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Comparative Study of Conventional Smart Tools for Modelling and Simulating Pump Storage Hydroelectric Power for Sustainable Energy Supply: A Focus on HOMER Software

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Abstract

Effective modelling and simulation tools for Pumped Storage Hydroelectric Power (PSHP) systems are becoming more and more necessary as the demand for sustainable energy solutions rises. To assess the effectiveness of traditional smart tools for PSHP system optimization, this study evaluates these optimization tools, focusing on the Hybrid Optimization of Multiple Energy Resources (HOMER) software. The study assesses the technical, financial, and operational modeling capabilities of several key software programs, including HOMER, MATLAB, Simulink, Dynamic Simulation (DSim), ANSYS Fluent, and OpenFOAM. HOMER offers a practical option for PSHP projects due to its streamlined interface, integrated optimization methods, and its capacity to simulate hybrid energy systems. Although they demand sophisticated programming abilities, MATLAB and Simulink provide reliable dynamic modeling. While it lacks features for economic optimization, DSim is excellent in transient analysis. Although they are computationally demanding and less accessible for economic feasibility assessments, ANSYS Fluent and OpenFOAM offer comprehensive fluid dynamics simulations. The study reveals that HOMER's lifecycle cost analysis, extensive component library, and adaptability in incorporating renewable energy sources are its greatest strengths. These features support the goals of improving grid stability and guaranteeing affordable energy options. The results highlight HOMER's excellence in striking a balance between economic considerations and technical performance, making it a robust tool for practitioners and researchers in renewable energy optimization and modelling.

Keywords: Pumped storage hydroelectric power, Hybrid optimization of multiple energy resources software, Energy storage modelling, Hybrid energy systems optimization.

1 | Introduction

Pumped Storage Hydroelectric Power (PSHP) is a dependable energy storage technology that has gained prominence due to the growing demand for sustainable energy solutions. In order to integrate renewable energy sources, balance grid stability, and guarantee energy supply during periods of peak demand, PSHP

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systems are becoming an essential tool. Thus, effective modelling and simulation technologies are necessary to optimize these systems. Considering its adaptability in analysing renewable energy systems, Hybrid Optimization of Multiple Energy Resources (HOMER) has become widely recognized among the software alternatives. A comparative analysis of conventional smart tools for PSHP modelling is still deficient, nevertheless. Several aspects of PSHP systems have been the subject of recent studies. In their evaluation of hybrid renewable energy systems, Kavadias and Triantafyllou [1] emphasized the necessity of robust optimization tools. The dynamic modelling issues of ternary pumped storage systems were highlighted by Dong et al. [2] and Satapathy et al. [3]. While Haeuslein et al. [4] investigated thermally pumped piston storage for the distribution of renewable energy, Bayazıt et al. [5] employed GIS models to study the conversion of multipurpose dams into PSHP facilities. These works highlight the variety of methodologies used in PSHP investigation.

Additionally, there have been ample debates about the possible integration of energy storage devices, especially PSHP, into hybrid renewable energy systems. In their thorough analysis of pump-hydro storage systems, Das et al. [6] highlighted the benefits for grid stability. Tahir [7] examined hybrid microgrid optimization strategies, highlighting the use of software tools to enhance efficiency.

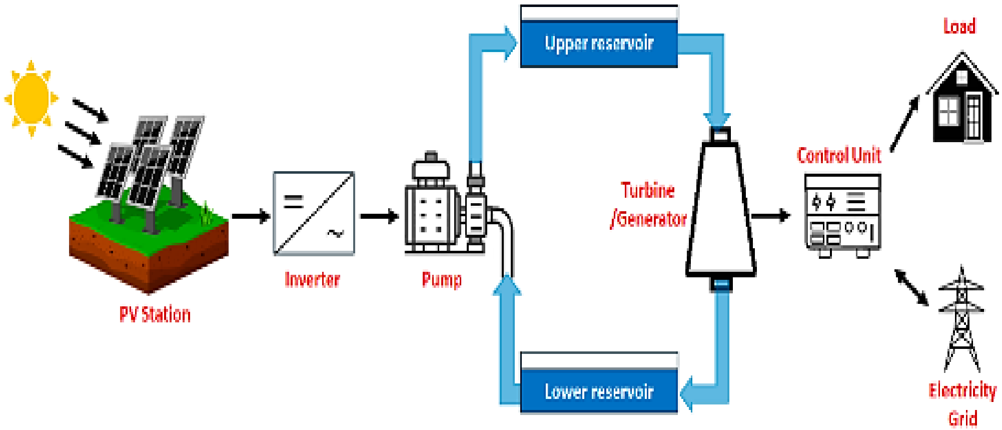

Fig. 1. Schematic illustration of a typical PSHP.

Techno-economic viability was further investigated by Khan et al. [8], who emphasized the significance of reliability analysis and ideal sizing. Their studies were premised on the importance of simulation tools for system design and performance evaluation, especially for hybrid systems that integrate solar panels, inverters, and other system units, as illustrated in Fig. 1. For the optimization of renewable energy systems, the HOMER software has gained widespread application. Big-Alabo [9] utilized it to simulate a 100 kW PSHP system, demonstrating its techno-economic analytical capabilities. A similar evaluation was conducted by Wang et al. [10] in their investigative studies to examine a crucial factor for precise simulations and nonlinear modeling issues, especially in pump-turbine dynamics. Despite its widespread use, HOMER has not been thoroughly evaluated against other traditional tools for PSHP modelling. To close this gap, this study will evaluate traditional smart tools for PSHP modelling and simulation, with a particular emphasis on HOMER. Their benefits, drawbacks, and suitability for use in scenarios involving sustainable energy supplies will all be evaluated. Drawing on insights from current studies, this study provides a valuable perspective on the selection of PSHP project tools. The results will enable practitioners and researchers to select the most suitable software for their specific needs, ultimately leading to more sustainable and effective energy systems.

2 | Software for Modelling and Simulation of PSH

The complexity of PSH systems necessitates sophisticated modelling and simulation capabilities. Software tools such as HOMER, MATLAB, Simulink, Dynamic Simulation (DSim), ANSYS Fluent, OpenFOAM, and specialized hydropower simulation platforms enable engineers to create detailed models that account for various physical and operational parameters. The intermittent nature of these energy sources requires a flexible and responsive energy storage solution, which is precisely what PSH systems offer [11], [12]. By utilizing simulation software, engineers can model the interaction between PSH systems and renewable energy sources, assessing how to best balance supply and demand in real-time. These tools facilitate the analysis of hydraulic, mechanical, and electrical components, allowing for a comprehensive understanding of system dynamics. The ability to simulate different operational scenarios is crucial for identifying optimal configurations and operational strategies that maximize efficiency and reliability [13]. Economic considerations also play a pivotal role in the modelling and implementation of PSH systems. The initial capital investment for constructing a pump storage facility is substantial, and thus, the economic feasibility of such projects must be rigorously evaluated. Software tools that incorporate economic modeling capabilities enable the assessment of lifecycle costs, investment costs, and return on investment under varying market conditions [14]. By simulating different financial scenarios, stakeholders can make informed decisions regarding project viability and funding strategies, ultimately leading to more sustainable energy solutions.

3 | HOMER Software for Modelling and Simulation of PSH

HOMER is a widely used software tool for modelling and analyzing hybrid renewable energy systems. It enables the optimization of energy production, storage, and distribution by considering various parameters, including renewable energy sources, energy storage options, load profiles, and economic factors [15]. The primary goal of HOMER is to maximize the utilization of renewable energy sources while ensuring a reliable and cost-effective power supply [16]. By considering the unique characteristics and availability of different renewable energy sources, such as solar, wind, hydro, and biomass, HOMER can effectively evaluate their integration into a hybrid system [17]. The software employs advanced optimization algorithms to determine the optimal mix of energy sources, storage technologies, and power distribution strategies [18]. HOMER has been employed in numerous studies to optimize power supply systems in different settings. For instance, Dodo et al. [19] utilized HOMER to optimize an autonomous hybrid power system for an Academic Institution. The study demonstrated the effectiveness of HOMER in achieving high renewable energy penetration and improving the reliability of the power supply. The survey conducted by Arévalo et al. [20] serves as a testament to the effectiveness of HOMER in addressing the specific energy needs of academic institutions. By considering factors such as the institution's energy demand profile, available renewable energy resources, and the potential for energy storage, HOMER facilitated the identification of an optimal solution that balances energy production and consumption. The researchers found that the optimized hybrid power system reduced reliance on non-renewable energy sources, resulting in significant environmental benefits.

Furthermore, HOMER's ability to assess economic factors enables decision-makers to evaluate the financial viability of different system configurations. It considers parameters such as equipment costs, maintenance expenses, fuel prices, and incentives for renewable energy generation [21]. Through these economic analyses, stakeholders can make informed decisions regarding the implementation of hybrid renewable energy systems, taking into account both environmental and financial considerations [22]. HOMER has been extensively utilized in numerous studies across various settings to optimize power supply systems. For example, [23] applied HOMER to optimize the configuration of a microgrid in a rural area. Their research demonstrated that HOMER was instrumental in identifying the most suitable mix of renewable energy sources and energy storage technologies to ensure a reliable and sustainable power supply.

Additionally, Ellabban and Alassi [24] utilized HOMER in the optimization of a hybrid renewable energy system for a remote community. The study demonstrated the software's ability to consider various scenarios, including load demand variations and renewable resource availability, to determine the optimal system configuration. The researchers concluded that HOMER enabled the modelling of a cost-effective system that maximized renewable energy utilization and improved the energy independence of the community. HOMER is a widely recognized and versatile software tool for the modelling and analysis of hybrid renewable energy systems [25], [26]. It offers advanced optimization algorithms that consider various parameters, including renewable energy sources, energy storage options, load profiles, and economic factors. The software has been successfully employed in multiple studies, including optimizing power supply systems for academic institutions [27] microgrids in rural areas [28], [29], and hybrid renewable energy systems for remote communities [10]. These studies demonstrate the effectiveness of HOMER in achieving high renewable energy penetration, enhancing system reliability, and considering economic viability in modelling sustainable energy solutions.

4 | MATLAB Software for Modelling and Simulation of PSH

The integration of MATLAB software in the modelling and simulation of pump storage hydroelectric power systems represents a significant advancement in the field of renewable energy engineering. This technology not only enhances electricity supply but also contributes to the stability and reliability of power grids [30]. MATLAB provides a robust platform for the dynamic modelling of pump storage systems. The ability to simulate the hydraulic and electrical components of these systems allows engineers to visualize and analyse the interactions between various elements, such as turbines, pumps, and reservoirs [31]. This visualization is crucial for understanding the operational dynamics under different load conditions and for predicting system behaviour during transient events. The graphical capabilities of MATLAB facilitate the creation of detailed simulations that can replicate real-world scenarios, thereby enabling engineers to identify potential issues before physical implementation. Moreover, MATLAB's extensive toolbox for control system modelling is particularly beneficial for optimizing the operational efficiency of pump storage facilities [32]. The software allows for the development of sophisticated control algorithms that can manage the switching between pumping and generating modes. By employing advanced control strategies, such as Model Predictive Control (MPC) or fuzzy logic, engineers can enhance the system's responsiveness to fluctuations in electricity demand. This adaptability is essential in modern power systems, where the integration of intermittent renewable energy sources necessitates a flexible and reliable backup solution [33]. In addition to modelling and control, MATLAB excels in the area of performance analysis. The software's computational capabilities enable engineers to conduct rigorous simulations that assess the efficiency and reliability of pump storage systems under various operational scenarios. This analytical approach not only improves the performance of individual installations but also contributes to the overall optimization of energy resources within a regional grid. Furthermore, the integration of MATLAB with other software tools and programming languages allows for a seamless exchange of data and methodologies among engineers, hydrologists, and environmental scientists [34]. This collaborative environment is essential for addressing the complex challenges associated with the modelling and implementation of pump storage systems, particularly in the context of environmental sustainability and regulatory compliance.

5 | Simulink Software for Modelling and Simulation of PSH

The integration of Simulink in the modelling and simulation of pump storage hydroelectric power systems presents a compelling case for enhancing electricity supply, particularly in the context of increasing demand for renewable energy sources and the need for grid stability [35]. PSH serves as a crucial component in the energy landscape, providing both energy storage and peak load management. The modelling capabilities of Simulink allow for the representation of dynamic systems in a user-friendly environment, which is particularly beneficial for the intricate nature of PSH systems. These systems involve multiple components, including turbines, pumps, reservoirs, and control systems, all of which interact in complex ways [36], [37]. Simulink's graphical interface enables engineers to create detailed models that can simulate the behaviour of these components under various operational scenarios. This capability is essential for understanding how different variables, such as water flow rates and energy demand fluctuations, impact system performance. By employing Simulink, design engineers can conduct simulations that reveal insights into system dynamics, leading to more informed decision-making during the modelling phase [38], [39]. Moreover, the integration of Simulink in the modelling process enhances the optimization of control strategies for PSH systems. Effective control mechanisms are vital for maximizing efficiency and ensuring the reliability of the energy supply. Simulink provides tools for developing and testing advanced control algorithms, such as MPC and fuzzy logic control, which can adapt to changing conditions in real-time [40]. These algorithms can optimize the operation of pumps and turbines, ensuring that energy is stored and released in a manner that aligns with grid demands.

The ability to simulate these control strategies before implementation allows for the identification of potential issues and the refinement of approaches, ultimately leading to improved system performance. Furthermore, the use of Simulink in simulating PSH systems contributes to enhanced risk management and system resilience [41]. As the energy landscape evolves, the integration of variable renewable energy sources, such as wind and solar, introduces new challenges related to grid stability and reliability. Pumped storage systems can act as a buffer, absorbing excess energy during periods of low demand and releasing it during peak demand [42]. By simulating various scenarios, including extreme weather events or sudden changes in energy supply, engineers can assess the robustness of PSH systems and develop strategies to mitigate risks.

6 | Dynamic Simulation Software for Modelling and Simulation of PSH

The integration of DSim in the modelling and simulation of PSHP systems presents a compelling case for enhancing electricity supply, particularly in the context of increasing demand for renewable energy sources and the need for grid stability [43]. PSH serves as a critical component in the energy landscape, providing a means to balance supply and demand through energy storage. The application of DSim in this domain not only facilitates a more nuanced understanding of system dynamics but also enhances the operational efficiency and reliability of PSH systems [44]. One of the major reasons for the integration of DSim in PSH modelling lies in its ability to model complex interactions within the system. Traditional simulation methods often fall short in capturing the dynamic behaviour of hydraulic systems, particularly under varying operational conditions. DSim enables the incorporation of real-time data and advanced algorithms, allowing engineers to simulate transient phenomena, such as water hammer effects, turbine dynamics, and reservoir interactions, with greater accuracy [45]. This level of detail is crucial for optimizing the modelling process of PSH facilities, as it informs decisions regarding turbine selection, reservoir sizing, and operational protocols. Moreover, the integration of DSim enhances the capability to conduct scenario analysis, which is vital for understanding the implications of different operational strategies on system performance [46]. By simulating various load profiles, water inflow scenarios, and market conditions, stakeholders can assess the resilience of PSH systems under diverse circumstances. This predictive capability is significant in the context of increasing variability in renewable energy generation, such as wind and solar power [47]. As these sources become more prevalent, the ability of PSH systems to respond dynamically to fluctuations in supply and demand will be paramount in maintaining grid stability and reliability. However, the complexity of DSim models requires significant computational resources and expertise, which may pose barriers for smaller developers or those in regions with limited access to advanced modelling tools [48]. Additionally, the accuracy of DSim outcomes depends on the quality of input data, necessitating robust data collection and management practices. Addressing these challenges will be essential for realizing the full potential of DSim in the PSH sector.

7 | ANSYS Fluent Software for Modelling and Simulation of PSH

The integration of ANSYS Fluent in the modelling and simulation of pump storage hydroelectric power systems represents a significant advancement in the optimization of electricity supply [49]. The application of Computational Fluid Dynamics (CFD) through ANSYS Fluent offers a robust framework for enhancing the modelling and operational efficiency of these systems, thereby contributing to the overall enhancement of electricity supply. The idea for utilizing ANSYS Fluent in the modelling of PSH systems is grounded in its ability to provide detailed insights into fluid dynamics, which are essential for optimizing the performance of hydraulic components [50]. Traditional modelling methodologies often rely on empirical data and simplified models, which can overlook critical flow phenomena that affect efficiency and reliability. ANSYS Fluent enables engineers to simulate complex flow patterns, turbulence, and pressure variations within the pump and turbine systems [51], [52]. By accurately modelling these interactions, design engineers can identify potential inefficiencies and implement modelling modifications that enhance performance. This capability is particularly crucial in the context of PSH systems, where the efficiency of both the pump and turbine modes directly impacts the overall energy conversion efficiency. Moreover, the integration of ANSYS Fluent facilitates a more iterative and responsive modelling process. The ability to conduct virtual experiments allows for rapid prototyping and testing of various modelling configurations without the need for costly physical models [53]. This not only accelerates the development timeline but also reduces the financial risks associated with modelling failures. However, the complexity and computational demands of CFD simulations can be prohibitive, particularly for smaller projects with limited budgets [54]. However, advancements in computational power and software optimization have significantly mitigated these concerns. The cost of high-performance computing resources has decreased, and cloud-based solutions have emerged, making sophisticated simulations more accessible to a broader range of stakeholders. Furthermore, the long-term benefits of improved modelling and operational efficiency often outweigh the initial investment in simulation technology. As the global energy landscape continues to evolve, the integration of ANSYS Fluent in the modelling and simulation of PSH systems will likely become a standard practice, driven by the imperative to enhance electricity supply and meet the growing demands of a sustainable future [55].

8 | OpenFOAM Software for Modelling and Simulation of PSH

The application of OpenFOAM in the modelling and simulation of pump storage hydroelectric power systems represents a significant advancement in the field of renewable energy engineering [56]. The integration of CFD tools, particularly OpenFOAM, into the modelling and operational analysis of these systems offers a robust framework for enhancing efficiency, reliability, and overall performance. OpenFOAM, an open-source CFD software, provides a versatile platform for simulating complex fluid dynamics phenomena inherent in PSH systems [57]. Its capability to model turbulent flows, heat transfer, and multiphase interactions allows engineers to conduct detailed analyses of the hydraulic behaviour within reservoirs, penstocks, and turbines. One of the primary advantages of employing OpenFOAM in the modelling phase of PSH systems is its ability to facilitate iterative modelling improvements through parametric studies. Engineers can systematically vary modelling parameters, such as turbine geometry, penstock diameter, and reservoir shape, to assess their impact on hydraulic efficiency and energy output [58]. This iterative process not only enhances the system's performance but also contributes to cost reductions by identifying optimal configurations before physical prototypes are constructed.

Furthermore, the visualization capabilities inherent in OpenFOAM enable the effective communication of complex flow phenomena to stakeholders, thereby fostering collaborative decision-making in the modeling process [59]. Moreover, the application of OpenFOAM extends beyond the initial modelling phase into the realm of operational optimization and predictive maintenance. By simulating real-time operational conditions, engineers can identify potential inefficiencies and operational bottlenecks within the PSH system. This predictive capability is particularly valuable in the context of aging infrastructure, where maintenance strategies can be informed by detailed flow analyses [60]. The ability to model and predict the performance of PSH systems under various operational scenarios enhances the reliability of electricity supply, thereby supporting grid stability and resilience. However, the implementation of OpenFOAM in the modelling and simulation of PSH systems is not without challenges. The complexity of the underlying physics, coupled with the need for accurate boundary conditions and material properties, necessitates a high level of expertise in both CFD and hydraulic engineering [61]. Furthermore, the computational resources required for large-scale simulations can be substantial, potentially limiting accessibility for smaller engineering firms or research institutions. Despite these challenges, the benefits of utilizing OpenFOAM in the modelling and simulation of PSH systems far outweigh the drawbacks, particularly as computational power continues to advance.

9 | Comparison of Potential Software for Modelling and Simulating PSH

The selection of appropriate software for modeling and simulating pump storage hydroelectric power systems is critical for optimizing performance and ensuring efficient electricity supply enhancement. Among the various software tools, HOMER and other potential software for modelling and simulating PSH were compared and contrasted (see *Table 1*), to justify the reason for selecting HOMER software as the choice of software for this study.

Table 1. Comparison between HOMER software and other potential software for modelling and simulating PSH.

S/N.	HOMER Software	MATLAB Software
1	HOMER provides built-in algorithms and optimization techniques specifically designed for evaluating the economic and technical feasibility of PSH systems. The Graphical User Interface (GUI) of HOMER allows users to input parameters and visualize results intuitively, thereby streamlining the modelling process. HOMER includes a wide range of pre-defined components, such as various types of pumps, turbines, and energy storage systems, which can be easily integrated into simulations. HOMER's optimization capabilities include hybrid systems, enabling it to identify the most cost-effective configurations for PSH projects.	MATLAB requires users to develop custom scripts and models, which can be time-consuming and may necessitate a deeper understanding of programming and numerical methods. The steep learning curve associated with the programming language of MATLAB can hinder rapid prototyping and iterative modelling. While MATLAB offers flexibility in modelling, it often requires users to source and validate component data independently, which can introduce inconsistencies and errors. MATLAB, while powerful in numerical analysis and simulation, lacks the same level of integrated optimization for hybrid energy systems, often requiring additional toolboxes or custom solutions to achieve comparable results.
	HOMER Software	**Simulink Software**
2	One of the primary advantages of HOMER is its ability to perform economic optimization, allowing users to evaluate the cost-effectiveness of various configurations and operational strategies. Another advantage of HOMER is its user-friendly interface, which facilitates rapid modelling and simulation. Users can easily input parameters, run simulations, and analyse results without extensive programming knowledge. HOMER's ability to model various energy resources and their interactions in a single platform is a significant advantage. It allows for the integration of multiple generation sources, including renewables and storage, which is essential for optimizing the operation of a PSH system. HOMER is a user-friendly interface that facilitates rapid modelling and simulation. Users can easily input parameters, run simulations, and analyse results without extensive programming knowledge.	While Simulink offers robust modelling capabilities, its primary focus is on dynamic system simulation rather than economic optimization. Simulink, while powerful, often requires a steeper learning curve and a more in-depth understanding of system dynamics and control theory, which may hinder its adoption among non-experts in the field. Simulink, although capable of modelling complex systems, often necessitates the integration of additional toolboxes and external libraries to achieve similar functionality, potentially complicating the modelling process and increasing the time required for simulation. The flexibility of Simulink in terms of customization and integration with other MATLAB tools is noteworthy. It allows for the development of tailored algorithms and the incorporation of real-time data, which can enhance the simulation accuracy. However, this flexibility comes at the cost of increased complexity, which may not be necessary for the straightforward economic analysis required in PSH modelling.
	Dynamic Simulation (DSim) Software	**HOMER Software**
3	HOMER software offers a user-friendly interface that facilitates the modelling of complex hybrid energy systems, including pump storage hydroelectric power. One of its primary advantages is its ability to perform optimization analyses, allowing users to evaluate multiple configurations and operational strategies simultaneously. HOMER can identify the most cost-effective solutions based on a variety of input parameters, including capital costs, operational expenses, and resource availability.	DSim, while powerful in its DSim capabilities, tends to focus more on the transient behaviour of systems rather than on optimization. This limitation can hinder its effectiveness in scenarios where economic considerations are as crucial as technical performance. DSim excels in modelling the intricate dynamics of fluid systems and can provide detailed insights into the operational characteristics of pump storage systems. However, its complexity often necessitates a steeper learning curve, which may deter less experienced users from fully leveraging its capabilities. DSim which may require users to develop custom models for specific components, thereby increasing the time and effort needed to conduct simulations.

Table 1. Continued.

	HOMER Software	Dynamic Simulation (DSim) Software
	HOMER's capacity to integrate renewable energy sources alongside traditional generation methods enhances its applicability in contemporary energy systems, which increasingly prioritize sustainability. Another notable advantage of HOMER is its extensive database of component models, which allows for rapid prototyping and scenario analysis. HOMER's robust reporting and visualization tools enable users to present their findings in a clear and comprehensible manner.	DSim, while capable of producing high-fidelity simulations, may not offer the same level of accessibility in terms of results presentation, potentially limiting its utility in collaborative environments where communication is key. DSim's flexibility in modelling allows for a more nuanced exploration of system dynamics, which can be advantageous in specific research contexts.
	HOMER Software	**ANSYS Fluent Software**
4	HOMER is designed to evaluate the economic feasibility and operational efficiency of various energy systems, including pump storage hydroelectric power. HOMER software is also designed to be accessible to users with varying levels of expertise, enabling engineers and project managers to quickly input data and interpret results without extensive training. In terms of simulation capabilities, HOMER excels in its ability to model hybrid systems that incorporate multiple energy sources and storage options. HOMER's ability to conduct lifecycle cost analysis is crucial for long-term project sustainability. This feature allows users to evaluate not only the initial capital costs but also the operational and maintenance expenses over the system's lifespan. Despite its advantages, it is important to acknowledge the limitations of HOMER. For instance, while it excels in economic modelling, it may not offer the same depth of fluid dynamics analysis as ANSYS Fluent.	ANSYS Fluent, while powerful for fluid dynamics simulations, lacks the same level of economic modelling capabilities. This limitation can hinder decision-making processes when evaluating the overall feasibility of a pump storage project. The complexity of ANSYS Fluent can lead to longer project timelines and increased costs associated with training and expertise development, making HOMER a more efficient choice for teams aiming to expedite project development. ANSYS Fluent, while capable of simulating fluid flow and heat transfer, does not inherently support the optimization of hybrid energy systems, limiting its applicability in scenarios where multiple energy sources must be considered. ANSYS Fluent primarily focuses on the technical aspects of fluid dynamics, which may not provide the holistic view required for long-term economic planning. Complex flow phenomena, such as turbulence and transient flow conditions, can be more accurately captured using ANSYS Fluent's advanced CFD capabilities.
	HOMER Software	**OpenFOAM Software**
5	HOMER software allows engineers and researchers to efficiently set up simulations without extensive programming knowledge. Another significant advantage of HOMER is its robust optimization capabilities. The software employs sophisticated algorithms to evaluate multiple scenarios and configurations, enabling users to identify the most cost-effective and efficient modelling for pump storage systems. HOMER’s ability to incorporate various energy sources and storage options into a single model enhances its versatility. This is particularly advantageous for pump storage hydroelectric systems, which often need to integrate with other renewable energy sources, such as solar or wind, to maximize efficiency and reliability.	OpenFOAM, while powerful and highly customizable, requires a steep learning curve due to its reliance on programming and CFD principles. This complexity can hinder the efficiency of the modelling process. OpenFOAM, while capable of detailed simulations, lacks the same level of integrated optimization tools, often necessitating additional software or manual calculations to achieve similar results. OpenFOAM, although capable of simulating fluid dynamics in detail, does not inherently provide the same level of integration for diverse energy resources. This limitation can complicate the modelling process and detract from the holistic understanding necessary for effective system modelling.

Table 1. Continued.

HOMER Software	OpenFOAM Software
The streamlined optimization process in HOMER can lead to faster decision-making and implementation timelines. HOMER's focus on system-level optimization and economic analysis provides a more pragmatic approach for engineers seeking to enhance electricity supply through pump storage hydroelectric systems.	OpenFOAM does offer certain advantages that cannot be overlooked. Its open-source nature allows for extensive customization and flexibility, enabling users to tailor simulations to specific needs. OpenFOAM excels in handling large-scale simulations and complex geometries, making it a powerful tool for detailed analysis of fluid dynamics in pump storage systems. However, for the purpose of initial modelling and optimization, the detailed CFD capabilities of OpenFOAM may be excessive.

From the comparison on potential software for modelling and simulating PSH in *Table 1*, HOMER software has obviously emerged as a better choice for the modelling and simulation of Pump Storage Hydroelectric Power systems aimed at enhancing electricity supply. Its focus on economic optimization, user-friendly interface, comprehensive component library, lifecycle cost analysis, practical reporting tools, and versatility in modeling diverse energy resources, as well as integrated modeling capabilities, align closely with the primary objectives of PSH system modeling outlined in this study. Moreover, the ability to balance technical performance with economic considerations is paramount in today's energy landscape, and HOMER's modelling aligns more closely with these critical objectives [62].

10 | Conclusion

With a focus on HOMER software, this study offers a critical assessment of popular smart tools for modelling and simulating PSHP systems. The analysis shows that HOMER remains unique owing to its integrated economic optimization, user-friendly interface, and capacity to model hybrid energy systems. Additionally, HOMER optimizes the modelling process, allowing for quick scenario analysis, in contrast to MATLAB and Simulink, which demand extensive experience. While it provides a thorough transient analysis, DSim is not exceptionally effective at economic evaluation.

Although they provide high-fidelity fluid dynamics simulations, ANSYS Fluent and OpenFOAM tend to be less useful for comprehensive project feasibility evaluations. The lifecycle cost analysis, pre-defined component library, and smooth integration of renewable energy sources are some of HOMER's strengths. It is highly effective in optimizing PSHP systems for sustainable energy projects due to these features. Furthermore, this research study emphasizes the importance of selecting software tools that strike a balance between technical precision and financial feasibility. For engineers and researchers looking to improve the supply of electricity using PSHP systems, HOMER offers the best option. For more thorough studies, future research should investigate hybrid approaches that combine sophisticated fluid dynamics tools with HOMER's economic modelling. Ultimately, our research promotes the adoption of sustainable energy solutions by enabling stakeholders to make informed decisions.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

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