

Development of a browser-based computational tool for preliminary estimation of vertical-axis wind turbine power output

Halimin Sobri¹, Fatahul Arifin^{1,2*}, Carlos RS³

¹Applied Master of Renewable Energy Engineering, State Polytechnic of Sriwijaya,
South Sumatra, 30128, Indonesia

²Department of Mechanical Engineering, State Polytechnic of Sriwijaya, South Sumatra,
30128, Indonesia

³Department of Electrical Engineering, State Polytechnic of Sriwijaya, South Sumatra,
30128, Indonesia

*Corresponding author: farifinus@polsri.ac.id

ABSTRACT

Rapid estimation of vertical-axis wind turbine (VAWT) power output is essential for preliminary assessment. However, existing approaches using spreadsheets, software, or simulations are resource-intensive and require a tedious process. This study presents a lightweight browser-based computational framework developed using JavaScript for rapid preliminary estimation of VAWT power output. The framework provides an interactive web interface that automatically estimates swept area, available wind power, mechanical power, and electrical power from user-defined parameters. Turbine-type selection is computationally incorporated through predefined representative power coefficients (C_p), enabling differentiated power-output estimation among the included VAWT configurations. The algorithm was implemented using client-side JavaScript, enabling parameter updating and automatic result display without software installation or server-side processing. An additional warning notification feature was set to appear when the input wind speed exceeds a reference threshold of 7 m/s. Functional verification was performed by comparing the framework outputs with manual spreadsheet estimation using the same analytical equations over a wind speed range of 1–10 m/s. The results showed close numerical agreement between the browser-based and spreadsheet-based calculations, confirming the consistent implementation of the underlying analytical equations within the JavaScript framework. The proposed framework provides an accessible, platform-independent tool for rapid preliminary estimation of VAWT power output. Furthermore, the framework offers a practical foundation for future integration into real-time monitoring systems.

Keywords: JavaScript; power output; VAWT; web application; wind energy

INTRODUCTION

Wind energy is one promising alternative for clean and affordable energy generation (GWEC 2025; Fahrur Aslami et al., 2023). Among various types of wind turbines,

vertical axis wind turbines (VAWTs) have received considerable attention due to their versatile application in urban areas with fluctuating wind conditions (Prasad et al., 2026; Bošnjaković, Veljić, and Hradovi

2025; Vitalevich, 2025). VAWTs are proven to have self-starting ability and are able to catch multidirectional wind; moreover, it has lower installation and maintenance requirements (Huang, Luo, and Li 2023). Therefore, it is widely used for green-energy generation in industrial, residential, and remote areas (Banerjee and Maity 2024; Kuang et al. 2022; Alzahrani et al. 2024). Consequently, preliminary estimation of the power output that can be generated under different turbine configurations and wind conditions is important during turbine selection, early-stage design, and feasibility assessment before experimental study.

Several approaches in VAWT performance estimation have been reported. Computational fluid dynamics (CFD) simulation is widely used in wind turbine studies due to its detailed aerodynamic predictions (Rezaeiha, Kalkman, and Blocken 2017; Fatahian et al. 2023). However, CFD requires substantial computational resources and expertise. On the other hand, engineering models such as the Double Multiple Streamtube (DMST) offer prediction accuracy at a reasonable computational cost (Gupta et al. 2025). A more recent study reported VAWT-X as an integrated analytical and engineering model for VAWT performance simulation (Lu and Zanj 2022). Nevertheless, these approaches are primarily intended to improve aerodynamic or operational performance prediction and may involve modeling procedures that are less suitable for rapid preliminary assessment. For early-stage design and feasibility evaluation, a simpler

approach that enables users to obtain an initial estimate of potential power output from basic turbine and environmental parameters may therefore be useful.

Other than using software or simulation, the VAWT preliminary performance evaluation is generally done by manual calculations or spreadsheets. These approaches require thorough evaluation to prevent calculation errors. Browser-based platforms present as simple and widely accessible computational tools (Liu et al. 2023; Ang et al. 2022). Their application in engineering enables rapid evaluation with minimal input (Borzi et al. 2021). Therefore, browser-based computational frameworks have become increasingly recognized as potential decision-support tools during preliminary engineering design and assessment (Christensen 2026; Lipatova, Goncharova, and Napreenko 2025; de Menezes et al. 2024). Recent advances in browser-based scientific computing demonstrate that modern JavaScript engines are capable of executing sophisticated numerical computations directly on the client side (Uvarov 2025). Frameworks such as *rom.js* have shown that browser-based computation can effectively support engineering analysis while eliminating server-side processing and software installation (Peña-Monferrer and Diaz-Marin 2022). These developments indicate that JavaScript is an efficient platform for lightweight scientific computing.

Despite the widespread availability of analytical equations describing wind energy conversion, research that translates these

formulations into browser-based computational tools for preliminary VAWT power-output estimation remains scarce. This study develops a JavaScript-based computational tool for the preliminary estimation of VAWT power output. The proposed framework implements fundamental wind energy conversion equations within a client-side JavaScript calculation engine and integrates turbine-type selection through predefined representative power coefficients (C_p). The framework requires only basic turbine and environmental parameters as input and automatically estimates the swept area, available wind power, mechanical power, and electrical power through an interactive browser-based interface without requiring server-side processing. Moreover, the framework integrates an operation-condition warning system that provides an advisory notification when the input wind speed exceeds a predefined reference threshold. By integrating turbine-type-dependent power coefficients, automated multi-stage power estimation, and an operating-condition warning feature within a single browser-based workflow, the framework is intended to support rapid and accessible preliminary assessment of potential VAWT power output without specialized software or programming expertise.

METHOD

The lightweight JavaScript-based computational framework was designed to transform conventional manual performance calculations into an interactive, rapid preliminary estimation of VAWT power output.

The framework operates by receiving user-defined turbine and environmental parameters as inputs, processing the data through a sequential calculation algorithm, and displaying the estimated power-related outputs through a browser-based interface. The developed system consists of three main components: (1) user input module, (2) a JavaScript-based calculation engine, and (3) an output that presents the calculated results and generates an operating-condition notification when the predefined reference threshold is exceeded. The overall computational workflow is depicted in Figure 1.

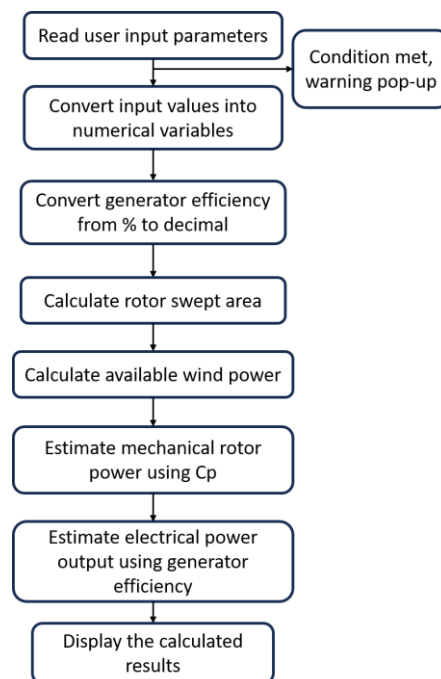


Figure 1. Computational framework

The developed framework requires several input parameters related to turbine characteristics, rotor geometry, operating conditions, and conversion efficiency. The input variables include turbine types, rotor diameter (D), rotor height (h), wind speed (v), air density (ρ , ρ_{air}), and

generator efficiency (η , eta). Turbine type is incorporated as a computational parameter through a predefined power coefficient (C_p) corresponding to the selected VAWT configuration (Figure 2). These parameters were selected based on the fundamental relationship between available wind energy and turbine energy conversion capability (Wang et al. 2023).

The screenshot displays the SOBR SmartSys application interface. At the top, there are 'Realtime' and 'About' buttons. The main section is titled 'Turbine Type' and 'Rotor D. (m)'. Under 'Turbine Type', three options are listed: 'Savonius ($C_p \approx 0.20$)', 'H-Rotor ($C_p \approx 0.30$)', and 'Darrieus ($C_p \approx 0.35$)'. The 'Savonius' option is selected, indicated by a green radio button. The 'Rotor D. (m)' field is set to '0.6'. Below these, the 'Rotor Height (m)' is set to '1.0' and 'Wind Speed (m/s)' is set to '4'. The 'Generator Efficiency (%)' is set to 'Savonius ($C_p \approx 0.20$)' and 'Air Density (kg/m^3)' is set to '1.225'. At the bottom, a table shows the calculated values: 'Swept area' is '0.600 m²', 'Available Wind Power' is '23.52 W', 'Mechanical Power Output' is '4.70 W', and 'Electrical Power Output Est' is '3.76 W'.

Figure 2. Turbine Type Selection and Estimated Power Output in the SOBR SmartSys Application

The rotor diameter and height are used to determine the effective swept area of the VAWT, whereas wind speed and air density define the available wind energy conditions. The selected turbine type determines the representative C_p applied in the mechanical power calculation, while generator efficiency represents the

conversion of mechanical power into established electrical power. The `'document.getElementById()'` method retrieves the input values, which are subsequently converted into numerical data using the `'parseFloat()'` function (Ambler and Cloud 2015). To ensure computational stability, empty or invalid input values are automatically assigned as zero values, preventing calculation errors during operation.

The calculation algorithm was developed based on the fundamental wind energy conversion equations. The first calculation step determines the swept area of the VAWT rotor, which represents the effective area interacting with the incoming airflow (Faisal et al. 2025). For the VAWT configurations considered in this study, the swept area of the rotor is calculated based on the following equation (Tong et al. 2023):

$$[A=D * H] \quad (1)$$

where (A) is the swept area (m^2), (D) is the rotor diameter (m), and (H) is the rotor height (m). The available wind power passing through the rotor swept area was subsequently estimated using:

$$[P_{\text{wind}}=0.5*\rho*A*\text{Math.pow}(v,3)] \quad (2)$$

where (P_{wind}) represents available wind power (W), (ρ , rho) is air density (kg/m^3), and (v) is wind speed (m/s) (Malecha and Dsouza 2023). In the JavaScript implementation, the cubic wind speed term is calculated using the `'Math.pow(v,3)'` function. The resulting value represents the theoretical wind power available

across the swept area before accounting for the energy-extraction characteristics of the selected turbine.

Since a turbine cannot extract all available wind energy, the mechanical power captured by the rotor is estimated using a representative C_p . The representative values of 0.20, 0.30, and 0.35 were assigned to the Savonius, H-Rotor, and Darrieus configurations, respectively. These values correspond to the lower bounds of the reported ranges (Torres et al. 2022; Sarmiento-Laurel et al. 2025; Essahraoui et al. 2026) and were selected as conservative assumptions for preliminary power-output estimation under the variable wind conditions considered in this study. The estimated mechanical power was subsequently calculated as:

$$[P_{\text{mech}} = P_{\text{wind}} * C_p] \quad (3)$$

where (P_{mech}) is the mechanical output power (W) and (C_p) is the representative power coefficient associated with the selected turbine types. Since efficiency is commonly expressed as a percentage, the input value is converted into decimal form before calculation using the function:

$$[\text{eta} = \parallel 0)/100] \quad (4)$$

Finally, the electrical output power is estimated by considering generator conversion efficiency:

$$[P_{\text{el}} = P_{\text{mech}} * \text{eta}] \quad (5)$$

where (P_{el}) represents electrical power output (W), and (η , eta) is generator efficiency.

The calculation process was implemented through a main JavaScript function named 'hitung()', which means calculate. This function acts as the computational engine of the framework, which performs all sequential calculations whenever the webpage is loaded or whenever the users modify the input parameters. The snippet of the JavaScript function is presented in Figure 3. The calculated outputs are displayed dynamically using HTML element manipulation through the 'innerText' property. The numerical outputs are formatted using the 'toFixed()' function to provide a consistent number of decimal places for readability.

```
const A = D * H;
const Pwind = 0.5 * rho * A * Math.pow(v,3);
const Pmech = Pwind * Cp;
const Pel = Pmech * eta;

document.getElementById("A").innerText = A.toFixed(3);
document.getElementById("Pwind").innerText = Pwind.toFixed(2);
document.getElementById("Pmech").innerText = Pmech.toFixed(2);
document.getElementById("Pel").innerText = Pel.toFixed(2);
//peringatan warning
const warning = document.getElementById("warning");
if(v > 4 ){
    warning.style.display = "block";
} else {
    warning.style.display = "none";
}
}

document.querySelectorAll("input, select").forEach(el=>{
    el.addEventListener("input", hitung);
    el.addEventListener("change", hitung);
});
```

Figure 3. Snippet of the JavaScript function

To improve usability, the framework was designed with an automatic recalculation mechanism. The absence of a manual calculation button is intended to provide continuous and automatic updates of the results whenever users modify any input field. This function is implemented using JavaScript event

listeners attached to all input and selection elements. The 'input' and 'change' events trigger the calculation function, allowing the performance estimation results to be updated immediately after parameter modification (Bernard and Sugandi 2026).

In addition to estimating power output, the developed framework incorporates an operating-condition warning system. Our previous computational and numerical investigation of a VAWT system indicated that a wind speed of 7 m/s is the threshold for favorable operating characteristics without aerodynamic losses, flow interference, and turbulence (Sobri, Arifin, and RS 2026). Therefore, an advisory notification is set to be triggered when the input wind speed exceeds a predefined reference threshold of 7 m/s. The warning is intended to alert users that the entered wind condition exceeds the reference operating range considered in the previous investigation and that further assessment may be required for the specific turbine and system configuration. Therefore, the threshold should not be interpreted as a universal structural safety limit, rated wind speed, or cut-out wind speed applicable to all VAWT designs.

RESULT AND DISCUSSION

Figure 4. A presents the normal graphical user interface (GUI) of the developed web-based computational tool for rapid estimation of VAWT power output. The interface is organized into two main sections, i.e., the input panel (upper section) and the output panel (lower section). The

input panel allows users to specify turbine characteristics, geometric, and aerodynamic parameters required to estimate the VAWT power output. The output panel in the lower section presents the calculated swept area, available wind power, mechanical power output, and estimated electrical power output. These parameters are updated instantaneously as input values change, enabling users to rapidly investigate the influence of operating conditions or turbine dimensions on the predicted power output. By executing all computations on the client side, the framework eliminates dependence on external software or server-side processing, allowing the calculator to operate efficiently on any modern web browser.

A

Turbine Type	Rotor D. (m)
H-Rotor (Cp ≈ 0.30)	0.6
Rotor Height (m)	Wind Speed (m/s)
1.0	2
Generator Efficiency (%)	Air Density (kg/m³)
80	1.225
* Swept area VAWT = D × H	

Calculation Result	
Swept area	0.600 m²
Available Wind Power	2.94 W
Mechanical Power Output	0.88 W
Electrical Power Output Est	0.71 W

B

Turbin Type

Savonius ($C_p \approx 0.20$)

Rotor D. (m)

0.6

Rotor Height (m)

1.0

Wind Speed (m/s)

9

WARNING
Wind Speed Exceeded (> 7 m/s)
Make sure turbine and system in safe condition

Generator Efficiency (%)

80

Air Density (kg/m^3)

1.225

* Swept area VAWT = $D \times H$

Calculation Result

Swept area	0.600 m²
Available Wind Power	267.91 W
Mechanical Power Output	53.58 W
Electrical Power Output Est	42.87 W

Figure 4. Browser-based graphical user interface of the developed computational framework under (A) normal and (B) high wind speed conditions with different turbine types and C_p values.

Figure 4(B) shows the successful incorporation of a basic warning notification feature in the computational tool. When the wind speed input exceeds a predefined reference threshold of 7 m/s, a warning message is automatically displayed to notify users to check the safety of the wind turbine system. It is worth noting that the reference threshold is not intended to represent a universal safety limit, as the safe operating wind speed strongly depends on turbine design, structural integrity, and local environmental

conditions (Saenz-Aguirre et al. 2022). The inclusion of this feature demonstrates that the proposed framework can provide numerical computation as well as simple decision-support functionality.

The functionality and sensitivity of the developed computational framework were evaluated through comparison with an independently developed spreadsheet implementing the same analytical equations. Calculations through both approaches were conducted using identical turbine specifications and conditions, with wind speed ranging from 1-10 m/s. As summarized in Table 1, the estimated power-related outputs obtained from the browser-based framework were compared with those generated by the independently developed spreadsheet for all investigated wind speeds. The comparison was conducted as a numerical verification of the JavaScript implementation. Agreement between the two calculation approaches was observed for all calculated parameters. This result confirms the successful numerical implementation of the analytical equations in the developed JavaScript-based tool for preliminary estimation of VAWT power output.

Table 1. Estimation result

Turbin type	Savonius
Cp	0.2
Rotor diameter (m)	0.6
Rotor height (m)	1
Generator Efficiency (%)	80
Air density (kg/m^3)	1.225

Framework estimation			
Wind Speed (m/s)	P_{wind} (W)	P_{mech} (W)	P_{el} (W)
1	0.37	0.07	0.06
2	2.94	0.59	0.47
3	9.92	1.98	1.59
4	23.52	4.7	3.76
5	45.94	9.19	7.35
6	79.38	15.88	12.73
7	126.05	25.21	20.17
8	188.16	37.63	30.11
9	267.91	53.58	42.87
10	367.5	73.5	58.8

Manual spreadsheet estimation			
Wind Speed (m/s)	P_{wind} (W)	P_{mech} (W)	P_{el} (W)
1	0.37	0.07	0.06
2	2.94	0.59	0.47
3	9.92	1.98	1.59
4	23.52	4.70	3.76
5	45.94	9.19	7.35
6	79.38	15.88	12.73
7	126.05	25.21	20.17
8	188.16	37.63	30.11
9	267.91	53.58	42.87
10	367.50	73.50	58.80

Red color represents a warning notification for the web calculator.

As illustrated in Figure 5, the estimated powers also indicate the sensitivity of calculated power output to changes in wind speed. All three output parameters increase nonlinearly with increasing wind speed, following the cubic relationship described in eq (2). For example, doubling the wind speed from 4 to 8 m/s increased the available wind power around eightfold, from 23.52 W to 188.16 W. The estimated mechanical and electrical power output also showed a proportional trend with a lower

magnitude. This behavior reflects the correlation of both parameters with C_p and generator efficiency, which represent the sequential conversion from available wind power to estimated mechanical and electrical power (Fábregas, Palencia, and Buitrago 2024). The verification results demonstrate that the proposed JavaScript-based framework correctly implements the analytical calculation procedure and consistently reproduces the expected relationships among the calculated power-related parameters.

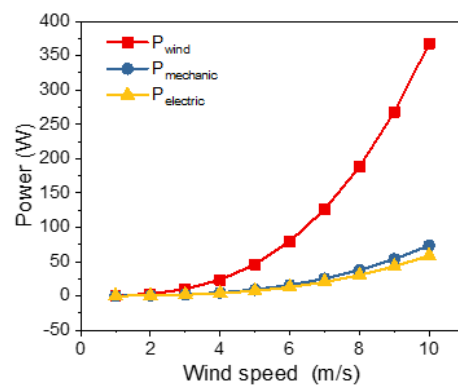


Figure 5. The estimated VAWT power outputs as a function of wind speed from data summarized in Table 1.

CONCLUSION

A lightweight JavaScript-based computational framework for rapid preliminary estimation of VAWT power output was successfully developed. The proposed framework eliminates the need for software installation or programming expertise, making it advantageous for rapid preliminary power-output assessment. Through an interactive interface, the framework enables users to input VAWT characteristics and environmental parameters, and the estimated swept area, available

wind power, mechanical power, and electrical power will be automatically displayed. In addition, an operational warning feature is also incorporated based on a predefined reference threshold of 7 m/s. The numerical implementation of the developed framework was verified through comparison with a spreadsheet-based manual estimation implementing the same equations. The comparison demonstrated close agreement between the browser-based and spreadsheet-based calculation results across the investigated operating conditions, supporting the correct implementation of the underlying analytical equations in the JavaScript-based tool. Further analysis of the trend of the estimated VAWT power output demonstrated that the framework consistently reproduces the expected nonlinear relationship between wind speed and power output, reflecting the cubic dependence of available wind energy on wind velocity. These results indicate that the proposed framework successfully implements the analytical calculation procedure in an accessible browser-based environment and can support rapid preliminary evaluation of potential VAWT power output. However, the present results represent software and numerical verification of the implemented analytical procedure rather than validation against experimental or independent turbine performance data. Further studies should therefore compare the estimated outputs with experimental measurements, manufacturer power curves, or independent literature data to evaluate the predictive performance of the model under

different operating conditions and turbine configurations.

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