro, then an integrated strategy will have been achieved.

Finally, Greece due to its geopolitical position and the energy bottleneck that has developed can create more exports, more profitable investments and meet the European esg targets by becoming more autonomous, greener, and more efficient.

ANNEX A

Economic Analysis of PV power 1000KW without trackers				
1.	Fundamentals			
1.1	Power		1,00	MWp
1.2	Yield		1.800	KWh/KWp
1.3	Electricity produced (annually)		1.800	MWh
1.4	Capacity Factor		20,55%	
2.	Business Plan			
2.1	Total Investment		1.218.000 €	
2.2	equity participation	20%	243.600 €	
2.3	Loan		974.400 €	
2.4	Loan Duration		15	
2.5	Interest Rate		4,0%	
2.6	Tax Rate		22%	
2.7	Reduction rate to present value		2,5%	
3.	Sales prices			
3.1	Sale Price (for 20 years)		65,67	€ / MWh
3.2	Αύξηση τιμής		0,00%	
3.2	Yield Reduction		0,20%	
4	Sales			
4.1	**Income**		**201.911 €**	
5	Expenses			
5.1	Intermittency (tax from LAGIE)	0,0%	- €	
5.2	Operational costs (maintenance/Insurance, etc.)		62.700 €	
	Cost for consumption of 33,44 kg/day of GREEN HYDRO	57.000 €		
	Maintenance (labor & parts)	1.500 €		
	Insurance (damages & loss of income)	1.200 €		
	Electricity Used	500 €		
	Accounting	2.200 €		
	Admin	300 €		
	Rent (max stremmata)		3.700 €	
	Total O&M		**66.400 €**	

5.3	Inflation		4,0%	
6	EBITDA			
6.1	EBITDA		135.511 €	
7	Indexes			
7.1	NPV		467.005 €	
7.2	IRR		15,26%	
7.3	PAYBACK		6,9	

ANNEX B

Loan					
1.1 Terms of the Loan					
a.	Loan		974.400		
b.	Interest Rate		4,00%		
c.	Duration (in years)		15		
d.	Grace Period (in months)		0		
1.2 Loan Flows					
Year	Loan	Installment	Amortization	Interest	Balance
0	974.400,00 €				
1		87.638,61 €	48.662,61 €	38.976,00 €	925.737,39 €
2		87.638,61 €	50.609,11 €	37.029,50 €	875.128,28 €
3		87.638,61 €	52.633,48 €	35.005,13 €	822.494,80 €
4		87.638,61 €	54.738,82 €	32.899,79 €	767.755,99 €
5		87.638,61 €	56.928,37 €	30.710,24 €	710.827,62 €
6		87.638,61 €	59.205,50 €	28.433,10 €	651.622,11 €
7		87.638,61 €	61.573,72 €	26.064,88 €	590.048,39 €
8		87.638,61 €	64.036,67 €	23.601,94 €	526.011,72 €
9		87.638,61 €	66.598,14 €	21.040,47 €	459.413,58 €
10		87.638,61 €	69.262,07 €	18.376,54 €	390.151,51 €
11		87.638,61 €	72.032,55 €	15.606,06 €	318.118,97 €
12		87.638,61 €	74.913,85 €	12.724,76 €	243.205,12 €
13		87.638,61 €	77.910,40 €	9.728,20 €	165.294,71 €
14		87.638,61 €	81.026,82 €	6.611,79 €	84.267,89 €
15		87.638,61 €	84.267,89 €	3.370,72 €	0,00 €
	Total	1.314.579,12 €	974.400,00 €	340.179,12 €	

ANNEX C

Flows																
Year	Proceeds	+Increase of Proceeds	- Reduction of Production	Income	Operational	Rent	Total O&M	Υπέρ ΟΤΑ	EBITDA	Depreciation	Interest	Taxes	Net Income	Total	Present Value	Present Value (in total)
0													-243.600	-243.600	-243.600	-243.600
1	201.911	0	0	201.911	62.700	3.700	66.400	0	135.511	65.000	38.976	6.938	40.934	-202.666	39.936	-203.664
2	201.911	201.911	201.507	201.507	62.700	3.700	66.400	0	135.107	65.000	37.029	7.277	40.191	-162.474	38.255	-165.409
3	201.911	201.911	201.104	201.104	62.700	3.700	66.400	0	134.704	65.000	35.005	7.634	39.432	-123.043	36.616	-128.793
4	201.911	201.911	200.702	200.702	62.700	3.700	66.400	0	134.302	65.000	32.900	8.008	38.655	-84.388	35.019	-93.774
5	201.911	201.911	200.300	200.300	62.700	3.700	66.400	0	133.900	65.000	30.710	8.402	37.860	-46.528	33.463	-60.311
6	201.911	201.911	199.900	199.900	62.700	3.700	66.400	0	133.500	65.000	28.433	8.815	37.046	-9.482	31.945	-28.366
7	201.911	201.911	199.500	199.500	62.700	3.700	66.400	0	133.100	65.000	26.065	9.248	36.214	26.732	30.465	2.099
8	201.911	201.911	199.101	199.101	62.700	3.700	66.400	0	132.701	65.000	23.602	9.702	35.360	62.092	29.022	31.121
9	201.911	201.911	198.703	198.703	62.700	3.700	66.400	0	132.303	65.000	21.040	10.178	34.486	96.579	27.614	58.735
10	201.911	201.911	198.305	198.305	62.700	3.700	66.400	0	131.905	65.000	18.377	10.676	33.590	130.169	26.241	84.976
11	201.911	201.911	197.909	197.909	62.700	3.700	66.400	0	131.509	0	15.606	25.499	18.371	148.540	14.002	98.978
12	201.911	201.911	197.513	197.513	62.700	3.700	66.400	0	131.113	0	12.725	26.045	17.429	165.969	12.959	111.937
13	201.911	201.911	197.118	197.118	62.700	3.700	66.400	0	130.718	0	9.728	26.618	16.461	182.431	11.942	123.878
14	201.911	201.911	196.724	196.724	62.700	3.700	66.400	0	130.324	0	6.612	27.217	15.468	197.899	10.947	134.826
15	201.911	201.911	196.330	196.330	62.700	3.700	66.400	0	129.930	0	3.371	27.843	14.448	212.348	9.976	144.802
16	201.911	201.911	195.937	195.937	62.700	3.700	66.400	0	129.537	0	0	28.498	101.039	313.387	68.063	212.864
17	201.911	201.911	195.546	195.546	62.700	3.700	66.400	0	129.146	0	0	28.412	100.734	414.120	66.202	279.066
18	201.911	201.911	195.155	195.155	62.700	3.700	66.400	0	128.755	0	0	28.326	100.429	514.549	64.391	343.457
19	201.911	201.911	194.764	194.764	62.700	3.700	66.400	0	128.364	0	0	28.240	100.124	614.673	62.630	406.088
20	201.911	201.911	194.375	194.375	62.700	3.700	66.400	0	127.975	0	0	28.154	99.820	714.493	60.917	467.005
													958.093			

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