BDC

Università degli Studi di Napoli Federico II

24

numero 2 | anno 2024

BDC
Università degli Studi di Napoli Federico II

Via Toledo, 402
80 134 Napoli
tel. + 39 081 2538659
fax + 39 081 2538649
e-mail info.bdc@unina.it
www.bdc.unina.it

Direttore Responsabile: Luigi Fusco Girard
BDC - Bollettino del Centro Calza Bini Università degli Studi di Napoli Federico II
Registrazione: Cancelleria del Tribunale di Napoli, n. 5144, 06.09.2000
BDC è pubblicato da FedOAPress (Federico II Open Access Press) e realizzato con Open Journal System

Print ISSN 1121-2918, electronic ISSN 2284-4732

Journal home page www.bdc.unina.it

BDC volume 24, issue 2, year 2024

print ISSN 1121-2918, electronic ISSN 2284-4732

Identification of suitable sites for Green Hydrogen Production from petroleum wastewater

Identificazione di siti idonei per la produzione di idrogeno verde utilizzando acque reflue dell'industria petrolifera

Rossella Scorzelli[a,*], Shiva Rahmani[a], Alfonso Annunziata[a], Michela Delfino[a], Francesco Scorza[a], Antonio D'Angola[a], Beniamino Murgante[a]

AUTHORS & ARTICLE INFO

[a] School of Engineering, University of Basilicata, Italy

* Corresponding author
email: rossella.scorzelli@unibas.it

ABSTRACT AND KEYWORDS

Identification of suitable sites for Green Hydrogen Production
Climate change requires urgent action to build a resilient society, capable of adapting to the current emergency. In this scenario, renewable energies play a crucial role. In particular, Green Hydrogen represents a viable alternative to fossil fuels. Its production through electrolysis makes it possible to generate energy without polluting emissions. This study identifies the criteria for selecting suitable sites for the production of Green Hydrogen using waste water from oil extraction in the industrial area of Viggiano, Italy. The methodology implemented involves a Multicriteria Spatial Analysis. Key criteria include technical, economic and environmental factors. The final output is a suitability map that facilitates the identification of the most suitable sites for the location of infrastructure for Green Hydrogen production.

Keywords: Green Hydrogen Infrastructure (GHI), electrolysis, Renewable Energy Sources (RES), land suitability map

Identificazione di siti idonei per la produzione di idrogeno verde
I cambiamenti climatici richiedono azioni urgenti con il fine di costituire una società resiliente, capace di adattarsi all'attuale emergenza. In questo scenario, le energie rinnovabili rivestono un ruolo cruciale. In particolare, l'Idrogeno Verde rappresenta una valida alternativa ai combustibili fossili. La sua produzione attraverso l'elettrolisi consente di generare energia senza emissioni inquinanti. Questo studio identifica i criteri per la selezione dei siti idonei alla produzione dell'Idrogeno Verde utilizzando le acque reflue dell'estrazioni petrolifere dell'area industriale di Viggiano, in Italia. La metodologia implementata prevede un'Analisi Spaziale Multicriteriale. I criteri chiave includono fattori tecnici, economici ed ambientali. L'output finale è rappresentato da una mappa di idoneità che facilita l'individuazione dei siti più adatti alla collocazione delle infrastrutture per la produzione di Idrogeno Verde.

Parole chiave: Infrastrutture per l'Idrogeno Verde, elettrolisi, Fonti Energetiche Rinnovabili (FER), mappa di idoneità dei suoli

1. Background

Increasing awareness of the environmental damage caused by increasingly impactful human activities has intensified the search for sustainable energy sources capable of reducing polluting emissions and mitigating climate change (Owusu & Asumadu-Sarkodie, 2016). The energy challenge affects several sectors and is also linked to social and economic dimensions (Ahl et al., 2022). Indeed, sustainable development is at the heart of international policies and strategies that aim to build an increasingly resilient society (Suprayitno et al., 2024.). In recent years, research has focused on the use of Renewable Energy Sources (RES) to replace fossil fuels. In this scenario, Green Hydrogen is emerging as a promising alternative due to its peculiarities (Scorzelli et al., 2023). In particular, the ability to generate clean energy through the process of electrolysis of water. Electrolysis is a process that uses electricity to separate the water molecule into oxygen and hydrogen gas (Nnabuife et al., 2024). The electricity required for this process is produced by RES such as photovoltaics and wind power, making the process completely sustainable. The hydrogen produced has several uses, such as an energy carrier in the decarbonisation processes of "hard to abate" industries, as fuel, or as a transportation fuel (Szałek et al., 2021). Green hydrogen infrastructure includes a series of facilities for production, storage and distribution. Production takes place mainly through electrolysers, which use renewable energy to separate water into hydrogen and oxygen. The hydrogen produced is then stored in low or high-pressure tanks, or in liquid form in cryogenic storage. New technologies are also exploring storage in solid materials.

For distribution, hydrogen can be transported by dedicated pipelines, tank trucks or rail wagons, with compression equipment facilitating transport. Hydrogen is eventually distributed via terminals and refuelling stations, where it is used in fuel cells for electricity generation, in co-generation plants or in industrial sectors to reduce the use of fossil fuels (Tashie-Lewis & Nnabuife, 2021). Depending on the use, different components have to be considered in the construction and placement of GHIs. This paper aims to examine the criteria that contribute to the identification of the most suitable sites for the siting of GHIs. The chosen case study sees the identification of the land suitability map for the location of the GHIs serving the industrial area of Viggiano (Basilicata, Italy). The latter is one of the largest oil extraction centres in Continental Europe. The hydrogen produced could in fact be used as an alternative fuel for the tankers serving the industry itself. The water needed for the electrolysis process could also be recovered from the liquid waste resulting from the oil extraction process. The final goal is the land suitability map through the integration of the Analytic Hierarchy Process (AHP) and the Geographic Information System (GIS). The paper is organized into three main sections. The first section focuses on the analysis method. The second section presents the case study, and the final section provides the concluding remarks.

2. Methodology: Spatial Multi-Criteria Analysis

The identification of suitable areas for the placement of GHIs requires consideration of several criteria, which have to be compared with each other in order to obtain the optimal compromise solution. This is achieved by means of the Analytich Hierarchy Process (AHP), which allows the different factors involved to be weighted (T. L. Saaty & Vargas, 1980). AHP is the best known and most widely used technique belonging to the Multi-Criteria Decision Methods (MCDM) (Kornyshova & Salinesi, 2007.). The solid theoretical basis allows this technique to be used to break down complex problems into simpler ones, making it applicable in various contexts (R. W. Saaty, 1987; T. L. Saaty, 2008). The problem is represented through a hierarchy consisting of several levels, the main one being the goal. This is followed by the level of criteria and sub-criteria and finally the level of alternatives. The pairwise comparison of elements belonging to the same level makes it easy to arrive at a judgement. Once the consistency of the judgments made has been verified, first the local weights of the compared elements are established and then the global weights of the alternatives, identifying the optimal one that constitutes the compromised solution. The integration of this technique with Geographical Information Systems (GIS) makes it possible to deal with complex decisions marked by spatially distributed criteria (Fischer & Nijkamp, 1992). In the hierarchical structure, the level of alternatives represented on a spatial basis disappears (Malczewski, 2006). Spatial Multi-Criteria Analysis (SMCA) is a support technique for decision-makers and planners that is also particularly useful in identifying optimal areas for the location of RES infrastructure. For example, Rapal et al., (2017) use SMCA to identify optimal sites for wind and solar farms in the Philippines. In Continental Ecuador, Villacreses et al., (2017) identify the location of wind farms as a case study. Tunc et al., (2019) identify ten SMCA-weighted factors for locating a solar power plant in Istanbul, Turkey. Different social, economic and environmental criteria are considered in the case study of Giamalaki and Tsoutsos (2019) in the Regional Unit of Rethymno. Semnan area, central province of Iran is classified according to nine classes of suitability for the location of wind farm (Yousefi et al., 2022). Various criteria, including climatology, location, geography, meteorology, and disaster susceptibility, were considered in the assessment of a solar plant in Sibuyan Island (Gacu et al., 2023). SMCA is used to calculate weights on physiographic and climatic data in a study area of Bangladesh to identify optimal locations for siting solar power plants (Islam et al., 2024).

This technique makes it easy to compare both qualitative and quantitative criteria. In assessing the suitability of land for the location of RES infrastructure, the identification of criteria is a key step. For GHIs, three main categories can be identified in general, technical, economic and environmental, as shown in the case study illustrated. For each, a spatial analysis is carried out. The main steps characterising the methodology implemented in this paper are as follows:

1. circumscription of the study area;
2. elaboration of the base map by eliminating constrained areas;
3. selection of the main criteria and sub-criteria;
4. calculation of the local weights of the criteria and sub-criteria using AHP;
5. processing of the representative maps of the criteria and sub-criteria in GIS;
6. overlay of the maps through map-algebra operations;
7. obtaining the Land Suitability Map;
8. identification of optimal sites for the placement of the GHI.

3. Elaboration of the case study

Hydrocarbon extraction in Italy, particularly in the Basilicata region, has played a key role in industrial development, with the Centro Oli Val d’Agri (COVA) operating one of the largest oil treatment plants in Europe. Crude oil is treated to separate the phases present (oil, gas and water), with the oil sent to the Taranto refinery and the gas fed into the national grid. Process water, generated during extraction, is treated and partly reinjected or disposed of. The research focuses on the use of purified process water for the production of green hydrogen through electrolysis.

3.1 Calculating hydrogen demand and water needed for production[1]

Calculating the demand for hydrogen to fuel COVA’s tankers required estimating the specific consumption of H_2 for the vehicles and the amount of water needed to produce it. The main calculation steps include (Sharaf & Orhan, 2014; Valverde et al., 2013):

1. estimated specific consumption of H_2 for Euro 6 articulated trucks:
   - 30 kg of H_2 to travel 400 km, with a specific consumption of 13 km/kg of H_2;
   - calculation of H_2 production from a 2 MW PEM electrolyser:
   - production capacity of 134 kg of H_2 per 3000 litres of water per hour:
   - estimated annual production: 938,000 kg of H_2 using approximately 21,000 m^3 of water;
2. demand of H_2 for road tankers:
   - estimated annual demand for H_2: 573,484 kg;
3. process water availability:
   - available water: 528,300 m^3 annually, which is higher than the amount required for H_2 production (12,839 m^3).

Calculations have shown that the available process water is sufficient to meet the demand for hydrogen. Finally, a 6 MW photovoltaic plant was dimensioned to support a 2 MW electrolyser, with a land occupation of approximately six hectares.

3.2 Identification of the study area

The first step was to identify the study area covering 1045 km^2, as shown in Figure 1. The COVA covers an area of approximately 171,700 m^2. The southeastern edge of the complex runs along the municipal boundary of Viggiano, while the surrounding areas, within a 1 km radius, fall within the municipal territories of Viggiano and Grumento Nova. In Figure 1, the COVA is represented by a blue dot.

Figure 1. Study map area.

Source: Own processing.

The area considers not only the municipality in which the COVA industry is located, but also the other twenty surrounding municipalities that identify the Val d’Agri area. Indeed, the Val d’Agri area comprises the municipalities of Viggiano, Armento, Aliano, Castronuovo di Sant’Andrea, Corleto Perticara, Gallicchio, Guardia

Perticara, Marsico Nuovo, Marsicovetere, Missanello, Moliterno, Montemurro, Paterno, Roccanova, San Chirico Raparo, San Martino d'Agri, Sant'Arcangelo, Sarconi, Spinoso, and Tramutola. Subsequently, areas deemed unsuitable for the location of GHIs, such as:

- the hazard areas of the Hydrogeological Structure Plan;
- the urban centers and rural areas are drawn from ISTAT data on national locations;
- areas protected by law concerning the regulatory framework for regional landscape planning, consisting of the European Landscape Convention (ECL).

3.3 Identification of the main criteria and sub-criteria

The identification phase of the criteria and related sub-criteria is crucial for the result (Table 1). The main criteria are divided into technical, economic, and environmental criteria. Technical sub-criteria include slope and solar radiation. Economic sub-criteria include road accessibility, accessibility to the industrial area (COVA), distance from RES, distance from the national electricity transmission network (TERNA). Finally, the environmental sub-criterion concerns ecosystem services. Evaluating the impact caused by a possible location of the facilities on ecosystem services is fundamental for a scenario of protecting natural resources and the benefits they offer.

Table 1. Individuation of main and sub-criteria, data collection and their sources

Main Criteria	Sub-Criteria	Data	Type of layer	Source
Technical	C_1: Slope	Digital Terrain Model (DTM)	Raster	Regional Spatial Data Infrastructure of Basilicata (RSDI)
	C_2: Solar radiation	Digital Terrain Model (DTM)	Raster	RSDI
Economic	C_3: Distance of roads	Road network	Vector	RSDI
	C_4: Distance of industry	Industrial lots	Vector	RSDI
	C_5: Distance of RES	Industrial lots	Vector	RSDI
	C_6: Distance of GAS pipelines	GAS distribution network	Vector	RSDI
Environmental	C_7: Ecosystem Services	Corine Land Cover	Raster	Integrated Valuation of Ecosystem Services and Trade-offs (INVEST)

Source: Own processing.

3.4 Calculation of the local weights of the criteria and sub-criteria using AHP

The application of AHP made it possible to identify the weight vector of the individual sub-criteria through a pairwise comparison matrix (Table 2). This process was the result of a literature review (Ali et al., 2022; Baufumé et al., 2013; Gacu et al., 2023; Giamalaki & Tsoutsos, 2019; Koc et al., 2019). The assignment of ratings according to Saaty's scale was performed by experts in the field. The weight vector identifies the importance of each sub-criterion in identifying soil suitability. The most influential sub-criterion in terms of percentage weight appears to be that of Ecosystem Services.

Table 2. Comparison matrix and weight vector

	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**w_i (%)**
C_1	1,00	0,25	0,17	0,17	0,20	0,20	0,25	3
C_2	4,00	1,00	0,33	0,33	0,33	0,33	0,25	6
C_3	6,00	3,00	1,00	1,00	0,50	0,50	0,25	11
C_4	6,00	3,00	1,00	1,00	0,50	0,50	0,25	11
C_5	5,00	3,00	2,00	2,00	1,00	1,00	0,25	15
C_6	5,00	3,00	2,00	2,00	1,00	1,00	0,25	15
C_7	4,00	4,00	4,00	4,00	4,00	4,00	1,00	37

Source: Own processing.

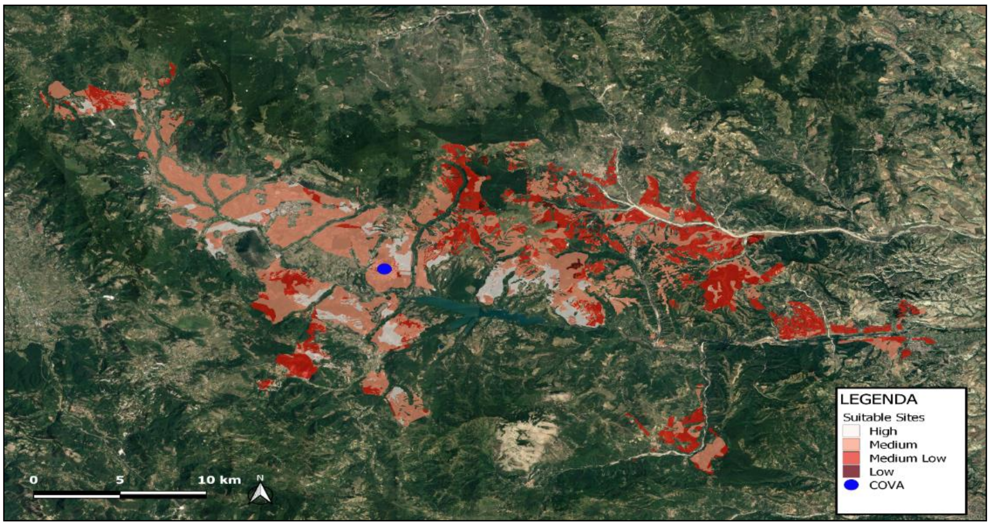
2.5 Spatial Analysis of sub-criteria

Subsequently, the individual layers were analysed using ArcGis, and all sub-criteria were reclassified in raster format. This reclassification was carried out considering the free areas identified from the previous constraint analysis, with a scoring system from one to five (from suitably high area to low suitability). The first sub-criterion analyzed was solar radiation, based on the 5-meter DEM model of the study area. The predominantly flat topography of the area allows for optimal solar radiation reception, particularly in higher-altitude zones, making solar panels a primary source of energy for green hydrogen production. The slope analysis revealed that a significant portion of the land has moderate to low slopes, making them suitable for potential photovoltaic installations. Accessibility criteria to roads and the Viggiano Oil Center were assessed using the ORS (Open Route Service) tool. This allowed for distance calculation based on isochrones, which are lines connecting locations reachable within the same time frame. Isolines were calculated from 10 to 50 minutes, with intervals of ten minutes, showing that the study area can be reached in less than 40 minutes by heavy vehicles. For accessibility to the Oil Center, the same method was applied. Additionally, the proximity to renewable energy sources (RES) was found to be high, as it is essential to locate areas with abundant and stable energy sources. The distance to the TERNA grid was also considered to evaluate the feasibility of “transporting” electricity to produce green hydrogen. The analysis did not reveal significant limitations. Lastly, the impact on Ecosystem Services was assessed, including habitat quality, carbon sequestration, and crop production, which are key indicators for maintaining biodiversity and mitigating climate change effects. Habitat quality involves the provision of various habitats essential for the survival of species and the preservation of biodiversity, serving as a key reference for assessing the ecosystem health of soils. Carbon sequestration refers to the amount of carbon absorbed from the atmosphere in the form of carbon dioxide through ecosystem processes, primarily by plant systems. This is vital as it helps reduce atmospheric CO_2, which contributes to global warming. Crop production refers to the ability to support the growth of crops and the production of food. This service depends on the availability of water and nutrients, which are in turn controlled by several soil properties, climate, and management practices. The mapping of these ecosystem services has made it possible to assess the impact of GHI site location, aiming to minimize environmental damage.

2.6 Land Suitability Map

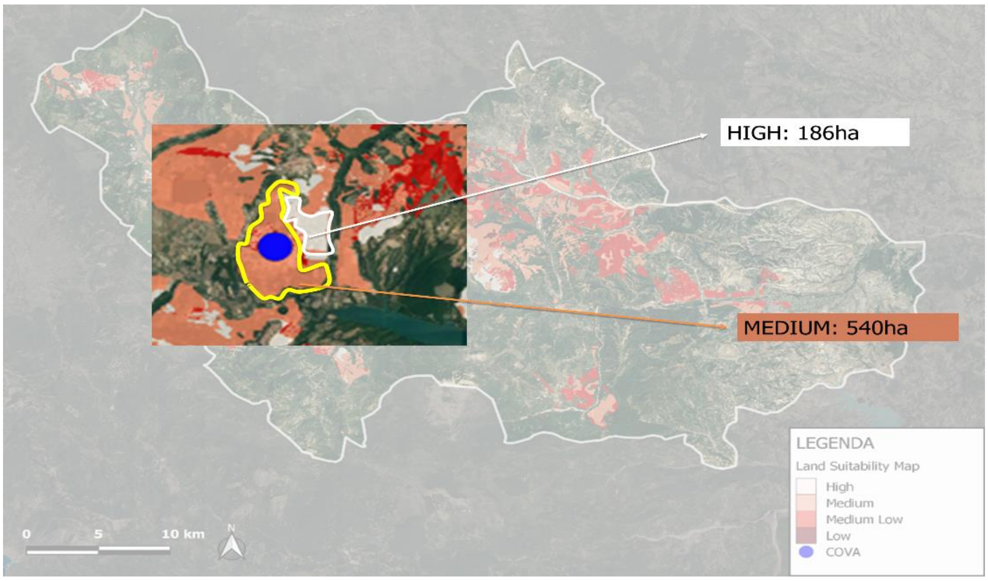
Following a detailed examination of all sub-criteria, the individual maps were combined using the Map-Algebra Overlay tool, with each map weighted according to the values calculated through the AHP method. The resulting Land Suitability Map (Figure 2) represents the key outcome of this study, which focuses on identifying the optimal sites for green hydrogen infrastructure.

Figure 2. Land Suitability Map



Source: Own Processing.

Figure 3. Zooming in on the Land Suitability Map



Source: Own Processing.

A detailed view of the land suitability map (Figure 3) shows that the highlighted regions indicate areas with high suitability (186 ha) and medium suitability (540 ha). The COVA plant (represented by the blue dot) is at the centre of the analysis. The 186 hectares identified as highly suitable for Green Hydrogen Infrastructure (GHI) development are predominantly located within areas already impacted by industrial activities, including brownfield sites or previously developed land. This ensures that the proposed installations align with sustainable land-use principles by prioritizing areas that are already 'consumed' in terms of soil sealing and development. It is essential to emphasize that the total area of 186 hectares significantly exceeds the space requirements for GHIs. Only a fraction of this land will be utilized, and the selected portions will focus on zones with pre-existing soil consumption, minimizing the impact on natural and agricultural landscapes. This strategic approach reinforces the commitment to limiting additional land use and promoting the requalification of disused or underutilized industrial areas.

4. Final Remarks

The approach outlined in this study offers a valuable tool for decision-makers, allowing them to evaluate and compare various options by incorporating both quantitative and qualitative criteria. Green hydrogen’s versatility is emphasized, showcasing its potential as a sustainable fuel alternative that can significantly contribute to reducing greenhouse gas emissions. Consequently, the exploration and implementation of green hydrogen technologies are vital to addressing the urgent challenge of climate change and advancing toward a low-emission economy. Furthermore, this study aligns with multiple Sustainable Development Goals (SDGs) of the 2030 Agenda (United Nations, 2015), emphasizing its broader impact on sustainability (Raman et al., 2024). In addition to supporting SDG 12 (responsible consumption and production) and SDG 13 (climate action) through reduced emissions and resource optimization, the research contributes to SDG 7 (affordable and clean energy) by promoting renewable energy technologies like green hydrogen as a cornerstone for a sustainable energy future (Jayachandran et al., 2022). Moreover, it addresses SDG 9 (industry, innovation, and infrastructure) by identifying pathways for integrating innovative energy solutions into industrial processes, enhancing the resilience and sustainability of infrastructure in energy-intensive sectors. The primary goal of this paper was to pinpoint the most suitable locations for the development of green hydrogen production, storage, and distribution infrastructure, with the aim of promoting sustainability and lowering carbon emissions. The methodology, which integrates the Analytic Hierarchy Process (AHP) within a Geographic Information System (GIS) framework, was applied to the case of identifying optimal sites for Green Hydrogen Infrastructure (GHI) in the Val d’Agri industrial area. This approach simplifies complex decision-making by breaking it down into more manageable sub-components, considering both quantitative and qualitative aspects. It serves as a critical tool for planners and stakeholders, enabling detailed comparisons of sites based on factors such as renewable energy sources, existing infrastructure, and transportation networks. The findings underscore that green hydrogen is a promising energy source, particularly in supporting energy-intensive sectors, and can play a crucial role in the global transition to a sustainable, low-carbon future. The multi-criteria spatial analysis provides a structured method for identifying ideal locations for hydrogen infrastructure, helping stakeholders make informed and strategic decisions. Negotiation and participatory planning are essential to reconcile community needs, environmental conservation, and sustainable economic development, thereby ensuring that green hydrogen becomes a pivotal element in the transition to a low-carbon economy. Moreover, the green hydrogen industry has the potential to significantly mitigate greenhouse gas emissions, particularly in sectors like heavy transportation, which accounts for roughly 25% of the EU's road transport emissions. This highlights the importance of swift and strategic action to achieve climate neutrality by 2050, as outlined in the European Green Deal. Green hydrogen, by serving as a clean, alternative fuel, can contribute significantly to these ambitious climate goals.

Notes

1. The data used for the calculations are taken from the COVA industry reports (year 2022).

Author Contributions

Conceptualization: Beniamino Murgante, Alfonso Annunziata, Rossella Scorzelli, Shiva Rahmani; Methodology: Beniamino Murgante, Alfonso Annunziata, Rossella Scorzelli, Shiva Rahmani, Michela Delfino; Software: Alfonso Annunziata, Shiva Rahmani, Michela Delfino; Formal Analysis: Francesco Scorza; Data Curation: Antonio D'Angola; Writing - Review & Editing: Alfonso Annunziata, Rossella Scorzelli, Shiva Rahmani, Michela Delfino; Supervision: Beniamino Murgante, Antonio D'Angola, Francesco Scorza.

Funding

This research received no external funding.

Acknowledgments. The authors would like to thank the "Centro Olio Val d'Agri" COVA for their willingness and for providing the necessary data to implement the case study through the Sustainability Report (2022).

Conflicts of Interest

The authors declare no conflict of interest.

Originality

The authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere, in English or any other language. The manuscript has been read and approved by all named authors and there are no other persons who satisfied the criteria for authorship but are not listed. The authors also declare to have obtained the permission to reproduce in this manuscript any text, illustrations, charts, tables, photographs, or other material from previously published sources (journals, books, websites, etc).

Use of generative AI and AI-assisted technologies

The authors declare that they did not use AI and AI-assisted technologies in the writing of the manuscript; this declaration only refers to the writing process, and not to the use of AI tools to analyse and draw insights from data as part of the research process. They also did not use AI or AI-assisted tools to create or alter images and this may include enhancing, obscuring, moving, removing, or introducing a specific feature within an image or figure, or eliminating any information present in the original.

References

Ahl, A., Goto, M., Yarime, M., Tanaka, K., & Sagawa, D. (2022). Challenges and opportunities of blockchain energy applications: Interrelatedness among technological, economic, social, environmental, and institutional dimensions. *Renewable and Sustainable Energy Reviews, 166*. https://doi.org/10.1016/j.rser.2022.112623

Ali, F., Bennui, A., Chowdhury, S., & Techato, K. (2022). Suitable Site Selection for Solar-Based Green Hydrogen in Southern Thailand Using GIS-MCDM Approach. *Sustainability (Switzerland)*, *14*(11). https://doi.org/10.3390/su14116597

Baufumé, S., Grüger, F., Grube, T., Krieg, D., Linssen, J., Weber, M., Hake, J. F., & Stolten, D. (2013). GIS-based scenario calculations for a nationwide German hydrogen pipeline infrastructure. *International Journal of Hydrogen Energy*, *38*(10), 3813–3829. https://doi.org/10.1016/J.IJHYDENE.2012.12.147

Fischer, M. M., & Nijkamp, P. (1992). Geographic information systems and spatial analysis. *The Annals of Regional Science*, *26*(1), 3–17. https://doi.org/10.1007/BF01581477

Gacu, J. G., Garcia, J. D., Fetalvero, E. G., Catajay-Mani, M. P., & Monjardin, C. E. F. (2023). Suitability Analysis Using GIS-Based Analytic Hierarchy Process (AHP) for Solar Power Exploration. *Energies*, *16*(18). https://doi.org/10.3390/en16186724

Giamalaki, M., & Tsoutsos, T. (2019). Sustainable siting of solar power installations in Mediterranean using a GIS/AHP approach. *Renewable Energy*, *141*, 64–75. https://doi.org/10.1016/j.renene.2019.03.100

Islam, M. R., Aziz, M. T., Alauddin, M., Kader, Z., & Islam, M. R. (2024). Site suitability assessment for solar power plants in Bangladesh: A GIS-based analytical hierarchy process (AHP) and multi-criteria decision analysis (MCDA) approach. *Renewable Energy, 220,* 119595. https://doi.org/10.1016/J.RENENE.2023.119595

Jayachandran, M., Gatla, R. K., Rao, K. P., Rao, G. S., Mohammed, S., Milyani, A. H., Azhari, A. A., Kalaiarasy, C., & Geetha, S. (2022). Challenges in achieving sustainable development goal 7: Affordable and clean energy in light of nascent technologies. *Sustainable Energy Technologies and Assessments*, *53*. https://doi.org/10.1016/j.seta.2022.102692

Koc, A., Turk, S., & Şahin, G. (n.d.). *Multi-criteria of wind-solar site selection problem using a GIS-AHP-based approach with an application in Igdir Province/Turkey*. https://doi.org/10.1007/s11356-019-06260-1/Published

Kornyshova, E., & Salinesi, C. (n.d.). *Proceedings of the 2007 IEEE Symposium on Computational Intelligence in Multicriteria Decision Making (MCDM 2007) MCDM Techniques Selection Approaches: State of the Art*.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, *20*(7), 703–726. https://doi.org/10.1080/13658810600661508

Nnabuife, S. G., Hamzat, A. K., Whidborne, J., Kuang, B., & Jenkins, K. W. (2024). Integration of renewable energy sources in tandem with electrolysis: A technology review for green hydrogen production. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2024.06.342

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. In *Cogent Engineering* (Vol. 3, Issue 1). Cogent OA. https://doi.org/10.1080/23311916.2016.1167990

Raman, R., Lathabai, H. H., & Nedungadi, P. (2024). Sustainable development goal 12 and its synergies with other SDGs: identification of key research contributions and policy insights. *Discover Sustainability*, *5*(1), 150. https://doi.org/10.1007/s43621-024-00289-0

Rapal, B. K. A. L., Sumabat, A. K. R., & Lopez, N. S. A. (2017). Analytic hierarchy process for multi-criteria site selection of utility-scale solar and wind projects. *Chemical Engineering Transactions*, *61*, 1255–1260. https://doi.org/10.3303/CET1761207

Saaty, R. W. (1987). The analytic hierarchy process-what it is and how it is used. *Mathematical Modelling*, *9*(3–5), 161 – 176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83–98. https://doi.org/10.1504/IJSSci.2008.01759

Saaty, T. L., & Vargas, L. G. (1980). Hierarchical analysis of behavior in competition: Prediction in chess. *Behavioral Science*, *25*(3), 180–191. https://doi.org/https://doi.org/10.1002/bs.3830250303

Scorzelli, R., Rahmani, S., Telesca, A., Fattoruso, G., & Murgante, B. (2023). Spatial Multi-criteria Analysis for Identifying Suitable Locations for Green Hydrogen Infrastructure. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *14107 LNCS*, 480–494. https://doi.org/10.1007/978-3-031-37114-1_33

Sharaf, O. Z., & Orhan, M. F. (2014). An overview of fuel cell technology: Fundamentals and applications. *Renewable and Sustainable Energy Reviews*, *32*, 810–853. https://doi.org/https://doi.org/10.1016/j.rser.2014.01.012

Suprayitno, D., Iskandar, S., Dahurandi, K., Hendarto, T., & Rumambi, F. J. (n.d.). *Migration Letters Public Policy In The Era Of Climate Change: Adapting Strategies For Sustainable Futures*. www.migrationletters.com

Szałek, A., Pielecha, I., & Cieslik, W. (2021). Fuel cell electric vehicle (Fcev) energy flow analysis in real driving conditions (rdc). *Energies*, *14*(16). https://doi.org/10.3390/en14165018

Tashie-Lewis, B. C., & Nnabuife, S. G. (2021). Hydrogen Production, Distribution, Storage and Power Conversion in a Hydrogen Economy - A Technology Review. In *Chemical Engineering Journal Advances* (Vol. 8). Elsevier B.V. https://doi.org/10.1016/j.ceja.2021.100172

Tunc, A., Tuncay, G., Alacakanat, Z., & Sevimli, F. S. (2019). Gis based solar power plants site selection using analytic hierarchy process (ahp) in istanbul, Turkey. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2/W13), 1353–1360. https://doi.org/10.5194/isprs-archives-XLII-2-W13-1353-2019

United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*.

Valverde, L., Rosa, F., del Real, A. J., Arce, A., & Bordons, C. (2013). Modeling, simulation and experimental set-up of a renewable hydrogen-based domestic microgrid. *International Journal of Hydrogen Energy*, *38*(27), 11672–11684. https://doi.org/https://doi.org/10.1016/j.ijhydene.2013.06.113

Villacreses, G., Gaona, G., Martínez-Gómez, J., & Jijón, D. J. (2017). Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: The case of continental Ecuador. *Renewable Energy*, *109*, 275–286. https://doi.org/https://doi.org/10.1016/j.renene.2017.03.041

Yousefi, H., Motlagh, S. G., & Montazeri, M. (2022). Multi-Criteria Decision-Making System for Wind Farm Site-Selection Using Geographic Information System (GIS): Case Study of Semnan Province, Iran. *Sustainability (Switzerland)*, *14*(13). https://doi.org/10.3390/su14137640