PEMETAAN KESESUAIAN LOKASI PEMBANGKIT LISTRIK TENAGA ANGIN MENGGUNAKAN METODE MCDM (KOMBINASI AHP – GIS) DI PROVINSI NUSA TENGGARA BARAT

TUGAS AKHIR

Diajukan sebagai persyaratan untuk memperoleh gelar Sarjana Terapan Geografi
di Program Studi D4 Survei Pemetaan dan Informasi Geografis

Disusun Oleh
Attala Zaidan Ghaffar
NIM: 2005629

PROGRAM STUDI SURVEI PEMETAAN DAN INFORMASI GEOGRAFIS
FAKULTAS PENDIDIKAN ILMU PENGETAHUAN SOSIAL
UNIVERSITAS PENDIDIKAN INDONESIA
2025

Pemetaan Kesesuaian Lokasi Pembangkit Listrik Tenaga Angin Menggunakan Metode MCDM (Kombinasi AHP – GIS) Di Provinsi Nusa Tenggara Barat

Oleh
Attala Zaidan Ghaffar

Sebuah tugas akhir yang diajukan untuk memenuhi salah satu syarat memperoleh gelar Sarjana Terapan Geografi pada Fakultas Pendidikan Ilmu Pengetahuan Sosial

Universitas Pendidikan Indonesia
Januari 2025

LEMBAR PENGESAHAN TUGAS AKHIR

Tugas Akhir ini disusun Untuk Memenuhi Salah Satu Syarat Memperoleh Gelar
Sarjana Terapan Geografi (S.Tr.Geo)
di
Program Studi D4 Survei Pemetaan dan Informasi Geografis
Fakultas Pendidikan Ilmu Pengetahuan Sosial
Universitas Pendidikan Indonesia

Oleh:
ATTALA ZAIDAN GHAFFAR
NIM: 2005629

Tanggal Ujian : 22 Januari 2024
Periode Wisuda : Juni 2025

Disetujui,

Pembimbing:

1. Dr. rer.nat. Nandi, M.T., M.Sc.
   NIP. 197907012005011002
2. Hendro Murtianto, S.Pd., M.Sc
   NIP. 198102152008121002

Penguji:

1. Dr. Iwan Setiawan, S.Pd., M.Si.
   NIP. 197106041999031002
2. Shafira Himayah, S.Pd., M.Sc.
   NIP. 920171219881117201
3. Haikal Muhammad Ihsan, S.Pd., M.Sc.
   NIP. 920200419940830101

Mengetahui,
Ketua Program Studi
Survei Pemetaan dan Informasi Geografis

Dr. Nanin Trianawati Sugito, ST., M.T.
NIP. 19830403 200801 2 013

ABSTRAK

PEMETAAN KESESUAIAN LOKASI PEMBANGKIT LISTRIK TENAGA ANGIN MENGGUNAKAN METODE MCDM (KOMBINASI AHP – GIS) DI PROVINSI NUSA TENGGARA BARAT

By
Attala Zaidan Ghaffar
NIM: 2005629
(Program Studi Survei Pemetaan dan Informasi Geografis)

Penelitian ini membahas permasalahan utama terkait identifikasi lokasi yang sesuai untuk pembangunan Pembangkit Listrik Tenaga Angin (PLT-Angin) di Provinsi Nusa Tenggara Barat (NTB), di mana potensi energi terbarukan belum dimanfaatkan secara optimal untuk mendukung pembangunan berkelanjutan. Tujuan utama penelitian ini adalah menentukan prioritas kriteria pemilihan lokasi menggunakan metode *Analytical Hierarchy Process* (AHP) dan mengintegrasikan hasilnya ke dalam pemodelan spasial berbasis *Geographic Information System* (GIS) untuk memetakan lokasi yang optimal. Penelitian ini mengadopsi pendekatan sistematis yang mencakup pembobotan kriteria melalui AHP, analisis *overlay* spasial berbasis GIS, serta validasi data lapangan untuk menghasilkan peta kesesuaian lokasi. Hasil penelitian menunjukkan bahwa 9,12% wilayah NTB tergolong sangat sesuai untuk pembangunan PLT-Angin, dengan area yang sebagian besar berada di delapan kabupaten/kota, seperti Lombok Barat, Lombok Tengah, dan Sumbawa. Faktor utama yang memengaruhi kesesuaian lokasi meliputi kecepatan angin (bobot 20%), kemiringan medan (18%), dan jarak ke pemukiman(18%), menunjukkan bahwa aspek fisik dan teknis menjadi pertimbangan dominan. Sementara itu, lebih dari 50% wilayah dinilai cukup cocok, dan sebagian kecil dinyatakan kurang sesuai atau tidak sesuai. Implikasi dari penelitian ini sangat signifikan untuk mendukung pengembangan energi terbarukan di Provinsi NTB. Temuan memberikan dasar ilmiah yang kuat bagi perencanaan strategis pembangunan PLT-Angin, khususnya dalam memprioritaskan lokasi yang efisien dan berkelanjutan. Selain itu, kerangka analisis ini dapat direplikasi untuk penelitian sejenis di wilayah lain dengan potensi energi terbarukan, sehingga mendukung transisi energi menuju masa depan yang lebih ramah lingkungan.

Kata Kunci: *Analytical Hierarchy Process, Geographic Information Systems*, Pembangkit Listrik Tenaga Angin, Provinsi Nusa Tenggara Barat.

ABSTRACT

MAPPING OF SUITABILITY OF WIND POWER PLANT LOCATION USING MCDM METHOD (COMBINATION OF AHP–GIS) IN WEST NUSA TENGGARA PROVINCE

By
Attala Zaidan Ghaffar
NIM: 2005629
(Program Study of Mapping and Geographic Information Survey)

This research examines the principal challenges associated with the identification of appropriate sites for the establishment of wind power facilities in the West Nusa Tenggara Province, where the potential for renewable energy has not been fully exploited to foster sustainable development. The primary aim of this investigation is to ascertain the prioritization of site selection criteria utilizing the Analytical Hierarchy Process (AHP) methodology and to incorporate the findings into Geographic Information System (GIS)-based spatial modeling for the purpose of delineating optimal locations. The AHP methodology is employed to assign weights to the criteria in this research, in conjunction with GIS-based spatial overlay analysis and validation through field data, to generate a location suitability map. The findings indicate that 9.12% of the NTB area is categorized as highly suitable for the construction of wind power plants, with most of these areas situated across eight districts/cities, including West Lombok, Central Lombok, and Sumbawa. The primary factors that impact location suitability encompass wind speed (weighted at 20%), terrain slope (18%), and proximity to settlements (18%), underscoring that physical and technical considerations are the predominant factors. Concurrently, over 50% of the area is deemed moderately suitable, while a minor portion is classified as less suitable or unsuitable. The implications of this research are profoundly significant in facilitating the advancement of renewable energy in the NTB Province. The results furnish a robust scientific foundation for strategizing the development of wind power plants, particularly in the prioritization of efficient and sustainable sites. Furthermore, this analytical framework is transferable to analogous studies in other regions with potential for renewable energy, thereby bolstering the transition towards a more ecologically sustainable future.

***Keywords**: Analytical Hierarchy Process, Geographic Information Systems, Wind Power Plant, West Nusa Tenggara Province.*

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR SINGKATAN

AHP	:	*Analytical Hierarchy Process*
AI	:	*Artificial Intelligence*
BA	:	*Birds Area* (area burung),
CFD	:	*Computational Fluid Dynamics* (CFD)
CI	:	*Consistency Index*
CR	:	*Consistency Ratio*
DA	:	*Distance to Airport* (jarak ke bandara)
DR	:	*Distance to Road* (akses jalan)
DS	:	*Distribution of Settlements* (persebaran permukiman)
EL	:	*Elevation* (ketinggian)
ELECTRE	:	*Elimination and Choice Translating Reality*
FA	:	*Faults* (patahan geologi)
GIS	:	*Geographic Information Systems*
IoT	:	*Internet of Things*
LU	:	*Land Use* (penggunaan lahan)
MCDM	:	*Multi Criteria Decision Making*

NTB	:	Nusa Tenggara Barat
OWA	:	*Ordered Weighted Averaging*
PA	:	Protected Area (area lindung)
PLT-Angin	:	Pembangkit Listrik Tenaga Angin
PROMETHEE	:	*Preference Ranking Organization Method for Enrichment Evaluation*
RI	:	*Rasio Index*
RD	:	*Rail Roads* (rel kereta)
SL	:	*Slope* (kemiringan medan),
SMCDM	:	*Spatial Multi-Criteria Decision Making*
TL	:	*Transmission Line* (jaringan transmisi listrik)
TOPSIS	:	*Technique for Order of Preference by Similarity to Ideal Solution*
VIKOR	:	*Vise Kriterijumska Optimizacija I Kompromisno Resenje*
WD	:	*Wind Density* (kepadatan angin)
WS	:	*Wind Speed* (kecepatan angin)
WW	:	*Water Ways* (aliran sungai)

DAFTAR LAMPIRAN

DAFTAR PUSTAKA

Abdullah, A. G., Shafii, M. A., Pramuditya, S., Setiadipura, T., & Anzhar, K. (2023). Multi-criteria decision making for nuclear power plant selection using fuzzy AHP: Evidence from Indonesia. *Energy and AI*, *14*, 100263. https://doi.org/https://doi.org/10.1016/j.egyai.2023.100263

Ahmed, I., Rehan, M., Basit, A., & Hong, K.-S. (2022). Greenhouse gases emission reduction for electric power generation sector by efficient dispatching of thermal plants integrated with renewable systems. *Scientific Reports*, *12*(1), 12380. https://doi.org/10.1038/s41598-022-15983-0

Ajanaku, B. A., Strager, M. P., & Collins, A. R. (2022). GIS-based multi-criteria decision analysis of utility-scale wind farm site suitability in West Virginia. *GeoJournal*, *87*(5), 3735–3757. https://doi.org/10.1007/s10708-021-10453-y

Al Garni, H. Z., & Awasthi, A. (2017). Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. *Applied Energy*, *206*, 1225–1240. https://doi.org/https://doi.org/10.1016/j.apenergy.2017.10.024

Alaqeel, T. A., & Suryanarayanan, S. (2018). A fuzzy Analytic Hierarchy Process algorithm to prioritize Smart Grid technologies for the Saudi electricity infrastructure. *Sustainable Energy, Grids and Networks*, *13*, 122–133.

Albraheem, L., & AlAwlaqi, L. (2023). Geospatial analysis of wind energy plant in Saudi Arabia using a GIS-AHP technique. *Energy Reports*, *9*, 5878–5898. https://doi.org/10.1016/j.egyr.2023.05.032

Ali, S., Lee, S. M., & Jang, C. M. (2017). Determination of the most optimal on-shore wind farm site location using a GIS-MCDM methodology: Evaluating the case of South Korea. *Energies*, *10*(12). https://doi.org/10.3390/en10122072

Alotaibi, O. S., & Anzah, F. (2023). Applying an AHP–GIS model to hybrid wind–solar energy site selection in a hot desert region: A case study of the Kuwaiti desert. *Geografisk Tidsskrift-Danish Journal of Geography*, *123*(1), 25–41. https://doi.org/10.1080/00167223.2023.2218891

Alphan, H. (2024). Incorporating visibility information into multi-criteria decision making (MCDM) for wind turbine deployment. *Applied Energy*, *353*, 122164. https://doi.org/https://doi.org/10.1016/j.apenergy.2023.122164

Amsharuk, A., & Łaska, G. (2022). A Review: Existing Methods for Solving Spatial Planning Problems for Wind Turbines in Poland. *Energies*, *15*(23). https://doi.org/10.3390/en15238957

Aragonés-Beltrán, P., Pastor-Ferrando, J. P., García-García, F., & Pascual-Agulló, A. (2010). An Analytic Network Process approach for siting a municipal solid waste

plant in the Metropolitan Area of Valencia (Spain). *Journal of Environmental Management*, *91*(5), 1071–1086. https://doi.org/https://doi.org/10.1016/j.jenvman.2009.12.007

Aras, H., Erdoğmuş, Ş., & Koç, E. (2004). Multi-criteria selection for a wind observation station location using analytic hierarchy process. *Renewable Energy*, *29*(8), 1383–1392. https://doi.org/https://doi.org/10.1016/j.renene.2003.12.020

Arca, D., Keskin Citiroglu, H., & Yalçınkaya, N. M. (2023). Determining optimal solar power plant (SPP) sites by technical and environmental analysis: the case of Safranbolu, Türkiye. *Environmental Science and Pollution Research*, *30*(17), 50829–50846. https://doi.org/10.1007/s11356-023-25879-9

Arı, E. S., & Gencer, C. (2020). The use and comparison of a deterministic, a stochastic, and a hybrid multiple-criteria decision-making method for site selection of wind power plants: An application in Turkey. *Wind Engineering*, *44*(1), 60–74. https://doi.org/10.1177/0309524X19849831

Asadi, M., & Pourhossein, K. (2019). Modeling and Siting of wind farms using Support Vector Regression (SVR). *Proceedings 2019 International Aegean Conference on Electrical Machines and Power Electronics, ACEMP 2019 and 2019 International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2019*, 511–516. https://doi.org/10.1109/ACEMP-OPTIM44294.2019.9007148

Asadi, M., Pourhossein, K., & Mohammadi-Ivatloo, B. (2023). GIS-assisted modeling of wind farm site selection based on support vector regression. *Journal of Cleaner Production*, *390*, 135993. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.135993

Asadi, M., Pourhossein, K., Noorollahi, Y., Marzband, M., & Iglesias, G. (2023). A New Decision Framework for Hybrid Solar and Wind Power Plant Site Selection Using Linear Regression Modeling Based on GIS-AHP. *Sustainability (Switzerland)*, *15*(10). https://doi.org/10.3390/su15108359

Asadi, M., Ramezanzade, M., & Pourhossein, K. (2023). A global evaluation model applied to wind power plant site selection. *Applied Energy*, *336*(January), 120840. https://doi.org/10.1016/j.apenergy.2023.120840

Asakereh, A., Soleymani, M., & Sheikhdavoodi, M. J. (2017). A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran. *Solar Energy*, *155*, 342–353. https://doi.org/https://doi.org/10.1016/j.solener.2017.05.075

Atici, K. B., Simsek, A. B., Ulucan, A., & Tosun, M. U. (2015). A GIS-based Multiple Criteria Decision Analysis approach for wind power plant site selection. *Utilities Policy*, *37*, 86–96. https://doi.org/10.1016/j.jup.2015.06.001

Aydin, N. Y., Kentel, E., & Duzgun, S. (2010). GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey.

Renewable and Sustainable Energy Reviews, *14*(1), 364–373. https://doi.org/https://doi.org/10.1016/j.rser.2009.07.023

Aydin, N. Y., Kentel, E., & Sebnem Duzgun, H. (2013). GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. *Energy Conversion and Management*, *70*, 90–106. https://doi.org/https://doi.org/10.1016/j.enconman.2013.02.004

Ayodele, T. R., Ogunjuyigbe, A. S. O., Odigie, O., & Munda, J. L. (2018). A multi-criteria GIS based model for wind farm site selection using interval type-2 fuzzy analytic hierarchy process: The case study of Nigeria. *Applied Energy*, *228*(June), 1853–1869. https://doi.org/10.1016/j.apenergy.2018.07.051

Azizi, A., Malekmohammadi, B., Jafari, H. R., Nasiri, H., & Amini Parsa, V. (2014). Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: case study of Ardabil province, Iran. *Environmental Monitoring and Assessment*, *186*(10), 6695–6709. https://doi.org/10.1007/s10661-014-3883-6

Azizi, A., Malekmohammadi, B., Jafari, H. R., Nasiri, H., & Parsa, V. A. (2014). Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: case study of Ardabil province, Iran. *Environmental Monitoring and Assessment*, *186*(10), 6695–6709. https://doi.org/10.1007/s10661-014-3883-6

Barzehkar, M., Parnell, K. E., Mobarghaee Dinan, N., & Brodie, G. (2021). Decision support tools for wind and solar farm site selection in Isfahan Province, Iran. *Clean Technologies and Environmental Policy*, *23*(4), 1179–1195. https://doi.org/10.1007/s10098-020-01978-w

Belouda, M., Jaafar, A., Sareni, B., Roboam, X., & Belhadj, J. (2013). Integrated optimal design and sensitivity analysis of a stand alone wind turbine system with storage for rural electrification. *Renewable and Sustainable Energy Reviews*, *28*, 616–624. https://doi.org/https://doi.org/10.1016/j.rser.2013.08.042

Brans, J. P., & Vincke, Ph. (1985). Note—A Preference Ranking Organisation Method. *Management Science*, *31*(6), 647–656. https://doi.org/10.1287/mnsc.31.6.647

Breyer, C., Khalili, S., Bogdanov, D., Ram, M., Oyewo, A. S., Aghahosseini, A., Gulagi, A., Solomon, A. A., Keiner, D., Lopez, G., Østergaard, P. A., Lund, H., Mathiesen, B. V, Jacobson, M. Z., Victoria, M., Teske, S., Pregger, T., Fthenakis, V., Raugei, M., … Sovacool, B. K. (2022). On the History and Future of 100% Renewable Energy Systems Research. *IEEE Access*, *10*, 78176–78218. https://doi.org/10.1109/ACCESS.2022.3193402

Calvert, K., Pearce, J. M., & Mabee, W. E. (2013). Toward renewable energy geo-information infrastructures: Applications of GIScience and remote sensing that build institutional capacity. *Renewable and Sustainable Energy Reviews*, *18*, 416–429. https://doi.org/https://doi.org/10.1016/j.rser.2012.10.024

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems*, *5*(3), 321–339. https://doi.org/10.1080/02693799108927858

Castorrini, A., Gentile, S., Geraldi, E., & Bonfiglioli, A. (2023). Investigations on offshore wind turbine inflow modelling using numerical weather prediction coupled with local-scale computational fluid dynamics. *Renewable and Sustainable Energy Reviews*, *171*, 113008. https://doi.org/https://doi.org/10.1016/j.rser.2022.113008

Charabi, Y., & Gastli, A. (2011). PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renewable Energy*, *36*(9), 2554–2561. https://doi.org/https://doi.org/10.1016/j.renene.2010.10.037

Clifton, A., Barber, S., Stökl, A., Frank, H., & Karlsson, T. (2022). Research challenges and needs for the deployment of wind energy in hilly and mountainous regions. *Wind Energy Science*, *7*(6), 2231–2254. https://doi.org/10.5194/wes-7-2231-2022

Crespo, A. (2023). Computational Fluid Dynamic Models of Wind Turbine Wakes. In *Energies* (Vol. 16, Issue 4). MDPI. https://doi.org/10.3390/en16041772

de Luis-Ruiz, J. M., Carcedo-Haya, J., Pereda-García, R., Castro-Alonso, P., & Pérez-Álvarez, R. (2022). Optimal location of hydraulic energy storage using geographic information systems and multi-criteria analysis. *Journal of Energy Storage*, *49*, 104159. https://doi.org/https://doi.org/10.1016/j.est.2022.104159

Dehghan Manshadi, M., Mousavi, M., Soltani, M., Mosavi, A., & Kovacs, L. (2022). Deep Learning for Modeling an Offshore Hybrid Wind–Wave Energy System. *Energies*, *15*(24). https://doi.org/10.3390/en15249484

Demir, G., Riaz, M., & Deveci, M. (2024). Wind farm site selection using geographic information system and fuzzy decision-making model. *Expert Systems with Applications*, *255*(PC), 124772. https://doi.org/10.1016/j.eswa.2024.124772

Díaz, H., & Guedes Soares, C. (2020). An integrated GIS approach for site selection of floating offshore wind farms in the Atlantic continental European coastline. *Renewable and Sustainable Energy Reviews*, *134*, 110328. https://doi.org/https://doi.org/10.1016/j.rser.2020.110328

Dinçer, A. E., Demir, A., & Yılmaz, K. (2023). Enhancing wind turbine site selection through a novel wake penalty criterion. *Energy*, *283*, 129096. https://doi.org/https://doi.org/10.1016/j.energy.2023.129096

Doorga, J. R. S., Hall, J. W., & Eyre, N. (2022). Geospatial multi-criteria analysis for identifying optimum wind and solar sites in Africa: Towards effective power sector decarbonization. *Renewable and Sustainable Energy Reviews*, *158*, 112107. https://doi.org/https://doi.org/10.1016/j.rser.2022.112107

Dutta, N., Noble, B., Poelzer, G., & Hanna, K. (2021). From Project Impacts to Strategic Decisions: Recurring Issues and Concerns in Wind Energy Environmental

Assessments. *Environmental Management*, *68*(4), 591–603. https://doi.org/10.1007/s00267-021-01518-2

Dweiri, F., Kumar, S., Khan, S. A., & Jain, V. (2016). Designing an integrated AHP based decision support system for supplier selection in automotive industry. *Expert Systems with Applications*, *62*, 273–283. https://doi.org/https://doi.org/10.1016/j.eswa.2016.06.030

Dyer, J. S. (1990). Remarks on the Analytic Hierarchy Process. *Management Science*, *36*(3), 249–258. https://doi.org/10.1287/mnsc.36.3.249

Elmahmoudi, F., Abra, O. E., Raihani, A., Serrar, O., & Bahatti, L. (2019). GIS based fuzzy analytic hierarchy process for wind energy sites selection. *Proceedings - 2019 International Conference on Advanced Communication Technologies and Networking, CommNet 2019*, *Mcdm*, 1–8. https://doi.org/10.1109/COMMNET.2019.8742365

Eroğlu, H. (2021). Multi-criteria decision analysis for wind power plant location selection based on fuzzy AHP and geographic information systems. In *Environment, Development and Sustainability* (Vol. 23, Issue 12). Springer Netherlands. https://doi.org/10.1007/s10668-021-01438-5

Forman, E. H., & Gass, S. I. (2001). The Analytic Hierarchy Process—An Exposition. *Operations Research*, *49*(4), 469–486. https://doi.org/10.1287/opre.49.4.469.11231

George, S. P., & Ashok, S. (2021). Adaptive distance protection for grid-connected wind farms based on optimal quadrilateral characteristics. *Computers & Electrical Engineering*, *93*, 107300. https://doi.org/https://doi.org/10.1016/j.compeleceng.2021.107300

Ghobadi, M., & Ahmadipari, M. (2018). Environmental Planning for Wind Power Plant Site Selection using a Fuzzy PROMETHEE-Based Outranking Method in Geographical Information System. *Environmental Energy and Economic Research*, *2*(2), 75–87. https://doi.org/10.22097/eeer.2018.148760.1041

Ghorbani Pashakolaie, V., Heydari, K., & Almena, A. (2023). Monetization of policy costs and sustainability benefits associated with renewable energy in fossil fuel-rich countries (FFRCs). *Environmental and Sustainability Indicators*, *19*, 100271. https://doi.org/https://doi.org/10.1016/j.indic.2023.100271

Gu, H., Wang, J., Lin, Q., & Gong, Q. (2015). Automatic Contour-Based Road Network Design for Optimized Wind Farm Micrositing. *IEEE Transactions on Sustainable Energy*, *6*(1), 281–289. https://doi.org/10.1109/TSTE.2014.2369432

Hannan, M. A., Al-Shetwi, A. Q., Mollik, M. S., Ker, P. J., Mannan, M., Mansor, M., Al-Masri, H. M. K., & Mahlia, T. M. I. (2023). Wind Energy Conversions, Controls, and Applications: A Review for Sustainable Technologies and Directions. In *Sustainability (Switzerland)* (Vol. 15, Issue 5). MDPI. https://doi.org/10.3390/su15053986

Harker, P. T., & Vargas, L. G. (1990). Reply to "Remarks on the Analytic Hierarchy Process" by J. S. Dyer. *Management Science*, *36*(3), 269–273. https://doi.org/10.1287/mnsc.36.3.269

Hosseini Dehshiri, S. S., & Hosseini Dehshiri, S. J. (2022). Locating wind farm for power and hydrogen production based on Geographic information system and multi-criteria decision making method: An application. *International Journal of Hydrogen Energy*, *47*(58), 24569–24583. https://doi.org/10.1016/j.ijhydene.2022.03.083

Huang, X., Hayashi, K., & Fujii, M. (2023). Resources time footprint analysis of onshore wind turbines combined with GIS-based site selection: A case study in Fujian Province, China. *Energy for Sustainable Development*, *74*(March), 102–114. https://doi.org/10.1016/j.esd.2023.03.012

Ishizaka, A., & Labib, A. (2009). Analytic Hierarchy Process and Expert Choice: Benefits and limitations. *OR Insight*, *22*(4), 201–220. https://doi.org/10.1057/ori.2009.10

Ishizaka, A., & Labib, A. (2011). Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications*, *38*(11), 14336–14345. https://doi.org/https://doi.org/10.1016/j.eswa.2011.04.143

Islam, K. D., Theppaya, T., Ali, F., Waewsak, J., Suepa, T., Taweekun, J., Titseesang, T., & Techato, K. (2021). Wind energy analysis in the coastal region of bangladesh. *Energies*, *14*(18). https://doi.org/10.3390/en14185628

Islam, M. R., Islam, M. R., & Imran, H. M. (2022). Assessing Wind Farm Site Suitability in Bangladesh: A GIS-AHP Approach. *Sustainability (Switzerland)*, *14*(22). https://doi.org/10.3390/su142214819

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Systems*, *9*(3), 251–273. https://doi.org/10.1080/02693799508902036

Kahraman, C., Onar, S. C., & Oztaysi, B. (2015). Fuzzy Multicriteria Decision-Making: A Literature Review. *International Journal of Computational Intelligence Systems*, *8*(4), 637–666. https://doi.org/10.1080/18756891.2015.1046325

Kaya, T., & Kahraman, C. (2010). Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy*, *35*(6), 2517–2527. https://doi.org/https://doi.org/10.1016/j.energy.2010.02.051

Kehinde Adeyeye, N. I., & Colton, J. (2020). Exploring the environmental and economic impacts of wind energy: a cost-benefit perspective. *International Journal of Sustainable Development & World Ecology*, *27*(8), 718–731. https://doi.org/10.1080/13504509.2020.1768171

Konstantinos, I., Georgios, T., & Garyfalos, A. (2019). A Decision Support System methodology for selecting wind farm installation locations using AHP and TOPSIS: Case study in Eastern Macedonia and Thrace region, Greece. *Energy Policy*, *132*, 232–246. https://doi.org/10.1016/j.enpol.2019.05.020

Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews*, *69*, 596–609. https://doi.org/https://doi.org/10.1016/j.rser.2016.11.191

Kwiesielewicz, M., & van Uden, E. (2004). Inconsistent and contradictory judgements in pairwise comparison method in the AHP. *Computers & Operations Research*, *31*(5), 713–719. https://doi.org/https://doi.org/10.1016/S0305-0548(03)00022-4

Lehmann, P., & Tafarte, P. (2024). Exclusion zones for renewable energy deployment: One man's blessing, another man's curse. *Resource and Energy Economics*, *76*, 101419. https://doi.org/https://doi.org/10.1016/j.reseneeco.2023.101419

Leung, L. C., & Cao, D. (2000). On consistency and ranking of alternatives in fuzzy AHP. *European Journal of Operational Research*, *124*(1), 102–113. https://doi.org/https://doi.org/10.1016/S0377-2217(99)00118-6

Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y. (2022). Review and outlook on the international renewable energy development. *Energy and Built Environment*, *3*(2), 139–157. https://doi.org/https://doi.org/10.1016/j.enbenv.2020.12.002

Li, P., Xu, Z., Wei, C., Bai, Q., & Liu, J. (2022). A novel PROMETHEE method based on GRA-DEMATEL for PLTSs and its application in selecting renewable energies. *Information Sciences*, *589*, 142–161. https://doi.org/https://doi.org/10.1016/j.ins.2021.12.090

Li, Z. (2018). Study of site suitability assessment of regional wind resources development based on multi-criteria decision. *Clean Technologies and Environmental Policy*, *20*(6), 1147–1166. https://doi.org/10.1007/s10098-018-1538-y

Lima, M. A., Mendes, L. F. R., Mothé, G. A., Linhares, F. G., de Castro, M. P. P., da Silva, M. G., & Sthel, M. S. (2020). Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil. *Environmental Development*, *33*, 100504. https://doi.org/https://doi.org/10.1016/j.envdev.2020.100504

Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*, *11*(7), 1584–1595. https://doi.org/https://doi.org/10.1016/j.rser.2005.11.005

Maleki, H., & Zahir, S. (2013). A Comprehensive Literature Review of the Rank Reversal Phenomenon in the Analytic Hierarchy Process. *Journal of Multi-Criteria Decision Analysis*, *20*(3–4), 141–155. https://doi.org/https://doi.org/10.1002/mcda.1479

Marttunen, M., Lienert, J., & Belton, V. (2017). Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. *European Journal of Operational Research*, *263*(1), 1–17. https://doi.org/https://doi.org/10.1016/j.ejor.2017.04.041

Maulidia, M., Dargusch, P., Ashworth, P., & Ardiansyah, F. (2019). Rethinking renewable energy targets and electricity sector reform in Indonesia: A private sector perspective. *Renewable and Sustainable Energy Reviews*, *101*, 231–247. https://doi.org/https://doi.org/10.1016/j.rser.2018.11.005

Mendoza, J. M. F., Gallego-Schmid, A., Velenturf, A. P. M., Jensen, P. D., & Ibarra, D. (2022). Circular economy business models and technology management strategies in the wind industry: Sustainability potential, industrial challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *163*, 112523. https://doi.org/https://doi.org/10.1016/j.rser.2022.112523

Messaoudi, D., Settou, N., & Allouhi, A. (2024). Geographical, technical, economic, and environmental potential for wind to hydrogen production in Algeria: GIS-based approach. *International Journal of Hydrogen Energy*, *50*, 142–160. https://doi.org/10.1016/j.ijhydene.2023.07.263

Miller, A., & Li, R. (2014). A geospatial approach for prioritizing wind farm development in Northeast Nebraska, USA. *ISPRS International Journal of Geo-Information*, *3*(3), 968–979. https://doi.org/10.3390/ijgi3030968

Moltames, R., Naghavi, M. S., Silakhori, M., Noorollahi, Y., Yousefi, H., Hajiaghaei-Keshteli, M., & Azizimehr, B. (2022). Multi-Criteria Decision Methods for Selecting a Wind Farm Site Using a Geographic Information System (GIS). *Sustainability (Switzerland)*, *14*(22). https://doi.org/10.3390/su142214742

Moradi, S., Yousefi, H., Noorollahi, Y., & Rosso, D. (2020). Multi-criteria decision support system for wind farm site selection and sensitivity analysis: Case study of Alborz Province, Iran. *Energy Strategy Reviews*, *29*, 100478. https://doi.org/https://doi.org/10.1016/j.esr.2020.100478

Nagababu, G., Puppala, H., Pritam, K., & Kantipudi, M. P. (2022). Two-stage GIS-MCDM based algorithm to identify plausible regions at micro level to install wind farms: A case study of India. *Energy*, *248*, 123594. https://doi.org/10.1016/j.energy.2022.123594

Nair, A., Kamalasadan, S., Geis-Schroer, J., Patel, S., & Smith, M. (2022). An Investigation of Grid Stability and a New Design of Adaptive Phase-Locked Loop for Wind-Integrated Weak Power Grid. *IEEE Transactions on Industry Applications*, *58*(5), 5871–5884. https://doi.org/10.1109/TIA.2022.3182308

Noorollahi, Y., Yousefi, H., & Mohammadi, M. (2016). Multi-criteria decision support system for wind farm site selection using GIS. *Sustainable Energy Technologies and Assessments*, *13*, 38–50. https://doi.org/https://doi.org/10.1016/j.seta.2015.11.007

Peri, E., & Tal, A. (2020). A sustainable way forward for wind power: Assessing turbines' environmental impacts using a holistic GIS analysis. *Applied Energy*, *279*(September), 115829. https://doi.org/10.1016/j.apenergy.2020.115829

Pohekar, S. D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and Sustainable Energy Reviews*, *8*(4), 365–381. https://doi.org/https://doi.org/10.1016/j.rser.2003.12.007

Quiroga-Novoa, P., Cuevas-Figueroa, G., Preciado, J. L., Floors, R., Peña, A., & Probst, O. (2021). Towards better wind resource modeling in complex terrain: A k-nearest neighbors approach. *Energies*, *14*(14). https://doi.org/10.3390/en14144364

Ragheb, M. (2017). Chapter 25 - Economics of Wind Power Generation. In T. M. Letcher (Ed.), *Wind Energy Engineering* (pp. 537–555). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-809451-8.00025-4

Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. *Journal of Environmental Management*, *63*(1), 27–35. https://doi.org/https://doi.org/10.1006/jema.2001.0455

Razeghi, M., Hajinezhad, A., Naseri, A., Noorollahi, Y., & Moosavian, S. F. (2023). Multi-criteria decision for selecting a wind farm location to supply energy to reverse osmosis devices and produce freshwater using GIS in Iran. *Energy Strategy Reviews*, *45*(September 2022), 101018. https://doi.org/10.1016/j.esr.2022.101018

Rediske, G., Burin, H. P., Rigo, P. D., Rosa, C. B., Michels, L., & Siluk, J. C. M. (2021). Wind power plant site selection: A systematic review. *Renewable and Sustainable Energy Reviews*, *148*, 111293. https://doi.org/https://doi.org/10.1016/j.rser.2021.111293

Rehman, A. U., Abidi, M. H., Umer, U., & Usmani, Y. S. (2019). Multi-criteria decision-making approach for selecting wind energy power plant locations. *Sustainability (Switzerland)*, *11*(21). https://doi.org/10.3390/su11216112

Resch, B., Sagl, G., Trnros, T., Bachmaier, A., Eggers, J. B., Herkel, S., Narmsara, S., & Gündra, H. (2014). GIS-based planning and modeling for renewable energy: Challenges and future research avenues. In *ISPRS International Journal of Geo-Information* (Vol. 3, Issue 2, pp. 662–692). MDPI AG. https://doi.org/10.3390/ijgi3020662

Reutter, F., Drechsler, M., Gawel, E., & Lehmann, P. (2024). Social Costs of Setback Distances for Onshore Wind Turbines: A Model Analysis Applied to the German State of Saxony. *Environmental and Resource Economics*, *87*(2), 437–463. https://doi.org/10.1007/s10640-023-00777-3

Rodrigues, M., Montañés, C., & Fueyo, N. (2010). A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. *Environmental Impact Assessment Review*, *30*(4), 240–246. https://doi.org/https://doi.org/10.1016/j.eiar.2009.10.004

Roy, B. (1991). The outranking approach and the foundations of electre methods. *Theory and Decision*, *31*(1), 49–73. https://doi.org/10.1007/BF00134132

Roy, L., & MacPhee, D. (2018). Meso-scale CFD simulation for wind resources: A case study of complex mountainous terrain. *Energies*, *11*(6). https://doi.org/10.3390/en11061366

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. https://doi.org/https://doi.org/10.1016/0377-2217(90)90057-I

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.2008.017590

Şahin, G., Koç, A., Doğan, S. Ş., & van Sark, W. (2024). Assessment of Wind Energy Potential and Optimal Site Selection for Wind Energy Plant Installations in Igdir/Turkey. *Sustainability (Switzerland)*, *16*(20). https://doi.org/10.3390/su16208775

Sánchez-Lozano, J. M., García-Cascales, M. S., & Lamata, M. T. (2014). Identification and selection of potential sites for onshore wind farms development in Region of Murcia, Spain. *Energy*, *73*, 311–324. https://doi.org/https://doi.org/10.1016/j.energy.2014.06.024

Sánchez-Lozano, J. M., García-Cascales, M. S., & Lamata, M. T. (2016). GIS-based onshore wind farm site selection using Fuzzy Multi-Criteria Decision-Making methods. Evaluating the case of Southeastern Spain. *Applied Energy*, *171*, 86–102. https://doi.org/https://doi.org/10.1016/j.apenergy.2016.03.030

Sánchez-Lozano, J. M., Ramos-Escudero, A., Gil-García, I. C., García-Cascales, M. S., & Molina-García, A. (2022). A GIS-based offshore wind site selection model using fuzzy multi-criteria decision-making with application to the case of the Gulf of Maine. *Expert Systems with Applications*, *210*, 118371. https://doi.org/https://doi.org/10.1016/j.eswa.2022.118371

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & Socorro García-Cascales, M. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renewable and Sustainable Energy Reviews*, *24*, 544–556. https://doi.org/https://doi.org/10.1016/j.rser.2013.03.019

Sari, F., & Yalcin, M. (2024). Investigation of the importance of criteria in potential wind farm sites via machine learning algorithms. *Journal of Cleaner Production*, *435*(December 2023), 140575. https://doi.org/10.1016/j.jclepro.2024.140575

Sayed, E. T., Wilberforce, T., Elsaid, K., Rabaia, M. K. H., Abdelkareem, M. A., Chae, K.-J., & Olabi, A. G. (2021). A critical review on environmental impacts of renewable energy systems and mitigation strategies: Wind, hydro, biomass and geothermal. *Science of The Total Environment*, *766*, 144505. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.144505

Shi, Y., Guo, R., Tang, Y., Lin, Y., & Yang, Z. (2023). Integrated Transmission Network Planning by Considering Wind Power's Uncertainty and Disasters. *Energies*, *16*(14). https://doi.org/10.3390/en16145336

Shin, J., Baek, S., & Rhee, Y. (2021). Wind farm layout optimization using a metamodel and ea/pso algorithm in korea offshore. *Energies*, *14*(1). https://doi.org/10.3390/en14010146

Shorabeh, S. N., Firozjaei, H. K., Firozjaei, M. K., Jelokhani-Niaraki, M., Homaee, M., & Nematollahi, O. (2022). The site selection of wind energy power plant using GIS-multi-criteria evaluation from economic perspectives. *Renewable and Sustainable Energy Reviews*, *168*, 112778. https://doi.org/https://doi.org/10.1016/j.rser.2022.112778

Singh, J., & Alam, J. M. (2023). Large-Eddy Simulation of Utility-Scale Wind Farm Sited over Complex Terrain. *Energies*, *16*(16). https://doi.org/10.3390/en16165941

Soares da Silva, D., & Horlings, L. G. (2020). The role of local energy initiatives in co-producing sustainable places. *Sustainability Science*, *15*(2), 363–377. https://doi.org/10.1007/s11625-019-00762-0

Sotiropoulou, K. F., & Vavatsikos, A. P. (2021). Onshore wind farms GIS-Assisted suitability analysis using PROMETHEE II. *Energy Policy*, *158*(February), 112531. https://doi.org/10.1016/j.enpol.2021.112531

Suheel, S. Z., Fazlizan, A., Razali, H., Wong, K. H., Molla, A. H., Rathore, R. S., Lipu, M. S. H., & Sarker, M. R. (2024). Comprehensive Analysis of Factors Underpinning the Superior Performance of Ducted Horizontal-Axis Helical Wind Turbines. *Energies* , *17*(12). https://doi.org/10.3390/en17123029

Summerfield-Ryan, O., & Park, S. (2023). The power of wind: The global wind energy industry's successes and failures. *Ecological Economics*, *210*, 107841. https://doi.org/https://doi.org/10.1016/j.ecolecon.2023.107841

Sun, L., Jiang, Y., Guo, Q., Ji, L., Xie, Y., Qiao, Q., Huang, G., & Xiao, K. (2021). A GIS-based multi-criteria decision-making method for the potential assessment and suitable sites selection of PV and CSP plants. *Resources, Conservation and Recycling*, *168*, 105306. https://doi.org/https://doi.org/10.1016/j.resconrec.2020.105306

Taherdoost, H., & Madanchian, M. (2023). A Comprehensive Overview of the ELECTRE Method in Multi Criteria Decision-Making. *Journal of Management Science & Engineering Research*, *6*(2), 5–16. https://doi.org/10.30564/jmser.v6i2.5637

Tahri, M., Hakdaoui, M., & Maanan, M. (2015). The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco. *Renewable and Sustainable Energy Reviews*, *51*, 1354–1362. https://doi.org/https://doi.org/10.1016/j.rser.2015.07.054

Tarife, R., Nakanishi, Y., Zhou, Y., Estoperez, N., & Tahud, A. (2023). Integrated GIS and Fuzzy-AHP Framework for Suitability Analysis of Hybrid Renewable Energy

Systems: A Case in Southern Philippines. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15032372

Tercan, E. (2021). Land suitability assessment for wind farms through best-worst method and GIS in Balıkesir province of Turkey. *Sustainable Energy Technologies and Assessments*, *47*(December 2020), 101491. https://doi.org/10.1016/j.seta.2021.101491

Uyan, M. (2013). GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. *Renewable and Sustainable Energy Reviews*, *28*, 11–17. https://doi.org/https://doi.org/10.1016/j.rser.2013.07.042

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research*, *169*(1), 1–29. https://doi.org/https://doi.org/10.1016/j.ejor.2004.04.028

van Haaren, R., & Fthenakis, V. (2011). GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State. *Renewable and Sustainable Energy Reviews*, *15*(7), 3332–3340. https://doi.org/https://doi.org/10.1016/j.rser.2011.04.010

van Kooten, G. C. (2016). The Economics of Wind Power. *Annual Review of Resource Economics*, *8*(Volume 8, 2016), 181–205. https://doi.org/https://doi.org/10.1146/annurev-resource-091115-022544

Vasileiou, M., Loukogeorgaki, E., & Vagiona, D. G. (2017). GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece. *Renewable and Sustainable Energy Reviews*, *73*, 745–757. https://doi.org/https://doi.org/10.1016/j.rser.2017.01.161

Vavatsikos, A. P., Arvanitidou, A., & Petsas, D. (2019). Wind farm investments portfolio formation using GIS-based suitability analysis and simulation procedures. *Journal of Environmental Management*, *252*(March), 109670. https://doi.org/10.1016/j.jenvman.2019.109670

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/10.1016/j.renene.2017.03.041

Voivontas, D., Assimacopoulos, D., Mourelatos, A., & Corominas, J. (1998). Evaluation of Renewable Energy potential using a GIS decision support system. *Renewable Energy*, *13*(3), 333–344. https://doi.org/https://doi.org/10.1016/S0960-1481(98)00006-8

Vuichard, P., Broughel, A., Wüstenhagen, R., Tabi, A., & Knauf, J. (2022). Keep it local and bird-friendly: Exploring the social acceptance of wind energy in Switzerland, Estonia, and Ukraine. *Energy Research & Social Science*, *88*, 102508. https://doi.org/https://doi.org/10.1016/j.erss.2022.102508

Wang, Y. (2023). The Most Promising New Energy Source-Wind Power. In *Highlights in Science, Engineering and Technology EENCT* (Vol. 2022).

Wang, Y., Wang, D., Yu, L., & Mao, J. (2023). What really influences the development of renewable energy? A systematic review and meta-analysis. *Environmental Science and Pollution Research*, *30*(22), 62213–62236. https://doi.org/10.1007/s11356-023-26286-w

Wu, Y., He, F., Zhou, J., Wu, C., Liu, F., Tao, Y., & Xu, C. (2021). Optimal site selection for distributed wind power coupled hydrogen storage project using a geographical information system based multi-criteria decision-making approach: A case in China. *Journal of Cleaner Production*, *299*, 126905. https://doi.org/10.1016/j.jclepro.2021.126905

Xie, S., & Zhang, J. (2023). TOPSIS-based comprehensive measure of variable importance in predictive modelling. *Expert Systems with Applications*, *232*, 120682. https://doi.org/https://doi.org/10.1016/j.eswa.2023.120682

Xu, Y., Li, Y., Zheng, L., Cui, L., Li, S., Li, W., & Cai, Y. (2020). Site selection of wind farms using GIS and multi-criteria decision-making method in Wafangdian, China. *Energy*, *207*. https://doi.org/10.1016/j.energy.2020.118222

Yaman, A. (2024). A GIS-based multi-criteria decision-making approach (GIS-MCDM) for determination of the most appropriate site selection of onshore wind farm in Adana, Turkey. *Clean Technologies and Environmental Policy*, *26*(12), 4231–4254. https://doi.org/10.1007/s10098-024-02866-3

Yildiz, S. S. (2024). Spatial multi-criteria decision-making approach for wind farm site selection: A case study in Balıkesir, Turkey. *Renewable and Sustainable Energy Reviews*, *192*. https://doi.org/10.1016/j.rser.2023.114158

Yousefi, H., Moradi, S., Zahedi, R., & Ranjbar, Z. (2024). Developed analytic hierarchy process and multi criteria decision support system for wind farm site selection using GIS: A regional-scale application with environmental responsibility. *Energy Conversion and Management: X*, *22*(February), 100594. https://doi.org/10.1016/j.ecmx.2024.100594

Zahedi, R., Ghorbani, M., Daneshgar, S., Gitifar, S., & Qezelbigloo, S. (2022). Potential measurement of Iran's western regional wind energy using GIS. *Journal of Cleaner Production*, *330*(July 2021), 129883. https://doi.org/10.1016/j.jclepro.2021.129883

Zambrano-Asanza, S., Quiros-Tortos, J., & Franco, J. F. (2021). Optimal site selection for photovoltaic power plants using a GIS-based multi-criteria decision making and spatial overlay with electric load. *Renewable and Sustainable Energy Reviews*, *143*, 110853. https://doi.org/https://doi.org/10.1016/j.rser.2021.110853

Zhang, J., Cheng, C., & Yu, S. (2024). Recognizing the mapping relationship between wind power output and meteorological information at a province level by coupling GIS and

CNN technologies. *Applied Energy*, *360*(February), 122791. https://doi.org/10.1016/j.apenergy.2024.122791