Escuela Técnica Superior de Ingeniería (ICAI)
Master´s degree in Industrial Engineering

Master´s Final Project

Towards a Socially Responsible Hydrogen Economy: exploring site selection criteria in Spain.

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Madrid
June 2024

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Hacia una Economía del Hidrógeno Socialmente Responsable: explorando los criterios de selección de localizaciones en España.

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Entidad Colaboradora: ICAI- Universidad Pontificia Comillas.

Resumen del Proyecto

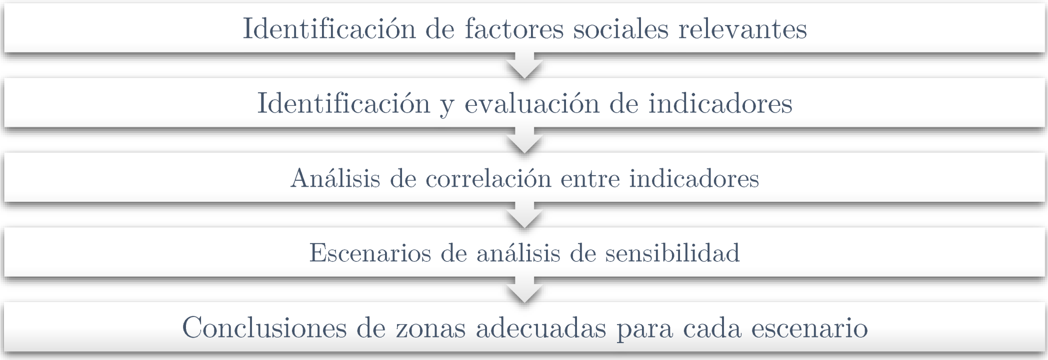
Introducción

La transición energética es una prioridad global que busca reemplazar las fuentes de energía fósil por energías renovables como la solar, eólica, hidroeléctrica y geotérmica. En este contexto, el hidrógeno verde, producido a partir de fuentes renovables, se presenta como una solución crucial para descarbonizar sectores difíciles de electrificar, como la industria pesada y el transporte marítimo y aéreo.

Metodología

El proyecto se realizó en colaboración con la Cátedra de Hidrógeno de ICAI la herramienta avanzada Q-GIS para el análisis espacial. El objetivo principal fue identificar las ubicaciones más adecuadas para la implementación de plantas de hidrógeno verde en España mediante el desarrollo de un índice de compatibilidad del hidrógeno (ICH2). Este índice integra criterios económicos, técnicos, ambientales y sociales.

El proceso comenzó con una recolección de datos exhaustiva y la selección de criterios. Para ver la influencia de cada criterio, se realiza un análisis de correlación para concluir que indicadores se acaban introduciendo en el modelo. Se realizaron análisis de escenarios para explorar diferentes esquemas de ponderación de los criterios seleccionados, y un análisis de sensibilidad para entender cómo los cambios en los pesos de los diferentes criterios afectan la selección de ubicaciones óptimas.



Resultados

Los resultados revelaron que regiones como Cáceres, Jaén, Badajoz, León, y Castellón consistentemente emergen como ubicaciones óptimas a través de diferentes escenarios. Estas regiones muestran una mezcla favorable de alto potencial de energía renovable, condiciones técnicas adecuadas y factores sociales que favorecen el despliegue exitoso de la infraestructura de hidrógeno. Además, provincias como Huelva, Almería, Zamora, y Ciudad Real también destacan cuando se consideran criterios sociales, indicando la importancia de un enfoque integral en la selección de sitios.

Conclusiones

El proyecto subraya la importancia de un enfoque holístico en la planificación estratégica de la infraestructura de hidrógeno verde. La incorporación de diversos criterios, con un énfasis particular en los factores sociales, es esencial para asegurar que los beneficios de las plantas de hidrógeno verde se extiendan más allá de las meras ganancias económicas, promoviendo el desarrollo regional, la creación de empleo y la equidad social. Los hallazgos sugieren que, si bien la viabilidad técnica y económica es crucial, abordar las disparidades sociales y promover un crecimiento equitativo es igualmente vital para el éxito y la aceptación a largo plazo de los proyectos de hidrógeno. Integrar regiones con alto potencial social y natural en la red de hidrógeno puede fortalecer la economía del hidrógeno en España y fomentar un desarrollo regional equilibrado y sostenible.

Towards a Socially Responsible Hydrogen Economy: exploring site selection criteria in Spain.

Author: García Rosado, Inés Amparo

Supervirsors: Serna Zuluaga, Santiago. Romero Mora, José Carlos.

Collaborating Entity: ICAI- Universidad Pontificia Comillas.

Project Summary

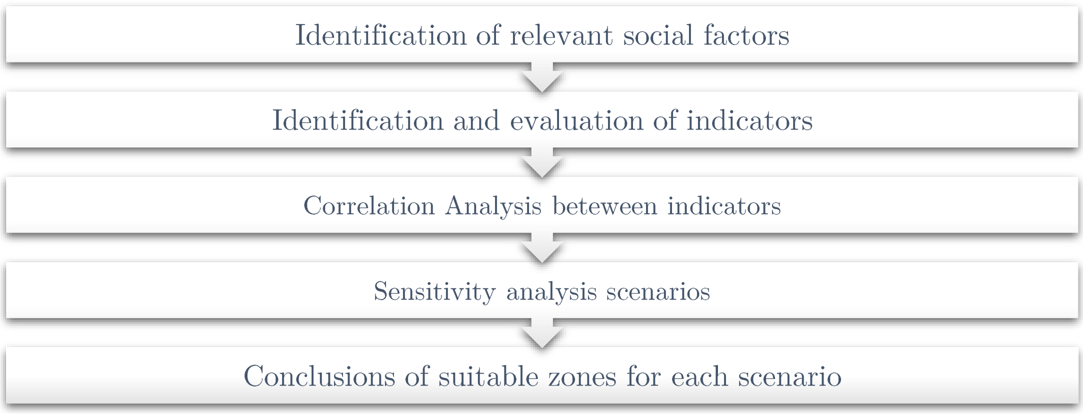
Introduction

The energy transition has become a global priority aiming to shift energy sources from fossil fuels to more sustainable sources such as renewable energies like solar, wind, hydroelectric, and geothermal. Green hydrogen, produced from renewable energy sources, is critical for achieving deep decarbonization, especially in sectors where electrification faces significant challenges, such as heavy industry, maritime transport, and aviation.

Methodology

The project was conducted under the auspices of the Hydrogen Chair at ICAI, utilizing the advanced Q-GIS tool for spatial analysis. The primary goal was to identify the most suitable locations for green hydrogen plant deployment by developing a comprehensive "H2 compatibility index". This index incorporates a multifaceted approach integrating economic, technical, environmental, and social criteria.

The methodology began with extensive data collection and the selection of criteria. To see the influence of each criterion, a correlation analysis was performed to determine which indicators would be included in the model. Scenario analyses were conducted to explore different weighting schemes for the selected criteria, and a sensitivity analysis was carried out to understand how changes in the weights of different criteria affect the selection of optimal locations.



Results

The results revealed that regions such as Cáceres, Jaén, Badajoz, León, and Castellón consistently emerge as optimal locations across different scenarios. These regions show a favourable mix of high renewable energy potential, suitable technical conditions, and social factors that support the successful deployment of hydrogen infrastructure. Additionally, provinces like Huelva, Almería, Zamora and Ciudad Real also stand out when social criteria are considered, indicating the importance of a comprehensive approach in site selection.

Conclusions

The project underscores the importance of a holistic approach in the strategic planning of green hydrogen infrastructure. Incorporating diverse criteria, with a particular emphasis on social factors, is essential to ensure that the benefits of green hydrogen plants extend beyond mere economic gains, promoting regional development, job creation, and social equity. The findings suggest that while technical and economic viability is crucial, addressing social disparities and promoting equitable growth is equally vital for the long-term success and acceptance of hydrogen projects. Integrating regions with high social and natural potential into the hydrogen network can strengthen Spain's hydrogen economy and foster balanced and sustainable regional development.

Acknowledgments

The completion of this project would not have been possible without the support of many people. First, I would like to express my sincere gratitude to my supervisors, Santiago and José Carlos, for their continuous support and assistance throughout the academic year. Thank you for showing as much interest in this work as I have, and for taking the time to address my questions despite your busy schedules.

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To all of you, thank you very much.

Table of Contents

Index of figures

1. Introduction

Energy transition has become a global priority in which it seeks to modify energy sources from fossil fuels to more sustainable sources, that is, renewable energies such as solar, wind, hydroelectric and geothermal.

This change is due to the growing global awareness of the negative effects of greenhouse gas emissions. Thus, different international agreements set goals to achieve decarbonization and achieve net zero emissions. Among them, the Kyoto Protocol, the Copenhagen Agreement, and the Paris Agreement of 2015 stand out [1]. The latter, intent to limit the global temperature increase in this century to 1.5 ° C, provides funding through the Green Climate Fund (GCF) to developing countries so that they can mitigate climate change, and reviews the countries' commitments every 5 years [2]. By 2030, Spain´s goal is to reduce total emissions 23% compared with 1990, although it plans to overachieve this target and reduce emissions by 39%. [3]

'Hard-to-abate sector' describes sectors where the transition to net zero is not straightforward, either due to a lack of technology or the prohibitive cost associated with it [4]. Various sectors face challenges in reducing emissions, particularly in industries like steel, cement, and aluminium. Additionally, the chemical sector and others, such as heavy-duty transportation, aviation, and shipping electrification´s is limited by the high energy density required. Hydrogen can act as energy vector to bring renewable electricity to these sectors and allow its decarbonisation, which explains why it has experienced a renewed interest in the last years.

As of April 2022, 131 countries, representing 88% of global greenhouse gas emissions, had committed to achieving net zero targets. Human-caused emissions have already caused a 1.1°C increase in global temperatures compared to pre-industrial levels. It's widely acknowledged that achieving net zero emissions by 2050 is crucial to limit this temperature rise to within 1.5°C. This renewed emphasis necessitates mitigating emissions from all energy end uses. While measures like energy efficiency, electrification, and renewables can address 70% of the required mitigation, hydrogen will be essential, but not indispensable, for decarbonizing hard-to-abate sectors like heavy industry, long-haul transport, and seasonal energy storage, where alternative options are less developed or more expensive. However, it can be done through other alternatives as biomethane or fossil fuels that capture CO2 [5]

Hydrogen is a clean fuel that produces no greenhouse gas emissions when burned. Therefore, it has the potential to be an important solution for decarbonizing hard-to-abate sectors, being used as a fuel for internal combustion engines, in fuel cells to generate electricity, or as raw material to produce synthetic fuels. The sustainability of these synthetic fuels also depends on the source of the CO2, being the one derived from biomass (biogenic CO2) sustainable and the one precedent from fossils not sustainable. Therefore, several countries and companies have announced plans and programs to use hydrogen as a key component in the transition towards a more sustainable energy matrix.

As for today, the idea of hydrogen is for it to be commercially produced and serve various purposes. Act as a feedstock in the chemical industry and refineries, used in the production of primary steel, and utilized in heat and power generation. Worldwide production amounts to approximately 75 million metric tons of pure hydrogen annually, with an additional 45 million metric tons produced as part of gas blends. This combined production is equivalent to about 3% of the world's total final energy demand, comparable to the annual energy consumption of Germany. [5].

Nowadays, hydrogen is used as feedstock for different matters and can be transformed into derivatives. It may interact with carbon from CO2 to form hydrocarbons and almost any other molecule. It may be used to generate ammonia, which can then be utilized as a feedstock for fertilizers or as fuel for novel purposes such as maritime transportation. It may also be used to make methanol, synthetic fuels, or as a reduction agent to substitute coal in iron manufacturing. When it is turned into these commodities, the energy density increases making long-distance transit and long-term storage less expensive.

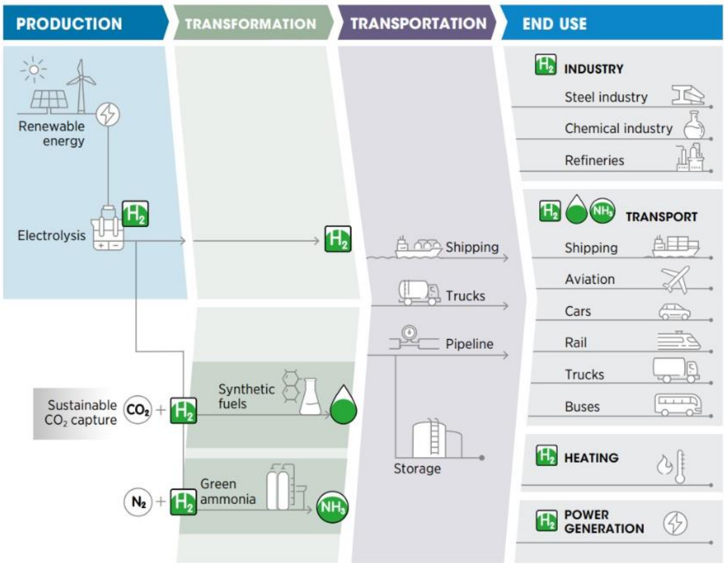


Figure 1. Green Hydrogen production, conversion and end uses across the energy system.

The production of hydrogen can be carried out from renewable sources (green), from natural gas without CO2 capture (grey), and with capture (blue). Thus, the sustainability of hydrogen depends largely on how it is produced, and although green hydrogen is considered the most environmentally sustainable option, blue hydrogen production method can also play an important role in this transition [6]. Hydrogen is used more as a versatile energy carrier as it offers flexibility across a wide range of applications. It can be generated from various feedstocks and utilized in a wide variety of sectors (Figure 1). Through electrolysis, renewable electricity can be converted into hydrogen, facilitating the integration of ever-expanding renewable energy sources with challenging-to-electrify end uses. This integration not only supports grid flexibility but also complements other smart electrification solutions like batteries, demand response, and vehicle-to-grid systems.

Hydrogen production plants face challenges in both energy efficiency and environmental impact. Conventional methods like steam methane reforming (SMR) are energy-intensive, while green hydrogen production through electrolysis requires significant electricity input. Improving energy efficiency in hydrogen production is crucial to reduce costs and environmental footprint. Additionally, hydrogen plants, especially those using fossil fuel-based methods, can generate greenhouse gas emissions and pollutants. Transitioning to clean and sustainable production technologies, such as renewable energy-powered electrolysis, is essential to minimize environmental impact and support climate goals. By enhancing energy efficiency and adopting cleaner production methods, hydrogen plants can contribute to a more sustainable energy future.

What is more, hydrogen can be employed for thermal uses in industries where high-temperature heat demand exceeds 200°C (as seen on the Figure 2) and electrification options are limited. This is particularly relevant in sectors such as ceramics, glass, and cement manufacturing. In these processes, hydrogen serves as a crucial energy source, providing the necessary high temperatures that other energy forms might not efficiently supply. This application of hydrogen not only meets specific industrial requirements but also offers a cleaner alternative to traditional fossil fuels, potentially reducing the environmental impact of these high-energy processes.

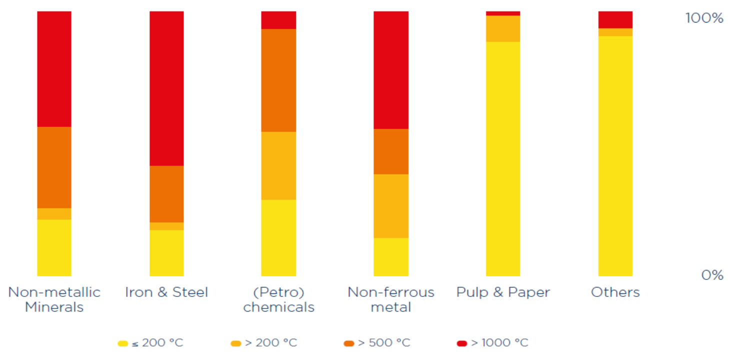


Figure 2. Potential of Industrial (high temperature) heat pumps for exploiting waste heat in EU Industries. [7]

Nevertheless, the utilization of hydrogen as an energy carrier remains restricted, primarily to road vehicles. As of June 2021, over 40,000 fuel cell electric vehicles, with grey hydrogen, were operational worldwide, with nearly 90% concentrated in four countries: Korea, the United States, China, and Japan. By the conclusion of 2020, there were approximately 6,000 fuel cell electric buses (with 95% located in China) and over 3,100 fuel cell electric trucks. These figures represent only a minute portion of the global vehicle fleet. The development of hydrogen infrastructure is essential for broadening its use as an energy carrier. It can be transported through pipelines, trucks, and ships. Pipelines provide an efficient method for long-distance transport, while trucks offer flexibility for shorter routes. Additionally, shipping methods, such as liquefied hydrogen or hydrogen carriers like ammonia, are being explored for international trade. This enables the export of green hydrogen from regions with abundant resources to areas with high demand.

Because of all the mentioned above, the European Union has set goals as basis for moving towards a sustainable energy model, and there has been such a growth on the interest in hydrogen, that the initial goals have increased in recent years. The EU launched their roadmap in February 2019, setting a target of 40GW of electrolysis. This target increased to approximately 80 GW in 2021 with REPowerEU. On the other hand, Spain´s hydrogen roadmap was published in 2020 with a target of 4 GW of electrolysis; however, the recent draft of the PNIEC increases this target to 11 GW. [8]

From an international perspective, interest in hydrogen production is not limited to Europe. China leads in electrolyser capacity additions, with a cumulative capacity of almost 220 MW in 2022 and an additional 750 MW expected to be operational by 2023. In January 2023, India launched the National Green Hydrogen Mission, aiming to produce 5 million tonnes of renewable hydrogen by 2030 and become a major electrolyser manufacturer. The United Kingdom has also been active, introducing its Low-Carbon Hydrogen Standard in July 2022 and starting a consultation for a certification scheme in February 2023. Meanwhile, the United States has provided significant incentives for clean hydrogen production under the Inflation Reduction Act (IRA) since August 2022, highlighting the global momentum in advancing hydrogen technology. [9]

Evidently, hydrogen plays a crucial role in driving the energy transition in the world. Narrowing it down to Europe, Spain can play a crucial part in achieving those objectives due to is geographic placement giving high solar radiation that makes it a valuable resource for photovoltaic deployment and the generation of green hydrogen. Therefore, this richness, combined with technological know-how, the leadership of its energy companies, and public-private investment, can turn Spain into producers and exporters of energy to Northern Europe [10].

One of the main projects related to hydrogen being developed in Spain is the Catalina PTX project, which aims to produce green hydrogen and green ammonia from renewable energy sources. It will supply green hydrogen to local, regional and national industries, mainly in the fertilizer sector [11]. Another project in study is the Tarragona hydrogen plant, which will produce green hydrogen from solar energy and supply it to a nearby chemical complex. This project is part of

Endesa's portfolio of 23 green hydrogen projects in Spain, which have an associated investment of 2.9 billion euros [12]. Finally, a hydrogen-electric high-speed train project is being developed, which will be the world's first hydrogen-electric train capable of going over 250 km/h. This prototype will retrofit existing diesel trains with hydrogen fuel cells and batteries, reducing noise and pollution. The project has received a multi-million dollar grant from the Spanish government and is expected to be operational by 2025.[13]

It is a key for those projects to be aligned with the Social Climate Fund (SCF) as an essential component of the European Union's strategy to ensure a fair and inclusive transition towards a green economy, as outlined in the European Green Deal. It aims to mitigate the social impact of climate change policies by providing financial support to vulnerable groups and regions most affected by the transition. With a budget aimed to mobilize at least €86.7 billion between 2026 and 2032, the SCF is designed to fund measures and investments in energy efficiency, renovation of buildings, clean heating and cooling, renewable energy integration, and zero- and low-emission mobility solutions. These efforts are part of the EU's broader objective to reduce greenhouse gas emissions and enhance sustainability while ensuring that the green transition is socially equitable.[14]

In the context of hydrogen plants' implementation, the SCF could play a crucial role in supporting the necessary infrastructure for hydrogen production, storage, and distribution. This includes investments in renewable energy to power hydrogen production processes, promoting energy efficiency to reduce overall demand, and facilitating the adoption of hydrogen fuel cell vehicles by supporting refuelling infrastructure. These initiatives align with the fund's objectives to foster zero- and low-emission mobility solutions and contribute to the EU's climate goals. Furthermore, the SCF can address social impacts such as employment changes and workforce retraining, ensuring support and opportunities for affected workers and communities.

The successful application of the SCF in deploying hydrogen plants requires integrating these projects within national Social Climate Plans. These plans should outline how the projects contribute to achieving the EU's climate objectives and social equity goals. By leveraging the SCF, Member States can ensure that the transition to a hydrogen economy is both environmentally sustainable and socially responsible, highlighting the importance of comprehensive planning and community engagement in the green transition.[15]

2. Problem Statement

The location of hydrogen production plants is influenced by a multitude of geospatial factors, each playing a critical role in the feasibility and sustainability of these projects. The significance of renewable resources cannot be overstated, as they are essential for reducing the overall cost of hydrogen production. Proximity to reliable and stable water sources is also crucial, given that water is a primary input in the electrolysis process used to produce green hydrogen. Additionally, the need for available land to build the necessary renewable energy infrastructure, such as solar and wind farms, is another key consideration.

Currently, Spain lacks the infrastructure to support widespread hydrogen production and distribution. Therefore, it is imperative that hydrogen plants are situated near points of consumption to minimize transportation challenges and associated costs. This strategic placement not only ensures the efficient delivery of hydrogen but also supports the broader objective of integrating hydrogen into existing energy systems seamlessly.

While previous literature has partially addressed these factors, the focus has often been on the technical and economic aspects, such as the cost of production and infrastructure requirements. However, to ensure a just transition to a hydrogen-based economy, it is equally important to analyse social criteria. Public perception, acceptance, policy, and regulation play significant roles in the successful implementation of hydrogen projects. The International Energy Agency (IEA) highlights the high cost of green hydrogen production due to expensive electrolysers and renewable energy sources, which presents a barrier to widespread adoption [16]. Additionally, the technical complexities and safety considerations associated with storing and transporting hydrogen necessitate a robust regulatory framework and significant investment in infrastructure.

Countries like Germany, Japan, South Korea, and Australia have successfully addressed these challenges, showcasing positive developments in hydrogen implementation. Germany's hydrogen-powered trains [17], Japan's network of hydrogen refuelling stations [18], South Korea's investment in large-scale electrolysis facilities [19], and Australia's green hydrogen projects exemplify how nations can drive progress in hydrogen technology while overcoming technical and social challenges [19].

Spain, with its ambitious plans to decarbonize its energy sector, recognizes hydrogen's role in its National Energy and Climate Plan. Projects like the e-fuels production plant in Bilbao and Iberdrola SA and Fertiberia's electrolyser capacity installation are positioning Spain as a leader in green hydrogen development. These initiatives are pivotal for reducing carbon emissions and fostering economic growth through job creation and technological innovation. [20]

Nevertheless, one of the main challenges in implementing hydrogen in Spain is achieving social acceptance. Understanding the sociological factors that influence the adoption and diffusion of hydrogen technologies, such as attitudes, beliefs, norms, values, behaviours, and policies, is crucial. By examining these social dimensions, we can design more effective and inclusive strategies to promote hydrogen's integration into the energy system.

Furthermore, this analysis will be enriched by leveraging insights from studies conducted by the Hydrogen Chair of ICAI, which offer a comprehensive overview of the state of green hydrogen technology, market trends, and strategic directions [21]. By incorporating a detailed examination of social impacts, this work aims to address the existing gap in the literature, providing a more rounded understanding of the factors that influence the successful implementation of hydrogen plants.

3. State of the art

The push towards green hydrogen as a significant step in our journey towards sustainable energy has led to a flurry of research across the globe. This research aims to find the best places for setting up hydrogen production facilities, focusing on using renewable sources like wind and solar power. Such efforts represent a major shift towards more environmentally friendly energy options. In some countries like Argentina and Algeria there have been studies made that mapped out the potential areas based on their suitability for green hydrogen production using renewable energies [22]. While these studies have made important strides in understanding the environmental and technical aspects of green hydrogen, they often overlook an equally important aspect: the social dimension.

In Algeria, for instance, a sophisticated methodology that combines Multi-Criteria Decision Making (MCDM) with Geographic Information Systems (GIS) has been adopted. This approach not only assesses the availability of natural resources but also integrates economic and technological criteria to identify the most suitable locations for hydrogen plants [23]. However, despite these methodological advancements, there's a notable deficiency in the inclusion of social indicators in these analyses. This gap underscores a significant shortfall in the current research landscape, as the integration of social considerations is paramount for achieving a holistic and sustainable energy transition.

According to a systematic literature review by Emodi Nnaemeka Vincent, Lovell Heather, Levitt Clinton, and Franklin Evan; prior knowledge, perceived cost, risks, environmental knowledge, higher education and income, infrastructure availability and proximity to hydrogen facilities are among the factors that influence societal acceptance of hydrogen technologies. However, the level of hydrogen awareness in more than 60% of the countries that were analysed is low, which may affect the evaluation of its potential impacts. [24]

As seen, the inclusion of social factors in the analysis of potential hydrogen plant locations is indispensable. It ensures that the transition towards hydrogen energy is not only environmentally sound and economically feasible but also socially equitable. This involves examining the potential impact of hydrogen plants on employment opportunities, community welfare, and the demographic composition of the areas under consideration. To achieve a deeper understanding of these social aspects, this analysis will reference essential documents outlining social taxonomies [25] and explore the 'S' component of the ESG (Environmental, Social, and Governance) framework in detail [26]. The ESG framework serves as a crucial tool for assessing the sustainability and ethical implications of corporate actions and investments, with the 'S' component specifically addressing social issues such as job creation, community impact, and regional demographics.

The integration of social considerations into the planning and development of hydrogen projects is not merely an academic exercise; it is a critical step towards ensuring that these projects are developed in a manner that is both sustainable and socially responsible. By acknowledging and addressing the social implications of hydrogen production, policymakers, industry leaders, and researchers can pave the way for energy projects that are not only technically viable and environmentally friendly but also socially beneficial. This comprehensive approach is essential for fostering widespread acceptance and support for green hydrogen as a key component of our future energy systems.

4. Methodology guide

In this chapter, it is presented a detailed methodology guide designed to systematically identify the most suitable locations for hydrogen plant implementation in Spain. The methodology integrates various criteria factors into a comprehensive Geographic Information System (GIS)-based analysis. This structured approach ensures that all relevant factors are considered in the decision-making process, promoting sustainable and inclusive development.

The methodology is visually summarized in Figure 3, which serves as a roadmap for the process. The diagram outlines the sequential steps, starting with the identification of relevant social factors and progressing through to the final conclusions of suitable zones for hydrogen plant locations.

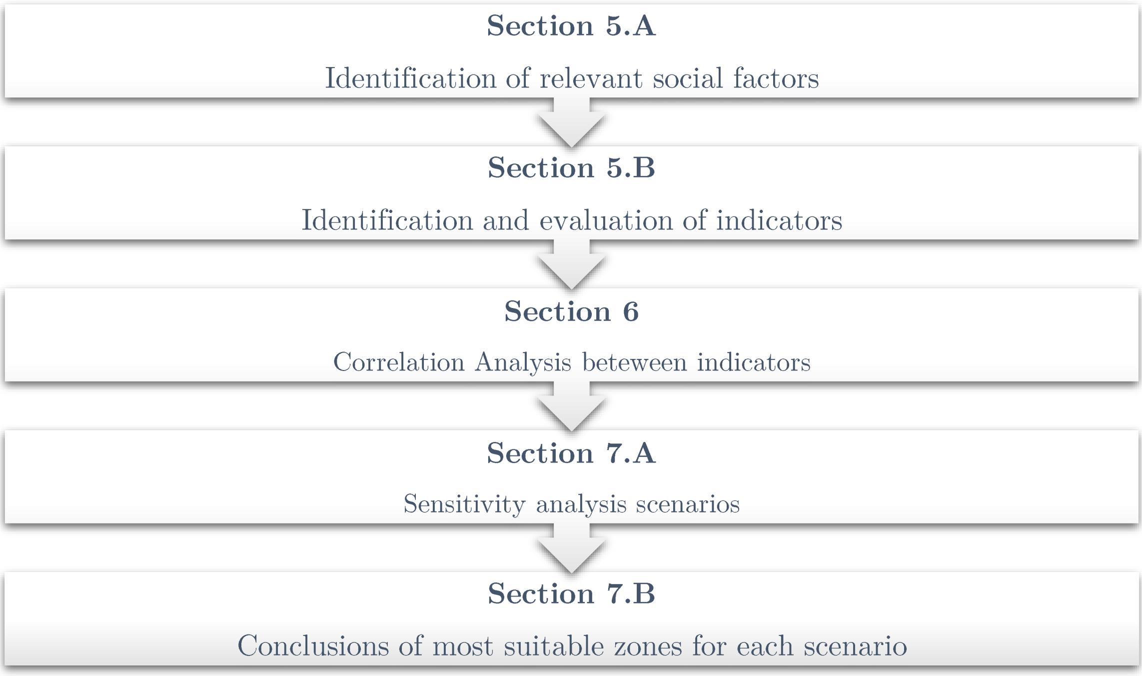


Figure 3. Methodology Guide. Own Development

Section 5.A: Identification of Relevant Social Factors

The initial step involves identifying the key social factors that impact the viability and acceptance of hydrogen plants. This includes demographic trends, education levels, employment rates, public health, and community safety. These factors are crucial as they impact the local acceptance and successful integration of hydrogen technologies. By understanding these social dynamics, we should ensure that the chosen locations not only support economic and technical feasibility but also promote social equity and regional development.

Section 5.B: Identification and Evaluation of Indicators

Following the identification of social factors, the next step is to evaluate specific indicators that represent these factors. This involves selecting measurable indicators that can be integrated into the GIS model. These indicators are crucial for assessing the suitability of different regions based on their social characteristics.

Section 6: Correlation Analysis Between Indicators

Once the indicators are identified, a correlation analysis is conducted to understand the relationships between them. This step helps to identify any overlapping or redundant indicators and ensures that the final set of indicators provides a comprehensive and non-redundant basis for the analysis.

Section 7.A: Sensitivity Analysis Scenarios

The core of the methodology involves a Multi-Criteria Decision-Making (MCDM) analysis using the identified indicators. This step includes conducting sensitivity analyses to understand how changes in the weighting of different criteria impact the overall suitability of locations. The sensitivity analysis helps to refine the model and ensures robustness in the decision-making process.

Section 7.B: Identification of Suitable Zones for Each Scenario

Finally, based on the MCDM analysis and sensitivity tests, conclusions are drawn regarding the most suitable zones for hydrogen plant implementation. This section synthesizes the findings from the previous steps and presents a clear set of recommendations for potential locations. The recommendations consider both quantitative data and qualitative insights, ensuring a holistic approach to site selection.

5. Most relevant Social Factors

The implementation of hydrogen projects, while holding the promise of sustainable energy and economic growth, brings forth a complex array of social challenges that must be meticulously navigated. These aspects can be considered both quantitative and qualitative because they encompass measurable data (like employment rates, educational levels, and demographic statistics) and subjective assessments (such as cultural values, public perception, and social acceptance). This dual nature allows for a comprehensive analysis of the social fabric that supports or challenges the implementation of hydrogen technologies.

Some of the factors that are easier to measure, include demographic trends, educational levels, employment rates, health statistics, water use, land use, emissions, and biodiversity considerations, are integral to the successful implementation of hydrogen plants. These elements offer a detailed snapshot of the potential workforce's capacity, community health baseline, socio-economic landscape, and the environmental footprint of such projects. For example, areas with a youthful demographic not only suggest a strong potential workforce for the emerging hydrogen industry but could also underline the necessity for significant education and training investments. Additionally, the efficient use of water and land, coupled with strategies to minimize emissions and protect biodiversity, are essential for maintaining ecological balance and ensuring the sustainability of hydrogen production. This meticulous approach to quantifying both social and environmental impacts lay the groundwork for informed and sustainable decision-making, crucial for countries like Spain that are committed to leading the charge in the global energy transition to cleaner sources. This multi-faceted analysis underscores the importance of holistic planning and management to achieve Spain's ambitious sustainable energy objectives, highlighting the country's dedication to not just economic growth but also environmental stewardship and social well-being.

By delving into detailed numerical data, we gain invaluable insights into the socio-economic and environmental fabric of the nation, guiding strategic decision-making for hydrogen project deployment. Therefore, the significance of employing a data-driven approach in this context cannot be overstressed. These quantifiable factors offer a comprehensive overview of Spain's readiness and potential barriers to integrating hydrogen technologies, enabling a nuanced analysis of regional variations that could impact project feasibility and social acceptance.

Exploring these indicators within the context of Spain's provinces is key due to the diverse economic, environmental, and social landscapes across these regions. Essentially, Spain's provinces are unique in their own ways, impacting how they might welcome or adapt to hydrogen energy technologies. This exploration is undertaken to achieve a higher level of geographic detail, allowing for more precise and targeted analysis.

For example, areas with a strong technological presence and higher levels of education might be quicker to embrace hydrogen as a clean energy source. On the other side, communities where the economy is struggling, and jobs are scarce could find the transition more challenging. Environmental conditions and the local job market can also move public opinion towards new energy solutions.

To conduct a detailed study of each factor, allowing for the manipulation of various scenarios to garner as much information as possible, various numerical indicators have been identified that can represent these factors in the mathematical analysis to be developed subsequently. Below a table can be found summarizing the indicators analysed for each factor.

It is important to highlight that the criteria in the table do not have a singular sense and their relevance will depend on the specific context of each case study. These criteria are not universally fixed in their interpretation; rather, they are dynamic and should be assessed based on the unique socio-economic, environmental, and cultural characteristics of the region being analysed. A criterion is classified as a cost (the lower, the better) or a benefit (the higher, the better), but this classification can vary. The dual nature of these indicators allows for a flexible and comprehensive approach to evaluating the feasibility and potential impact of hydrogen projects across diverse regions.

Factors	Indicators	Type
Demographic / Economic	Population	Quantitative
	Age distribution	Quantitative
	Annual Net Income	Quantitative
	GINI Index	Quantitative
Education	Education Level	Quantitative
Employment	Unemployment Rate	Quantitative
Public Health and Community Safety	OECD Better Life Index: Environment	Quantitative
Sustainable Resource Management	Water Stress	Quantitative
Biodiversity	Natural Reserves	Qualitative
Social Acceptance		Qualitative
Changes in Socioeconomic Dynamics		Qualitative
Cultural Influences		Qualitative
Human Rights		Qualitative

Table 1. Summary Social Factors and Indicators

5.1 Demographic and Economic Factors

Demographic factors are essential for understanding the population around potential hydrogen plant locations. Hydrogen plants in areas with high population density may require more robust strategies in terms of safety and communication to mitigate any public concern. In Spain, the uneven population distribution and demographic aging are critical factors that can affect both labour availability and the perception and acceptance of new technologies.

Population

Analysing the population distribution map of Spain in Figure 4, provided by the *Instituto Nacional de Estadística,* it can show significant insights into strategic planning for hydrogen plant locations [27]. Regions with higher population, such as those in the darkest shade, likely indicate major urban centres with existing infrastructure that could support the complex logistics associated with hydrogen production and distribution. These areas may also provide a ready workforce and a market for hydrogen as a fuel source, possibly simplifying the challenges of both supply and demand.

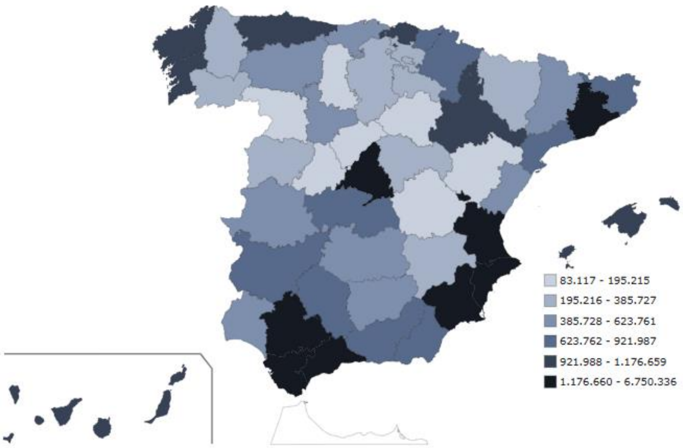


Figure 4. Official population figures of the Spanish Provinces on January 1st, 2022 (Persons).

Conversely, the lighter-shaded areas, representing regions with lower population figures, might offer different advantages, such as available land for larger hydrogen production facilities or the potential for revitalizing local economies through new job creation. However, these regions might also pose challenges in terms of infrastructure development, skilled labour availability, and creating a market for hydrogen consumption.

Age Distribution

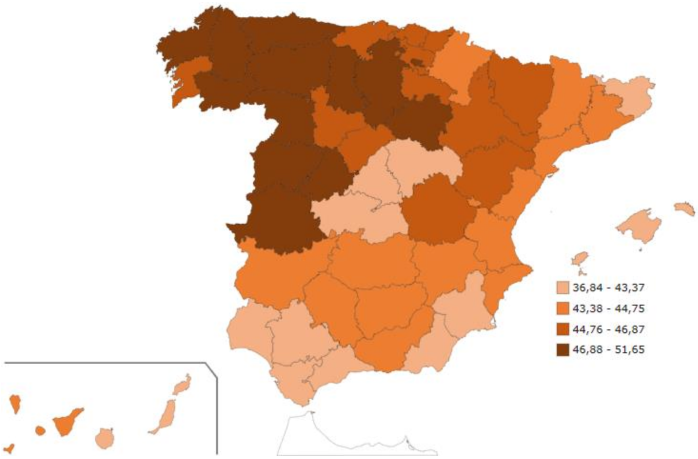


Figure 5. Average Age of the Population by Province 2023 (years old)

The following map that shows the distribution of ages in Spain [28], reveals significant insights for the implementation of hydrogen plants. Provinces with younger populations, indicated by lighter shades, are likely to have a more dynamic and adaptable workforce, facilitating quicker adoption of new technologies such as hydrogen energy. These areas may benefit from a more receptive community and a workforce ready to embrace innovative solutions, driving local economic growth and attracting further investment.

Conversely, provinces with older populations, represented by darker shades, might face challenges in adapting to new industrial developments. These regions may require comprehensive community engagement strategies and targeted training programs to prepare the existing workforce for roles in the hydrogen sector.

Overall, the average age distribution across provinces highlights the importance of tailoring hydrogen plant implementation strategies to regional demographic characteristics. Younger regions can be prioritized for initial projects due to their potential for rapid adoption and economic stimulation, while older regions may benefit from phased implementation supported by robust workforce reskilling and infrastructure development initiatives. By aligning strategies with demographic realities, Spain can ensure the successful and equitable integration of hydrogen energy technologies.

Average annual net income

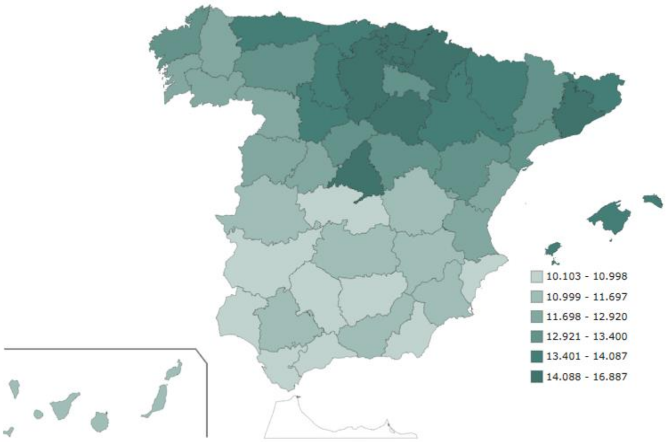


Figure 6. Average income per person 2021 (€)

The map provided in Figure 6 [29], appears to illustrate the average net income per person by province in Spain. When considering the implementation of hydrogen plants, the economic profile of a region is a significant factor.

Provinces with darker shades, indicating higher incomes, may be more suitable for adopting new technologies due to their greater economic capacity. These regions could have more interest in investing in hydrogen infrastructure and create a receptive market for its benefits, facilitating successful implementation.

In contrast, provinces with lighter shades, indicating lower incomes, can greatly benefit from the implementation of hydrogen plants from an economic revitalization perspective. The job creation and infrastructure investment associated with hydrogen plants can significantly boost economic development in these areas. Regional and local governments might be more inclined to offer incentives and support to attract these investments, thereby improving local economic and social conditions.

Provinces with medium incomes, indicated by intermediate shades, represent a balance between investment capacity and the need for economic development. These areas may have adequate infrastructure to support the implementation of hydrogen plants and benefit from the employment opportunities and economic growth these plants can provide. Selecting locations in these provinces can be strategic to ensure a balanced distribution of the economic and social benefits of hydrogen energy development in Spain.

In summary, average income per person is a crucial factor in decision-making for the implementation of hydrogen plants. Regions with higher incomes can lead technological adoption, while regions with lower incomes can receive significant boosts in economic and social development. Regions with medium incomes offer a balance for sustainable and equitable development of hydrogen infrastructure in the country, ensuring that the benefits of hydrogen are widely distributed and support economic growth across all provinces. Understanding the economic capacity of each community can help tailor the approach to introducing hydrogen infrastructure in a manner that aligns with regional economic capabilities and goals.

GINI Index

The Gini Index measures income inequality within a population and is crucial for understanding economic distribution across different regions. A lower index indicates a more equitable income distribution, while a higher index reflects greater inequality. This index provides an additional perspective to socioeconomic analysis, allowing for an evaluation of not only average incomes but also how these incomes are distributed among the population.

Incorporating the Gini Index into the analysis of hydrogen plant implementation is essential for several reasons. In areas with high inequality, local governments may be more inclined to offer tax incentives and supportive policies to attract investments that promote employment and reduce income disparity. Conversely, regions with lower inequality may show greater social acceptance and less resistance to new industrial projects due to a more stable economic base and fewer social tensions.

The provided map [30] shows that the northern and some central regions of Spain have lower Gini indices, indicating a more equitable income distribution and, therefore, a potentially more favourable environment for the implementation of hydrogen plants. On the other hand, the southern regions and some in the east display higher Gini indices, suggesting greater challenges in terms of economic inequality. This analysis is crucial for making informed decisions about the location of hydrogen plants, maximizing both economic benefits and positive social impact.

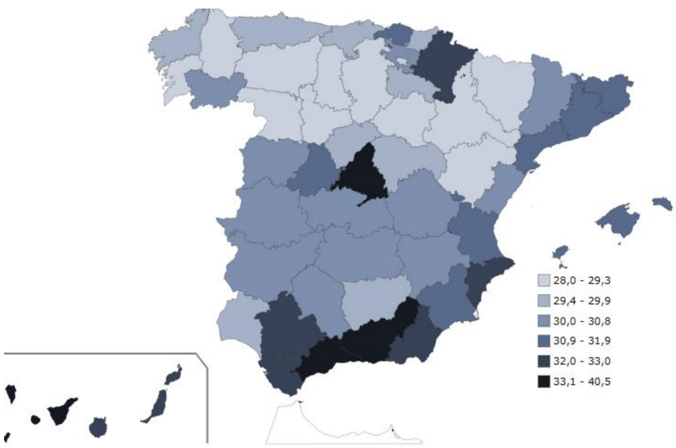


Figure 7. GINI Index per province, 2021 (%)

5.2 Education

Education is a cornerstone for the development of a hydrogen-based economy. Awareness and training in hydrogen technologies can facilitate the transition, creating a qualified workforce and an informed society. In Spain, investment in specific educational programs on renewable energies and hydrogen technologies can accelerate the adoption of these technologies and enhance the country's competitiveness in the global energy sector.

Incorporating insights from the study on *Social acceptance of green hydrogen in Germany*, it becomes evident that education not only serves as the bedrock for cultivating a hydrogen-fuelled economy but also plays a pivotal role in fostering societal acceptance and trust in hydrogen technologies [31]. The concept of responsible innovation, as highlighted in the German context, underscores the critical importance of engaging communities and stakeholders from the onset of hydrogen projects.

This approach is instrumental in building trust and shaping a positive perception towards green hydrogen technologies. Drawing on this evidence, the significance of educational initiatives extends beyond merely developing a skilled workforce and an informed society in Spain. It also encompasses the broader objective of nurturing a culture of responsible innovation within the realm of renewable energies and hydrogen technologies. By aligning educational programs with the principles of responsible innovation, Spain can not only expedite the adoption of these technologies but also enhance its global competitiveness in the energy sector.

Education Level

This indicator has only been found in an autonomous community level; however, it gives a clear perspective of the education level distribution in Spain.

The information on the educational level achieved by the adult population in Spain, represented in Figure 8, is crucial for determining the most suitable location for the implementation of hydrogen plants. This map show the percentages of the population with different educational levels [32]. A comprehensive analysis of how this level of education could impact the implementation of hydrogen plants in Spain could be:

Figure 8. Population aged 16 and over by educational attainment, sex, and autonomous community. Percentages relative to the total of each community.

The availability of skilled labour is crucial for the successful implementation and operation of hydrogen plants. Regions with higher education levels among the adult population possess a competitive edge due to their skilled and technically proficient labour force. This human capital is vital for the construction, operation, and maintenance of hydrogen plants, which demand advanced knowledge in engineering, technology, and environmental management.

Furthermore, areas with a well-educated population are more capable of swiftly adapting to new technologies and industrial processes. Higher education facilitates ongoing training and professional retraining, enabling workers to acquire the skills necessary for emerging industries like hydrogen. This adaptability reduces training time and costs, enhancing the operational efficiency of hydrogen plants. Additionally, regions with higher educational levels can act as economic development engines, particularly in areas with high unemployment rates or less developed economies. These regions are better positioned to attract investments and hydrogen projects, providing a favourable environment for innovation and technological advancement.

As a conclusion, the distribution of university-educated individuals across Spain's autonomous communities has significant implications for the hydrogen industry. These regions are potentially well-equipped to supply the skilled workforce necessary for the development and operation of hydrogen plants. Furthermore, they may offer a conducive environment for research and innovation, ensuring the long-term success and integration of hydrogen technology within the Spanish energy sector. The presence of educated professionals can also facilitate a smooth transition toward a greener economy, influence public policy, and contribute to the sustainable development of the local communities where hydrogen plants might be implemented.

5.3 Employment

Creating jobs is a key benefit of the growing hydrogen industry, having a significant and clear effect on job markets. The building, running, and upkeep of hydrogen plants will offer many job opportunities, ranging from basic to high-tech positions. In Spain, the move towards green hydrogen is expected to revive struggling industrial areas and create new, advanced technology careers.

The creation of jobs is an essential benefit of the expanding hydrogen industry, significantly impacting employment rates and social conditions. As hydrogen plants are built, operated, and maintained, a wide range of job opportunities will emerge, from basic positions to advanced technological roles. This growth is particularly important in Spain, where the focus on green hydrogen promises to rejuvenate declining industrial sectors and open innovative career paths in advanced technology fields. The improvement in employment rates is a crucial social factor, as it can lead to better living standards, reduce unemployment, and foster a more prosperous community. This makes the development of hydrogen plants in Spain not just an economic activity, but also a social catalyst that can enhance the well-being of its people.

A recent report published in January 2024 by Cepsa, sheds light on the transformative potential of green hydrogen in catalysing employment growth across various European nations, projecting Spain as the leader with an anticipated surge of 181,000 new jobs over the next 16 years [33]. This positions Spain ahead of other key players such as the United Kingdom, Germany, and France, highlighting the country's pivotal role in advancing green hydrogen production and associated job markets. However, the journey to realizing this employment boom is not without its challenges. Italy, Spain, and Germany, in particular, are identified as facing significant skills gaps that necessitate strategic interventions through vocational training programs, comprehensive workforce mapping initiatives, and robust public-private partnerships to ensure a skilled, ready-to-deploy workforce. [34]

Unemployment rate

The provided map shows the unemployment rates by province in Spain for the fourth quarter of 2023, according to the Active Population Survey (EPA)[35]. The map uses shades of green to represent varying levels of unemployment, with lighter shades indicating lower unemployment rates and darker shades representing higher rates.

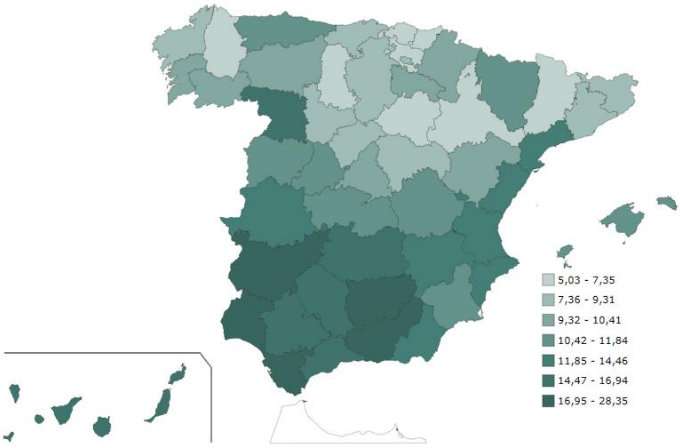


Figure 9. Unemployment rate by province´s population in 2023 (%).

Labor Market Dynamics: High unemployment rates within certain autonomous communities present a dual opportunity. Firstly, they signify a latent workforce that could be mobilized, with the right incentives and training, into the emerging hydrogen industry. This is especially pertinent for Spain's shift towards a green economy, where the hydrogen sector is anticipated to play a pivotal role. For instance, a region with a legacy in automotive or heavy industry, now experiencing higher unemployment, may possess a workforce with transferable skills that are highly advantageous for the technical and engineering demands of hydrogen plant operations.

High unemployment rates within certain autonomous communities present a dual opportunity. They signify a latent workforce that could be mobilized into the emerging hydrogen industry with the right incentives and training. This is especially pertinent for Spain's shift towards a green economy, where the hydrogen sector is anticipated to play a pivotal role. For instance, regions with a legacy in automotive or heavy industry, now experiencing higher unemployment, may possess a workforce with transferable skills advantageous for the technical and engineering demands of hydrogen plant operations.

The success of integrating an unemployed demographic into the hydrogen sector hinges on targeted educational initiatives. This necessitates a symbiotic relationship between industry leaders and educational institutions to align the current skillset of the unemployed with the competencies required for hydrogen technology roles. Establishing specialized vocational training centres, potentially subsidized or incentivized by regional governments, could address any skills gap and expedite workforce readiness. Labor costs are a significant component of operational expenditure for any industrial facility. In regions where unemployment is higher, there could be a more competitive labour market, potentially leading to cost efficiencies. However, it is crucial to align such economic strategies with ethical labour practices and ensure that wage structures reflect the specialized skill level required for these roles, promoting sustainable and equitable economic growth.

Positioning hydrogen plants in areas with elevated unemployment rates could act as a catalyst for regional economic development, stimulating economic activity, attracting ancillary businesses, and elevating property values. This economic regeneration can enhance social cohesion and public sentiment towards the hydrogen industry, creating a supportive environment for the plant's operation. Governmental bodies often prioritize unemployment reduction through measures such as subsidies, tax incentives, and infrastructure support, which hydrogen plants can benefit from. Additionally, sustainability training should be incorporated into workforce development programs to ensure employees act as stewards of the environment, reflecting a forward-thinking approach that aligns economic development with ecological sustainability. Establishing a culture of lifelong learning within the workforce can safeguard the long-term viability and competitiveness of the hydrogen industry in Spain.

In summary, the varied unemployment rates across Spain's regions are key to strategically introducing hydrogen plants, offering a chance to boost the local workforce for the green economy's needs. Addressing this involves targeted education to match skills with industry demands, ensuring ethical labour practices for economic efficiency, and fostering regional development through job creation. Aligning these efforts with public policies can enhance community support, making hydrogen plants catalysts for not just energy transformation but also for social and economic revitalization.

5.4 Public Health and Community Safety

Public health is a primary consideration in the implementation of hydrogen plants, especially due to potential risks associated with hydrogen production, storage, and transport. Implementing rigorous safety measures and monitoring air and water quality are essential to protect community health. Spain, with its high-quality public health system, is well-positioned to establish monitoring protocols and respond quickly to any incidents.

In the case of hydrogen, the risk of explosion is much lower than other more common fuels since it becomes explosive at concentrations between 18.3% and 59%. In comparison, gasoline vapours can explode at concentrations just over 1% [36]. Additionally, while hydrogen tends to rise and disperse into the atmosphere, heavier gases such as propane or gasoline vapours tend to accumulate near the ground, increasing the risk of explosion. It is also important to note that hydrogen is non-toxic and non-polluting, does not stain, does not smell, and with current technology, its production does not harm the environment. The risk of hydrogen contaminating water is negligible because, being lighter than air, it quickly escapes and is very safe.

However, the health and safety of communities near hydrogen plants remain of utmost priority. While the risk of explosion from hydrogen itself is lower, accidents related to hydrogen transport and risks to coastal and marine habitats must still be quantified and effectively managed. The accidental release of hydrogen in closed spaces can have serious consequences due to its flammability. Therefore, strict safety measures and emergency protocols are vital. In Spain, with its extensive coastline and the importance of tourism and fishing, protecting these habitats is crucial for the local economy and food security. It is also important to specify that some derivatives of hydrogen, such as ammonia, do pose serious risks to the population and the environment.

OECD Better Life Index: Environment

The environmental quality of a region, particularly concerning air and water pollution, directly impacts the strategic decision-making for hydrogen plant locations due to their implications on public health and operational sustainability.

Spain boasts an air pollution level of 10 micrograms per cubic meter of PM2.5 (particles so small that they can be inhaled deep into the lungs and even enter the bloodstream from emissions of vehicles, industrial facilities, and residential heating using coal, oil, or wood), that are notably lower than the OECD average of 14 micrograms [37]. This suggests a relatively cleaner air environment, which is critical for areas considering hydrogen production. Lower air pollution levels contribute positively to public health and reduce the environmental impact of new industrial activities, such as hydrogen plants. Cleaner air also means fewer airborne particulates that could potentially hinder the efficiency of hydrogen production technologies.

On the other hand, Spain faces challenges with water quality, with only 76% of its population satisfied with their local water quality, which is below the OECD average of 84%. This could pose a significant challenge in regions where hydrogen production might rely heavily on water, especially through methods like electrolysis, which requires substantial amounts of clean water. The lower satisfaction might indicate potential issues with water contamination that could affect not only human health but also the operational aspects of hydrogen production.

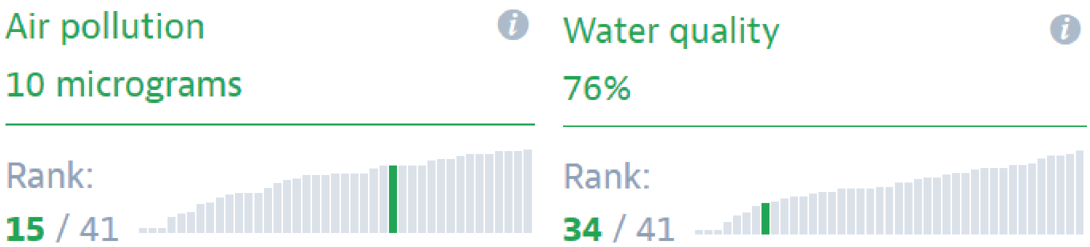


Figure 10. OECD Better life Index – Environment

The use of fossil fuels and high pollution levels pose significant health risks, including respiratory and cardiovascular diseases. Renewable hydrogen offers a solution to these problems by providing a clean energy source that reduces air pollution and associated health risks. Transitioning to hydrogen can lead to improved air quality and better health outcomes for communities.

In summary, as seen on Figure 10 where Spain (green line) is compared to the rest or European countries, while Spain's commendable air quality provides a supportive backdrop for hydrogen plant implementation, addressing water quality issues through effective management and infrastructure improvements will be crucial to ensure the sustainable integration of hydrogen production facilities, especially in regions prone to water stress or lower water quality satisfaction.

5.5 Sustainable Resource Management

When implementing hydrogen plants, particularly through water electrolysis, the efficient use of resources like water and land becomes paramount to ensure the sustainability of these operations [38]. The process demands 9 litres of water minimum for the reaction to occur. In practice, the actual volumes are around 30 l/kg H2 when accounting for water losses, cooling, and other factors. Nevertheless, these volumes are low compared to other uses such as agriculture [39]. . Furthermore, efficient land management and stringent pollution prevention measures, for example for production of some elements as ammonia, are essential to safeguard ecosystems and public health, addressing Spain's unique climatic variability challenges.

Water Risk

This analysis utilizes data from Spain's autonomous communities to understand the regions' water risk levels, which is a critical factor for the implementation of hydrogen plants. The map provided in Figure 11 displays the water risk index, as published by the Aqueduct Atlas. This index incorporates several factors such as hydric stress, drought frequency, and other water scarcity indicators. Higher "water risk" scores indicate a greater risk of water scarcity. The categories range from 0 to 5, with 5 indicating an extremely high risk and 0 indicating a moderately low risk. [40]

Hydrogen production via water electrolysis requires significant quantities of water to split into hydrogen and oxygen. Therefore, understanding the regions' water risk levels is essential to ensure sustainable and reliable hydrogen production. Regions with lower water risk levels may be more suitable for hosting hydrogen plants, as they would have a more stable and sufficient water supply, reducing the risk of operational disruptions due to water shortages.

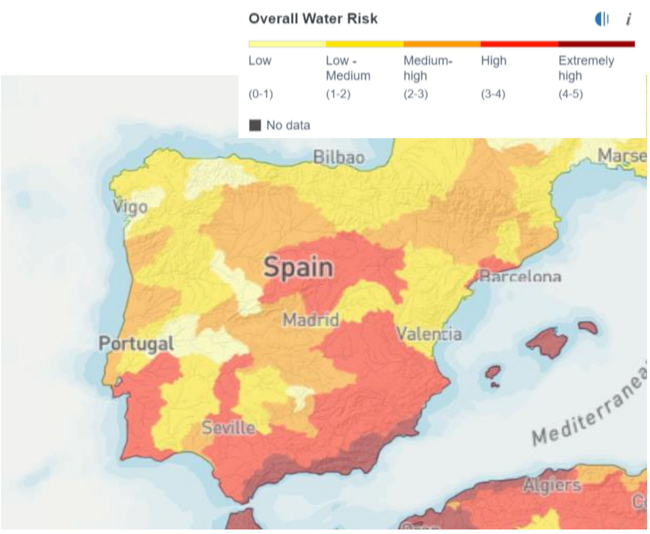


Figure 11. Overall water risk in Spain (higher the number, higher the risk)

Using water in regions with lower risk levels is a sustainable choice, as it helps avoid exacerbating existing water scarcity issues. Hydrogen plants need to manage water intake and output carefully to ensure the production process does not negatively impact local water supplies. Regions with lower water risk levels have more capacity to absorb the impact of water usage by hydrogen plants without compromising local ecosystems or water availability for other critical uses.

Areas with lower water risk may also reduce operational costs associated with water procurement for hydrogen production, as they might not need extensive water management systems or costly water sourcing strategies. Additionally, regions with both low water risk and existing infrastructure for hydrogen production and transportation, such as pipelines and storage facilities, might be more viable candidates for plant locations.

The map indicates that regions like northern and northwestern Spain have lower water risk levels, making them more favourable for hydrogen plant locations compared to southern regions, which face higher water risk. This geographic disparity highlights the importance of selecting plant locations that balance water availability with other technical, economic, and social factors.

In conclusion, understanding the water risk levels across Spain's autonomous communities is crucial for the sustainable implementation of hydrogen plants, particularly those using water electrolysis technology. The map suggests that certain regions have a natural advantage for such initiatives due to lower water risk levels. However, it is essential to balance this with other factors such as regional water usage patterns, seasonal variability, and agricultural demands to ensure that hydrogen plants are implemented in the most suitable locations without exacerbating existing water challenges. The insights provided by the water risk index can help refine the decision-making process, ensuring that hydrogen plants are in regions best suited to support their operations sustainably.

5.6 Biodiversity Preservation and Eco-Sustainability

Spain's diverse ecosystems, rich in biodiversity and natural resources, demand a concerted effort to integrate conservation practices within hydrogen development projects. The implementation of hydrogen plants must be conscientiously planned to minimize their impact on local wildlife and habitats, employing strategies for habitat preservation and species protection. The country's commitment to conserving its natural heritage, through compensatory and mitigation measures, reinforces the importance of biodiversity in maintaining ecological balance and providing essential services to the community.

Environmental aspects such as land use, water use, emissions, energy communities, self-consumption, and CO2 neutrality are fundamental. Quantifying these factors allows evaluating the overall sustainability of hydrogen plants and their contribution to climate goals.

On the other hand, understanding the societal impact of hydrogen energy projects requires looking beyond numbers and into the qualitative factors that shape how these projects are received by communities. This includes cultural attitudes towards technology and the environment, concerns about human rights, and the importance of labour conditions. These factors are key to gaining public support and ensuring that hydrogen projects are not just technically feasible but also socially sustainable. For example, communities with strong environmental values may welcome hydrogen projects, while those reliant on traditional energy sources might resist due to fears of job loss. In Spain, the focus on social dialogue and labour rights sets a positive example of how to align hydrogen projects with broader social goals. Addressing these qualitative measures involves understanding local contexts and values, a task that's complex but crucial for the successful integration of hydrogen energy. This approach not only respects the community's voice but also enhances the project's acceptance and impact.

Natural Reserves

The areas designated as LIC (Sites of Community Importance) and SPA (Special Protection Areas) on the map (Figure 12) indicate territories within the European

Union's Natura 2000 network. These zones are of high ecological importance and are protected to preserve biodiversity, particularly endangered species, and habitats.[41]

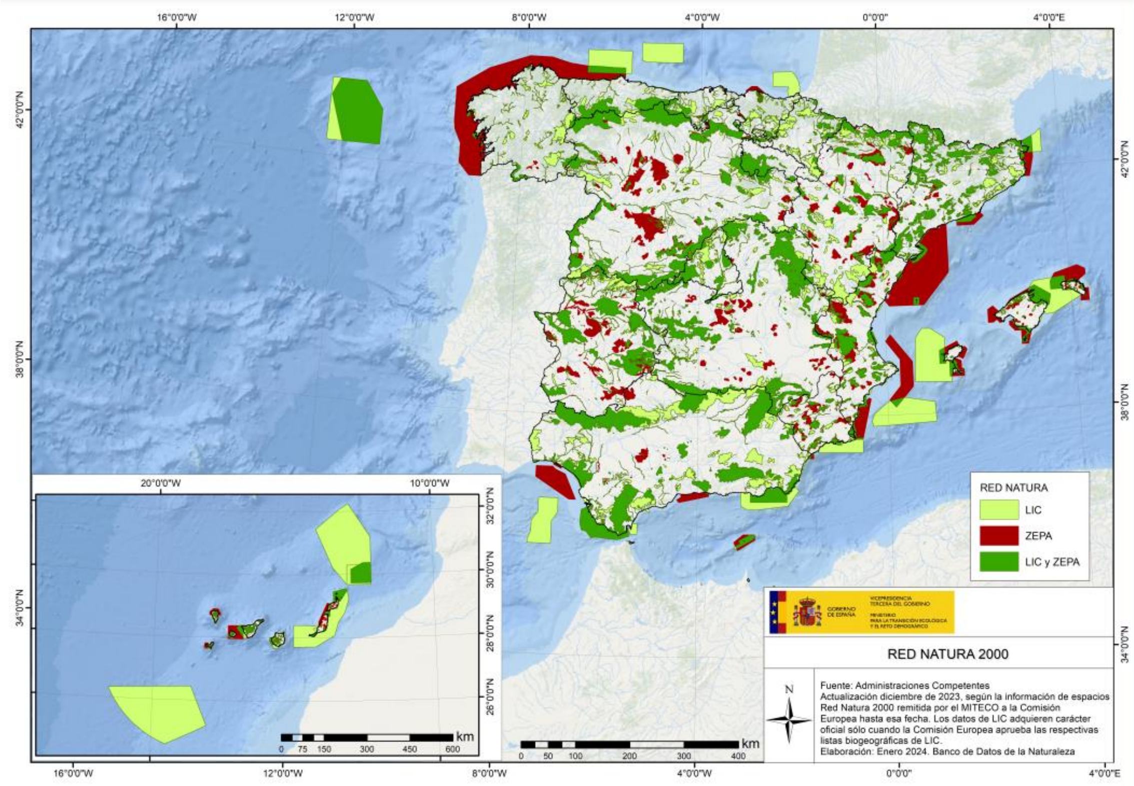


Figure 12. Red Natura 2000 (Ministry of Agriculture and Fisheries, Food and Environment).

The presence of these natural reserves is a critical factor in the planning of infrastructure for green hydrogen plants due to stringent environmental regulations aimed at preserving the ecological integrity of these areas.

Development restrictions in areas designated as LIC and SPA significantly limit the establishment of new industrial infrastructure, including hydrogen plants. Any proposal to develop hydrogen plants in or near these areas would require detailed environmental impact assessments and mitigation measures to protect local ecosystems. While these restrictions can limit plant locations, they also present an opportunity to demonstrate a commitment to sustainability by choosing production technologies and practices that minimize environmental impact. Plants should be located at a prudent distance from LIC and SPA zones to avoid pollution and disturbance of critical habitats, which can limit suitable sites and increase transportation costs if plants are placed further from demand centres.

Close cooperation with environmental authorities is essential for any development near protected areas to ensure that hydrogen plants operate within legal and ethical boundaries established for environmental protection. Additionally, the proximity to these areas can be leveraged to educate and raise awareness about green hydrogen as a clean energy source and its role in environmental protection. By integrating these considerations, hydrogen projects can support conservation efforts while promoting the benefits of sustainable energy solutions.

In summary, natural reserves marked as LIC and SPA can limit the location and design of green hydrogen plants in Spain. Any development must consider and respect current environmental legislation, focusing on the harmonization of industrial development with nature conservation.

5.7 Social Acceptance.

The community's perception and attitudes towards hydrogen energy play a critical role in its widespread acceptance. Effective information and education campaigns are essential to highlight hydrogen's environmental benefits and its crucial role in the energy transition. Such efforts aim to foster a positive public perception, accelerating the adoption of hydrogen technologies within the country.

Trust in the safety, benefits, and equitable distribution of hydrogen technology is foundational to its social acceptance. The development of clear policies and strategic communication about hydrogen's role in the green economy is crucial, ensuring that the adoption of hydrogen infrastructure and markets aligns with Spain's environmental and innovation objectives.

5.8 Changes in Socioeconomic Dynamics

The introduction of the hydrogen industry can alter local socioeconomic dynamics, offering new economic opportunities but also challenging existing structures. It is vital to ensure that these changes benefit a broad range of actors and do not exacerbate inequalities. In Spain, where reindustrialization and a just transition are key goals, the hydrogen industry has the potential to contribute significantly to economic revitalization, especially in less developed regions.

For instance, the SHYNE consortium in Spain exemplifies how large-scale investment in renewable hydrogen can generate over 13,000 jobs, showcasing the potential for economic revitalization, especially in less developed regions; however, it is important to notice that It is a project still in the very early stages of development and of the jobs they announce, probably not even 1% have been generated yet. [42]. What is more, the shift towards a hydrogen economy could disrupt existing industries and labour markets, necessitating careful planning and investment in workforce retraining and education. The emphasis on renewable hydrogen production in Spain, as highlighted by projects like SHYNE and Project Catalina, underscores the necessity of aligning renewable energy capacity with the demands of the hydrogen sector to ensure sustainable growth. This alignment is crucial to avoid creating a 'hydrogen bubble' where the pace of industry growth outstrips the availability of renewable energy, potentially leading to economic and environmental setbacks. [43] [44]

5.9 Cultural Influences

Cultural factors influence public perception and the acceptance of hydrogen as an energy source. Traditions, values, and social norms can affect the adoption rate of new technologies. In the case of Spain, with its strong commitment to sustainability and innovation, there is an opportunity to integrate the hydrogen economy into the cultural fabric, promoting sustainable energy practices as part of the national identity.

5.10 Human Rights Consideration

Respecting human rights is fundamental in the development of hydrogen infrastructure. This includes ensuring safe, equitable, and fair working conditions, as well as preventing the involuntary displacement of communities. Spain, with its robust legal framework and commitment to human rights, can lead by example in the ethical implementation of hydrogen projects.

As a conclusion, it is evident that hydrogen energy projects offer substantial social and economic benefits, including significant job creation. However, realizing this potential requires addressing skill gaps through education and training. The integration of hydrogen technologies into society depends on a variety of factors such as demographic trends, environmental awareness, and cultural perceptions. Spain's emphasis on social dialogue, labour rights, and community engagement can be an effective model for integrating hydrogen projects that align with local values, enhance safety, and promote public health.

Environmental sustainability is also crucial, focusing on biodiversity conservation, resource efficiency, and CO2 neutrality to support the expansion of hydrogen infrastructure. Spain's proactive approach in transitioning to green hydrogen demonstrates a commitment to responsibly advancing its energy sector. Therefore, a collaborative strategy that leverages comprehensive data and understands community impacts is essential. Such an approach ensures that the move towards a hydrogen-driven economy not only contributes to climate change mitigation but also strengthens economic resilience, balancing technological advancement with environmental and social welfare.

6. Correlation Analysis of the Indicators

In this section, various indicators will be interrelated to evaluate them more comprehensively. The goal is to determine which indicators are most important for integration into the model. For a more precise evaluation, these will primarily be quantitative indicators, although qualitative indicators should also be considered to make a final decision.

A correlation matrix has been done to have a more visual and quantifiable solution.

	Age Avg.	*Income* Avg.	*Water Risk*	*Unemployment*	*GINI Index*	*Edu* Avg.	*Pop* Avg.
Age Avg.	1	0,220	-0,559	-0,588	-0,548	-0,079	-0,045
Income Avg.	0,220	1	-0,121	-0,588	-0,608	0,790	-0,231
Water Risk	-0,559	-0,121	1	0,376	0,409	-0,127	-0,081
Unemployment	-0,507	-0,588	0,376	1	0,893	-0,426	-0,034
GINI Index	-0,548	-0,608	0,409	0,893	1	-0,417	0,000
Edu. Avg.	-0,079	0,790	-0,127	-0,426	-0,417	1	-0,203
Pop. Avg.	-0,045	-0,231	-0,081	-0,034	0,000	-0,203	1

Table 2. Correlation Matrix between Social Indicators. Own Development

The correlation matrix provided illustrates the relationships between several socio-economic and environmental indicators. Each cell in the matrix represents the correlation coefficient between two indicators, with values ranging from -1 to 1. A value closer to 1 indicates a strong positive correlation, meaning the two variables increase together, while a value closer to -1 indicates a strong negative correlation, meaning one variable increases as the other decreases. A value near 0 suggests no significant correlation between the variables.

One of the most notable correlations in the matrix is between unemployment and the GINI Index, which is 0.893. This strong positive correlation suggests that regions with higher unemployment also tend to have greater income inequality. When selecting locations for green hydrogen plants, it is crucial to consider this relationship. By implementing hydrogen projects in areas with high unemployment, it is possible to create job opportunities and potentially reduce income inequality, thereby gaining community support and fostering social stability.

Another significant correlation is between income and education levels, which stands at 0.790. This positive correlation implies that regions with higher average incomes tend to have better education levels. These areas could be more suitable for the deployment of hydrogen technology, as they likely have the financial and human resources necessary to support the development and maintenance of new infrastructure. Educated populations are also more likely to adopt and innovate with new technologies, facilitating the successful implementation of hydrogen plants.

The correlation between water risk and the GINI Index (0.409) and unemployment (0.376) is also worth noting. While these correlations are moderate, they highlight the importance of water availability in socio-economic planning. Regions with higher water risk might face additional challenges that could impact the feasibility of hydrogen plants, such as water scarcity affecting the operational stability and sustainability of hydrogen production.

Given these insights, the indicators chosen for inclusion in the model are water risk, unemployment, education, and population. Water risk is a critical factor because hydrogen production requires substantial water use. Unemployment is selected to address and potentially alleviate local economic challenges by creating job opportunities. Education is important for ensuring a skilled workforce capable of supporting and advancing hydrogen technology. Population is included to assess market potential and logistical considerations for hydrogen distribution and have a social impact trying to help those rural areas, or the more depopulated regions of Spain. ("La España Vaciada").

The decision to exclude other indicators, such as age and income, is based on their correlations with the selected indicators. For example, income is strongly correlated with education (0.790) and GINI Index (-0.608), indicating that it is already indirectly considered through these factors. Similarly, the age average shows weaker correlations with the key indicators, making it less impactful in the model.

By focusing on these selected indicators, the model provides a comprehensive understanding of the socio-economic and environmental landscape, enabling targeted, equitable, and sustainable development of hydrogen infrastructure across Spain.

7. Sensibility analysis scenarios and Suitable Zones

The Chair of Hydrogen Studies at the Pontifical University of Comillas (ICAI-ICADE), in collaboration with Management Solutions, has developed an innovative GIS tool to identify optimal locations for hydrogen projects. This tool, designed to support the transition to a greener economy using renewable hydrogen, uses detailed spatial information to assess and score potential locations for hydrogen production plants. Using a combination of raster and vector data, and both geographic and projected coordinate reference systems, the tool can manage and manipulate spatial data with precision.

The tool can analyse various environmental and economic criteria, such as the availability of renewable energies (solar and wind), existing infrastructure (such as electrical and gas networks), water availability, and environmental impact. This allows for the calculation of an "H2 compatibility index," which helps determine the suitability of each location based on the adaptation of these criteria weights to the specific needs of the project. This flexibility makes the tool not only a valuable resource for preliminary planning but also a crucial instrument for conducting deeper, customized evaluations that align hydrogen projects with Spain's sustainable development and innovation objectives.

The indicators that have been chosen in the previous section, will now be part of this model, integrating the social factor that needs to give a more rounded decision. After normalizing the data found through a QGIS analysis, they are integrated with other economical, technical, and environmental criteria that has already been found by the chair of Hydrogen studies.

The indicators introduced into the model can be classified in two ways. On one hand, they can be introduced as a benefit, meaning that the higher the value of that parameter, the higher the score a province receives for being selected as a potential site for a hydrogen plant. This indicates that the factor is beneficial from a social perspective. On the other hand, indicators can be introduced as a cost, where a higher parameter value results in a lower score for that location. The concept of cost here means that the parameter represents a disadvantage or a challenge that needs to be mitigated

Some parameters have a more straightforward logic in determining whether they should be considered a benefit or a cost, such as solar energy potential or water availability. Green hydrogen production benefits from areas with higher solar energy and lower water risk. However, there is an added complexity when including social criteria. Sometimes the same indicator, such as population, can be perceived in both ways. In some cases, a higher population might be seen as better due to higher demand, a larger pool of qualified personnel, etc. In other cases, a higher population might be considered a cost if the goal is to prioritize regions with lower population densities to stimulate economic growth in underdeveloped areas, address regional disparities, and support the revitalization of sparsely populated regions.

Figure 13. PV Capacity factor.

Initially, solar availability is identified through the study "Global Photovoltaic Power Potential by Country," which provides harmonized data on solar resources, crucial for assessing the feasibility of large-scale photovoltaic plants from a regional perspective. This step is crucial because it establishes the basis for determining areas with high solar energy potential that can be optimized for hydrogen production through electrolysis, a process that requires a constant and abundant source of renewable electrical energy [45].

On the other hand, the methodology adopted to determine potential hydrogen demand is based on identifying key industrial consumers in each province, such as refineries, ammonia, steel, ceramics, glass, metal processing, and cement industries [46]. This indicator is introduced as a benefit to prioritize locations that are closer to the demand for hydrogen as they are more attractive.

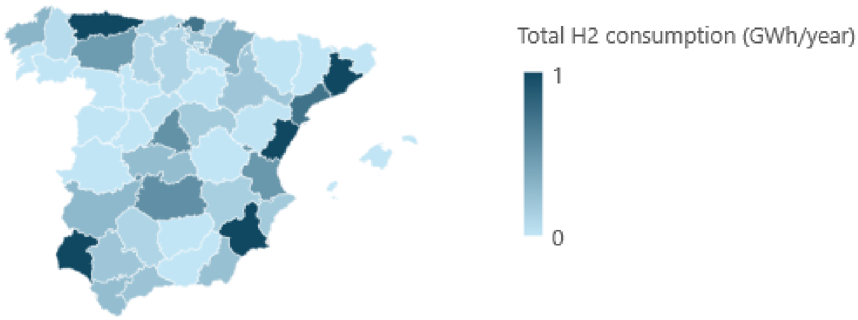


Figure 14. Hydrogen Consumption. [7]

What is more, this assessment is supported by public information on production capacities and energy consumption of these facilities, integrating factors such as water risk index and land availability, excluding protected areas and zones of high ecological value. Therefore, Land use is considered a benefit as not only have protected areas been excluded, but the analysis also favors land uses that are compatible with PV installations, ensuring that agricultural land is preserved for food production.

Integrating this data into the Q-GIS model allows to map the most suitable areas for establishing hydrogen plants, considering both the supply of renewable resources and industrial demand and environmental conditions, facilitating informed and strategic decision-making for sustainable hydrogen infrastructure development in Spain.[47] [48]

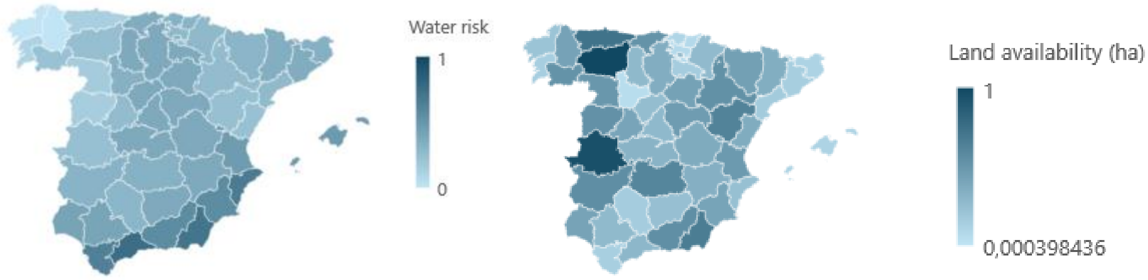


Figure 15. Water risk and Land Availability.

It is important to explain that in this study, the water risk indicator has been included as a cost in the equation, since the preference is to locate the plants in areas with a higher probability of water availability and lower risk. Additionally, when incorporating the social factor of population, considering it from a social demographic perspective, it is also included as a cost rather than a benefit. This is because the aim is to address the issue of "Empty Spain" and promote development in socially disadvantaged areas. Conversely, education and unemployment indicators have been introduced as benefits. High levels of education correlate with higher income levels and lower income inequality, making regions with better educational outcomes more stable and economically viable for long-term hydrogen plant projects. Similarly, focusing on areas with high unemployment as a benefit highlights regions where job creation is most needed, thus supporting economic revitalization and workforce readiness.

With all these elements, the calculation of an "H2 compatibility index" (ICH_2) is made, analysing some scenarios through the Multiple-criteria decision-making (MCDM) process, giving different weights to each of the paraments and discussing how can this challenge the location of the hydrogen plants. It is important to note that arbitrary data is being used for these calculations, and there are other methodologies available to derive these weights more objectively. These alternative methods could include statistical analyses, stakeholder consultations, or expert opinion elicitation, which would potentially provide more accurate and representative data for determining the optimal locations for hydrogen plants.

$$ICH_2 = \sum[W_{economic} \cdot (W_1 \cdot Pot\ Solar + W_2 \cdot H2\ consump.) + W_{technical\ \&\ environmental}\ (W_3 \cdot Water\ Risk + W_4 \cdot Land\ availab) + W_{social} \cdot (W_5 \cdot Edu_{Level} + W_6 \cdot Population + W_7 \cdot Unemployment)]$$

Equation 1. H2 Compatibility Index (ICH_2)

Due to the challenges that arose from the different units, scales, distributions, and outliers of each indicator, it was necessary to normalize these indicators. To achieve a standardized analysis and ensure consistency across all indicators, a logarithmic transformation was first applied, followed by normalization. This adjustment allows for a more balanced and comparable dataset across all regions.

$$x^{'} = \log_{10}(x + 1)$$

Equation 2. Logarithmic Adjustment

$$X_{norm}^{benefit} = \frac{x_i^{'} - x_{min}^{'}}{x_{max}^{'} - x_{min}^{'}}$$

Equation 3. Normalized benefit equation

$$X_{norm}^{cost} = 1 - \frac{x_i^{'} - x_{min}^{'}}{x_{max}^{'} - x_{min}^{'}}$$

Equation 4. Normalized cost equation

In the following figures, a summary of the scenarios to be studied is presented, along with the corresponding weights assigned to the various indicators. Additionally, the results are displayed using a choropleth map It is important to note that the Canary Islands, Ceuta, and Melilla have not been considered for this study, as their geographical isolation and distance from the mainland significantly complicate the integration of hydrogen infrastructure. This isolation poses logistical challenges and increases transportation costs, making these locations less feasible for inclusion in a comprehensive national hydrogen strategy focused on the mainland. All the mathematical results can be found in the ANEX of the document

Scenarios			0		1	2	3	4	5
Economic Criteria		$W_{economic}$	**0.5**		**05**	**0.33**	**0.33**	**0.33**	**0.33**
	PV	W_1	1		0.5	0.5	0.5	0.5	0.5
	H2 Consumption	W_2	0		0.5	0.5	0.5	0.5	0.5
Technical & Environmental Criteria		$W_{technical\ \&\ environmental}$	**0.5**		**0.5**	**0.33**	**0.33**	**0.33**	**0.33**
	Water risk	W_3	0.5		0.5	0.5	0.5	0.5	0.5
	Land Availability	W_4	0.5		0.5	0.5	0.5	0.5	0.5
Social Criteria		W_{social}	**0**		**0**	**0.33**	**0.33**	**0.33**	**0.33**
	Education	W_5	0		0	0.33	1	0	0
	Population	W_6	0		0	0.33	0	1	0
	Unemployment	W_7	0		0	0.33	0	0	1

Table 3. Summary of Scenarios Weight Inputs

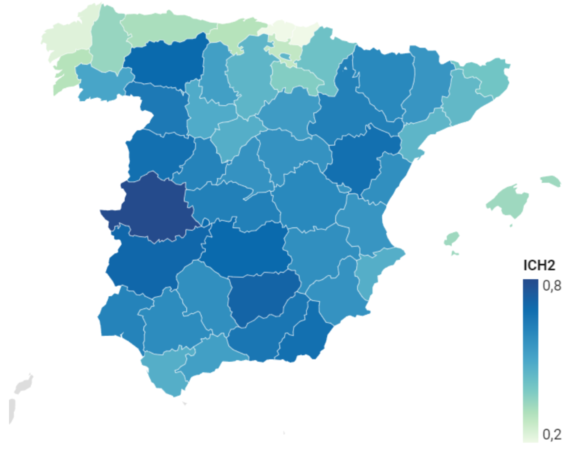
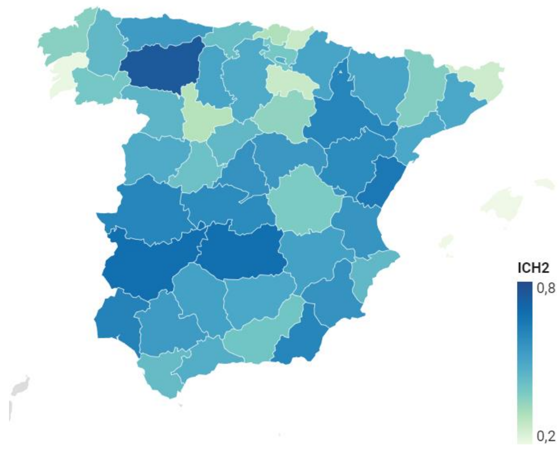
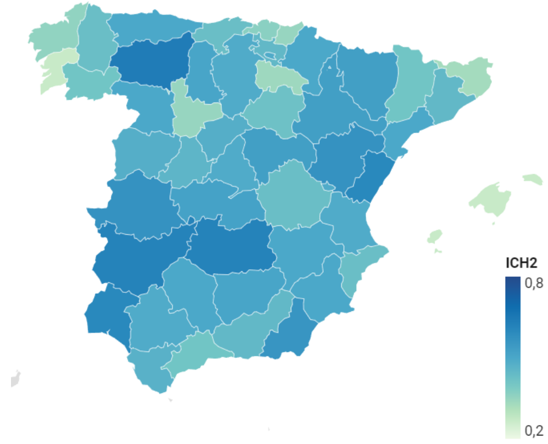
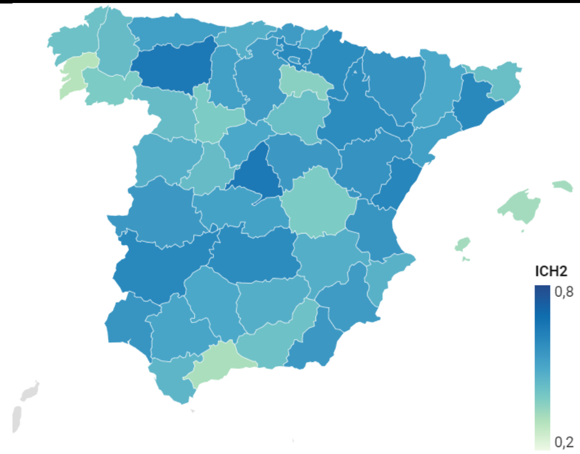
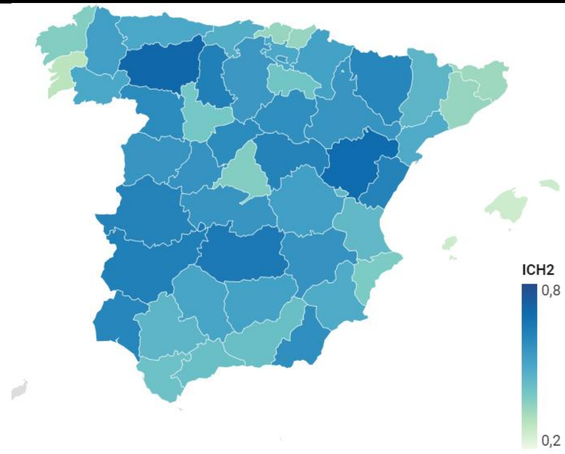
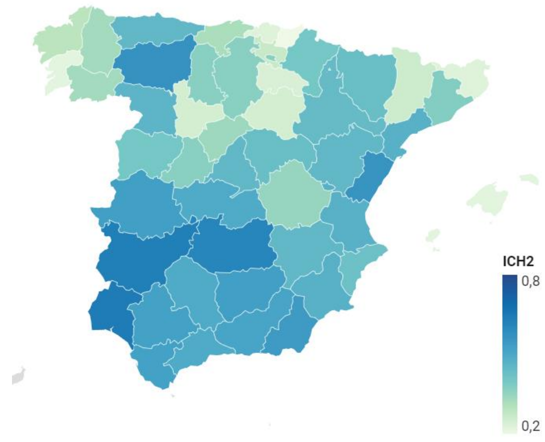
Scenario 0:	Scenario 1	Scenario 2
		
Scenario 3	**Scenario 4**	**Scenario 5**
		

Table 4. Summary of Scenarios Results

7.1 Scenario 0

To get a clear picture of the potential that regions in Spain have solely based on their natural resources, we begin with a basic scenario that excludes both hydrogen consumption and social criteria. This initial approach allows for an evaluation based only on three key factors: photovoltaic (PV) potential, water risk, and available land. By focusing on these three criteria—economic, technical, and environmental—we can identify the regions with the most favorable natural resources for the implementation of green hydrogen plants, free from the influence of socioeconomic variables. This provides a crucial baseline that helps us understand which areas have the greatest natural advantages for green hydrogen production.

This establishes a starting point on which additional criteria can be superimposed in later scenarios to see how the results are affected by the inclusion of social factors and hydrogen consumption.

Scenario 0: Without Hydrogen Consumption and without Social Criteria			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.5	PV	$W_1 = 1$
		H2 Consumption	$W_2 = 0$
Technical & Environmental Criteria	0.5	Water	$W_3 = 0.5$
		Land	$W_4 = 0.5$
Social Criteria	0	Education	$W_5 = 0$
		Population	$W_6 = 0$
		Unemployment	$W_7 = 0$

Table 5. Sensitivity Analysis Scenario 0

7.2 Scenario 1

In this scenario, equal weight is assigned to all criteria except the social criterion, which is assigned a value of zero. This scenario serves as a baseline for understanding the following impact of integrating a social criterion into decision-making processes. The economic criteria are evenly weighted between photovoltaic (PV) potential and hydrogen consumption, highlighting the equal importance of energy generation capacity and consumption needs in the analysis. This initial scenario allows for a clear evaluation of how the exclusion of social factors influences outcomes, setting a foundation for subsequent analyses where social variables are incrementally included to assess their impact on the overall decision-making framework for hydrogen plant location.

Scenario 1: Without Social Criteria			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.5	PV	$W_1 = 0.5$
		H2 Consumption	$W_2 = 0.5$
Technical & Environmental Criteria	0.5	Water	$W_3 = 0.5$
		Land	$W_4 = 0.5$
Social Criteria	0	Education	$W_5 = 0$
		Population	$W_6 = 0$
		Unemployment	$W_7 = 0$

Table 6. Sensibility Analysis Scenario 1

7.3 Scenario 2

In Scenario 2, the social criterion is introduced and assigned equal weighting alongside the economic, technical, and environmental criteria. This approach ensures a balanced consideration across all dimensions of sustainability. The sub-criteria within the social domain—education, population and unemployment—are equally weighted to avoid pre-judging the relative impact of these factors and to observe how the inclusion of social factors influences the decision-making framework.

This scenario facilitates a comprehensive analysis that incorporates the wider social context affecting potential hydrogen plant locations. It allows for an examination of how integrating social considerations might shift priorities or outcomes compared to a scenario where they are excluded. This methodological choice underscores the importance of a holistic approach in infrastructure planning, ensuring that the impacts on and benefits to local communities are adequately considered right from the outset.

Scenario 2:			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.33	PV	$W_1 = 0.5$
		H2 Consumption	$W_2 = 0.5$
Technical & Environmental Criteria	0.33	Water	$W_3 = 0.5$
		Land	$W_4 = 0.5$
Social Criteria	0.33	Education	$W_5 = 0.33$
		Population	$W_6 = 0.33$
		Unemployment	$W_7 = 0.33$

Table 7. Sensibility Analysis Scenario 2

7.4 Scenario 3

In Scenario 3, we only focus on the Education sub-criterion within the social domain, assigning it full weighting while omitting consideration of Population and Unemployment factors. This deliberate adjustment aims to highlight the pivotal role of education in the decision-making process for potential hydrogen plant locations.

Education, when given full weight in our sustainability framework, becomes the sole determinant within the social criteria, emphasizing its critical influence on local development and community welfare. By prioritizing education, we seek to explore how investing in human capital and knowledge infrastructure can significantly shape the long-term viability and success of hydrogen plant implementations.

The relationship between education and average income is crucial, as higher education levels correlate with higher incomes, leading to positive social effects by reducing economic disparities and fostering a skilled workforce. This correlation suggests that areas with better educational outcomes may experience greater economic stability and growth, enhancing the success of hydrogen plant projects. Additionally, education is negatively correlated with the GINI index, indicating that regions with higher education levels may have lower income inequality. Investing in education supports economic development and addresses social inequalities, contributing to more equitable and stable areas for long-term hydrogen plant implementation.

Scenario 3:			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.33	PV	W_1 = 0.5
		H2 Consumption	W_2 =0.5
Technical & Environmental Criteria	0.33	Water	W_3 = 0.5
		Land	W_4 = 0.5
Social Criteria	0.33	Education	W_5 = 1
		Population	W_6 = 0
		Unemployment	W_7 = 0

Table 8. Sensibility Analysis Scenario 3

7.5 Scenario 4

Scenario 4 places exclusive emphasis on the Population sub-criterion within the social domain. This scenario is particularly insightful as it underscores the pivotal role of demographic analysis in infrastructure planning. Examining population metrics such as size, distribution, and demographic trends offers crucial insights into understanding resource demands, infrastructure requirements, and community impacts associated with hydrogen plant developments.

Additionally, as explained before, the population factor is introduced as a cost in this analysis to prioritize the development of hydrogen plants in less populated areas, addressing the issue of "Empty Spain" (La España vaciada) and fostering development in regions that are socially and economically disadvantaged. While a lower population might indicate a smaller available workforce, incorporating this social perspective allows for targeted interventions in these areas. This approach aims to stimulate local economies, create job opportunities, and reverse depopulation trends by bringing new infrastructure and investment to these underdeveloped regions.

By doing so, it could help to balance development efforts and promote equitable growth across various regions. It acknowledges that, despite the challenges associated with a smaller population, such as limited immediate workforce availability, the long-term socio-economic benefits of revitalizing these areas outweigh the initial drawbacks. Thus, focusing on population as a cost not only helps to support these disadvantaged regions but also ensures a more inclusive and balanced national development strategy.

Scenario 4:			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.33	PV	W_1 = 0.5
		H2 Consumption	W_2 =0.5
Technical & Environmental Criteria	0.33	Water	W_3 = 0.5
		Land	W_4 = 0.5
Social Criteria	0.33	Education	W_5 = 0
		Population	W_6 = 1
		Unemployment	W_7 = 0

Table 9. Sensibility Analysis Scenario 4

7.6 Scenario 5

Scenario 5 concentrates solely on the Unemployment sub-criterion within the social domain, allocating it full weighting while disregarding Education and Population factors. This deliberate adjustment aims to assess the impact of unemployment on the decision-making process for locating potential hydrogen plants.

In this scenario, Unemployment is given primary importance within the social criteria, underscoring its crucial role in influencing local economic conditions, workforce readiness, and community well-being. By focusing on unemployment, we seek to understand how joblessness rates, employment opportunities, and labour market dynamics can affect the viability and socio-economic benefits of hydrogen plant projects.

This approach is particularly valuable as it highlights the significance of employment considerations in infrastructure planning. By making unemployment the key social indicator, Scenario 5 aims to guide decisions that promote job creation, economic inclusivity, and sustainable development practices. The analysis acknowledges the interconnectedness of unemployment with other factors such as average income and income inequality, as reflected in the correlation matrix. High unemployment areas tend to have lower average incomes and higher GINI index values, making them prime candidates for interventions aimed at economic revitalization.

Scenario 5:			
Criteria	Weight	Sub-criteria	Weight
Economic Criteria	0.33	PV	W_1 = 0.5
		H2 Consumption	W_2 =0.5
Technical & Environmental Criteria	0.33	Water	W_3 = 0.5
		Land	W_4 = 0.5
Social Criteria	0.33	Education	W_5 = 0
		Population	W_6 = 0
		Unemployment	W_7 = 1

Table 10. Sensibility Analysis Scenario 5

7.7 Scenarios Results

Scenario 0

In Scenario 0, the top provinces identified for green hydrogen production are Cáceres, Jaén, Badajoz, León, and Ciudad Real, based on their natural resources: photovoltaic (PV) potential, water risk, and land availability, excluding hydrogen consumption and social criteria. Cáceres stands out for its balanced mix of good PV potential and significant land availability with manageable water risk, Jaén benefits from high PV potential and adequate land, and Badajoz combines high PV potential with low water risk, creating a stable environment for hydrogen production. León offers strong PV potential and ample land, while Ciudad Real provides excellent PV potential, substantial land, and manageable water risk, supporting continuous hydrogen plant operations.

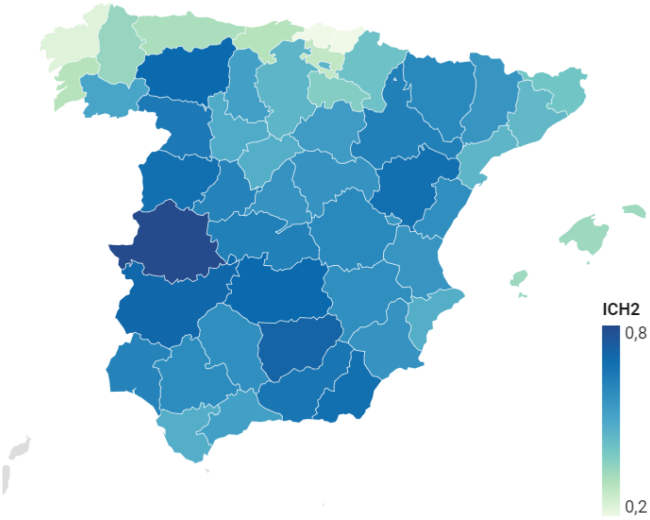


Figure 16. Results Scenario 0. Own Development

These provinces, despite varying water risk levels, they maintain a balance that supports sustainable hydrogen initiatives. Collectively, these regions offer a robust foundation for green hydrogen infrastructure due to their favourable environmental and technical conditions.

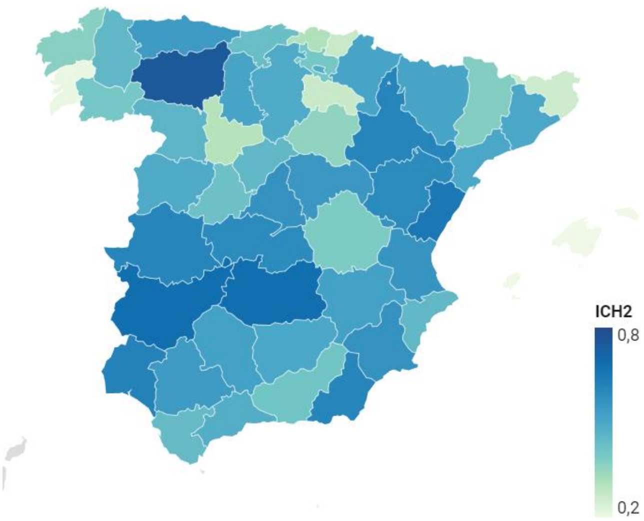


Figure 17. Results Scenario 1. Own Development

Scenario 1

This scenario serves as a baseline for understanding the impact of excluding social factors in the decision-making process for locating hydrogen plants, as it includes the indicator of hydrogen consumption.

The analysis identifies the following top provinces for green hydrogen production as seen on Figure 17: León, Ciudad Real, Badajoz, Castellón, Huelva and Zaragoza.

Comparing it with Scenario 0, León, Ciudad Real, Badajoz, Almería, Cáceres, and Teruel are consistently top candidates due to their strong natural resource bases. However, when introducing hydrogen consumption, it highlights Castellón as a top candidate, emphasizing its strong position in energy generation capacity and consumption needs. Additionally, provinces like Huelva and Zaragoza emerge as strong candidates due to their favorable mix of resources and consumption potential. Despite the inclusion of hydrogen consumption, the overall top provinces remain largely consistent, underscoring their balanced natural resources and suitability for green hydrogen production.

Scenario 2

In Scenario 2, the introduction of social criteria alongside economic, technical, and environmental criteria highlights León, Badajoz, Ciudad Real, Huelva, Castellón, Teruel, Cáceres, Almería, Huesca, and Guadalajara as top candidates due to their favourable social metrics. Despite population being introduced as a cost, these regions stand out because of their strong social factors, such as high education levels and low unemployment rates, which compensate for their varying geographic sizes and population densities.

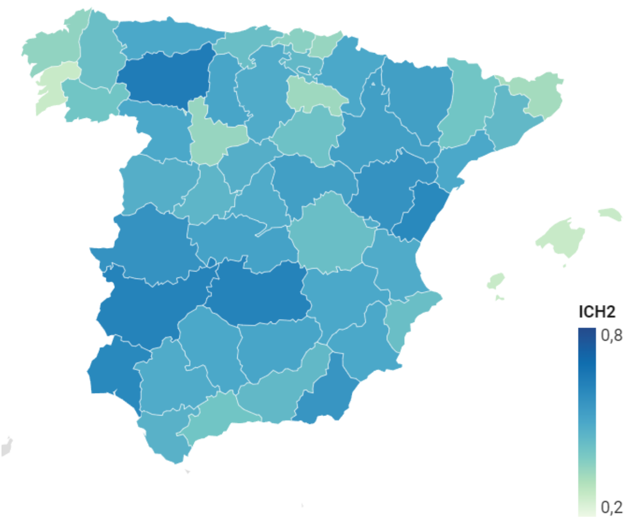


Figure 18. Results Scenario 2. Own Development

Notably, León, Badajoz, Ciudad Real, Huelva, Castellón, Teruel, Cáceres, and Almería continue to maintain their positions at the top, reflecting their balanced strengths across all criteria. This comparison underscores the importance of a holistic approach that balances natural resources with socio-economic factors to ensure sustainable and equitable infrastructure development.

What is more, the introduction of social criteria brings new provinces like Huesca and Guadalajara into the top 10, highlighting their strong educational infrastructure and low unemployment rates.

Scenario 3

In Scenario 3, the focus is solely on the Education sub-criterion within the social domain. This adjustment highlights the pivotal role of education, and León, Madrid, and Castellón emerge as top candidates due to their strong educational metrics alongside economic, technical, and environmental criteria. León maintains its strong position, Madrid appears prominently due to its robust educational infrastructure and high average income, contributing to economic stability and growth, while Castellón continues to excel with its mix of good PV potential and favourable education levels.

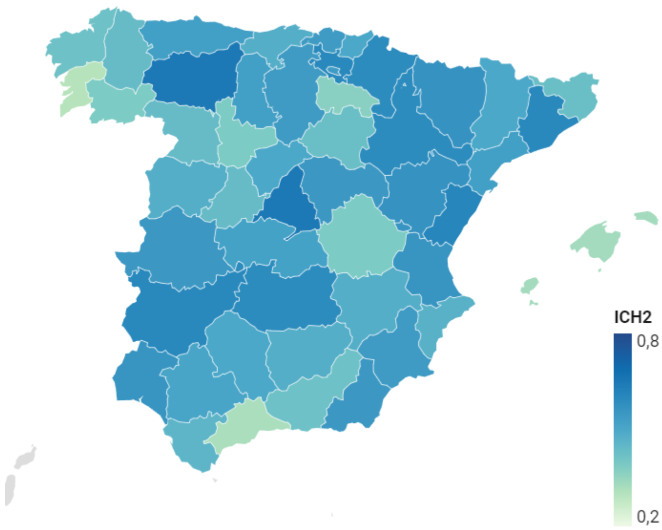


Figure 19. Results Scenario 3. Own Development

Barcelona and Álava follow closely, benefiting from strong educational metrics that support local development and community welfare. Barcelona is highlighted for its educational infrastructure and potential for economic development, while Álava also shows strong educational outcomes.

When compared to Scenario 2, Scenario 3 brings new provinces like Madrid, Barcelona, Álava, and Navarra into prominence due to their strong educational metrics. This comparison underscores the significant impact of education on local development and the importance of a well-educated workforce in supporting sustainable and successful hydrogen plant projects.

Scenario 4

This scenario highlights the role of demographic analysis in infrastructure planning, prioritizing less populated areas to address "Empty Spain" (La España vaciada) and foster development in disadvantaged regions.

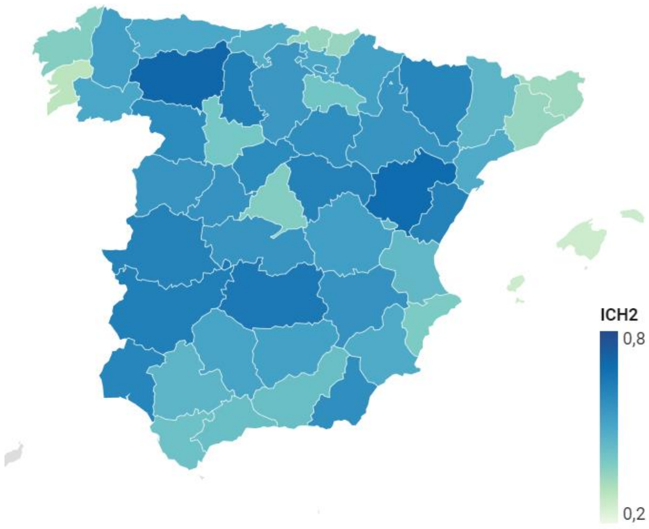


Figure 20.Results Scenario 4. Own development.

The analysis identifies León, Teruel, Ciudad Real, Palencia, Badajoz, Cáceres, Castellón, Guadalajara, Huelva, and Huesca as top candidates due to their strengths in PV potential, land availability, and low population density. This unique approach brings provinces like Zamora and Huelva into prominence, which may not have been as highly ranked in scenarios focusing on education or unemployment. The emphasis on population as a cost helps identify regions where hydrogen projects can have a transformative socio-economic impact, supporting the goal of reversing depopulation trends and revitalizing underdeveloped areas.

Comparing it with the previous scenario, the shift in focus to population highlights the importance of targeting underpopulated regions for development to stimulate local economies and create job opportunities, balancing the need for immediate workforce availability with long-term socio-economic benefits. This brings Palencia and Guadalajara into prominence due to their low population density and suitability for revitalizing less populated areas.

Scenario 5

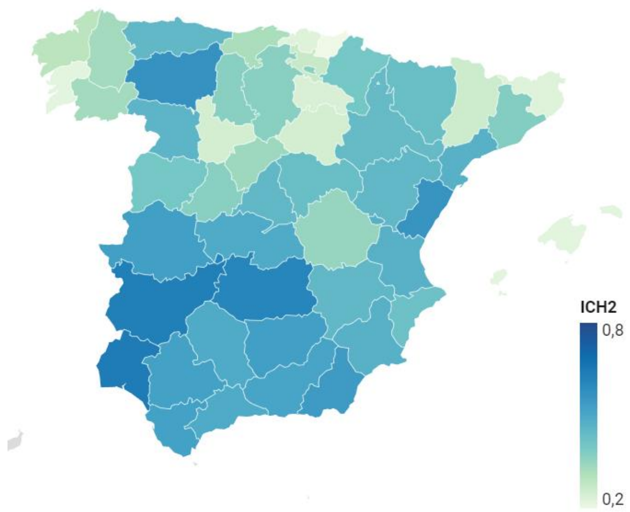


Figure 21. Results Scenario 5. Own development.

In Scenario 5, the focus is solely on the Unemployment. This scenario highlights the crucial role of addressing unemployment in influencing local economic conditions and workforce readiness. The analysis identifies Huelva, Badajoz, and Ciudad Real as top candidates due to their high unemployment rates, indicating a need for job creation and economic revitalization.

Additionally, León, Castellón, and Almería also rank highly, reflecting their strong potential for renewable energy production and high unemployment rates. Jaén, Cáceres, Cádiz, and Sevilla round out the top candidates. This scenario brings provinces like Cádiz and Sevilla into prominence due to their high unemployment rates and the need for economic revitalization. Provinces such as Huelva, Jaén, Badajoz, and León consistently appear in the top rankings across scenarios, demonstrating their robust natural and social resources. The shift in focus to unemployment highlights the importance of targeting regions with high joblessness for development to stimulate local economies and create job opportunities.

8. Comparison with the Hydrogen Infrastructure Plan

Enagás proposes to create two renewable hydrogen transmission axes in Spain. The first encompasses the Cantabrian Coast Axis, the Ebro Valley Axis, and the Levante Axis; the second, the Vía de la Plata Axis connected to the Puertollano Hydrogen Valley. The company also poses to develop two underground hydrogen storage facilities in Cantabria and the Basque Country.[49]

The analysis of hydrogen plant location results across various scenarios reveals a strong alignment with Spain's planned hydrogen route map, especially when social indicators are introduced. Incorporating social criteria such as education, population, and unemployment into the analysis, highlights provinces like León, Badajoz, Ciudad Real, Huelva, Castellón, and Cáceres, which consistently appear across different scenarios.

When comparing the selected locations with the planned hydrogen infrastructure map, several consistently identified provinces align well. For instance, León, Badajoz, Ciudad Real, Huelva, Castellón, and Cáceres are positioned advantageously along key routes, facilitating a future efficient transportation and distribution of hydrogen. This alignment suggests that the integration of these provinces into the

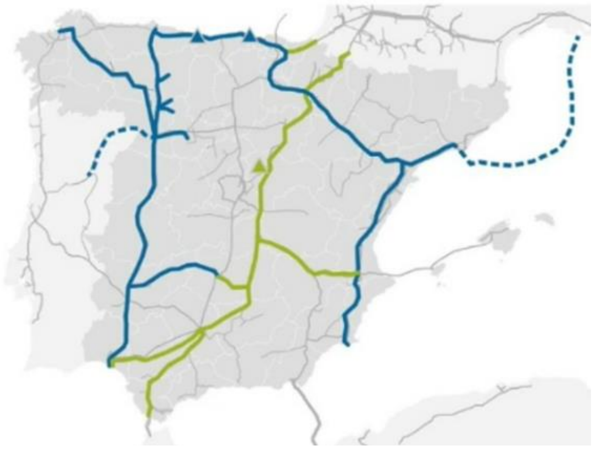


Figure 22. Spanish Hydrogen infrastructure 2030

national hydrogen strategy would support both regional and national objectives, enhancing the overall effectiveness of Spain's hydrogen initiatives.

Additionally, the comparison highlights some potential gaps and opportunities. Regions like Almería, Jaén, and Cádiz, which rank highly based on natural resources and social criteria but are not well-connected within the network, show strong potential for development. Addressing these gaps by expanding the network to include these high-potential areas could ensure a more comprehensive and inclusive hydrogen infrastructure, enhancing Spain's capability to foster a robust and resilient hydrogen economy.

Overall, the integration of social indicators into the hydrogen plant location analysis aligns well with infrastructure plan validating the strategic importance of both coastal and inland regions. It emphasizes the need to consider educational, demographic, and unemployment factors to ensure sustainable and community-focused development. Expanding the hydrogen network to include regions with strong social and natural advantages will enhance Spain's capability to foster a robust and resilient hydrogen economy, promoting equitable growth and regional development.

9. Final Conclusions

The integration of social criteria in the selection process for hydrogen plant locations is crucial for achieving a comprehensive balance between economic, technical, environmental, and social dimensions. This holistic approach not only meets the immediate needs of energy production but also fosters sustainable and equitable regional development across Spain.

The importance of including social factors in the analysis cannot be overstated. Traditionally, site selection processes often prioritize economic and technical criteria, potentially overlooking the broader socio-economic impacts of infrastructure projects. This TFM specifically aims to integrate social factors such as education, population density, and unemployment rates to ensure that the benefits of green hydrogen plants extend beyond economic gains. By addressing social disparities and targeting underdeveloped regions, the project seeks to promote equitable growth and community well-being.

This project aimed to identify the most suitable locations for green hydrogen plants in Spain by incorporating a comprehensive set of criteria, including social factors. The methodology used combined extensive data collection, spatial analysis using Q-GIS, and a Multi-Criteria Decision-Making (MCDM) approach to create a Hydrogen Compatibility Index (H2 compatibility index). It started by studying the most relevant social factors and filtering them into the indicators that best could represent them in the model by a correlation matrix.

This process presented a challenge, as some criteria can be interpreted in different ways. For instance, while higher population density might suggest a readily available workforce, it could also indicate higher land costs and increased competition for resources. Similarly, education and unemployment indicators were considered as benefits, emphasizing the positive impact of a skilled workforce and the need for job creation, respectively. Balancing these perspectives was crucial in developing a robust and equitable site selection model.

The scenarios varied from excluding social criteria entirely to focusing solely on specific social indicators like education, population, and unemployment, demonstrating how different criteria combinations influence the optimal locations for hydrogen plants. In Scenario 0, regions like Cáceres, Jaén, Badajoz, León, and Ciudad Real emerged as top candidates based on natural resource availability. Scenario 1 introduced hydrogen consumption, highlighting León, Ciudad Real, Badajoz and Castellón for its energy generation and consumption capacity. Including social criteria in Scenario 2 brought provinces like Teruel, Almería, Huesca, and Guadalajara into prominence, while Scenario 3 emphasized education, highlighting Madrid, Barcelona, Navarra, and Álava. Scenario 4 focused on population as a cost, prioritizing less populated areas like Teruel, Ciudad Real, Palencia and Badajoz to address "Empty Spain." Lastly, Scenario 5, which focused on unemployment, identified high unemployment areas like Cádiz and Sevilla as candidates for economic revitalization.

In addition, the analysis of hydrogen plant locations reveals strong alignment with Enagás´ 2030 hydrogen infrastructure map, especially when social indicators are included. Incorporating education, population, and unemployment criteria highlights new regions and emphasizes the importance of a balanced approach. This alignment supports regional and national objectives, enhancing Spain's hydrogen strategy.

Furthermore, examining the database of existing and developing hydrogen plants, it is noticeable that many of the highlighted provinces already host or are in the process of developing hydrogen projects. For example, Castellón, Cáceres, León, Jaén, Badajoz, and Ciudad Real, which feature prominently in the analysis, have ongoing hydrogen initiatives. This congruence underscores the practical relevance of the study's findings and reinforces the strategic importance of these regions in Spain's transition to a hydrogen-based economy. The presence of existing projects in these areas can provide a foundation for scaling up hydrogen production and infrastructure, leveraging existing investments and expertise to accelerate progress

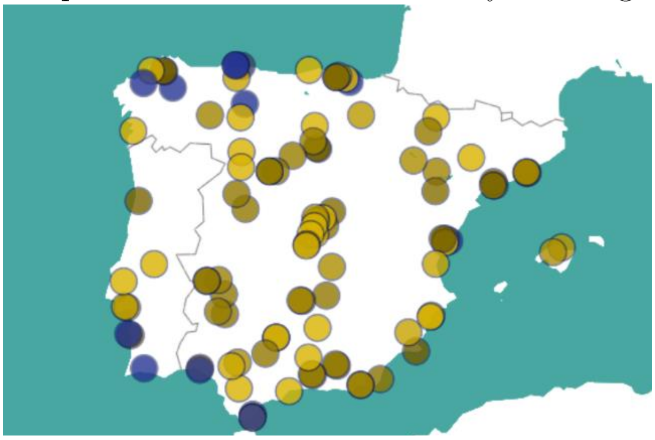


Figure 23. Current hydrogen project's location in Spain.[51]

By correlating the identified suitable zones with Spain's planned hydrogen routes and current hydrogen projects, this study offers a robust framework for making informed decisions about future hydrogen plant locations. It highlights regions that not only meet technical and economic criteria but also align with strategic infrastructure plans and existing developmental efforts, thereby supporting a coordinated and comprehensive approach to advancing Spain's hydrogen economy.

However, it is important to note that this model serves as a good guide and orientation for decision-making. Given the novelty of hydrogen technology and the limited information available, the selection of factors and indicators in this analysis is based on a comprehensive review of existing literature. The sense given to each criterion results from internal discussions and comparisons with other studies. A more rigorous and detailed model might lead to different results, highlighting other regions as optimal for hydrogen plant locations. As the field evolves and more data becomes available, the criteria and weighting used should be revisited to ensure the most accurate and beneficial outcomes for Spain's hydrogen infrastructure development.

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ANEX A - Alignment with the Sustainable Development Goals (SDGs)

The implementation of green hydrogen in Spain aligns closely with several Sustainable Development Goals (SDGs) set by the United Nations. This initiative not only advances the country's energy transition but also contributes to broader objectives related to people and prosperity, encapsulated within the 5Ps framework of the SDGs. Below are mentioned some SDGs that could be linked to this initiative.

Figure 24. Alignment with SDGs[50]

SDG 7: Affordable and Clean Energy

Green hydrogen presents a viable solution for the decarbonization of sectors that face challenges with electrification, such as heavy industry, maritime transport, and aviation. By integrating hydrogen into these sectors, Spain can significantly reduce its carbon footprint, facilitating a transition towards a fully decarbonized economy. This supports SDG 7 by ensuring access to affordable, reliable, sustainable, and modern energy for all.

SDG 9: Industry, Innovation, and Infrastructure

The development of these facilities involves the deployment of cutting-edge technologies for electrolysis and the establishment of a robust hydrogen supply chain. This not only strengthens the renewable energy industry but also propels technological innovation in the broader industrial sector.

SDG 11: Sustainable Cities and Communities

Integrating hydrogen into urban energy systems can play a critical role in reducing air pollution and improving urban sustainability. Hydrogen-powered public transport and heating systems, for example, can significantly lower emissions in cities. This contributes to SDG 11 by making cities and human settlements inclusive, safe, resilient, and sustainable. Cleaner air and reduced carbon footprints enhance the quality of urban life, supporting healthier living environments and more sustainable communities.

SDG 13: Climate Action

Green hydrogen production addresses SDG 13 directly by offering a low-carbon alternative. The process involves using renewable energy sources, thus reducing carbon emissions associated with traditional hydrogen production methods. By promoting the adoption of green hydrogen, Spain contributes significantly to global efforts to combat climate change and achieve a more sustainable and resilient planet.

The alignment with these SDGs underscores the multi-faceted benefits of green hydrogen implementation. By contributing to affordable and clean energy, fostering industrial innovation, enhancing urban sustainability, and supporting climate action, Spain's green hydrogen initiative plays a crucial role in advancing sustainable development. The initiative not only addresses immediate environmental challenges but also promotes long-term socio-economic benefits, including job creation, economic resilience, and social equity.

ANEX B – Scenario 0 model

	Economic Crietria		**Technical & Environmental Criteria**		**Social Criteria**			Total
Weight	**0.50**		**0.50**		**0**			1
Total	**1**		**1**		**0**			
Weight	**1**	**0**	**0.5**	**0.5**	**0**	**0**	**0**	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemplyment_Norm**	**ICH**
Almería	0.98	0.07	0.90	0.66	0.41	0.18	0.40	0.88
Granada	1.00	0.00	0.88	0.55	0.43	0.82	0.70	0.86
Murcia	0.91	0.32	0.90	0.42	0.48	0.91	0.27	0.78
Málaga	0.90	0.06	0.93	0.30	0.00	0.58	0.49	0.75
Cáceres	0.82	0.00	0.34	0.95	0.43	0.12	0.38	0.74
Albacete	0.89	0.04	0.78	0.34	0.41	0.22	0.30	0.73
Ciudad Real	0.87	0.16	0.55	0.61	0.40	0.86	0.48	0.72
Valencia	0.80	0.15	0.79	0.48	0.56	0.22	0.30	0.72
Huelva	0.88	0.31	0.66	0.42	0.44	0.98	0.67	0.71
Cádiz	0.87	0.08	0.93	0.14	0.49	0.61	0.68	0.70
Alicante	0.82	0.05	0.92	0.24	0.51	0.05	0.35	0.70
Sevilla	0.90	0.06	0.67	0.28	0.44	0.03	0.46	0.69
Badajoz	0.86	0.08	0.43	0.55	0.45	0.19	0.54	0.68
Teruel	0.79	0.00	0.47	0.62	0.53	0.25	0.19	0.67
Cuenca	0.84	0.00	0.62	0.37	0.41	0.44	0.27	0.67
Guadalajara	0.76	0.05	0.67	0.46	0.53	0.28	0.18	0.66
Toledo	0.89	0.07	0.55	0.32	0.38	0.66	0.29	0.66
León	0.61	0.14	0.41	1.00	0.46	0.31	0.23	0.66
Zaragoza	0.75	0.06	0.51	0.54	0.54	0.47	0.08	0.64
Madrid	0.82	0.16	0.59	0.28	0.80	0.03	0.20	0.63
Ávila	0.79	0.00	0.48	0.41	0.46	0.29	0.27	0.62

Córdoba	0.87	0.03	0.56	0.16	0.47	0.42	0.45	0.62
Soria	0.70	0.00	0.64	0.43	0.56	0.21	0.01	0.62
Baleares	0.66	0.00	1.00	0.11	0.62	0.00	0.27	0.61
Salamanca	0.77	0.00	0.33	0.53	0.48	0.13	0.24	0.60
Huesca	0.73	0.00	0.46	0.44	0.69	0.31	0.25	0.59
Zamora	0.74	0.00	0.35	0.50	0.39	0.02	0.45	0.58
Castellón	0.73	1.00	0.46	0.37	0.52	0.78	0.38	0.57
Segovia	0.69	0.01	0.65	0.26	0.60	0.29	0.13	0.57
Lleida	0.70	0.00	0.50	0.35	0.75	0.45	0.02	0.56
Tarragona	0.69	0.21	0.67	0.17	0.61	0.82	0.40	0.55
Palencia	0.69	0.03	0.51	0.28	0.56	0.20	0.08	0.54
Barcelona	0.68	0.30	0.64	0.15	0.81	0.39	0.15	0.54
Valladolid	0.75	0.00	0.55	0.05	0.57	1.00	0.15	0.53
Jaén	0.87	0.00	0.07	0.24	0.43	0.14	0.60	0.51
Girona	0.58	0.00	0.61	0.11	0.78	0.50	0.18	0.47
Burgos	0.50	0.03	0.49	0.35	0.64	0.30	0.14	0.46
Ourense	0.46	0.00	0.36	0.52	0.36	0.39	0.20	0.45
Melilla	0.73	0.00	0.09	0.00	0.59	0.00	0.96	0.39
La Rioja	0.45	0.00	0.49	0.16	0.58	0.51	0.19	0.39
Navarra	0.42	0.10	0.38	0.27	0.77	0.37	0.18	0.37
Pontevedra	0.36	0.00	0.60	0.14	0.48	0.21	0.23	0.37
Asturias	0.06	0.54	0.57	0.73	0.53	0.18	0.29	0.35
Ceuta	0.65	0.00	0.09	0.00	0.56	0.00	1.00	0.35
Cantabria	0.11	0.04	0.54	0.52	0.56	0.52	0.11	0.32
Lugo	0.22	0.02	0.41	0.42	0.44	0.81	0.10	0.32
A Coruña	0.19	0.09	0.64	0.21	0.51	0.14	0.15	0.31
Álava	0.24	0.07	0.37	0.08	0.99	0.29	0.00	0.23
Vizcaya	0.03	0.21	0.66	0.10	1.00	0.15	0.07	0.20
Guipúzcoa	0.00	0.03	0.56	0.07	0.95	0.17	0.06	0.16

ANEX C – Scenario 1 model

	Economic Cirietria		**Technical & Environmental Criteria**		**Social Criteria**			Total
Weight	**0,50**		**0,50**		**0**			1
Total	**1**		**1**		**0**			
Weight	**0,5**	**0,5**	**0,5**	**0,5**	**0**	**0**	**0**	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemployment_Norm**	**ICH2**
León	0.61	0.79	0.59	1.00	0.46	0.62	0.23	0.75
Ciudad Real	0.87	0.81	0.45	0.59	0.40	0.60	0.48	0.68
Badajoz	0.86	0.74	0.57	0.53	0.45	0.53	0.54	0.68
Castellón	0.73	1.00	0.54	0.33	0.52	0.56	0.38	0.65
Huelva	0.88	0.88	0.34	0.39	0.44	0.59	0.67	0.62
Zaragoza	0.75	0.70	0.49	0.51	0.54	0.45	0.08	0.61
Almería	0.98	0.72	0.10	0.65	0.41	0.51	0.40	0.61
Cáceres	0.82	0.00	0.66	0.95	0.43	0.66	0.38	0.61
Toledo	0.89	0.73	0.45	0.28	0.38	0.52	0.29	0.59
Teruel	0.79	0.42	0.53	0.60	0.53	0.90	0.19	0.59
Madrid	0.82	0.81	0.41	0.24	0.80	0.00	0.20	0.57
Murcia	0.91	0.88	0.10	0.38	0.48	0.34	0.27	0.57
Valencia	0.80	0.80	0.21	0.45	0.56	0.22	0.30	0.56
Guadalajara	0.76	0.68	0.33	0.43	0.53	0.75	0.18	0.55
Sevilla	0.90	0.70	0.33	0.24	0.44	0.29	0.46	0.54
Asturias	0.06	0.94	0.43	0.71	0.53	0.44	0.29	0.54
Albacete	0.89	0.67	0.22	0.31	0.41	0.66	0.30	0.52
Córdoba	0.87	0.64	0.44	0.11	0.47	0.50	0.45	0.52
Palencia	0.69	0.63	0.49	0.24	0.56	0.87	0.08	0.51
Huesca	0.73	0.37	0.54	0.41	0.69	0.79	0.25	0.51

Navarra	0.42	0.76	0.62	0.23	0.77	0.54	0.18	0.51
Barcelona	0.68	0.87	0.36	0.10	0.81	0.04	0.15	0.50
Jaén	0.87	0.00	0.93	0.20	0.43	0.55	0.60	0.50
Tarragona	0.69	0.84	0.33	0.12	0.61	0.49	0.40	0.50
Burgos	0.50	0.63	0.51	0.32	0.64	0.68	0.14	0.49
Salamanca	0.77	0.00	0.67	0.51	0.48	0.70	0.24	0.49
Málaga	0.90	0.71	0.07	0.26	0.00	0.32	0.49	0.48
Zamora	0.74	0.00	0.65	0.47	0.39	0.85	0.45	0.46
Segovia	0.69	0.53	0.35	0.22	0.60	0.87	0.13	0.45
Alicante	0.82	0.69	0.08	0.19	0.51	0.29	0.35	0.45
Lugo	0.22	0.58	0.59	0.39	0.44	0.70	0.10	0.45
Cádiz	0.87	0.73	0.07	0.09	0.49	0.39	0.68	0.44
Cantabria	0.11	0.66	0.46	0.50	0.56	0.56	0.11	0.43
Ávila	0.79	0.00	0.52	0.38	0.46	0.87	0.27	0.42
Granada	1.00	0.00	0.12	0.52	0.43	0.46	0.70	0.41
Álava	0.24	0.71	0.63	0.03	0.99	0.69	0.00	0.40
Ourense	0.46	0.00	0.64	0.50	0.36	0.71	0.20	0.40
Cuenca	0.84	0.00	0.38	0.34	0.41	0.82	0.27	0.39
Lleida	0.70	0.00	0.50	0.32	0.75	0.63	0.02	0.38
A Coruña	0.19	0.75	0.36	0.17	0.51	0.41	0.15	0.37
Soria	0.70	0.00	0.36	0.40	0.56	1.00	0.01	0.36
Vizcaya	0.03	0.84	0.34	0.05	1.00	0.41	0.07	0.31
Valladolid	0.75	0.00	0.45	0.00	0.57	0.59	0.15	0.30
Guipúzkoa	0.00	0.63	0.44	0.02	0.95	0.51	0.06	0.27
La Rioja	0.45	0.00	0.51	0.11	0.58	0.70	0.19	0.27
Girona	0.58	0.00	0.39	0.06	0.78	0.50	0.18	0.26
Pontevedra	0.36	0.00	0.40	0.10	0.48	0.45	0.23	0.21
Baleares	0.66	0.04	0.00	0.06	0.62	0.40	0.27	0.19

ANEX D – Scenario 2 model

	Economic CCirtetria		Technical & Environmental Criteria		Social Criteria			Total
Weight	0,33		0,33		0,33			1
Total	1		1		1			
Weight	0,5	0,5	0,5	0,5	0,33	0,33	0,33	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemployment_Norm**	**ICH2**
León	0.61	0.79	0.59	1.00	0.46	0.62	0.23	0.64
Badajoz	0.86	0.74	0.57	0.53	0.45	0.53	0.54	0.62
Ciudad Real	0.87	0.81	0.45	0.59	0.40	0.60	0.48	0.62
Huelva	0.88	0.88	0.34	0.39	0.44	0.59	0.67	0.60
Castellón	0.73	1.00	0.54	0.33	0.52	0.56	0.38	0.60
Teruel	0.79	0.42	0.53	0.60	0.53	0.90	0.19	0.57
Cáceres	0.82	0.00	0.66	0.95	0.43	0.66	0.38	0.57
Almería	0.98	0.72	0.10	0.65	0.41	0.51	0.40	0.56
Huesca	0.73	0.37	0.54	0.41	0.69	0.79	0.25	0.53
Guadalajara	0.76	0.68	0.33	0.43	0.53	0.75	0.18	0.53
Zaragoza	0.75	0.70	0.49	0.51	0.54	0.45	0.08	0.53
Toledo	0.89	0.73	0.45	0.28	0.38	0.52	0.29	0.52
Palencia	0.69	0.63	0.49	0.24	0.56	0.87	0.08	0.51
Jaén	0.87	0.00	0.93	0.20	0.43	0.55	0.60	0.51
Navarra	0.42	0.76	0.62	0.23	0.77	0.54	0.18	0.50
Córdoba	0.87	0.64	0.44	0.11	0.47	0.50	0.45	0.50
Albacete	0.89	0.67	0.22	0.31	0.41	0.66	0.30	0.50
Murcia	0.91	0.88	0.10	0.38	0.48	0.34	0.27	0.50
Tarragona	0.69	0.84	0.33	0.12	0.61	0.49	0.40	0.50
Zamora	0.74	0.00	0.65	0.47	0.39	0.85	0.45	0.50

Asturias	0.06	0.94	0.43	0.71	0.53	0.44	0.29	0.50
Valencia	0.80	0.80	0.21	0.45	0.56	0.22	0.30	0.49
Sevilla	0.90	0.70	0.33	0.24	0.44	0.29	0.46	0.49
Madrid	0.82	0.81	0.41	0.24	0.80	0.00	0.20	0.49
Burgos	0.50	0.63	0.51	0.32	0.64	0.68	0.14	0.49
Salamanca	0.77	0.00	0.67	0.51	0.48	0.70	0.24	0.48
Segovia	0.69	0.53	0.35	0.22	0.60	0.87	0.13	0.48
Cádiz	0.87	0.73	0.07	0.09	0.49	0.39	0.68	0.47
Ávila	0.79	0.00	0.52	0.38	0.46	0.87	0.27	0.46
Álava	0.24	0.71	0.63	0.03	0.99	0.69	0.00	0.45
Granada	1.00	0.00	0.12	0.52	0.43	0.46	0.70	0.45
Barcelona	0.68	0.87	0.36	0.10	0.81	0.04	0.15	0.45
Lugo	0.22	0.58	0.59	0.39	0.44	0.70	0.10	0.43
Alicante	0.82	0.69	0.08	0.19	0.51	0.29	0.35	0.43
Cuenca	0.84	0.00	0.38	0.34	0.41	0.82	0.27	0.43
Cantabria	0.11	0.66	0.46	0.50	0.56	0.56	0.11	0.43
Soria	0.70	0.00	0.36	0.40	0.56	1.00	0.01	0.42
Málaga	0.90	0.71	0.07	0.26	0.00	0.32	0.49	0.41
Ourense	0.46	0.00	0.64	0.50	0.36	0.71	0.20	0.41
Lleida	0.70	0.00	0.50	0.32	0.75	0.63	0.02	0.41
Vizcaya	0.03	0.84	0.34	0.05	1.00	0.41	0.07	0.37
A Coruña	0.19	0.75	0.36	0.17	0.51	0.41	0.15	0.36
Guipúzkoa	0.00	0.63	0.44	0.02	0.95	0.51	0.06	0.35
Valladolid	0.75	0.00	0.45	0.00	0.57	0.59	0.15	0.35
La Rioja	0.45	0.00	0.51	0.11	0.58	0.70	0.19	0.34
Girona	0.58	0.00	0.39	0.06	0.78	0.50	0.18	0.33
Pontevedra	0.36	0.00	0.40	0.10	0.48	0.45	0.23	0.27
Baleares	0.66	0.04	0.00	0.06	0.62	0.40	0.27	0.27

ANEX E – Scenario 3 model

	Economic Cietria		Technical & Environmental Criteria		Social Criteria			Total
Weight	0,33		0,33		0,33			1
Total	1		1		1			
Weight	0,5	0,5	0,5	0,5	1	0	0	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemployment_Norm**	**ICH2**
León	0.61	0.79	0.59	1.00	0.46	0.62	0.23	0.65
Madrid	0.82	0.81	0.41	0.24	0.80	0.00	0.20	0.65
Castellón	0.73	1.00	0.54	0.33	0.52	0.56	0.38	0.61
Barcelona	0.68	0.87	0.36	0.10	0.81	0.04	0.15	0.60
Badajoz	0.86	0.74	0.57	0.53	0.45	0.53	0.54	0.60
Álava	0.24	0.71	0.63	0.03	0.99	0.69	0.00	0.60
Navarra	0.42	0.76	0.62	0.23	0.77	0.54	0.18	0.59
Zaragoza	0.75	0.70	0.49	0.51	0.54	0.45	0.08	0.59
Ciudad Real	0.87	0.81	0.45	0.59	0.40	0.60	0.48	0.59
Huesca	0.73	0.37	0.54	0.41	0.69	0.79	0.25	0.57
Teruel	0.79	0.42	0.53	0.60	0.53	0.90	0.19	0.57
Valencia	0.80	0.80	0.21	0.45	0.56	0.22	0.30	0.56
Huelva	0.88	0.88	0.34	0.39	0.44	0.59	0.67	0.56
Cáceres	0.82	0.00	0.66	0.95	0.43	0.66	0.38	0.55
Guadalajara	0.76	0.68	0.33	0.43	0.53	0.75	0.18	0.55
Almería	0.98	0.72	0.10	0.65	0.41	0.51	0.40	0.55
Vizcaya	0.03	0.84	0.34	0.05	1.00	0.41	0.07	0.54
Burgos	0.50	0.63	0.51	0.32	0.64	0.68	0.14	0.54
Murcia	0.91	0.88	0.10	0.38	0.48	0.34	0.27	0.54
Tarragona	0.69	0.84	0.33	0.12	0.61	0.49	0.40	0.53

Asturias	0.06	0.94	0.43	0.71	0.53	0.44	0.29	0.53
Palencia	0.69	0.63	0.49	0.24	0.56	0.87	0.08	0.53
Toledo	0.89	0.73	0.45	0.28	0.38	0.52	0.29	0.52
Sevilla	0.90	0.70	0.33	0.24	0.44	0.29	0.46	0.51
Lleida	0.70	0.00	0.50	0.32	0.75	0.63	0.02	0.50
Córdoba	0.87	0.64	0.44	0.11	0.47	0.50	0.45	0.50
Guipúzkoa	0.00	0.63	0.44	0.02	0.95	0.51	0.06	0.50
Segovia	0.69	0.53	0.35	0.22	0.60	0.87	0.13	0.50
Salamanca	0.77	0.00	0.67	0.51	0.48	0.70	0.24	0.48
Albacete	0.89	0.67	0.22	0.31	0.41	0.66	0.30	0.48
Jaén	0.87	0.00	0.93	0.20	0.43	0.55	0.60	0.48
Cantabria	0.11	0.66	0.46	0.50	0.56	0.56	0.11	0.48
Alicante	0.82	0.69	0.08	0.19	0.51	0.29	0.35	0.47
Cádiz	0.87	0.73	0.07	0.09	0.49	0.39	0.68	0.46
Lugo	0.22	0.58	0.59	0.39	0.44	0.70	0.10	0.44
Zamora	0.74	0.00	0.65	0.47	0.39	0.85	0.45	0.44
Ávila	0.79	0.00	0.52	0.38	0.46	0.87	0.27	0.44
Girona	0.58	0.00	0.39	0.06	0.78	0.50	0.18	0.43
Soria	0.70	0.00	0.36	0.40	0.56	1.00	0.01	0.43
Granada	1.00	0.00	0.12	0.52	0.43	0.46	0.70	0.42
A Coruña	0.19	0.75	0.36	0.17	0.51	0.41	0.15	0.42
Cuenca	0.84	0.00	0.38	0.34	0.41	0.82	0.27	0.39
Valladolid	0.75	0.00	0.45	0.00	0.57	0.59	0.15	0.39
Ourense	0.46	0.00	0.64	0.50	0.36	0.71	0.20	0.39
La Rioja	0.45	0.00	0.51	0.11	0.58	0.70	0.19	0.37
Baleares	0.66	0.04	0.00	0.06	0.62	0.40	0.27	0.33
Málaga	0.90	0.71	0.07	0.26	0.00	0.32	0.49	0.32
Pontevedra	0.36	0.00	0.40	0.10	0.48	0.45	0.23	0.30

ANEX F – Scenario 4 model

	Economic Crietria		**Technical & Environmental Criteria**		**Social Criteria**			Total
Weight	**0,33**		**0,33**		**0,33**			1
Total	**1**		**1**		**1**			
Weight	**0,5**	**0,5**	**0,5**	**0,5**	**0**	**1**	**0**	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemplyment_Norm**	**ICH2**
León	0.61	0.79	0.59	1.00	0.46	0.62	0.23	0.71
Teruel	0.79	0.42	0.53	0.60	0.53	0.90	0.19	0.69
Ciudad Real	0.87	0.81	0.45	0.59	0.40	0.60	0.48	0.65
Palencia	0.69	0.63	0.49	0.24	0.56	0.87	0.08	0.63
Badajoz	0.86	0.74	0.57	0.53	0.45	0.53	0.54	0.63
Cáceres	0.82	0.00	0.66	0.95	0.43	0.66	0.38	0.62
Castellón	0.73	1.00	0.54	0.33	0.52	0.56	0.38	0.62
Guadalajara	0.76	0.68	0.33	0.43	0.53	0.75	0.18	0.62
Huelva	0.88	0.88	0.34	0.39	0.44	0.59	0.67	0.61
Huesca	0.73	0.37	0.54	0.41	0.69	0.79	0.25	0.61
Zamora	0.74	0.00	0.65	0.47	0.39	0.85	0.45	0.59
Segovia	0.69	0.53	0.35	0.22	0.60	0.87	0.13	0.59
Almería	0.98	0.72	0.10	0.65	0.41	0.51	0.40	0.58
Soria	0.70	0.00	0.36	0.40	0.56	1.00	0.01	0.58
Ávila	0.79	0.00	0.52	0.38	0.46	0.87	0.27	0.57
Albacete	0.89	0.67	0.22	0.31	0.41	0.66	0.30	0.57
Toledo	0.89	0.73	0.45	0.28	0.38	0.52	0.29	0.56
Zaragoza	0.75	0.70	0.49	0.51	0.54	0.45	0.08	0.56
Salamanca	0.77	0.00	0.67	0.51	0.48	0.70	0.24	0.56
Burgos	0.50	0.63	0.51	0.32	0.64	0.68	0.14	0.55

Cuenca	0.84	0.00	0.38	0.34	0.41	0.82	0.27	0.53
Lugo	0.22	0.58	0.59	0.39	0.44	0.70	0.10	0.53
Navarra	0.42	0.76	0.62	0.23	0.77	0.54	0.18	0.52
Jaén	0.87	0.00	0.93	0.20	0.43	0.55	0.60	0.52
Córdoba	0.87	0.64	0.44	0.11	0.47	0.50	0.45	0.51
Ourense	0.46	0.00	0.64	0.50	0.36	0.71	0.20	0.50
Asturias	0.06	0.94	0.43	0.71	0.53	0.44	0.29	0.50
Álava	0.24	0.71	0.63	0.03	0.99	0.69	0.00	0.50
Tarragona	0.69	0.84	0.33	0.12	0.61	0.49	0.40	0.49
Murcia	0.91	0.88	0.10	0.38	0.48	0.34	0.27	0.49
Cantabria	0.11	0.66	0.46	0.50	0.56	0.56	0.11	0.48
Lleida	0.70	0.00	0.50	0.32	0.75	0.63	0.02	0.46
Sevilla	0.90	0.70	0.33	0.24	0.44	0.29	0.46	0.46
Valencia	0.80	0.80	0.21	0.45	0.56	0.22	0.30	0.45
Málaga	0.90	0.71	0.07	0.26	0.00	0.32	0.49	0.43
Granada	1.00	0.00	0.12	0.52	0.43	0.46	0.70	0.43
Cádiz	0.87	0.73	0.07	0.09	0.49	0.39	0.68	0.42
La Rioja	0.45	0.00	0.51	0.11	0.58	0.70	0.19	0.41
Valladolid	0.75	0.00	0.45	0.00	0.57	0.59	0.15	0.40
Alicante	0.82	0.69	0.08	0.19	0.51	0.29	0.35	0.39
A Coruña	0.19	0.75	0.36	0.17	0.51	0.41	0.15	0.38
Madrid	0.82	0.81	0.41	0.24	0.80	0.00	0.20	0.38
Guipúzkoa	0.00	0.63	0.44	0.02	0.95	0.51	0.06	0.35
Barcelona	0.68	0.87	0.36	0.10	0.81	0.04	0.15	0.35
Vizcaya	0.03	0.84	0.34	0.05	1.00	0.41	0.07	0.35
Girona	0.58	0.00	0.39	0.06	0.78	0.50	0.18	0.34
Pontevedra	0.36	0.00	0.40	0.10	0.48	0.45	0.23	0.29
Baleares	0.66	0.04	0.00	0.06	0.62	0.40	0.27	0.26

ANEX G – Scenario 5 model

	Economic Crietria		**Technical & Environmental Criteria**		**Social Criteria**			Total
Weight	**0,33**		**0,33**		**0,33**			1
Total	**1**		**1**		**1**			
Weight	**0,5**	**0,5**	**0,5**	**0,5**	**0**	**0**	**1**	
Province	**PV_Norm**	**Consumption_Norm**	**Water_Norm**	**Land_Norm**	**Edu_Nmean**	**Pop_Nmean**	**Unemplyment_Norm**	**ICH2**
Huelva	0.88	0.88	0.34	0.39	0.44	0.59	0.67	0.64
Badajoz	0.86	0.74	0.57	0.53	0.45	0.53	0.54	0.63
Ciudad Real	0.87	0.81	0.45	0.59	0.40	0.60	0.48	0.61
León	0.61	0.79	0.59	1.00	0.46	0.62	0.23	0.57
Castellón	0.73	1.00	0.54	0.33	0.52	0.56	0.38	0.56
Almería	0.98	0.72	0.10	0.65	0.41	0.51	0.40	0.54
Jaén	0.87	0.00	0.93	0.20	0.43	0.55	0.60	0.53
Cáceres	0.82	0.00	0.66	0.95	0.43	0.66	0.38	0.53
Cádiz	0.87	0.73	0.07	0.09	0.49	0.39	0.68	0.52
Sevilla	0.90	0.70	0.33	0.24	0.44	0.29	0.46	0.52
Granada	1.00	0.00	0.12	0.52	0.43	0.46	0.70	0.51
Córdoba	0.87	0.64	0.44	0.11	0.47	0.50	0.45	0.49
Toledo	0.89	0.73	0.45	0.28	0.38	0.52	0.29	0.49
Málaga	0.90	0.71	0.07	0.26	0.00	0.32	0.49	0.49
Valencia	0.80	0.80	0.21	0.45	0.56	0.22	0.30	0.47
Murcia	0.91	0.88	0.10	0.38	0.48	0.34	0.27	0.47
Tarragona	0.69	0.84	0.33	0.12	0.61	0.49	0.40	0.47
Zamora	0.74	0.00	0.65	0.47	0.39	0.85	0.45	0.46
Asturias	0.06	0.94	0.43	0.71	0.53	0.44	0.29	0.45
Teruel	0.79	0.42	0.53	0.60	0.53	0.90	0.19	0.45
Albacete	0.89	0.67	0.22	0.31	0.41	0.66	0.30	0.45
Madrid	0.82	0.81	0.41	0.24	0.80	0.00	0.20	0.45
Zaragoza	0.75	0.70	0.49	0.51	0.54	0.45	0.08	0.44

Guadalajara	0.76	0.68	0.33	0.43	0.53	0.75	0.18	0.43
Huesca	0.73	0.37	0.54	0.41	0.69	0.79	0.25	0.43
Alicante	0.82	0.69	0.08	0.19	0.51	0.29	0.35	0.42
Salamanca	0.77	0.00	0.67	0.51	0.48	0.70	0.24	0.40
Navarra	0.42	0.76	0.62	0.23	0.77	0.54	0.18	0.40
Barcelona	0.68	0.87	0.36	0.10	0.81	0.04	0.15	0.38
Burgos	0.50	0.63	0.51	0.32	0.64	0.68	0.14	0.37
Ávila	0.79	0.00	0.52	0.38	0.46	0.87	0.27	0.37
Palencia	0.69	0.63	0.49	0.24	0.56	0.87	0.08	0.37
Cuenca	0.84	0.00	0.38	0.34	0.41	0.82	0.27	0.35
Segovia	0.69	0.53	0.35	0.22	0.60	0.87	0.13	0.34
Ourense	0.46	0.00	0.64	0.50	0.36	0.71	0.20	0.33
Lugo	0.22	0.58	0.59	0.39	0.44	0.70	0.10	0.33
Cantabria	0.11	0.66	0.46	0.50	0.56	0.56	0.11	0.32
A Coruña	0.19	0.75	0.36	0.17	0.51	0.41	0.15	0.29
Álava	0.24	0.71	0.63	0.03	0.99	0.69	0.00	0.27
Lleida	0.70	0.00	0.50	0.32	0.75	0.63	0.02	0.26
Valladolid	0.75	0.00	0.45	0.00	0.57	0.59	0.15	0.25
Soria	0.70	0.00	0.36	0.40	0.56	1.00	0.01	0.25
La Rioja	0.45	0.00	0.51	0.11	0.58	0.70	0.19	0.24
Girona	0.58	0.00	0.39	0.06	0.78	0.50	0.18	0.23
Vizcaya	0.03	0.84	0.34	0.05	1.00	0.41	0.07	0.23
Pontevedra	0.36	0.00	0.40	0.10	0.48	0.45	0.23	0.22
Baleares	0.66	0.04	0.00	0.06	0.62	0.40	0.27	0.22
Guipúzkoa	0.00	0.63	0.44	0.02	0.95	0.51	0.06	0.20