Python-Based Renewable Energy Resource Analyser (RERA): A Multi-Criteria Decision Support Tool for Renewable Energy Site Suitability in Namibia

Jeffrey N.S. SHIGWEDHA, Namibia and Oluibukun AJAYI, Namibia

Keywords: Renewable Energy, Site Suitability, Analytic Hierarchy Process, Spatial Decision Support, Namibia

Summary: Namibia faces a persistent energy deficit, with only about 56% of the population having access to electricity, and nearly 60% of the country's national demand is met through imports. To support evidence-based renewable energy planning, this study developed the Renewable Energy Resource Analyser (RERA), a Python-based, cross-platform GIS tool for analysing renewable energy site suitability. RERA integrates multiple spatial datasets and applies the Analytic Hierarchy Process (AHP) to evaluate and rank suitable locations for solar, wind, and green hydrogen developments.

The system was developed using Python 3.12 and key geospatial libraries, including Tkinter, Rasterio, GeoPandas, and NumPy, and incorporates geospatial datasets such as road networks, wind speeds, terrain, and existing electrical infrastructure datasets. RERA consists of two core modules: a Data Viewer for interactive visualisation of vector and raster data, and an AHP Suitability Module that enables pairwise comparison of spatial criteria, applies spatial decay to proximity-based datasets, and generates normalised suitability heatmaps.

The results demonstrate that combining AHP with spatial standardization techniques provides a transparent and reproducible framework for site selection. Operating fully offline, RERA is well suited to data-constrained environments and offers a scalable, open-source decision-support platform for renewable energy planning in Namibia and similar contexts.

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1. Introduction

Namibia faces a dual challenge of limited domestic electricity supply and persistent gaps in access for its population. The country's population is approximately three million, yet only 57 percent of residents have reliable access to electricity (Namibia Statistics Agency, 2024; Tracking SDG7, 2023). The current supply relies on a small set of large generation facilities and imports, a pattern that constrains long-term energy security and raises fiscal pressures on the national utility.

The national generation portfolio includes a 240 megawatt hydroelectric plant at Ruacana, a 120 megawatt coal-fired plant at van Eck, a 24 megawatt heavy fuel oil plant operated by Paratus at Walvis Bay with an additional unit anticipated in recent years, and a 5.78 megawatt solar installation at Trekkopje in the Erongo region (Energypedia, 2018). Namibia's annual consumption is roughly 3000 gigawatt hours, while domestic generation has historically ranged between about 1300 and 1700 gigawatt hours per year since 2000. The resulting shortfall has required substantial electricity imports, principally from neighbouring South Africa. These imports carry a high cost, for example, Nampower reportedly spent around N$3.4 billion on imports in 2021, covering roughly 60 per cent of the country's needs in that year (Heita, 2022).

These conditions create an imperative to expand local generation capacity and to direct investment where technical, environmental and socio-economic factors align. Renewable technologies offer an avenue for increasing generation near demand centres and for extending electrification to underserved regions. National policy initiatives, such as the National Integrated Resource Plan and elements of the Harambee Prosperity Plan II, signal the government's intent to prioritise generation capacity expansion and encourage renewable energy development (Ministry of Industries, Mines and Energy, 2022; Republic of Namibia, 2023). Project proposals and discussions in regional fora further indicate growing interest in renewable projects at the time of this study (Lazarus, 2025).

Effective deployment of renewable generation requires decision support tools that combine geospatial data, stakeholder preferences, technical constraints and policy criteria into systematic site selection workflows. Such tools help planners and investors evaluate trade-offs among land suitability, resource availability, environmental protection, grid proximity and socio-economic impacts. The Python-based Renewable Energy Resource Analyser, hereafter RERA, is developed as a multi-criteria decision support tool to address this need. RERA integrates spatial data visualization with a transparent weighting framework, enabling reproducible ranking of candidate sites for renewable energy projects in the Namibian context.

This paper describes the design, implementation, and evaluation of RERA. The tool is implemented in Python and couples geographic information system methods with the Analytic Hierarchy Process for weighting criteria and scoring sites. The contribution of this work is threefold. First, the tool provides an accessible platform for visualising national and regional energy-related datasets, allowing technical staff and non-specialists to better understand the distribution of resources and constraints. Second, the integration of a formal multi-criteria method produces repeatable site suitability outcomes that reflect user-defined priorities and expert judgement. Third, the study demonstrates the application of this combined approach in Namibia, including examples that illustrate how the choices of criteria and weights alter the final suitability rankings.

1.1 Objectives

The study was designed to produce a practical software prototype and to demonstrate its applicability to national energy planning. Specific objectives are as follows.

1. Develop a Python-based application that presents geospatial data on energy resources, infrastructure and constraints, and that supports interactive visual exploration of these datasets.
2. Implement a reproducible multi-criteria decision-making workflow that uses the Analytic Hierarchy Process to derive weights for site selection criteria, and that applies those weights to produce ranked suitability maps for renewable energy siting.
3. Evaluate the tool using case studies in Namibia, and assess how alternative weightings or data layers influence recommended sites and the implications for policy and investment decisions.

The Analytic Hierarchy Process provides a structured mechanism for eliciting relative importance across multiple criteria and for combining expert judgements with measured indicators (Saaty, 1980). In this study, the method is applied to reconcile conflicting objectives such as resource potential, environmental protection and proximity to transmission infrastructure, and to produce a transparent record of the assumptions that underlie suitability results. The subsequent sections present related work, describe the data and methods, detail the RERA implementation, and discuss results and implications for renewable energy planning in Namibia.

2. Materials and Methods

The development of the Renewable Energy Resource Analyser (RERA) utilizes a Geographic Information Systems Multi-Criteria Decision Analysis (GIS-MCDA) framework. This methodology is designed to transform heterogeneous spatial data into a unified decision-making index (Malczewski, 1999).

2.1 System Architecture

The development of RERA comprises several system components, including programming languages, software, and datasets as discussed below:

- **HTML (HyperText Markup Language):** A standard language used to create the structure of web pages. It defines elements like headings, paragraphs, links, images, and other content.

RERA was developed using Python 3.12. The application utilizes several specialized libraries for GIS and data processing:

- **Tkinter**: For the Graphical User Interface (GUI).
- **GeoPandas & Rasterio**: For handling vector and raster data.
- **Numpy & Scipy**: For mathematical calculations and matrix operations.
- **TkinterMapView**: For rendering OpenStreetMap base layers.
- **GeoServer**: An open-source server written in Java that allows users to share, process, and edit geospatial data, which according to Its website supports various data formats and publishes data using open standards, making it highly interoperable (The Open Source Geospatial Foundation, n.d.).

The architecture is divided into three functional tiers: the Data Layer, the Logic Layer, and the Presentation Layer.

Data Layer/Backend: To manage heavy spatial computations, the system utilizes GeoPandas for vector processing and Rasterio for raster manipulation. A significant architectural hurdle was the high memory overhead of high-resolution GeoTIFF files. To solve this, GeoServer was implemented as an intermediary, serving data via Web Map Service (WMS) protocols to maintain application performance.

Logic Layer (Analytical Engine): The mathematical backbone uses NumPy for high-speed matrix operations required by the Analytic Hierarchy Process (AHP) and SciPy for calculating spatial decay constants.

Presentation Layer/Frontend: The interface was constructed using Tkinter, integrated with TkinterMapView. This allows for a dynamic, interactive environment where users can toggle layers, adjust opacity, and view metadata in real-time.

2.2 Data Acquisition

Ten datasets were strategically chosen to represent the multi-faceted nature of renewable energy siting in Namibia. Table 1 presents the datasets utilized in this study along with the primary justifications for the selection of each of these datasets

Dataset Name	Description/Attributes	Primary Justifications
NamRoads.geojson	Roads Found in Namibia Format: .geojson Source of Dataset: Digital Namibia (https://digitalnamibia.nsa.org.na/) CRS: EPSG:4326 - WGS 84	Included to account for logistical feasibility; heavy equipment for wind turbines and solar panels requires reliable road access for construction and long-term maintenance.
Powerlines.geojson	Power Lines in Namibia Format: .geojson Source of Dataset: Digital Namibia (https://digitalnamibia.nsa.org.na/) CRS: EPSG:4326 - WGS 84	These layers from Digital Namibia allow the model to prioritize sites near the existing national grid, reducing the "evacuation" cost of getting power from the plant to the consumer.
Substations.geojson	Existing Power Substations in Namibia Format: .geojson Source of Dataset: Digital Namibia (https://digitalnamibia.nsa.org.na/) CRS: EPSG:4326 - WGS 84	
R.E. Sources.geojson	Existing Renewable Energy Resources in Namibia Format: .geojson Source of Dataset: Digital Namibia	This dataset provides a "ground truth" for the model. By comparing existing solar or wind farms to the generated suitability heatmaps, you can validate that the RERA tool correctly identifies high-potential areas.

	(https://digitalnamibia.nsa.org.na/) CRS: EPSG:4326 - WGS 84	
DNI.tif	Direct Normal Irradiation Levels in Namibia Format: .tif Source of Dataset: Global Solar Atlas (https://globalsolaratlas.info/map?c=-22.93816,17.072754,6) CRS: EPSG:4326 - WGS 84	Selected from the Global Solar Atlas because Namibia has some of the highest solar radiation levels globally; this layer identifies areas with the highest potential for solar thermal and PV power.
NamDEM.tif	A Digital Elevation Model depicting the terrain of Namibia Format: .tif Source of Dataset: Google Earth Engine CRS: EPSG:4326 - WGS 84	Sourced from Google Earth Engine to analyze terrain and slope. Steep slopes significantly increase construction costs and can cause shadowing for solar arrays.
NAM_wind-speed_100m.tif	Wind Speeds at 100 metres above Sea Level Format:.tif Source of Dataset: Global Wind Atlas (https://globalwindatlas.info/en/) CRS: EPSG:4326 - WGS 84	Sourced from the Global Wind Atlas to identify high-velocity wind corridors, particularly along the coast, which are essential for wind turbine efficiency.
Perennial Catchment Areas.geojson	Perennial Catchment Areas found in Namibia Format: .geojson Source of Dataset: Atlas of Namibia	These layers serve a dual purpose: identifying water sources for Green Hydrogen production and acting as environmental "exclusion zones" where building might be

	(https://www.uni-koeln.de/sfb389/e/e1/download/atlas_namibia/e1_download_physical_geography_e.htm#rivers1) CRS: EPSG:4326 - WGS 84	restricted due to flood risks or ecological protection.
Major Rivers.geojson	Major Rivers found in Namibia Format: .geojson Source of Dataset: Atlas of Namibia (https://www.uni-koeln.de/sfb389/e/e1/download/atlas_namibia/e1_download_physical_geography_e.htm#rivers1) CRS: EPSG:4326 - WGS 84	
Land Tenure.geojson	The different types of land uses in Namibia Format: .geojson Source of Dataset: Digital Namibia (https://digitalnamibia.nsa.org.na/) CRS: EPSG:4326 - WGS 84	This dataset from Digital Namibia is critical for identifying land ownership types (e.g., communal, commercial, or protected areas). It helps planners avoid protected national parks or identify land where acquisition is more straightforward.

Table 1: Table of Datasets

2.3 Spatial Data Pre-processing and Standardization

Because the aforementioned datasets exist in disparate units (e.g., kWh/m^2 for solar potential versus meters for distance), Criterion Standardization was necessary to transform all values into a dimensionless scale from 0 (unsuitable) to 1 (highly suitable). For proximity-based data (such as distance to roads or power lines), the system uses Spatial Decay modeling (Hansen, 1959) to determine how suitability changes as one moves further away from a feature. The RERA tool offers three distinct logic models for this transformation:

1. **Linear Decay:** This model assumes suitability decreases at a constant rate and is used for features where influence is directly proportional to distance.
2. **Squared (Power) Decay:** This represents an aggressive drop-off, ideal for infrastructure (e.g., power lines) where immediate proximity is significantly more valuable than distal locations.
3. **Exponential Decay:** This models a rapid initial decay that tapers off, often used for environmental impacts or complex diminishing returns.

2.4 Analytic Hierarchy Process (AHP) Framework

The AHP framework reduces human bias by requiring users to perform Pairwise Comparisons. Instead of weighing all factors at once, the user compares only two criteria at a time using a scale of 1 (equal importance) to 9 (extreme importance). The system processes these comparisons through a structured workflow:

1. **Comparison Synthesis:** The tool organizes every individual comparison into a reciprocal grid to determine the relative standing of each factor.
2. **Weight Derivation:** The system calculates a final "weight" or percentage of importance for each criterion, ensuring they all sum to 100%, by analyzing the relationships between all factors.
3. **Reliability Check:** To ensure the user's choices are logical and not contradictory (e.g., if A is better than B, and B is better than C, then C cannot be better than A), the system calculates a Consistency Ratio (CR). A ratio below 0.1 confirms that the decision-making process is mathematically sound and reliable for the final analysis

2.5 Weighted Multi-Criteria Overlay

The final stage of the analysis is the Weighted Linear Combination (WLC), which synthesizes all the standardized data layers into a single result. In this process, the system stacks every individual map layer, applying the specific weights calculated during the AHP phase to each pixel. The final output is a Suitability Heatmap, where values approaching 1.0 represent "Perfect Sites" that satisfy all technical, economic, and environmental requirements. This visual synthesis allows energy planners to instantly identify high-potential zones while seeing the direct trade-offs between natural resource availability and infrastructural constraints.

3. Results and Model Application

The model application has two distinct sections: the RERA Data Viewer and the AHP Suitability Module:

3.1 RERA Data Viewer

This is a module of the application that allows users to load, visualise and inspect various geospatial datasets and consist of the following parts:

- **Map Interface:** The map interface allows users to pan, zoom while raster data is displayed on a basemap loaded from OpenStreetMap.
- **Layer Controls and Sidebar:** A sidebar displays available data layers with checkboxes for users to toggle through each layer, while also allowing users to change the opacity of a layer. The application loads all datasets found in the /data folder and displays them in an interactive GUI.
-

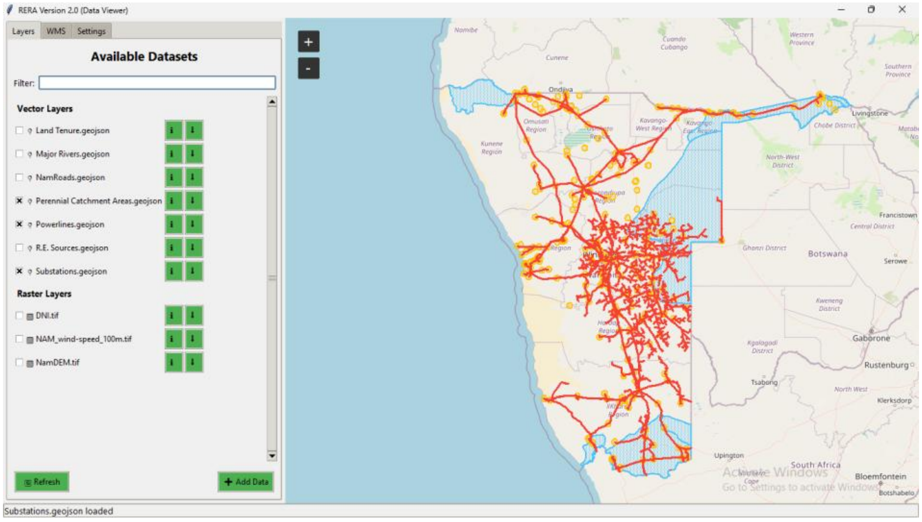


Figure 1: Vector dataset viewing section in the RERA app.

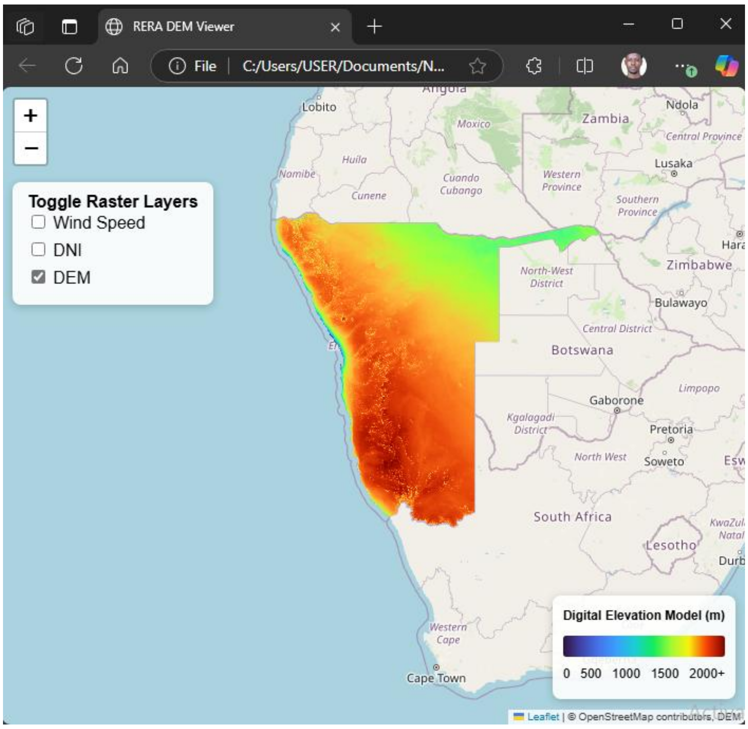


Figure 2: Raster dataset viewing section on webpage.

- **Spatial Data Clearinghouse:** Users can preview their desired layers and have an option to view each dataset's metadata. Users can then download individual datasets from the sidebar.

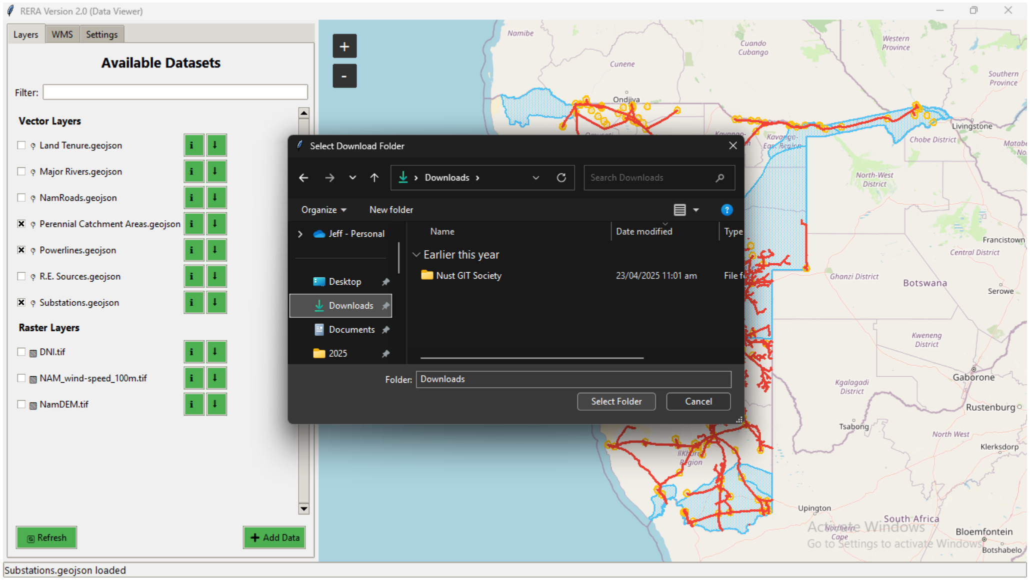


Figure 3: Popup window where end users select where the downloaded dataset should be stored.

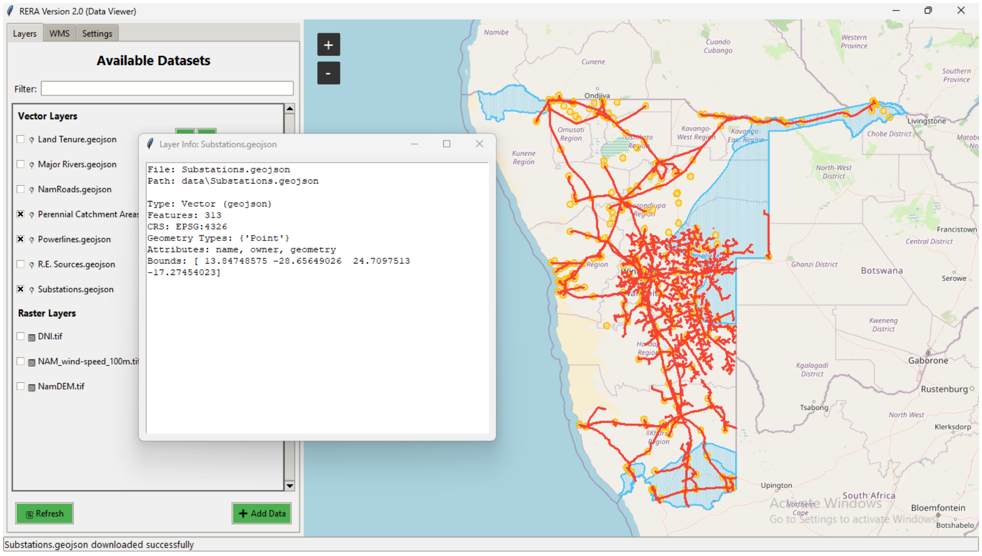


Figure 4: Metadata about Renewable Energy Resource Datasets.

3.2 AHP Suitability Module

The Suitability Module is the session of RERA that allows users to implement the AHP to support weighted decision-making across multiple datasets that generate normalized raster outputs (heatmaps) that highlight the most suitable areas for renewable energy projects. It consists of the following sections.

- **Dataset Loader:** Allows users to upload desired datasets for spatial analysis. In the dataset loader: Vector datasets like roads, rivers, and powerlines are turned into raster layers using a method called spatial decay. This helps show how important it is to be close to those features.

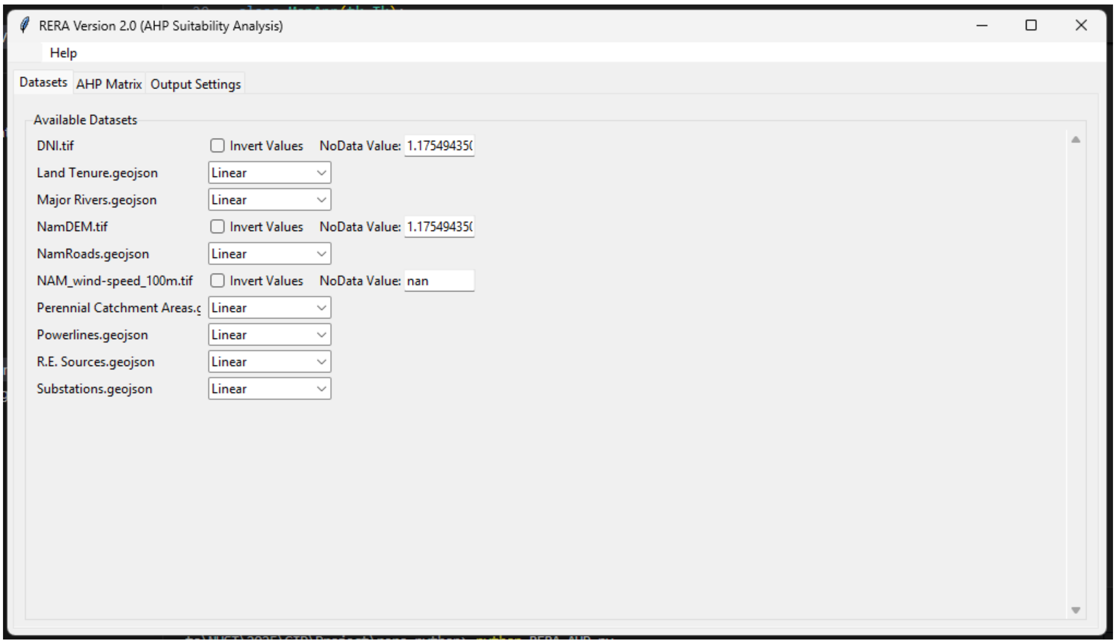


Figure 5: Dataset Loader for AHP section of RERA.

- **AHP Matrix:** Allows users to allocate important values within a pairwise matrix. Outlined in red are the functionalities that allow users to load or clear importance value presets (whether solar, wind or green hydrogen farms) within the pairwise matrix.

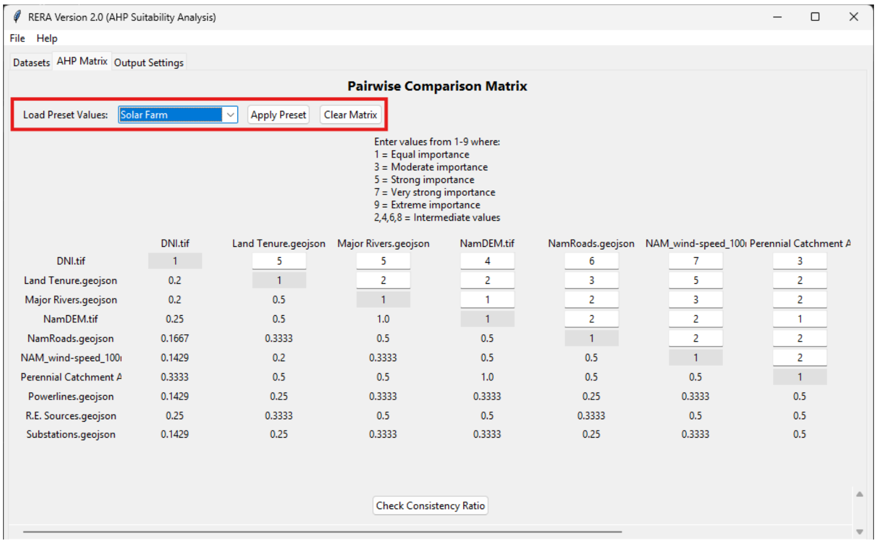


Figure 6: RERA AHP Pairwise Matrix.

	DNI	LAND TENURE	MAJOR RIVERS	DEM	ROADS	WIND SPEED	CATCHMENT AREA	POWERLINES	R.E. SOURCES	SUBSTATIONS
DNI	1	5	5	4	6	7	3	7	4	7
LAND TENURE	0.2	1	2	2	3	5	2	4	3	4
MAJOR RIVERS	0.2	0.5	1	1	2	3	2	3	2	3
DEM	0.25	0.5	1	1	2	2	1	3	2	3
ROADS	0.166667	0.333333	0.5	0.5	1	2	2	4	3	4
WIND SPEED	0.142857	0.2	0.333333	0.5	0.5	1	2	3	2	3
CATCHMENT AREAS	0.333333	0.5	0.5	1	0.5	0.5	1	2	2	2
POWERLINES	0.142857	0.25	0.333333	0.333333	0.25	0.333333	0.5	1	2	3
R.E. SOURCES	0.25	0.333333	0.5	0.5	0.333333	0.5	0.5	0.5	1	2
SUBSTATIONS	0.142857	0.25	0.333333	0.333333	0.25	0.333333	0.5	0.333333	0.5	1

Table 2: Table of Pairwise Values for Determining Solar Farms

- **Output Hub**: Allows users to determine where their suitability output will be stored. Outlined in red are the functionalities that allow users to export the importance values, weights and dataset settings into a CSV file.

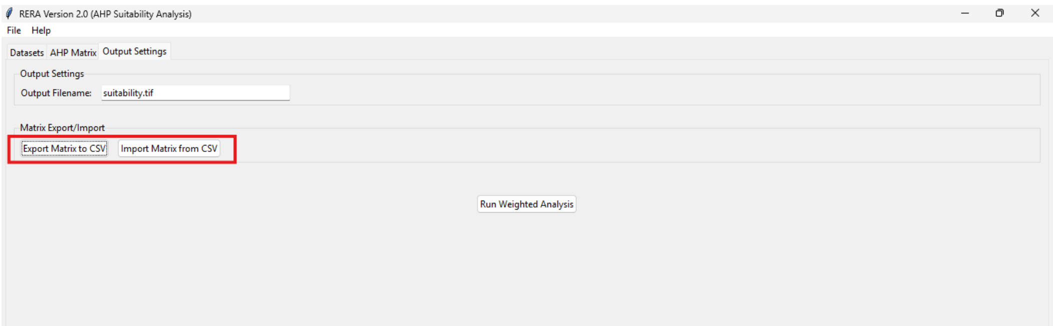
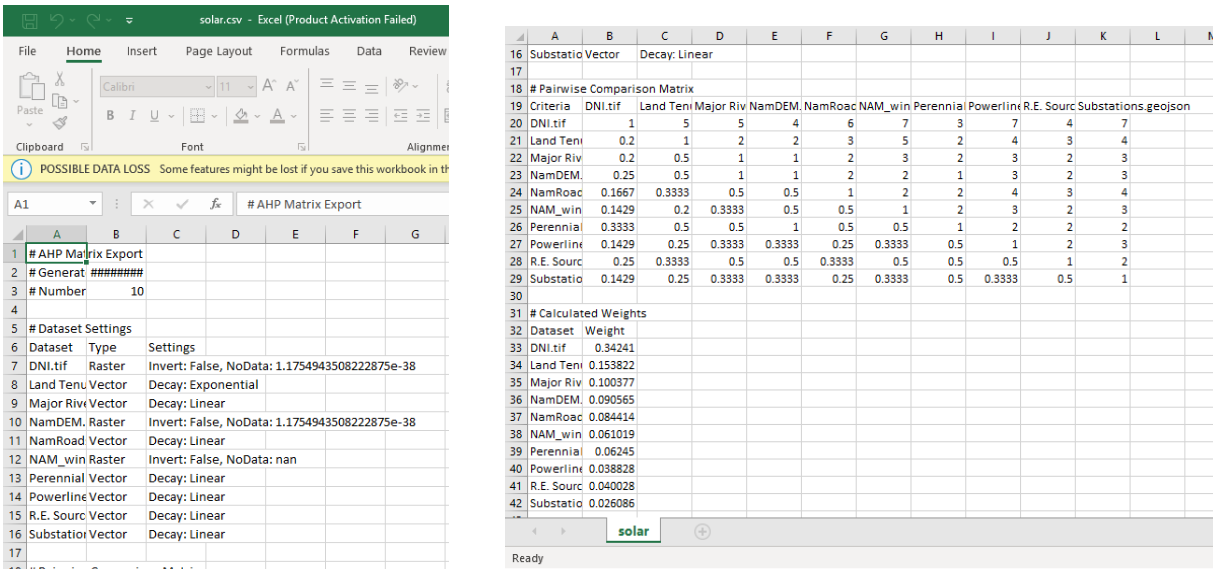


Figure 7: Output Hub for Exporting Dataset



	A	B	C
1	# AHP Matrix Export		
2	# Generat	########	
3	# Number	10	
4			
5	# Dataset Settings		
6	Dataset	Type	Settings
7	DNI.tif	Raster	Invert: False, NoData: 1.1754943508222875e-38
8	Land Tenu	Vector	Decay: Exponential
9	Major Rive	Vector	Decay: Linear
10	NamDEM.	Raster	Invert: False, NoData: 1.1754943508222875e-38
11	NamRoad	Vector	Decay: Linear
12	NAM_win	Raster	Invert: False, NoData: nan
13	Perennial	Vector	Decay: Linear
14	Powerline	Vector	Decay: Linear
15	R.E. Sourc	Vector	Decay: Linear
16	Substation	Vector	Decay: Linear

	A	B	C	D	E	F	G	H	I	J	K
18	# Pairwise Comparison Matrix										
19	Criteria	DNI.tif	Land Ten	Major Riv	NamDEM.	NamRoad	NAM_win	Perennial	Powerline	R.E. Sourc	Substations.geojson
20	DNI.tif	1	5	5	4	6	7	3	7	4	7
21	Land Ten	0.2	1	2	2	3	5	2	4	3	4
22	Major Riv	0.2	0.5	1	1	2	3	2	3	2	3
23	NamDEM.	0.25	0.5	1	1	2	2	1	3	2	3
24	NamRoad	0.1667	0.3333	0.5	0.5	1	2	2	4	3	4
25	NAM_win	0.1429	0.2	0.3333	0.5	0.5	1	2	3	2	3
26	Perennial	0.3333	0.5	0.5	1	0.5	0.5	1	2	2	2
27	Powerline	0.1429	0.25	0.3333	0.3333	0.25	0.3333	0.5	1	2	3
28	R.E. Sourc	0.25	0.3333	0.5	0.5	0.3333	0.5	0.5	0.5	1	2
29	Substatio	0.1429	0.25	0.3333	0.3333	0.25	0.3333	0.5	0.3333	0.5	1

	A	B
31	# Calculated Weights	
32	Dataset	Weight
33	DNI.tif	0.34241
34	Land Ten	0.153822
35	Major Riv	0.100377
36	NamDEM.	0.090565
37	NamRoad	0.084414
38	NAM_win	0.061019
39	Perennial	0.06245
40	Powerline	0.038828
41	R.E. Sourc	0.040028
42	Substatio	0.026086

Figure 8: Exported CSV file containing Solar Farm AHP Information

It should be noted that the pairwise comparison values used in the AHP matrix in Figure 6 & Table 2 above for implementing solar farms (as well as the other two presets for wind & green hydrogen farms) were assigned arbitrarily for the purpose of developing and testing the prototype application's functionality. These values were not derived from expert consultation but were instead selected to simulate realistic relative importance relationships between criteria and to validate the end-to-end implementation of the AHP workflow. As such, the resulting weights and suitability outputs should be interpreted strictly as demonstrative rather than prescriptive. In a production or decision-support context, these values would need to be refined through structured expert judgment, policy guidelines, or sensitivity analysis to ensure decision validity and reliability.

Despite the solar farm preset achieving a consistency ratio (CR < 0.1) within the AHP framework of about 6.3% (or 0.063, with the Direct Normal Irradiation taking the highest priority of the datasets with a percentage of 34.2 %, while existing substations/infrastructure taking the lowest priority of the datasets with a percentage of 2.6 %), the resulting suitability heatmaps revealed unforeseen challenges in the final raster synthesis.

In several test scenarios, the resulting suitability raster did not exhibit the expected emergence of distinct suitability hotspots. Instead, the final heatmap reflected a visual stacking of input criteria, whereby multiple datasets appeared to be additively overlaid rather than integrated into clearly differentiated high-suitability zones for wind, solar, or green hydrogen development. This behaviour is attributed to the prototype nature of the RERA model, where uniform normalisation, linear weighting, and limited spatial contrast between criteria can lead to cumulative visual dominance of overlapping layers, even when acceptable consistency ratios like previously stated are achieved within the AHP framework.

As RERA is in its current iteration, this discrepancy is viewed as a necessary developmental benchmark rather than a failure of the underlying model. This prototype serves as a foundational proof-of-concept, and future iterations will focus on refining the normalization algorithms and exploring more sophisticated, non-linear aggregation methods to achieve a more balanced and nuanced spatial output that better reflects the complexity of the Namibian landscape.

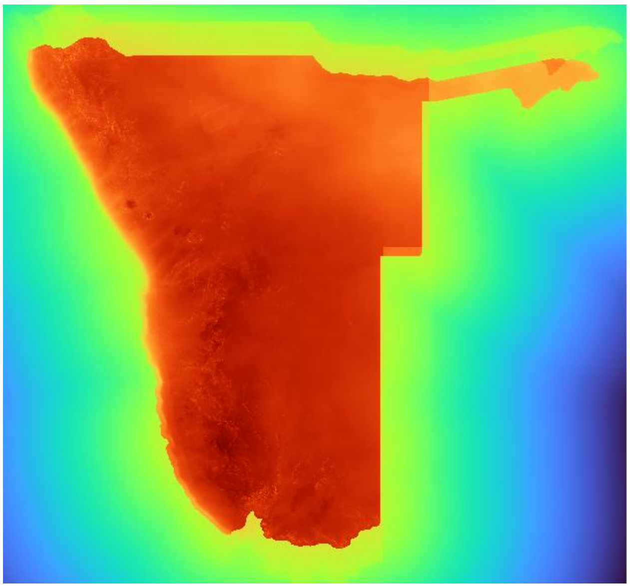


Figure 10: Final solar farm suitability map

Conclusion

This study presents the design and implementation of the Renewable Energy Resource Analyser (RERA), a Python-based spatial decision-support system developed to address Namibia's growing need for evidence-based renewable energy planning. The application successfully demonstrates how heterogeneous spatial datasets can be transformed into a unified, transparent, and reproducible framework for site suitability assessments of solar, wind, and green hydrogen energy developments.

The results confirm that multi-criteria decision analysis, when combined with spatial normalization and decay-based proximity modelling, provides a powerful mechanism for balancing technical, environmental, and infrastructural constraints. The generated suitability heatmap is meant to illustrate how priority regions emerge through the weighted interaction of key criteria such as resource availability, land tenure, terrain, infrastructure proximity, and environmental considerations. Importantly, the modular design of RERA allows users to interrogate each stage of the analytical workflow, thereby enhancing transparency and interpretability critical requirements for planning and policy-oriented applications.

While the AHP pairwise comparison values used in this prototype were intentionally arbitrary and designed solely for functional validation, the system architecture is robust enough to support expert-driven weighting, sensitivity analysis, and policy-aligned decision frameworks in future deployments. As such, RERA should be viewed not as a prescriptive planning solution, but as a flexible analytical platform capable of supporting informed decision-making when coupled with domain expertise and stakeholder input.

In conclusion, RERA demonstrates the practical feasibility of deploying open-source geospatial technologies and multi-criteria decision methodologies to support renewable energy planning in data-constrained environments. The tool provides a solid foundation for further enhancement, including expert calibration, large-scale deployment, and integration with national energy planning systems. Beyond Namibia, the framework offers a transferable blueprint for other regions seeking transparent, adaptable, and locally relevant renewable energy site selection tools.

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Biographical Notes

Jeffrey Shigwedha is a Geographic Information Technology Honors student at the Namibia University of Science and Technology (NUST).

His practical experience includes a GIS internship at the Ministry of Industry, Mines and Energy in Namibia, where he worked as a web-map application developer and data assistant. A role that provided him with end-to-end exposure to geospatial database management, cartographic styling and web service publication. He has further strengthened his data management skills through his current internship at the Namibia Statistics Agency, contributing to the National Housing Information System by supporting large-scale data digitisation, quality control, and GIS-supported information management.

Alongside his technical work, Jeffrey has demonstrated leadership and professional engagement. He serves as Project Coordinator for the NUST Geoinformation Technology Society, where he is responsible for project planning, logistics coordination, and liaison with external partners.

In terms of scholarly activity, Jeffrey has submitted an abstract to the FIG Working Week titled “Python-Based Renewable Energy Resource Analyser (RERA): A Multi-Criteria Decision Support Tool for Renewable Energy Site Suitability in Namibia.” This work highlights his interest in integrating GIS, programming, and multi-criteria analysis to address national development challenges in renewable energy planning.

Contact Information

Jeffrey N.S. Shigwedha

Organization: Department of Land and Spatial Sciences, Namibia University of Science and Technology (NUST), Namibia

Address: PO Box 98621, Pelican Square, Tauben Glen, Windhoek

City: Windhoek
Country: Namibia

Tel: +264 81 748 4728

Email: jsnshigwedha@gmail.com

Prof. Oluibukun Ajayi

Organization: Department of Land and Spatial Sciences, Namibia University of Science and Technology (NUST), Namibia
City: Windhoek
Country: Namibia

Tel: +264 61 207 2961
Email: oajayi@nust.na