Forward-Stepwise Regression Analysis to Establish the Optimal Combination of Trends in Renewable Energy Development in Taiwan

Shu-Kuei Lin[1], Fu-Hsiang Kuo[2*]

[1] Graduate Institute of Technological and Vocational Education, National Taipei University of Technology, Taipei City, Taiwan, R.O.C.

[2] Department of Finance, National Yunlin University of Science and Technology, Yunlin County, Taiwan, R.O.C.

*Corresponding author: s1185072@gmail.com

Abstract. The development of renewable energy (RE) is a crucial national policy in Taiwan, aligning with global sustainability trends. This study, using data from 2019 to 2023, identifies the optimal mix of RE sources through correlation and statistical regression analysis (SRA). Findings show solar photovoltaic, geothermal, and offshore wind power significantly contribute to total renewable energy (TRE), while onshore wind, solid fuels, gas fuels, and waste energy have lesser impacts. The study recommends prioritizing conventional hydropower, solar photovoltaic, and offshore wind to boost TRE, reduce reliance on single sources, and stabilize energy supply, supporting Taiwan's sustainable development and energy self-sufficiency goals.
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Keywords: Renewable energy, Correlation coefficient, Global renewable energy trends, Policy and technological assessment, Stepwise regression analysis.

1 Introduction

In recent years, Taiwan has actively promoted low-carbon transformation and is committed to advancing towards net-zero emissions. To achieve sustainable energy objectives, Taiwan introduced policy measures through the revised Renewable Energy Development Act (REDA) in 2009. The REDA emphasizes that RE is derived from natural sources through appropriate technological conversion and is sustainable without depletion.

As outlined in the Review of Taiwan's Energy Situation (2023), Taiwan's renewable energy (RE) development spans six categories: conventional hydropower, geothermal, solar photovoltaic, wind, biomass, and waste. The nation's goal is to attain net-zero emissions by fostering a diverse energy landscape through the utilization of these RE sources. This strategy underscores Taiwan's commitment to sustainability and environmental stewardship in its energy sector.

In summary, our main research questions are: What is the optimal combination of renewable energy sources for power generation in Taiwan, considering their respective impacts on total renewable energy generation and national energy policy goals?

2 Literature Reviews

Energy is crucial for modern life (Keyuraphan et al., 2012). However, fossil fuel reliance contributes to environmental issues like greenhouse gas emissions and global warming (Lee & Chang, 2018; Trappey et al., 2012). International agreements, like the Kyoto Protocol and the Paris Climate Change Conference, stress the need for sustainable energy (Lee & Chang, 2018). Renewable energy (RE) emerges as a solution, promoting research and application in sustainable energy (Ayoub & Yuji, 2012; Duić et al., 2008; Moosavian et al., 2024; Xu et al., 2024).

RE offers advantages over fossil fuels, being abundant and eco-friendly. However, its production depends on weather conditions, affecting reliability (Lee & Chang, 2018). Despite environmental benefits, RE often faces higher electricity costs than fossil fuels, hindering widespread adoption (Chen et al., 2023; Kılkış et al., 2019; Ostadzad, 2023; Nema et al., 2009). Continued technological and economic advancements are needed to enhance RE competitiveness.

Research in RE involves big data analysis, multi-criteria decision-making, and literature reviews. For instance, Shin et al. (2015) used text mining to analyze RE-related newspaper articles in Korea, aiming to understand core issues and predict RE development. Campos-Guzmán et al. (2019) and Estévez et al. (2021) used multi-criteria decision-making methods to assess RE technologies' sustainability and trends, stressing stakeholder involvement in RE policies.

In Taiwan, research mainly focuses on policy analysis, developmental trends, and energy supply and demand structure, offering recommendations for sustainable development (Hsu, 1994; Liu et al., 2005; Tsai, 2023; Wu et al., 2023). Lee & Chang (2018) ranked RE sources using Multiple Criteria Decision Making, suggesting hydropower as most favorable, followed by solar, wind, biomass, and geothermal energy. Predictions indicate RE will account for a significant portion of Taiwan's electricity generation by 2025 (Hong and Magararu, 2021).

The SRA is commonly used across disciplines to study variable relationships over time or levels (Boukezzoula et al., 2018). For instance, Yan et al. (2007) emphasized regression testing's importance in software development. Boukezzoula et al. (2018) applied SRA to analyze the correlation between element analysis and industrial properties of anthracite coal in China. Similarly, Liu et al. (2023) and Luo et al. (2023) used SRA to identify key influencing factors in different contexts.

Despite RE's importance, limited quantitative analysis exists on identifying the optimal RE source combination. This study aims to address this gap by employing correlation analysis to identify RE sources with significant development potential and regression analysis to determine the best development model.

3 Methodology

3.1 Pearson's product moment correlation coefficient

We utilized correlation analysis, a statistical tool assessing linear relationships between two continuous variables. The correlation coefficient gauges the strength of the presumed linear association between the variables. The basic model configurations are depicted in Equation (1) and (Mukaka, 2012):

$$\mathbf{r} = \frac{\sum_{i=1}^{n}(x_i - x)(y_i - y)}{\sqrt{[\sum_{i=1}^{n}(x_i - \overline{x})^2][(y_i - \overline{y})^2]}} \quad (1)$$

3.2 SRA Method

Multi-objective optimization plays a crucial role in establishing quantitative relationships for combinations to find optimal solutions. Its significance lies in identifying interactions and trade-offs among different objectives to achieve overall optimal outcomes. As most variables exhibit quantitative characteristics, the choice of employing methods like regression analysis becomes essential in building predictive models, further enhancing the understanding of combination performance. Such analytical approaches contribute to accurately predicting relationships between different variables, providing a substantive foundation for developing more effective trends in renewable energy development.

The construction of multiple linear regression (MLR) model helped to investigate the impact of several independent variables (x1, x2,…, xk) for one dependent variable (y). The SRA method is an extension of the linear regression model based on Pearson correlation coefficients. The final multiple regression model takes the following form through a gradual process of adding or removing variables (Equation (2)):

1. $y=\alpha+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3+\beta_4 x_4+\ldots+\beta_k x_k+e_i$ (2)

4 Empirical Results and Analysis

4.1 Variables Description and Prediction Models

A. Variables Description

According to the Taiwan Power Company Sustainability Report (TPCSR) (2023), Taiwan's RE power generation is currently divided into 5 major parts: Hydro, Geothermal, Solar Photovoltaic, Wind, Biomass and Waste. The Wind part is divided into Onshore and Offshore, and the Biomass is divided into Solid and Biogas and the other two categories. In total, there are eight distinct types of RE.

Therefore, before constructing the empirical model, an exhaustive compilation of preliminary assessment factors is conducted. In this regard, the present study draws upon the TPCSR (2023) to identify impact variables utilized in the GRA methodology. The variables under consideration in this study encompass: Total RE (y_1): Total power generation from RE, Conventional hydropower (x_1), Geothermal (x_2), Solar photovoltaic (x_3), Onshore (x_4), Offshore (x_5), Solid (x_6), Biogas (x_7) and Waste (x_8).

B. Prediction Models

The optimal group prediction model for renewable energy power generation in Equation (3) is explained as follows:

$$y_j=\alpha+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3+\beta_4 x_4+\beta_5 x_5+\beta_6 x_6+\beta_7 x_7+\beta_8 x_8+e_j \quad (3)$$

4.2 Correlation Analysis

4.2.2 Analyzing the correlation between diverse RE sources and power generation

In further analysis, we examined the interrelationship between RE generation and total electricity generation (TEG). We subdivided RE into six main categories, including conventional hydropower (CH), geothermal, solar photovoltaic (SP), wind power (WP), biomass energy (BE), and waste, and conducted a detailed analysis of their power generation relationships. The following is an explanation of these findings (Table 1):

Table 1 The relationship between diverse RE sources and power generation.

	y_1	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
y_1	1	0.43	.85**	.89**	-0.04	.673**	-0.19	0.07	-0.13

* $p < 0.05$, ** $p < 0.01$

The correlation analysis indicates different impacts of renewable energy sources on total renewable energy (TRE) generation. Conventional hydropower (CH) has a modest positive correlation with TRE (0.43), influenced by factors like water scarcity. Geothermal energy shows a strong positive correlation (0.85), highlighting its significant role. Solar photovoltaic (SP) generation has a very strong positive correlation with TRE (0.89), underscoring its importance. Onshore wind power has a weak negative correlation (-0.04), indicating minimal impact, while offshore wind power has a strong positive correlation (0.673), showing a substantial contribution. Solid biomass and biogas have weak correlations with TRE (-0.19 and 0.07), suggesting limited impact. Waste-to-energy shows a weak negative correlation (-0.13). In summary, solar photovoltaic, geothermal, and offshore wind power significantly impact TRE, while onshore wind, solid biomass, biogas, and waste energy have smaller roles.

4.2.3 SRA Method

The study by Bardy et al. (2015) notes that correlation indicates similarity, not causation. Determining causality is challenging due to potential external factors, unconsidered variables, sample size, and selection bias. Correlation assumes linear relationships, which may not reflect non-linear ones, and omitted variables can mislead interpretations.

Therefore, based on the results of correlation analysis, it was observed that Conventional hydropower (x_1)、Geothermal (x_2)、Solar photovoltaic (x_3) and Offshore wind (x_5) are positively correlated with RE generation. Among them, Geothermal (x_2)、Solar photovoltaic (x_3) and Offshore wind (x_5) exhibit significant correlations. Consequently, a further analysis using the SRA method will be conducted on these four types of renewable energy sources (Conventional hydropower (x_1)、Geothermal

(x_2) 、Solar photovoltaic (x_3) and Offshore wind (x_5)) to identify the optimal trends in TRE.

Thus, further analysis using SRA will focus on these four sources to identify optimal TRE trends. Regression analyses, particularly for Geothermal (x_2), were conducted to assess its impact on TRE, as presented in Table2:

Table 2 SRA method analysis results

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	Constant	2402885.6	307461.1		7.81	.000		
	X3	1.161	.139	.897	8.37	.000	1.00	1.00
2	Constant	1637296.2	269133.47		6.08	.000		
	X3	1.111	.095	.858	11.67	.000	.98	1.01
	X1	.786	.173	.333	4.53	.000	.98	1.01
3	Constant	598648.02	142569.6		4.19	.001		
	X3	1.191	.036	.920	33.13	.000	.93	1.06
	X1	.952	.066	.404	14.44	.000	.92	1.08
	X5	1.565	.154	.290	10.14	.000	.88	1.13

The study reveals that among the three models, Model 3 outperforms Model 1 and Model 2. The explanation for this superiority is as follows:

The equation for Model 3, derived from the research findings (Table no. 4), can be written as follows (Equation (5)):

$$y_1=598648.022+0.952\times x_1+1.191\times x_3+1.565\times x_5 \quad (5)$$

In summary, Model 3 demonstrates statistical significance, and each explanatory variable significantly influences the model. The model performs well in terms of multicollinearity.

Based on the analysis, among the four RE sources (Conventional hydropower, Geothermal, Solar photovoltaic, and Offshore wind), the combination of Conventional hydropower, Solar photovoltaic, and Offshore wind emerges as the optimal and most efficient mix for power generation. This finding suggests that in scenarios with limited resources, priority should be given to the development of Solar photovoltaic due to its significant role in this optimal combination. However, in resource-rich contexts, it is advisable to simultaneously develop Conventional hydropower, Solar photovoltaic, and Offshore wind to pursue a more comprehensive and sustainable approach to renewable energy. Such a strategy aims to enhance energy efficiency, meet energy demands, and mitigate environmental impacts effectively.

5 Concluding Remarks

To establish the optimal combination of trends in RE development, this study first employs correlation analysis to eliminate variables with negative or low correlations, followed by the SRA method. The analysis reveals that solar photovoltaic generation, geothermal, and offshore wind power are crucial for influencing TRE, whereas onshore wind, solid fuels, gas fuels, and waste energy have a modest impact.

Given Taiwan's current renewable energy landscape, the focus should be on Conventional hydropower (x_1), Solar photovoltaic (x_3), and Offshore wind (x_5) for power generation. These sources significantly impact TRE, ensuring both feasibility and effectiveness for sustainable development. This diverse energy mix reduces dependency on a single source and enhances supply stability, aligning with global trends to reduce carbon emissions and achieve energy diversification.

This integrated approach will help Taiwan efficiently promote renewable energy, achieve sustainable development goals, and increase energy self-sufficiency. However, the findings are based on current models and data, and any application should consider Taiwan’s evolving RE environment for more accurate results.

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