

Assessment of Small Hydropower Potential Using QGIS, SAGA, and SWAT: A Case Study of the Lijia River Basin

Yu-Feng Chung^{1*}, Chih-Hsun Hsueh²

¹National Taitung University, Department of green energy and information technology

²National Chung Hsing University, Department of Electrical Engineering

Abstract. This study integrates GIS, SAGA, and the SWAT+ model to establish a systematic framework for assessing small hydropower potential in mountainous rivers of Taiwan. Using DEM, soil, land-use, and meteorological data, the Lijia River Basin was delineated into 17 sub-watersheds. Slope and head were calculated with QGIS and SAGA, while SWAT+ simulated daily streamflow for 2024. The results show that Sub-watershed 5, characterized by steep slopes and stable flows, is suitable for turbines such as Francis, Pelton, and Cross-Flow. Turbine-site matching demonstrated how hydrological and topographic attributes can be effectively integrated to identify potential sites. Although demonstrated in a single basin, the framework is scalable and applicable to other rivers with similar characteristics. Overall, the proposed approach provides a cost-effective, replicable, and practical method for supporting decentralized small hydropower development in remote areas.

1 Introduction

The rapid growth of global energy demand and the escalating challenges of climate change have positioned renewable energy development as a central objective in energy transition strategies worldwide. Among various options, small hydropower has gained attention due to its low environmental impact, flexibility for decentralized deployment, and operational stability. According to the International Renewable Energy Agency (IRENA), hydropower accounted for about 44% of global renewable installed capacity in 2021, underscoring its significance in the global energy mix. However, with large-scale hydropower development reaching saturation and creating considerable ecological and social concerns, small hydropower is increasingly recognized as a sustainable alternative [1,2].

Recent advances in Geographic Information System (GIS) technologies and hydrological modelling have enabled more systematic approaches to evaluating small hydropower potential. QGIS, together with its SAGA module, allows for efficient watershed delineation, slope analysis, and head estimation, providing useful tools for preliminary site screening. Nevertheless, reliance solely on topographic analysis may neglect temporal variability in

* Corresponding author: cyf1973@nttu.edu.tw

river discharge, limiting the accuracy of power potential assessments. Hydrological conditions must therefore be integrated into the evaluation to ensure more reliable results.

To address this gap, this study integrates GIS, SAGA, and the SWAT+ (Soil and Water Assessment Tool) model into a comprehensive framework for assessing small hydropower potential. The framework is applied to the Lijia River Basin in Taitung, Taiwan, where watershed delineation, head calculation, streamflow simulation, and turbine selection are carried out. The findings aim to establish a scientific basis for small hydropower site selection and to support decentralized and sustainable energy development in Taiwan's rural regions.

2 Materials and Methods

2.1 Overview of GIS, SAGA, and SWAT

QGIS (Quantum Geographic Information System) is a free and open-source platform designed for the editing, analysis, and visualization of geospatial data. It supports a wide range of data formats and enables integration with various databases and web mapping services, making it suitable for spatial data processing, cartographic applications, and geographic analysis. In this study, QGIS was primarily utilized for terrain and spatial analyses, data integration, and map production to support the assessment of small hydropower potential.

SAGA GIS (System for Automated Geoscientific Analyses) is a free and open-source GIS software specialized in geospatial analysis and terrain processing. Its modular architecture allows analytical tasks to be performed through both scripting languages (e.g., Python, C++) and a graphical user interface (GUI). Moreover, SAGA can be integrated with other GIS platforms and libraries, including GRASS GIS and GDAL, thereby enhancing its versatility for geoscientific and hydrological applications.

SWAT (Soil and Water Assessment Tool) is a hydrological model developed by the United States Department of Agriculture to simulate watershed-scale hydrological processes, including precipitation, surface runoff, groundwater recharge, and streamflow [3,4]. In recent years, SWAT has been increasingly applied in research, particularly in combination with GIS, to evaluate water resource availability and assess the potential of small hydropower development. Its capability to simulate temporal variability in hydrological conditions makes it especially valuable for selecting suitable hydropower sites.

2.2 Research Framework and Design

This study aims to establish a systematic framework for assessing small hydropower potential. The overall structure, illustrated in Figure 1, consists of four main steps.

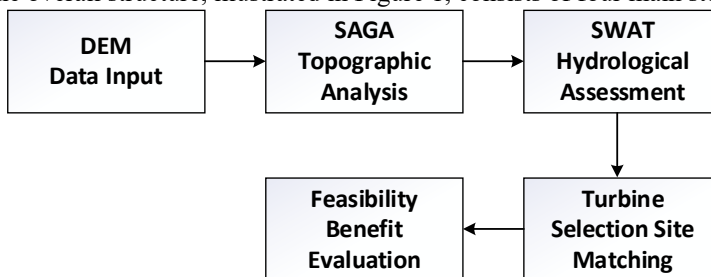


Fig. 1. The proposed research framework.

First, baseline data were collected and pre-processed, including the digital elevation model (DEM), land use, soil, and meteorological data. These datasets were standardized in

terms of projection coordinates, and sink filling was performed to ensure the accuracy of subsequent analyses.

Second, terrain and hydrological analyses were conducted using QGIS and SAGA. These included watershed and sub-watershed delineation, slope calculation, and head estimation along river reaches, which facilitated the rapid identification of sub-watersheds with development potential.

Third, DEM, land use, soil, and meteorological data were incorporated into the SWAT+ model to simulate daily streamflow for the year 2024. The main river channels were divided into 100-meter intervals, and the average streamflow and head were calculated for each segment to establish a hydrological condition dataset.

Finally, turbine types were matched to individual segments based on their operational ranges, enabling the estimation of hydropower potential and the identification of candidate sites. A preliminary feasibility and benefit analysis was also conducted to evaluate their development prospects.

Through this framework, which combines rapid terrain analysis (QGIS + SAGA) with hydrological simulation (SWAT+), the study provides a comprehensive assessment of small hydropower potential in the Lijia River Basin, while also demonstrating the general applicability of the proposed methodology.

2.3 Computation of Slope

This study employed a digital elevation model (DEM) obtained from the governmental open data platform and imported it into SAGA for analysis. The DEM was selected primarily because it is freely accessible and publicly available, thereby reducing research costs while ensuring data reliability.

Within QGIS, the built-in tools and SAGA plugins were used to compute river channels and slope. Slope is one of the critical factors influencing the potential of small hydropower development, as it directly determines the hydraulic head, which is a key parameter in calculating hydropower output. Generally, steeper slopes correspond to higher potential energy in water flow, resulting in greater capacity for conversion into electricity. By utilizing DEM data, slope variations across the watershed can be accurately quantified, providing essential insights into the identification of locations most suitable for small hydropower development.

2.4 Simulation of Streamflow

In the research process, the DEM was first imported into the QSWAT model, and inflow and outflow points were defined to conduct preliminary simulations of river networks and wetlands. Land use and soil data were then incorporated to calculate spatial parameters, followed by the integration of meteorological data to drive the hydrological simulations. Based on topographic characteristics, precipitation, and evapotranspiration inputs, the QSWAT model simulates runoff and streamflow dynamics within the watershed. The simulation outputs provide detailed streamflow information for potential sites, serving as a critical basis for evaluating small hydropower potential.

2.5 Formulation of Hydropower Potential

Traditional site assessments for hydropower development often require substantial initial investment and rely heavily on expert judgment, which presents limitations for the wider deployment of small hydropower. With the advancement of computer-aided technologies, analytical tools have been developed to improve efficiency and reduce labor demands.

For head-type small hydropower systems, the core of the evaluation lies in determining the available hydraulic head and river discharge. When combined with turbine and generator efficiencies, the power output can be estimated using the following equation (1) [5]:

$$P = \rho \times g \times Q \times H \times \eta \quad (1)$$

where P is the power output (kW), ρ is the fluid density (kg/m^3), g is the gravitational acceleration (9.81 m/s^2), Q is the discharge (m^3/s), H is the hydraulic head (m), and η is the combined efficiency of the turbine and generator.

For run-of-river small hydropower systems, the power output can be estimated using equation (2) [6]:

$$P = \frac{1}{2} \rho \times A \times V^3 \times \eta \quad (2)$$

where P is the power output (kW), ρ is the fluid density (kg/m^3), A is the cross-sectional area of the turbine (m^2), V is the flow velocity (m/s), and η is the combined turbine and generator efficiency.

By applying these two complementary approaches, the hydropower potential of different site conditions can be systematically assessed, enabling more reliable matching of hydrological and topographic characteristics with appropriate turbine technologies.

2.6 Selection of Hydraulic Turbines

In the preliminary planning stage of small hydropower systems, the choice of turbine type plays a critical role in determining both system feasibility and overall efficiency. Since different turbine types operate within distinct ranges of hydraulic head (as summarized in Table 1), an appropriate matching process is essential for reliable site evaluation. In this study, turbine selection was based on the simulated hydraulic head values, with reference to common classification standards for turbine types such as Pelton, Francis, and Kaplan. Each sub-watershed was assessed to identify suitable turbine categories, enabling a preliminary classification of development potential.

The outcomes of this analysis provide a foundation for integrating streamflow data and hydropower potential calculations in subsequent steps. Furthermore, the turbine–site matching process supports future planning and engineering design by narrowing down feasible development options for small hydropower projects [7].

Table 1. According to the classification table of small hydropower turbines based on head ranges.

Turbine Type	Water Head (m)	Flow Rate (m^3/s)
Cross Flow	5~100	0.1~10
Francis Turbine	15~300	0.3-20
Kaplan	5~80	5-50
Pelton	15~500	0.1~3

3 Results

3.1 Sub-watershed Delineation and Screening

Using SAGA, the Lijia River Basin was delineated into 17 sub-watersheds (Figure 2). By inputting the fundamental parameters and geospatial data (DEM, soil, and land use) into the SWAT model, a hydrological network structure was successfully established, consisting of the 17 sub-watersheds and their corresponding river channels. For each sub-watershed, the

maximum and minimum elevation points were extracted to calculate the hydraulic head (Table 2). To better reflect the actual topographic conditions, slope calculations were based on the distance along the river channels rather than straight-line distances, thereby enhancing the hydrological relevance of the slope analysis.

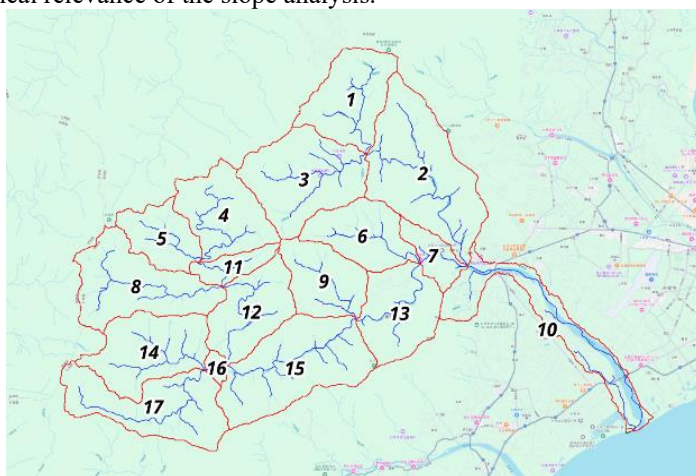


Fig. 2. Sub-watershed delineation of the Lijia River Basin based on SAGA.

Table 2. Slope Data of the 17 Sub-watersheds in the Lijia River Basin.

Sub watershed	Elevation Difference (m)	path length(m)	slope (%)
1	798.2633	3318.703	24.0526
2	754.8473	8971.848	8.4132
3	1006.4630	5419.298	18.5719
4	707.3555	7156.166	9.8854
5	1137.5820	3619.957	31.4253
6	849.8759	4714.110	18.0283
7	173.7266	2440.334	7.1190
8	1130.3100	6985.326	16.1812
9	981.1530	4201.451	23.3527
10	294.7092	12192.750	2.4171
11	311.3124	1793.343	17.3593
12	476.0327	5805.965	8.1990
13	523.3283	4840.208	10.8121
14	1176.6700	4511.455	26.0818
15	704.9944	7675.404	9.1851
16	68.9299	1088.372	6.3333
17	1293.7560	8532.933	15.1619

In the preliminary screening stage, Sub-watershed 5, which exhibited the steepest average slope among all delineated units, was selected as a demonstration case for detailed analysis. The selection was made to highlight the influence of steep terrain on hydropower potential, as higher slopes generally correspond to greater hydraulic heads and thus higher energy conversion capacity. Within this sub-watershed, the main river channel was segmented into 100-meter intervals using a linear division approach, generating a series of nodes along the channel (Figure 3). Elevation differences between adjacent nodes were then extracted to calculate the hydraulic head values for each interval. This procedure not only allowed for a more refined representation of spatial variations in available head but also provided essential input data for subsequent turbine matching and hydropower potential estimation.

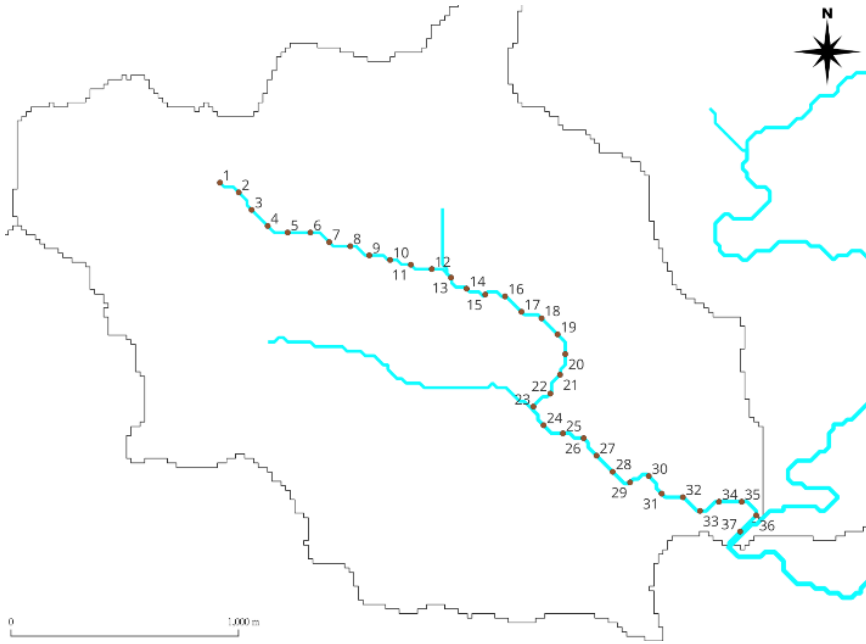


Fig. 3. Segmented nodes at 100-meter intervals along the main river channel of Sub-watershed 5.

3.2 Streamflow Simulation Results

The SWAT+ model was applied to simulate daily streamflow variations in the Lijia River Basin for the year 2024, with the results subsequently imported into the QGIS platform for spatial visualization (Figure 4). The simulations revealed a gradual increase in discharge from upstream to downstream reaches, consistent with the basin's topography and tributary confluences. Significant differences in discharge were observed among sub-watersheds due to variations in catchment area, rainfall distribution, and terrain conditions. Downstream sub-watersheds (e.g., Sub-watersheds 10 and 13) exhibited substantially higher flows because of larger drainage areas and the confluence of multiple tributaries. In contrast, the upstream and midstream sub-watersheds were characterized by relatively lower flows, yet maintained stable baseflow conditions.

These results not only provide a critical foundation for subsequent hydropower potential assessment and turbine allocation but also will be integrated with the segmented nodes shown in Figure 3 to establish average discharge data for each river segment.

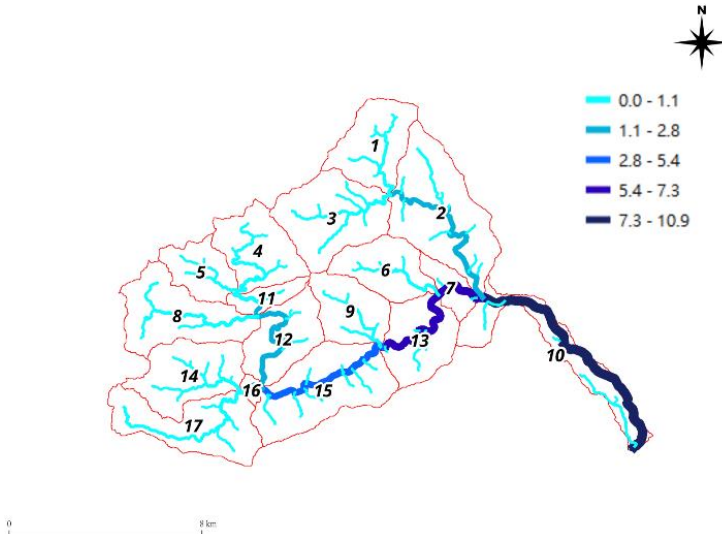


Fig. 4. SWAT+ daily streamflow results of the Lijia River Basin (2024).

3.3 Turbine Selection Results

After completing slope and streamflow analyses, the average discharge values simulated by the SWAT+ model were integrated into the previously defined 100-meter segmented nodes along the river channels. These values were then combined with the corresponding hydraulic head measurements to construct a spatial dataset containing both “head” and “flow” attributes. Based on the applicability criteria of five common small hydropower turbines (covering ranges of head and flow, as shown in Table 1), each segment was compared and matched to the most suitable turbine type.

The turbine types considered in this study included Kaplan, Tubular, Francis, Cross-Flow, and Pelton. For each segment, if the hydraulic head and flow fell within the operational range of a specific turbine, the segment was classified as suitable for that type. The turbine selection results for the main channel of Sub-watershed 5 are illustrated in Figures 5–7, while Table 3 summarizes the potential sites along with their corresponding turbine recommendations.

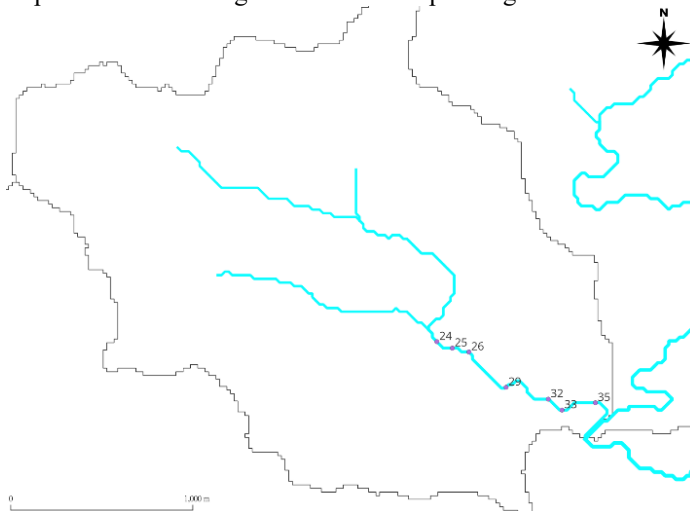


Fig. 5. Turbine selection results for each segment in Sub-watershed 5 –Francis turbine.

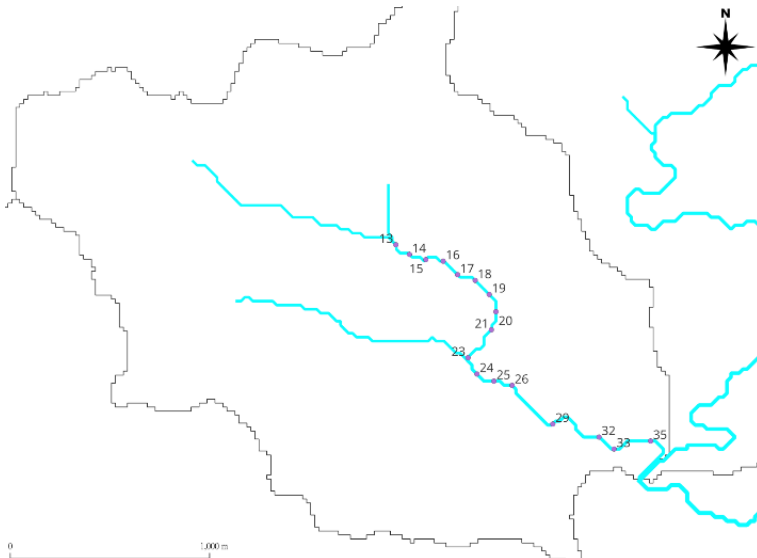


Fig. 6. Turbine selection results for each segment in Sub-watershed 5 – Pelton turbine.

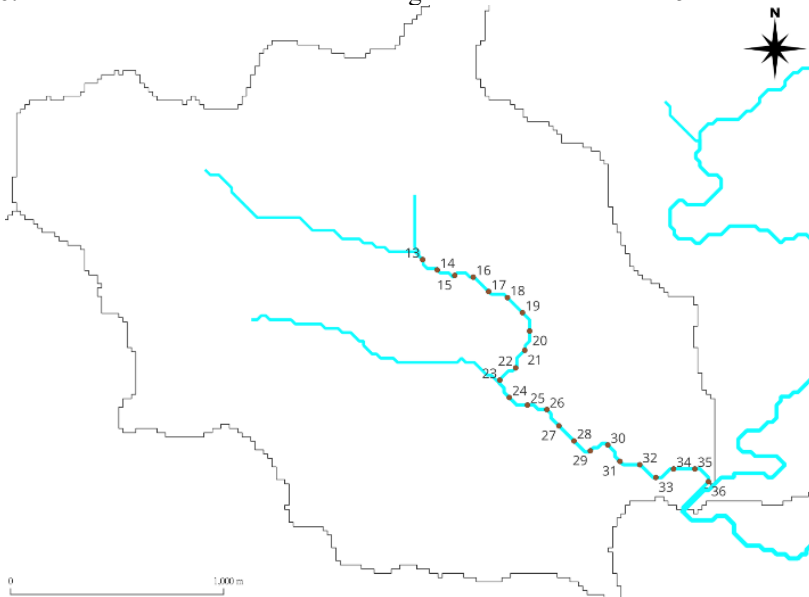


Fig. 7. Turbine selection results for each segment in Sub-watershed 5 – Cross-Flow turbine.

Through this approach, the study developed an integrated spatial analysis framework for turbine selection that combines topographic slope data with hydrological simulations. This framework not only supports small hydropower planning in the Lijia River Basin but also demonstrates applicability to other river basins with similar topographic characteristics, offering valuable guidance for future site selection and decision-making.

Table 3. Potential Small Hydropower Sites and Turbine Recommendations.

ID	Head(m)	Francis	Pelton	Cross -Flow
13	57.09229		✓	✓
14	27.62707		✓	✓
15	18.57813		✓	✓
16	32.17078		✓	✓
17	21.14331		✓	✓
18	21.85498		✓	✓
19	23.49670		✓	✓
20	31.01453		✓	✓
21	16.21179		✓	✓
22	14.32373			✓
23	32.04455		✓	✓
24	16.75135	✓	✓	✓
25	23.39795	✓	✓	✓
26	32.58557	✓	✓	✓
27	14.82446			✓
28	13.41406			✓
29	23.43470	✓	✓	✓
30	12.01001			✓
31	11.56359			✓
32	19.06629	✓	✓	✓
33	21.17059	✓	✓	✓
34	5.64075			✓
35	22.45495	✓	✓	✓
36	8.49775			✓

4 Discussion

This study demonstrated the feasibility of integrating GIS, SAGA, and the SWAT+ model into a systematic framework for assessing small hydropower potential in mountainous river basins. The delineation and screening results revealed that certain sub-watersheds, such as Sub-watershed 5, possess significant slope gradients and relatively stable streamflow, making them suitable for turbines like Francis, Pelton, or Cross-Flow. These findings confirm that topographic steepness and hydrological stability are decisive factors in identifying viable small hydropower sites.

Compared with conventional site assessments, which are often costly and heavily dependent on expert judgment, the proposed methodology offers a more data-driven and replicable approach. The combination of QGIS/SAGA for terrain analysis and SWAT+ for hydrological simulation enhances accuracy by capturing both spatial variability and temporal dynamics. This dual integration addresses a common limitation in earlier studies, which either relied solely on topographic indicators or neglected flow variability.

Furthermore, the spatial turbine–site matching process provides practical insights for engineering planning by narrowing down feasible turbine options for specific river segments. This not only supports decision-making for small hydropower projects in Taiwan but also

demonstrates potential for application in other regions with similar short and steep river characteristics.

Nevertheless, several limitations should be acknowledged. First, the streamflow simulation relied on available DEM, land-use, soil, and meteorological datasets, which may contain uncertainties in spatial resolution and temporal coverage. Second, the analysis focused on a single year (2024), without considering inter-annual variability or the potential impacts of climate change on flow regimes. Finally, socio-environmental aspects such as ecological conservation, sediment transport, and community acceptance were not incorporated, though they are critical for the sustainable implementation of small hydropower.

Future studies should therefore expand the temporal scope of hydrological simulations to include long-term climate variability and explore the integration of ecological and socio-economic factors into the assessment framework. Applying the methodology to multiple river basins across Taiwan or other mountainous regions could further validate its general applicability and robustness.

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References

1. J. Jung, H. Han, K. Kim, H. S. Kim, *Energies*. 2021, *14*, 3643.
2. Y. Kong, J. Wang, Z. Kong, F. Song, Z. Liu, C. Wei, *Renewable and Sustainable Energy Reviews*. 2015, *48*, 425–433.
3. B. Narsimlu, A. K. Gosain, B. R. Chahar, S. K. Singh, P. K. Srivastava, *Environmental Processes*. 2015, *2*, 79–95.
4. R. Al-Soufi, J. S. Rowan, R. W. Duck, A. Werritty, *IAHS PUBLICATION*. 2006, *306*, 601.
5. O. Paish, *Renewable and Sustainable Energy Reviews*. 2002, *6*, 537–556.
6. E. Chica, F. Perez, A. Rubio-Clemente, S. Agudelo, *WIT Transactions on Ecology and the Environment*. 2015, *195*, 137–148.
7. D. A. Zema, A. Nicotra, V. Tamburino, S. M. Zimbone, *Renewable Energy*. 2016, *85*, 498–506.