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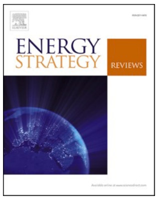

Techno-economic impact analysis for renewable energy-based hydrogen storage integrated grid electric vehicle charging stations in different potential locations of Malaysia

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ABSTRACT

This study investigates the techno-economic impacts analysis of renewable energy-based hybrid energy storage system integrated grid electric vehicles charging station (EVCS) in Malaysia. Focusing on three potential locations namely Pulau Pinang, Johor Bharu and Kuala Terengganu, the research aims to address the increasing electricity demand from the expanding electric vehicle (EV) infrastructure while mitigating grid instability issues caused by sudden load surges, increased electrical losses, and overload of high voltage devices that leads to power quality issues. Using the HOMER Pro platform, the study models and optimises an EVCS configuration-based hybrid energy storage system that incorporates renewable energy sources (RES) such as photovoltaic (PV), wind turbines (WT), lithium-ion (Li-ion) batteries, hydrogen (H_2) tank, fuel cell (FC) and electrolysers considering various geographical and meteorological conditions. The hybrid energy storage configuration offers a long-term energy storage solution, surpassing current batteries' capabilities while providing a stable electricity supply for a sustainable EVCS system. The results demonstrated favourable outcomes, with the total Net Present Cost (NPC) ranging from $1.4 million to $3.4 million across all locations, and the Cost of Energy (COE) ranging from $0.03/kWh to $0.16/kWh. These findings suggest that the optimization methodology is adaptable for implementation in diverse locations with different meteorological conditions. This innovation is beneficial for developing renewable-based EVCS infrastructures, which can support economic growth in Malaysia. In addition, the study emphasizes the necessity of advanced control algorithms to manage power quality issues during peak demand and suggests future field trials to validate the system's real-world performance. Additionally, the optimized EVCS-based hybrid energy storage system contributes to reducing carbon dioxide (CO_2) emissions, promoting a cleaner environment and an eco-friendly energy ecosystem.

1. Introduction

Recently, the exponential growth in sustainable energy usage and reducing GHG emissions has triggered an increase deployment of EVs. In the power sector, the adoption of RES is pivotal in addressing these emission challenges and advancing the agenda of grid decarbonization [1]. Meanwhile, Electric Vehicles (EVs) adoption can reduce emissions in the transportation sector which provides low or no carbon sources [2]. Thus, the global adoption of EVs deserves exorbitant attention nowadays which can reduce traffic congestion and contribute to a healthier living environment [3,4].

As per the findings of the International Energy Agency (IEA), the global EV fleet has witnessed remarkable growth, surging from 7.2 million in 2019 to an impressive 10 million by the year 2022. This

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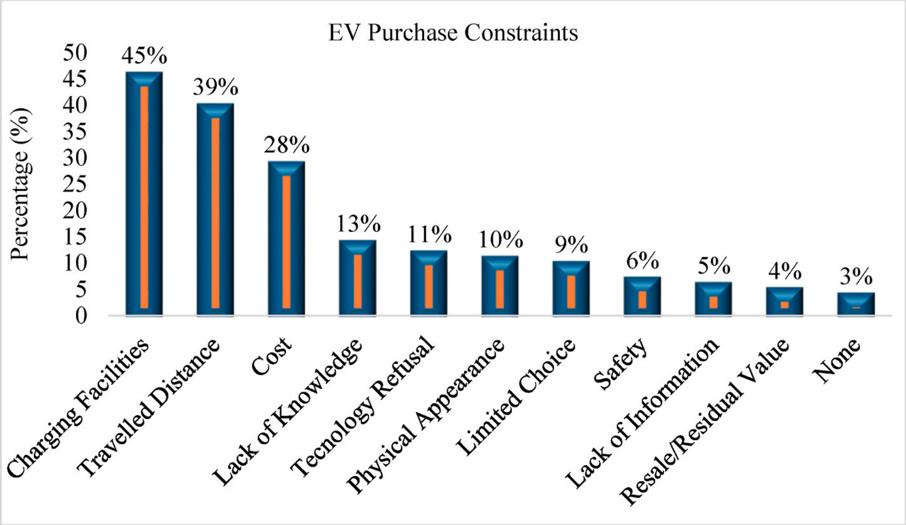
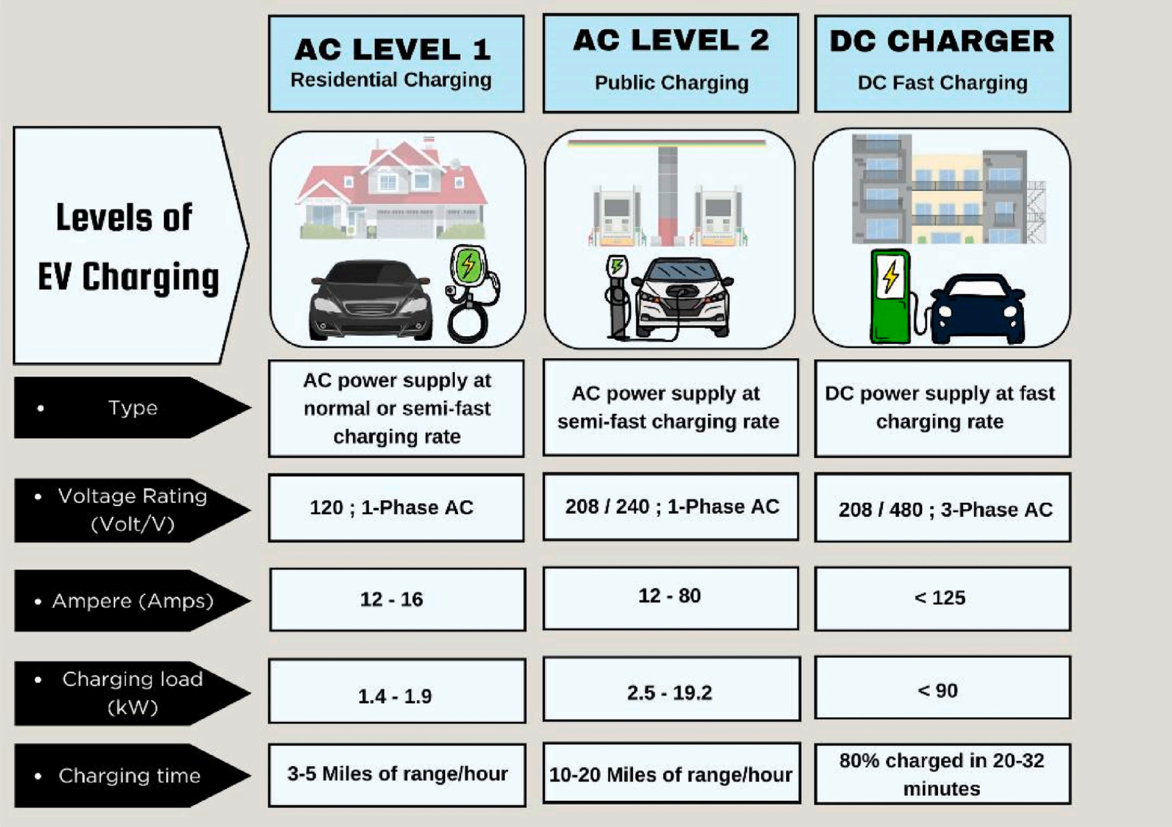


Fig. 1. The possible constraints of purchasing an EV mobility [12].



Levels of EV Charging	AC LEVEL 1 Residential Charging	AC LEVEL 2 Public Charging	DC CHARGER DC Fast Charging
• Type	AC power supply at normal or semi-fast charging rate	AC power supply at semi-fast charging rate	DC power supply at fast charging rate
• Voltage Rating (Volt/V)	120 ; 1-Phase AC	208 / 240 ; 1-Phase AC	208 / 480 ; 3-Phase AC
• Ampere (Amps)	12 - 16	12 - 80	< 125
• Charging load (kW)	1.4 - 1.9	2.5 - 19.2	< 90
• Charging time	3-5 Miles of range/hour	10-20 Miles of range/hour	80% charged in 20-32 minutes

Fig. 2. Different types of charging infrastructure for EVs application to represent the current status of EVCS technology [17].

upward trajectory is projected to continue, with an anticipated increase of around 14 million EVs in the year 2023 [5]. Thus, this achievement can potentially provide a clear pathway to the target of Net Zero Emission in 2050 from the transportation sector that is in line with CO_2 emission reduction and an eco-friendly environment [6]. To further facilitate the global expansion of EVs, EVCS play a pivotal role in providing affordable and environmentally friendly electricity sourced from both the grid and renewable energy resources [7]. The widespread availability of EVCS ensures that users can embark on long-distance journeys with the assurance of convenient access to charging facilities [8]. Despite the potential future reduction in EV costs, the primary barrier preventing the widespread adoption of EVs is the scarcity of charging station (CS) and the limited range per charge as illustrated in Fig. 1. Hence, the establishment of a dependable and adequate CS infrastructure is imperative to efficiently cater to the growing demand for EV charging while upholding grid stability and economic viability.

The unstructured deployment of EVCS poses technical and economic challenges, such as harmonic interference, voltage irregularities, and increased peak load demand, destabilizing the grid [9–11]. During low solar generation, the BESS are vital but limited by their energy density.

Table 1
Current related literature study based on hybrid energy storage system for EVCS infrastructure.

Ref.	Year	Hybrid design	Methods	Aims	Advantages	Research Gap
[19]	2023	PV, WT, BESS	Demand response (DR) program, Fuzzy-neural network, PSO.	• Optimal energy management strategy of RES and EV load to mitigate the uncertainty behaviour for efficient fast CS operation considering economic analysis and power quality issues.	• Provide essential scheduling energy consumption while minimizing the RES imbalance to the CS for efficient operation and flexibility.	• Complex formulation of objective function considering wind speed prediction and DR. • Entertaining multiple system constraints that consist in the first and second structures of the model.
[20]	2023	PV, BESS, WT,	Techno-economic analysis based on modified salp swarm optimization.	• Investigate the technical and financial viability of grid and RES-powered energy systems for an environmentally sustainable EVCS in India for efficient operation.	• Optimum RES-powered energy system-based PV, WT and grid with the least COE production and optimum sizing configuration.	• Lack of environmental analysis and BESS impact on the EVCS. • Potential H_2 generation for excess energy generation is not considered.
[21]	2023	WT and H_2,	HOMER optimization.	• Optimal configuration of hybrid CS for fuel cell (FC) vehicles operation based on grid-connected WT system and off-grid operation for efficient operation optimum H_2 production.	• Maximized the green H_2 production-based grid-connected and stand-alone WT generation for refueling FC vehicles operation.	• The PV generation integration are not considered which potentially gives a beneficial impact to the system. Lack of detailed H_2 production and FC generation explanation.
[22]	2023	PV and H_2	MPC based method for minimizing the penalty cost of EMS strategy of electric-hydrogen CS.	• An EMS strategy for multiple electricity-hydrogen integrated CS for efficient operation and optimal coordination which considers technical and economic viability parameters.	• Meeting the electric and H_2 demand simultaneously based on coordinated multiple electric-hydrogen integrated CS while minimizing the cost.	• Complex formulation and system constraints on the EMS strategy. Lack of impact of the BESS on the system towards maximizing the RES utilization for efficient EVCS operation.
[27]	2022	PV, BESS, WT, H_2	HOMER optimization	• Optimal capacity configuration of the upstream hybrid energy system to provide green H_2 and power based on the RES production considering economic feasibility towards carbon emission reduction.	• Integrative techno-economic analysis study on the green methanol plant generated by excess H_2 production based RES generation considering carbon tax.	• Higher COE analysis produced by the system with methanol production and the impact of economies of scale on the analyzed system is not readily apparent in this study.

To address these issues, incorporating H_2 technology into a hybrid energy storage system provides a long-term solution, enhancing capacity beyond traditional batteries. Integrating RES with a hybrid energy storage system in EVCS infrastructure ensures reliable power, reduces costs, and alleviates grid strain, positioning EVCS as a sustainable alternative to traditional gas stations.

1.1. Literature review

The transportation sector is experiencing three major transformations: the rise of autonomous vehicles, the growth of shared mobility services, and the widespread adoption of electrification. Consequently, the development of EV charging infrastructure must account for the synergies and benefits of these advancements. With the increasing popularity of EVs, there will be a significant rise in electricity demand on the power grid that lead to complex congestion which necessitates infrastructure upgrades [13,14]. Fig. 2 illustrates the different levels of charging available at EV charging stations. According to the literature, residential charging facilities are the most popular and essential option compared to other charging locations for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). Therefore, to establish an efficient charging infrastructure, it is crucial to implement a robust communication network for seamless data exchange, an optimization unit to reduce charging duration at stations, and a prediction unit to enhance the optimization process through informed decision-making, thereby improving reliability [15,16].

In [18], a fast CS was investigated in Canada that considered four scenarios combining nuclear, renewable, and diesel-based generation. The nuclear-renewable-based hybrid system emerged as the most cost-effective with a COE of $0.26 per kWh and zero emission. However, the study remained limited to techno-economic analysis, neglecting critical sustainability factors such as environmental impact. Another study introduced a novel framework using a fuzzy-neural network and particle swarm optimization (PSO) algorithm for fast CS strategy-based RES. This framework aims to reduce power quality issues while considering investment costs [19]. Additionally, the design of stand-alone CS-based RES generation of photovoltaic (PV), wind turbine (WT), biodiesel, BESS, and H_2 are presented to achieve an optimal EVCS configuration taking into account the metrological condition of the site study [10]. The result showed satisfactory performance with the desired capacity of the source and positive economic analysis for various locations in Qatar. A techno-economic analysis for three Indian sites explores four configurations that integrate the grid, PV, WT, and BESS as outlined in Ref. [20]. The results reveal that the configuration encompassing all available components proves to be the most cost-effective across all sites, yielding a COE ranging from $0.0051 to $0.0468 per kilowatt-hour ($/kWh). However, it is noted that the study, despite its consideration of integrating RE sources, lacks a comprehensive comparison of optimal configurations. Crucially, sustainability indices such as land usage, payback period, and CO_2 emissions are overlooked in the selection process, highlighting the need for a more thorough assessment.

In reference [21] an optimized hybrid refueling CS configuration based on three WT configurations with a storage device was developed using HOMER software for efficient H_2 production of FC vehicles in Oman. The findings indicate that the grid-connected WT is optimal, achieving the lowest Cost of Hydrogen (COH) at 6.24 €/kg. However, the study overlooks the potential of PV integration, which could potentially enhance the system's effectiveness. Additionally, in Ref. [22] a model predictive control (MPC) method was also used to minimise the penalty cost of the energy management system (EMS) strategy of the electric-hydrogen CS unit. The study focused on a singular design, lacking a comprehensive assessment of various design configurations for optimal hybrid EVCS selection. Furthermore, research in Ref. [23] presented a techno-economic analysis of solar PV CS for security bikes in Pakistan to analyzes the power reliability, energy cost, and CO_2 emissions. However, it's worth highlighting that the profitability index and internal rate of return were not included as factors in this particular study, which are aspects of considerable importance for the economic viability of EVCS infrastructure. Furthermore, overlooking other impacts such as battery lifecycle issues and variability in solar energy production is not thoroughly analyzed, which can potentially affect system reliability.

A recent study has explored the integration of RES with EVCS configuration that is supplemented by green H_2 production using techno-economic analysis [24]. This study estimates energy production from PV and WT systems, implements an energy dispatch strategy to manage the excess energy and uses PEM electrolyzers for H_2 production. The levelized cost of energy (LCOE) and renewable fraction (RF) with optimization technique namely Pareto Search Algorithm in Matlab is used to determine optimal configurations. However, limitations such as scalability, and high initial cost need a further extension of research to validate these systems' feasibility and economic viability. Similarly, in Ref. [25], a techno-economic analysis was conducted for off-grid EVCS generation, utilizing RES and H_2 production. This analysis considered the levelized cost of hydrogen (LCOH) production across five different cities in India, employing HOMER Pro optimization. It's worth noting that the total electricity generated by the proposed EVCS configuration amounted to 25 GWh, resulting in 20,744.07 metric tons of CO_2 emissions. The economic output and environmental impact varied across cities due to the differing configuration capacities for each energy source and local climate conditions. In a similar vein, reference [26] focused on H_2 production for fertilizer manufacturing and its environmental performance. The study applied multi-criteria decision-making approaches to determine an optimal system configuration for the hybrid energy system in rural northern Ghana.

It is clear that numerous studies have been undertaken in various countries to evaluate the impact of integrating multiple energy-generating systems considering technical and economic evaluation performance. These investigations aim to analyze the impact of both H_2 and electricity production to obtain an optimum configuration and operation of the EVCS system. Table 1 summarized the current related literature study in the domain of EVCS infrastructure to ensure optimal system operation. Future research should aim to address these gaps by conducting more holistic evaluations of hybrid energy storage systems, incorporating environmental impact assessments, and exploring the full potential of BESS and H_2 integration in EVCS infrastructure.

1.2. Novelty and contribution

The optimal solutions that were sought in the above literature were optimal in terms of minimizing cost and operation. As H_2 technology matures further, which major energy carrier that is expected to play a major role in the world's quest for sustainable energy development, it is necessary to explore the full potential of BESS and H_2 integration in EVCS infrastructure. The large amount of excess electricity from the system can able to store in the H_2 tank and generated for future utilization providing long-term energy storage solutions while exceeding today's battery capacity [28]. Moreover, a large capacity of BESS is required for the battery to store the excess RE production from the systems to ensure a long-hour discharging process. This phenomenon leads to a high cost of investment and a huge land area requirement to accommodate such a storage system. In addition, H_2 produced from the water electrolysis within the energy systems play an important role in achieving net-zero emissions targets in the European economy. This approach is in line with Malaysia's policy target of producing 10,000 EVCS by the year 2025 to achieve an eco-friendly environment and carbon footprint reduction [29].

To ensure the resilience and stability operation of renewable energy generation, this study introduces a hybrid energy storage system comprising H_2 and lithium-ion (Li-ion) batteries for EVCS. The primary goal is to establish a dependable electricity supply while reducing CO_2 emissions and mitigating load peak conditions. This system integrates controllable, self-generated PV and WT systems to both provide electricity and charge the Li-ion battery. This approach effectively counters grid fluctuations and enhances overall profitability. In addition, a FC with regenerative power capacity and a H_2 storage system, known for their notably high energy density, are independently configured within the system. H_2 systems use electrolyzers to produce and store H_2 tank during excess energy and to provide it to EVCS using FC at energy scarcity. The study's objective is to develop an innovative techno-economic methodology that identifies the optimal site-specific EVCS configuration and evaluates its environmental impact to meet charging demands efficiently. The research also involves the integration of RES with the EVCS charging infrastructure, along with an operational strategy, and an economic analysis. The optimization process is conducted through modelling and simulation using HOMER Pro software in three Malaysian cities, considering diverse geographical and meteorological conditions. The primary objective of this research is to address the potential power demands of three distinct locations in Malaysia while assessing the feasibility of H_2 generation for EV applications. By adopting this approach, valuable insights can be gained into enhancing the reliability of EVCS infrastructure, aiding policy and decision-makers in effective planning. Furthermore, the study incorporates socioeconomic and environmental impact analyses to evaluate the cost implications and CO_2 emissions associated with different configurations. This holistic approach aims to achieve optimal sizing and configuration of EVCS, ensuring efficient operation, grid stability, emission reduction, and economic viability. The key contributions of this study include.

- A novel hybrid energy storage system combining H_2 and Li-ion batteries capable of reliably meeting daily EV charging demands to provide a long term energy storage system.
- An effective methodology for evaluating the optimal techno-economic configuration and operational strategy of hybrid energy storage solution for EVCS charging infrastructure.
- Modelling, simulating, and optimizing the proposed hybrid energy storage system of EVCS using technical and economic data from integrated components and location-specific meteorological inputs to evaluate the cost-effectiveness and technical feasibility in the configuration.
- A sensitivity analysis to evaluate the robustness of the chosen configuration when subjected to various uncertain factors.
- Provide useful suggestions and effective recommendations for future developments of EVCS infrastructures for discovering the potential direction and growth of EV utilization.

1.3. Research gap

Based on the literature reported above, Li-ion batteries and H_2 are considered suitable solutions for electric energy storage. However, there is a noticeable gap in comprehensive comparisons between these two technologies, particularly regarding their integration with RE source in EVCS infrastructures. The hybrid energy storage system technology that incorporates H_2 is still under investigation, especially in Malaysia where the H_2 technologies are in the early stage of research and developments [30,31]. In the power sector, H_2 can help balance the variability of RE sources by storing surplus energy and providing long-term storage solutions. It also offers flexibility to the grid and compensates for the reduction in fossil fuel use as well as reducing in GHG emissions. Several shortcomings have been identified in the existing literature on hybrid energy storage systems for EVCS, particularly those integrating both H_2 and Li-ion batteries. Most studies lack a detailed representation of the H_2 supply-demand chain that result in inadequate depiction of the systems operation. Critical aspect such as RE integration, carbon capture, utilization, hybrid system, and socio-economic impact are often neglected, especially in the context of Malaysia. Additionally, many studies consider only limited design options without thoroughly analyzing all possible configurations and components to assess the impact of a hybrid energy storage system. For example, the operation of H_2 generated by excess RE can be used to meet EVCS demand over extended periods, but this potential is not fully explored. Furthermore, the integration of hybrid energy storage system that combine both H_2 and Li-ion battery technologies is still limited. Most studies focus on the optimal sizing of components for efficient system operation but do not fully explore the

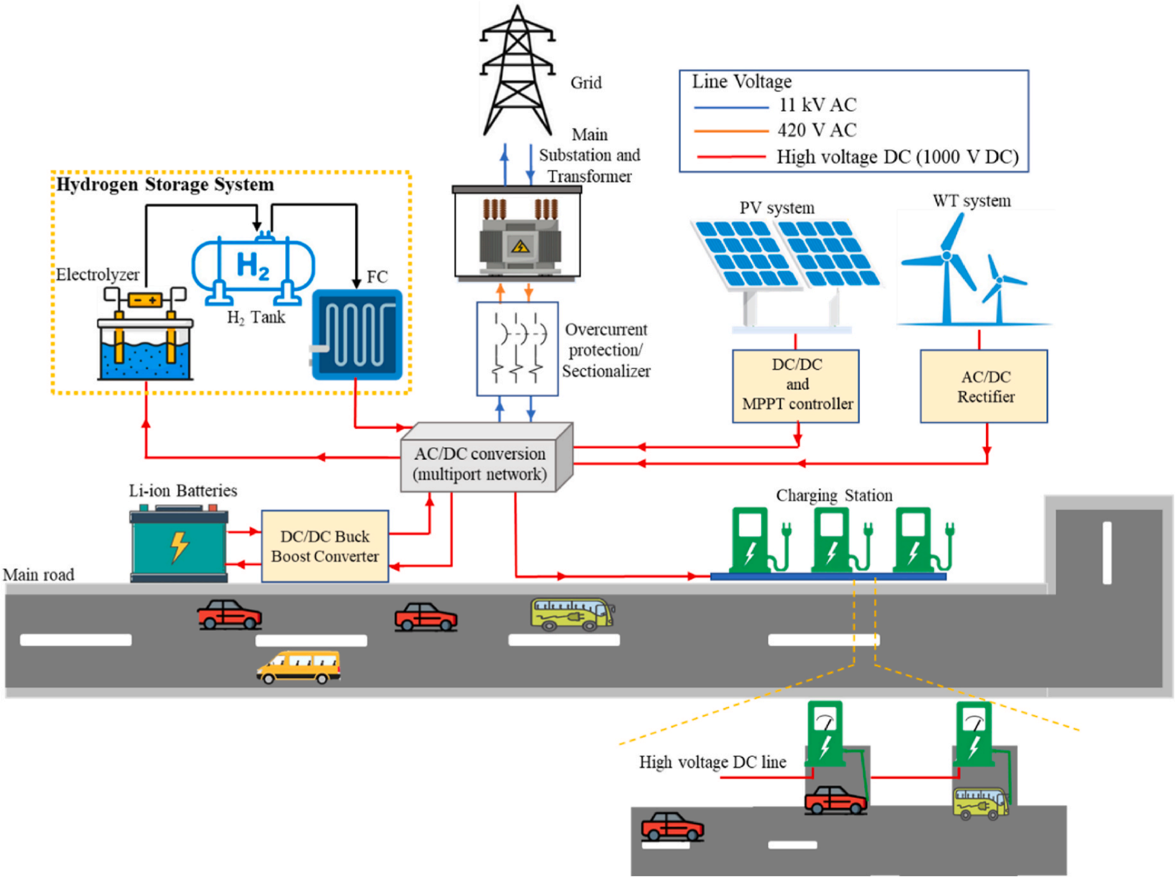


Fig. 3. An overview of the EVCS configuration-based hybrid energy storage system including H_2, Li-ion battery and RES penetration.

potential benefits of integrating both technologies. Although the penetration of BESS has provided a significant improvement in the recent systems to compensate for the shortage of electricity generation due to its fast dynamic response, however low energy density and short storage times remain major issues. These gaps highlight the need for more comprehensive studies that address a wider range of factors and configurations to optimize the integration of hybrid energy storage system in EVCS infrastructures.

1.4. Main objective and scope of the study

As previously noted, the EV manufacturing sector emerges as a prominent industry in South Asian nations, representing the future of the automotive landscape with a focus on minimizing carbon emissions. To expedite the proliferation of EVs in Malaysia, an ambitious goal has been established, aiming to attain a 15 % market share for eco-friendly vehicles by 2030. Additionally, by 2025, the target is to establish 10,000 CS. These objectives align with a comprehensive energy transition policy, underscoring the nation's commitment to widespread e-mobility adoption. The scope of this study is to develop an optimal EVCS-based hybrid energy storage system configuration considering the site-specific condition and environmental impact to generate the required charging demand efficiently. The study focused on the development and optimization of an EVCS-based hybrid energy storage system of H_2 and Li-ion batteries to achieve a stable electricity supply with a reduction in CO_2 emission and load peak condition. Three different locations in Malaysia were considered in this study to evaluate the optimal site-specific EVCS configuration and environmental impact to generate the required charging demand using HOMER Pro software optimization. In addition, the article explored the incorporation of RES into the hybrid EVCS, as well as an operational strategy. This comprehensive technique was used to comprehensively examine the system's socioeconomic and environmental implications. The specific objective of this study can be summarized as follows.

- To design and develop an EVCS-based hybrid energy storage system of H_2 and Li-ion batteries a stable electricity supply with a reduction in CO_2 emission and load peak condition.
- To develop a hybrid energy storage system based on EVCS structure that incorporates H_2, Li-ion battery, and FC as multiple sustainable energy storage alternatives to ensure uninterruptable charging operations during the unavailability of RES generation.
- To optimize the EVCS-based hybrid energy storage system for three different selected locations in Malaysia to ensure the system's efficiency and reliability.
- To analyze the developed EVCS configuration and assess the technical and economic feasibility of the overall system for optimal operation considering various geographical locations and metrological conditions.

1.5. Research alignment

This study introduces a hybrid energy storage system comprising H_2 and Li-ion batteries for EVCS to ensure resilient and stable renewable energy generation. The system consists of a self-generated PV and WT system, Li-ion battery, H_2 tank, FC and electrolyzer as well as a system converter to provide dependable electricity, reduce CO_2 emissions, and mitigate peak load conditions. An FC and H_2 storage system, with high energy density, is used to manage excess energy and supply during scarcity. The study's objective is to develop a techno-economic methodology for optimal site-specific EVCS configuration, considering environmental impact, using HOMER Pro software in three Malaysian cities.

The EVCS system is run based on the three different potential locations in Malaysia namely Pulau Pinang, Johor Bharu, and Kuala Terengganu to verify the effectiveness of the proposed configuration. The developed EVCS model was simulated and designed through HOMER Pro software with integrated real resource assessment and load requirements. This research evaluates potential power demands, and H_2 generation feasibility, and incorporates socioeconomic and environmental analyses to aid policy and decision-makers in enhancing EVCS infrastructure.

The remainder of this paper is organized as follows: Section 2 presents the details configuration and actual specification of the different system components of EVCS development. Section 3 discussed the H_2 energy production-based generation including a conceptual framework for EVCS configuration. The explanation of objective function, operational constraints, economic and environmental formulation and resources used for the development of optimal EVCS system is performed in section 4. The main findings and discussion are summarized in section 5. Finally, conclusive remarks are given in section 6.

2. System specification and configuration

The proposed hybrid energy storage system for the EVCS encompasses several components, including a PV and WT system, an electrolyzer, an FC, a Li-ion batteries, a system converter, and an H_2 tank. The visual representation of this EVCS configuration can be found in Fig. 3. In line with the tariff schedule in Malaysia, two rates were considered: \$0.10 as the purchasing price and \$0.30 as the selling price for grid power. This was done to evaluate the cost of grid power consumption. The H_2 required for the FC operation is produced using an electrolyzer, with the generated the H_2 stored in an H_2 tank. The proton exchange membrane (PEM) type of electrolyzer is chosen in this study that driven by energy harnessed from the RES, facilitating the electrolysis process to generate H_2 and oxygen molecules [32]. The PEM technology is distinguished by its rapid dynamic response, rendering it highly suitable for integration with variable RES generation. The electrolysis process decomposes the water into H_2 and oxygen based on the electrical current which circulate between two electrodes immersed in the water and separated by non-electrical conducting material. By using the reversible process called FC, the electricity can be generated from the production of H_2. The surplus production of the H_2 are then conveyed to the H_2 tank for future utilization [33]. An inverter is employed to facilitate the DC to AC signal conversion. The hybrid renewable energy system, comprising solar PV/FC and Li-ion battery, is directly linked to the DC bus. This direct connection facilitates the transfer of energy from the distribution side generation to the inverter. Additionally, the DC bus serves the purpose of meeting the energy requirements of the electrolyzer for H_2 generation. Further details regarding the modelling of the system's components are elaborated upon in the subsequent section.

2.1. Solar PV module

Within the PV system, there is an integrated DC-DC boost converter designed to align the PV voltage with the DC bus system seamlessly. Typically, the generation of electricity from PV panels relies heavily on the level of solar radiation in the chosen location. Through precise alignment of the panel's tilt angle and orientation to capture sunlight effectively, the PV system can harvest a sufficient amount of energy [34]. In this study, the Peimar SG310MBF type of PV module was chosen with a capital cost of \$2650.00, a \$2500.00 replacement cost, and a lifetime is 25 years with 19.1 % efficiency. Hence, HOMER Pro was employed to optimize the selected PV system and calculate its output power using the following formula [35]:

$$P_{PV} = V_{PV} \times i_{PV} \times Z_{PV} \tag{1}$$

where V_{PV} (V), i_{PV} (A) and Z_{PV} are the voltage, current and number of PV modules, respectively. The hourly production for the PV output generation is calculated using Eq. (2).

$$P_{PV} = Y_{PV} f_{PV} \left[\frac{G_T}{G_{T,STC}}\right] \times \left[1 + \alpha_p \left(T_C - T_{C,STC}\right)\right] \tag{2}$$

where Y_{PV} represented rated capacity in (kW) and f_{PV} is the PV derating factor in (%). The G_T and $G_{T,STC}$ are the solar radiation incident on the PV array in (kW/m^2) and at standard test conditions in (1 kW/m^2), respectively. The α_p, T_C and $T_{C,STC}$ is the temperature coefficient, PV cell temperature and cell temperature at standard test conditions (25 °C), respectively.

2.2. WT system

Incorporated into our proposed design is a WT system, strategically positioned to complement the PV system during nighttime and overcast days. This WT system assumes the role of the secondary energy generator within the overall system, catering to the electricity needs of the EVCS and H_2 production [32]. Energy is harnessed from the wind through the employment of a horizontal axis wind turbine. Notably, this subsystem offers a significant advantage over the CPV/T system, as it retains the capability to generate electricity even during nighttime, provided the wind speed remains within the desired parameters. Hence, the Leitwind86 (1 MW) WT system was selected for this study, featuring a rated speed of 11 m/s, capital cost of \$1,300,000.00, \$1200.00 replacement cost and a lifetime is 25 years [36]. The wind speed of the WT system at hub height conditions can be calculated using the following Eq. (3) [37]:

$$U_{hub} = U_{anem} \times \left[\frac{Z_{hub}}{Z_{anem}}\right]^{\alpha} \tag{3}$$

where U_{hub} is the wind speed (m/s), U_{anem} is the wind speed at anemometer height (m/s), Z_{hub} and Z_{anem} are the hub height of the WT (m) and the anemometer height (m). Moreover, the α is denoted as the power-law exponent.

In this study, the WT model is presumed to encompass a combined loss factor of 2.3 %, incorporating 0.3 % for turbine availability and turbine performance losses, and 0.5 % for environmental losses, wake effect losses, and electrical losses, respectively. The calculation for the WT system's output power is as follows:

$$P_{wt} = \left(\frac{\rho}{\rho_o}\right)^{\alpha} \times \rho_{wt,STP} \tag{4}$$

where P_{wt} is the WT output power and $\rho_{wt,STP}$ is the WT output power at standard temperature and pressure. The ρ is the actual air density in (kg/m^3) and ρ_o is the air density at standard temperature and pressure at (1.225 kg/m^3). Compared to other RES options, the construction time is short for the WT system implementation [38]. Globally, the efficiency of WT has increased recently whereas the cost has reduced.

2.3. Battery storage system

The battery storage system plays a vital role in stabilizing the fluctuations of the PV and WT systems in response to load variations. It is recognized as a pivotal component in numerous application systems, capable of regulating system voltage and frequency, and providing power to the load in the event of a power supply shortage from the RES system [39]. When the power generated by the RES system exceeds the current load demands, surplus energy is intelligently stored within the BESS for future utilization. In this research, a conventional 100 kWh Li-ion battery was specifically chosen for its noteworthy energy density and prolonged operational lifespan. The associated costs, encompassing a capital investment of \$7000.00 and an annual replacement budget of \$100.00, were meticulously considered [40,41]. The projected operational longevity of the battery system was conservatively estimated at 15

Table 2
The techno-economic data and specification for the EVCS configuration used in the optimization model.

System component	Value	References
PV unit (Peimar SG310MBF)		[25,43,44]
Rated capacity (kW)	1	
Capital cost ($/kW)	2650	
Replacement cost ($/kW)	2500	
Operation and maintenance ($/yr)	10	
Derating factor (%)	80	
Efficiency (%)	19.1	
Lifetime (yr)	25	
Li-ion Battery (Generic 100 kWh Lithium Ion)		
Nominal voltage (V)	600	
Nominal capacity (kWh)	100	
Maximum capacity (Ah)	167	
Roundtrip efficiency ($)	90	
Maximum charging current (A)	167	
Minimum state of charge (%)	20	
Capital cost ($/unit)	7000	
Replacement cost ($/unit)	100	
Operation and maintenance ($/yr)	100	
Lifetime (yr)	15	
WT system (Leitwind86)		
Rated power (kW)	1000	
Capital cost ($/kW)	1,300,000	
Operation and maintenance ($/yr)	1200	
Lifetime (yr)	25	
Hub height (m)	80	
Rotor diameter (m)	52.9	
Blade number	3	
Cut-out wind speed (m/s)	28–34	
Converter (Dynapower SPS-100)		
Efficiency (%)	95	
Lifetime (yr)	15	
Capital cost ($/kW)	347	
Replacement cost ($/kW)	315	
Operation and maintenance ($/yr)	7	

years. The energy ($E_{Battery}$) and state of charge ($Battery_{SOC}$) at time t can be formulated as Eqs. (5) and (6), respectively. The details formulation of the energy in the BESS is explained in Ref. [42].

$$E_{Battery} = E_{Battery,0} + \int_0^t V_{Battery} \times I_{Battery} dt \tag{5}$$

$$Battery_{SOC} = \frac{E_{Battery}}{E_{Battery,max}} \times 100\% \tag{6}$$

where $V_{Battery}$ and $I_{Battery}$ are the voltage and current of the Li-ion battery in the system. The technical and economic specifications of the EVCS component used by the optimization model are listed in Table 2. The specification of each component of the system is utilized and declared in the optimization model to obtain an optimum configuration and operation of the system. The EVCS configuration was developed and run based on the stated parameters in order to find the optimal configuration considering technical and economic feasibility.

3. Hydrogen-based EVCS production

The H_2 energy is considered the most sustainable alternative production to fossil fuels for ensuring energy sustainability due to its high energy density and long-term energy storage [45,46]. Due to emerging technology of RES integration such as powered-based H_2 and BESS that provide minimal carbon emission, proven viability and good renewable fraction, the hydrogen FC technology has received global attention [47,48]. The production of H_2 can be achieved through various methods, including fossil fuels, nuclear systems, biomass production, and RES. Nevertheless, conventional H_2 production methods present a range of environmental challenges, notably encompassing GHG emissions and the lack of sustainability in production [49,50]. Therefore, the penetration of RES-based H_2 production that utilizes an electrochemical reaction-based electrolysis process is a vital strategy and gained interest among researchers to alleviate the pressure of energy supply, ensure energy efficiency and promote environmental protection [51]. Thus, FC and electrolyzer are the two major components for the realization of H_2 production in order to supply electricity sustainably and efficiently. Fig. 4 illustrates the integrated H_2 system in EVCS configuration. It consists of an electrolyzer, FC, Li-ion battery, a system converter, and an H_2 tank. The H_2 stored in the H_2 tank serves a dual purpose: it can be converted into electricity through the FC, acting as a backup unit within the hybrid energy storage system. This backup power source is available to meet electrical demands during production periods. When the load demand aligns with the power generated by the RES, it seamlessly fulfills the immediate demand. Any surplus energy is efficiently directed to the electrolyzer, facilitating the generation of H_2. The details modeling of the H_2 components and H_2 production is discussed in the following section.

3.1. Electrolyzer for hydrogen production

An electrolyzer is a sophisticated device that employs an electrochemical process to effectively split water into its elemental components: H_2 and oxygen (O_2). This isolated H_2 is then efficiently stored in a dedicated H_2 tank, awaiting utilization in the FC for electricity generation, as visually represented in Fig. 4 [52]. In general, three classifications were reported for the type of electrolyzer namely PEM, Alkaline Electrolyzers (AE) and Solid Oxide Electrolyzers (SOE) [53]. Simplicity, efficient operation (over 85 %), high-purity hydrogen (99.999 %), small footprint, high current density and low heat dissipation are the advantages of utilizing the PEM electrolyzers [54,55]. In this study, the PEM electrolyzer was selected to power the H_2 production system through the RES generation within the setup. The characteristics of PEM electrolyzers allow them to respond quickly to variations in electrical input, making them suitable for applications with variable RES generation. The efficiency of the electrolyzer was conservatively estimated at 80 % of the higher heating value. As a result, the power required by the electrolyzer can be articulated as:

$$P_{EZ} = \frac{mass_{H_2} \times H_{H_2}}{\eta_{H_2}} \tag{7}$$

where η_{H_2} represents the overall efficiency of the electrolyzer, while $mass_{H_2}$ denotes the mass flow rate of H_2 produced by the electrolyzer in (kg/s). The heating value of H_2 fuel (MJ/kg) and the DC power supplied to the electrolyzer, designated as H_{H_2} and P_{EZ}, respectively, are also factors under consideration [56]. The constraint for the electrolyzer should be satisfied by the optimization as follows:

$$E_{MLR} \le E_{EZ} \le E_{Rated} \tag{8}$$

where E_{MLR}, E_{EZ}, and E_{Rated} are the energy minimum load ratio, the energy of electrolyzer in (kWh) and rated energy of electrolyzer, respectively. The minimum load ratio is calculated as 20 % of the E_{Rated}, ensuring that the electrolyzer operates at a level that maintains its efficiency. This means the electrolyzer will produce at least 20 % of its rated energy to avoid operating at inefficient low levels [57].

3.2. FC for electricity production

An FC is a complex device that uses the chemical energy stored in H_2 in conjunction with an oxidizing agent often O_2 to power electrical loads. The device comprises three essential components, namely an anode, a cathode and an electrolyte. The FC functions by utilizing the stored H_2 gas from the H_2 tank as its primary fuel source. This H_2 is then converted into electricity, which subsequently powers electrical loads, especially during periods of high demand or unavailability of RES generation [58]. Essentially, the FC operates in a manner reverse to that of

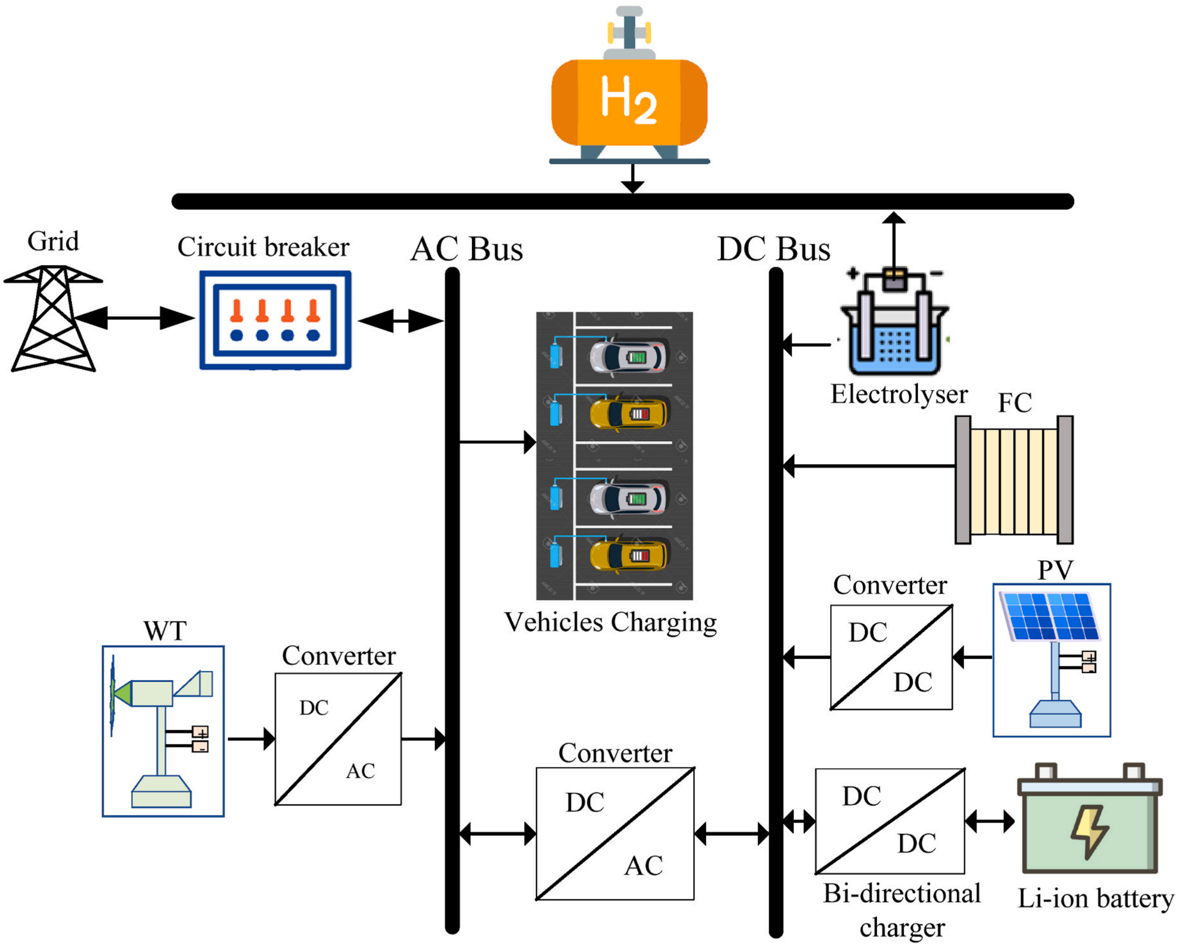


Fig. 4. An integrated H_2-based EVCS configuration with the proposed HOMER Pro optimization controller to obtain an optimal configuration and operation. The H_2 consists of an electrolyzer, FC and H_2 tank to perform the electrolysis process to produce electricity during the short power demand of the system as to provide long term energy storage system.

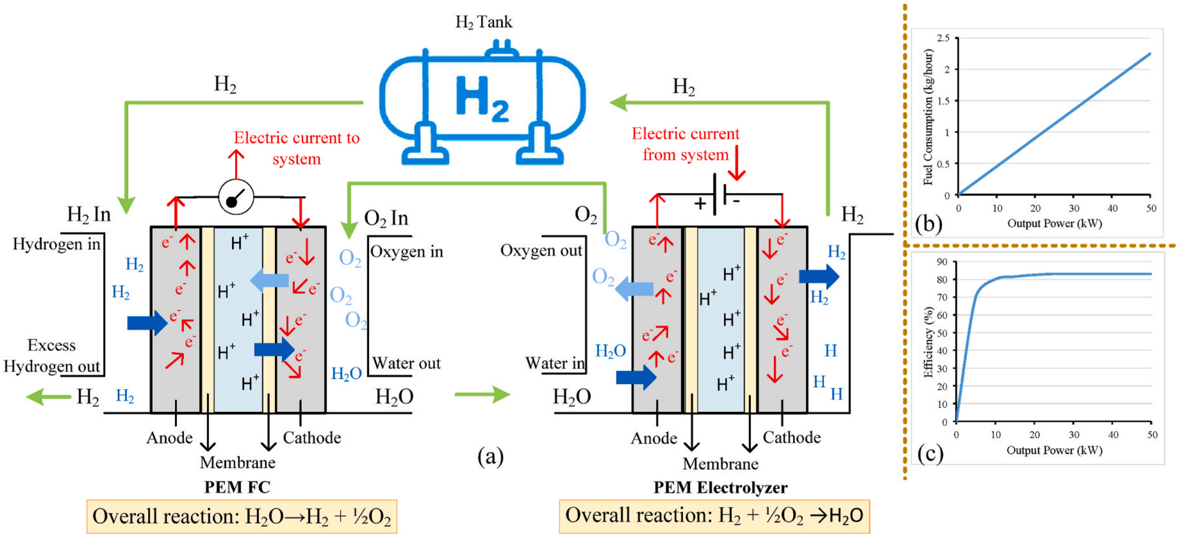


Fig. 5. (a) Configuration operation of H_2 energy storage system including PEM FC and PEM electrolyzer that utilized H_2 tank for stored H_2. The FC produce electricity for the entire system while the electrolyzer receives excess electricity from the system, (b) H_2 consumption of FC with respect to the power production, and (c) the effect of efficient H_2 production towards power production [48].

Table 3
The techno-economic specification data of H_2 production based EVCS configuration for optimization model.

System component	Values	References
PEM Electrolyzer		[61,62]
Lifetime (yr)	15	[43,63,64]
Efficiency (%)	85	
Capital cost ($/kW)	1000	
Operation and maintenance ($/yr)	100	
H_2 Tank		
Initial tank level (%)	10	
Lifetime (yr)	25	
Capital cost ($/kW)	500	
Operation and maintenance ($/yr)	100	
FC		
Lifetime (yr)	15	
Capital cost ($/kW)	500	
Operation and maintenance ($/operation hour)	0.030	
Fuel price ($/kg)	0.950	
Replacement ($)	500	

electrolysis, where it combines H_2 and O_2 to generate electricity, resulting in water and heat as byproducts as follows:

$$\frac{1}{2}O_2 + H_2 \rightarrow H_2O + Electricity + Heat \tag{9}$$

The correlation between H_2 consumption, output power, and FC efficiency is illustrated in Fig. 5. The power (P_{Fc}) produced by the FC stack is calculated by

$$P_{FC} = N \times V_{FC} \times I_{FC} \tag{10}$$

where N represents the number of cells in the stack series and I_{FC} is the FC current. The FC's output voltage (V_{FC}) is expressed as shown in Eq. (11) as follows:

$$V_{FC} = E - V_{act} - V_{\Omega} - V_{con} \tag{11}$$

where E, V_{act}, V_{Ω}, and V_{con} are the FC internal voltage, activation voltage, ohmic voltage, and concentration voltage, respectively. Thus, the electrical efficiency (η_{FC}) of the FC is given by:

$$\eta_{FC} = \frac{P_{FC}}{m_{H_2}} HHV_{H_2} \tag{12}$$

where m_{H_2} (kg/s) and HHV_{H_2} are the mass flow rate and the higher heating value of H_2 fuel, respectively. The FC is connected to a DC-DC boost converter to match the voltage with the DC bus voltage. The details relation of efficiency, operation and consumption of FC is illustrated in Fig. 5.

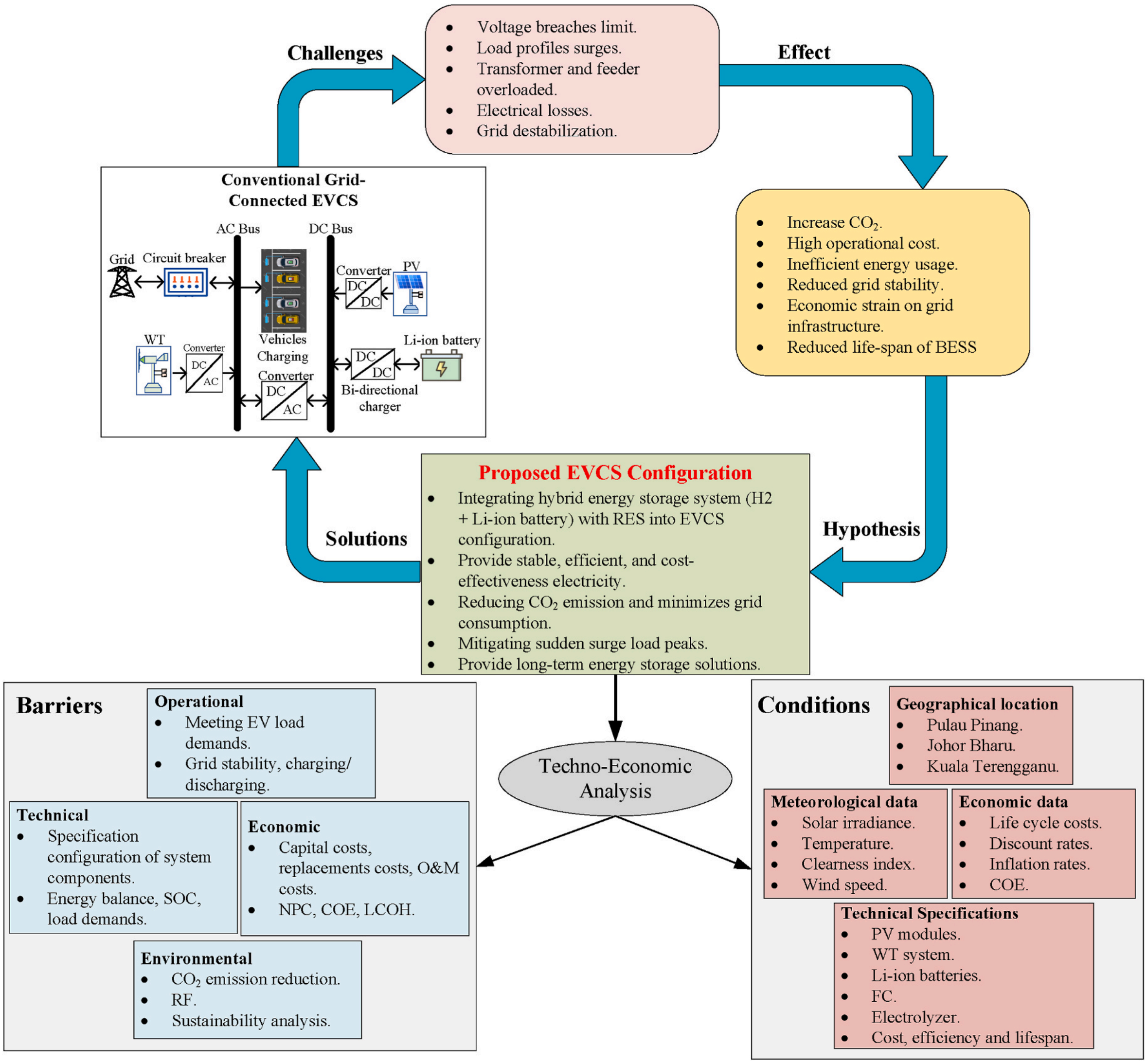


Fig. 6. Block diagram of the hypothesis and main aim of the study.

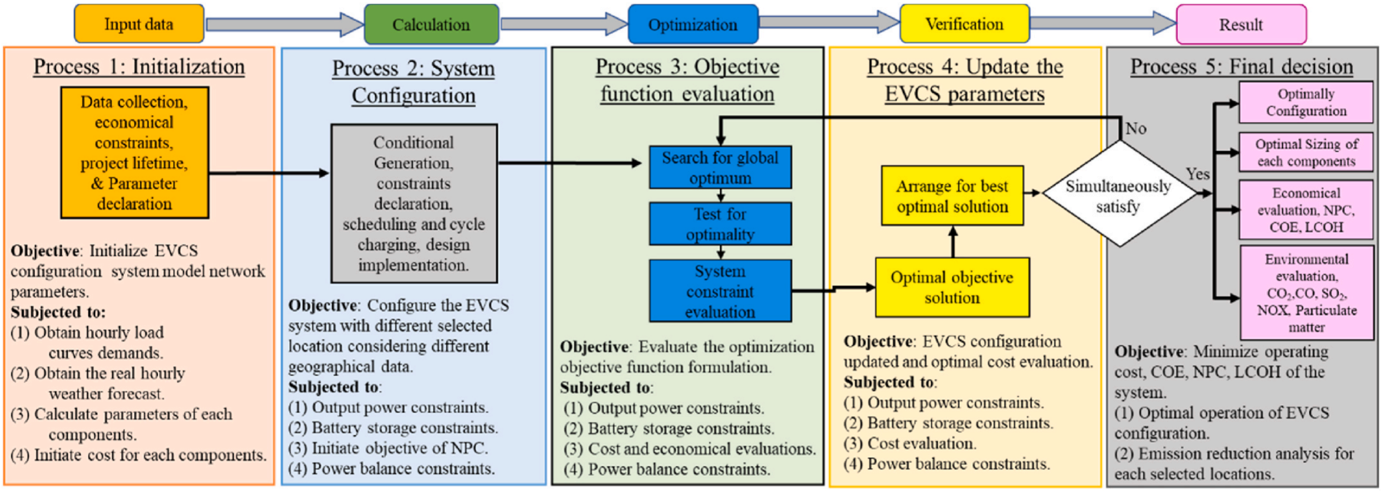


Fig. 7. Detailed overall structure of the proposed EVCS configuration using optimization model to obtain an optimum configuration and operation of the entire system.

3.3. H_2 tank

The produced H_2 by the electrolyzer is injected into the H_2 tank which is illustrated in Fig. 5. The H_2 demand is consistently satisfied using H_2 stored in the H_2 tanks. Consequently, the quantity of accumulated H_2 in the storage tanks at any given hour (t) corresponds to the difference between the H_2 production and the H_2 demand. This relationship can be represented as demonstrated in Eq. (13) as follows [59]:

$$C_{H_2T}(t) = C_{H_2T}(t-1) + m_{H_2}(t) - L_{\dot{H_2}}(t) \tag{13}$$

where $C_{H_2T}(t)$, $L_{\dot{H_2}}(t)$ and H_2T are the H_2 tank capacity, H_2 load at an hour (t) and H_2 tank, respectively. The excess electricity that occurs in the EVCS system is used to charge the Li-ion battery. Otherwise, instead of injecting the power to the grid system, the excess electricity is utilized to produced H_2 for the purposed of storage in the H_2 storage tank. Throughout the operational period of the system, it's imperative for the H_2 tanks to adhere to the following constraints [60]:

$$C_{H_2T\_min} \leq C_{H_2T} \leq C_{H_2T\_max} \tag{14}$$

where $C_{H_2T\_min}$ and $C_{H_2T\_max}$ are maximum and minimum capacity limits of the H_2 tanks, respectively. Table 3 represents the technical and economic specifications of the H_2 component employed in the optimization model.

3.4. Hypothesis and barrier of the study

The study hypothesizes that integrating a hybrid energy storage system combining H_2 and Li-ion batteries within an EVCS will provide a stable electricity supply, reduce CO_2 emissions, manage load peaks efficiently, and be both technically and economically feasible in various Malaysian locations. This hypothesis is depicted in the diagram, which highlights the challenges faced by conventional grid-connected EVCS, such as voltage breaches, transformer overloads, and high operational costs leading to increased CO_2 emissions and reduced grid stability. The proposed EVCS configuration aims to address these issues by integrating HESS with RES, ensuring stable, efficient, and cost-effective electricity while minimizes grid consumption and mitigating sudden load peaks. Fig. 6 illustrates the techno-economic analysis required to validate this hypothesis, considering operational, technical, economic, and environmental barriers. It emphasizes the specific conditions for the analysis, including geographical locations, meteorological data, economic data, and technical specifications, to ensure the proposed solution's feasibility and effectiveness. The aim is to validate the hypothesis by demonstrating that the proposed EVCS-based hybrid energy storage system can effectively meet modern EV charging demands while addressing environmental and economic concerns.

4. Methods and problem formulations

The fundamental objective of this study is to create a model and optimize a hybrid energy storage system for EVCS, combining H_2 and Li-ion battery technologies. The primary aim is to identify the optimal configuration that minimizes the COE, and NPC and contributes to a reduction in CO_2 emissions. Considering the different location approaches, the proposed EVCS configuration is compared with the existing models to examine the socioeconomic and environmental impact of the system. The comprehensive structure of the proposed approaches is depicted in Fig. 7. The optimal sizing and configuration of the EVCS were determined based on commercial tools of HOMER Pro software. In this study, five segments were involved to complete the optimization process that considered various parameters and system constraints to obtain optimal EVCS configuration. The HOMER Pro tools were used to assess and examine the technical and economic viability of the configuration to obtain an optimal solution with the least economic indicators such as COE, NPC and LCOH, respectively that satisfy the system's constraints [43,65]. The details optimization process of the proposed system is illustrated in Fig. 8.

The input variables encompassed meteorological data specific to the selected region, including solar irradiance, temperature, and clearness index. Additionally, load data profiles, system parameters, and economic data, such as the lifecycle cost of components, discount rates, and inflation rates, were factored in the input data section. This comprehensive set of variables was instrumental in assessing system performance and attaining precise optimization results. The feasibility is to achieve the power balance for the system for each generation for every hourly time step in the year subject to the constraints. Optimal feasibility is attained by setting a primary objective to evaluate the installation and operational costs for a sustainable configuration throughout the project's lifespan [66]. The detail's objective function and constraints evaluation for the optimization are further discussed in the following subsection.

4.1. Objective function and constraints

The primary goal of this research is to develop an optimum EVCS configuration-based hybrid energy storage system in order to establish the best site-specific EVCS configuration and environmental effect in

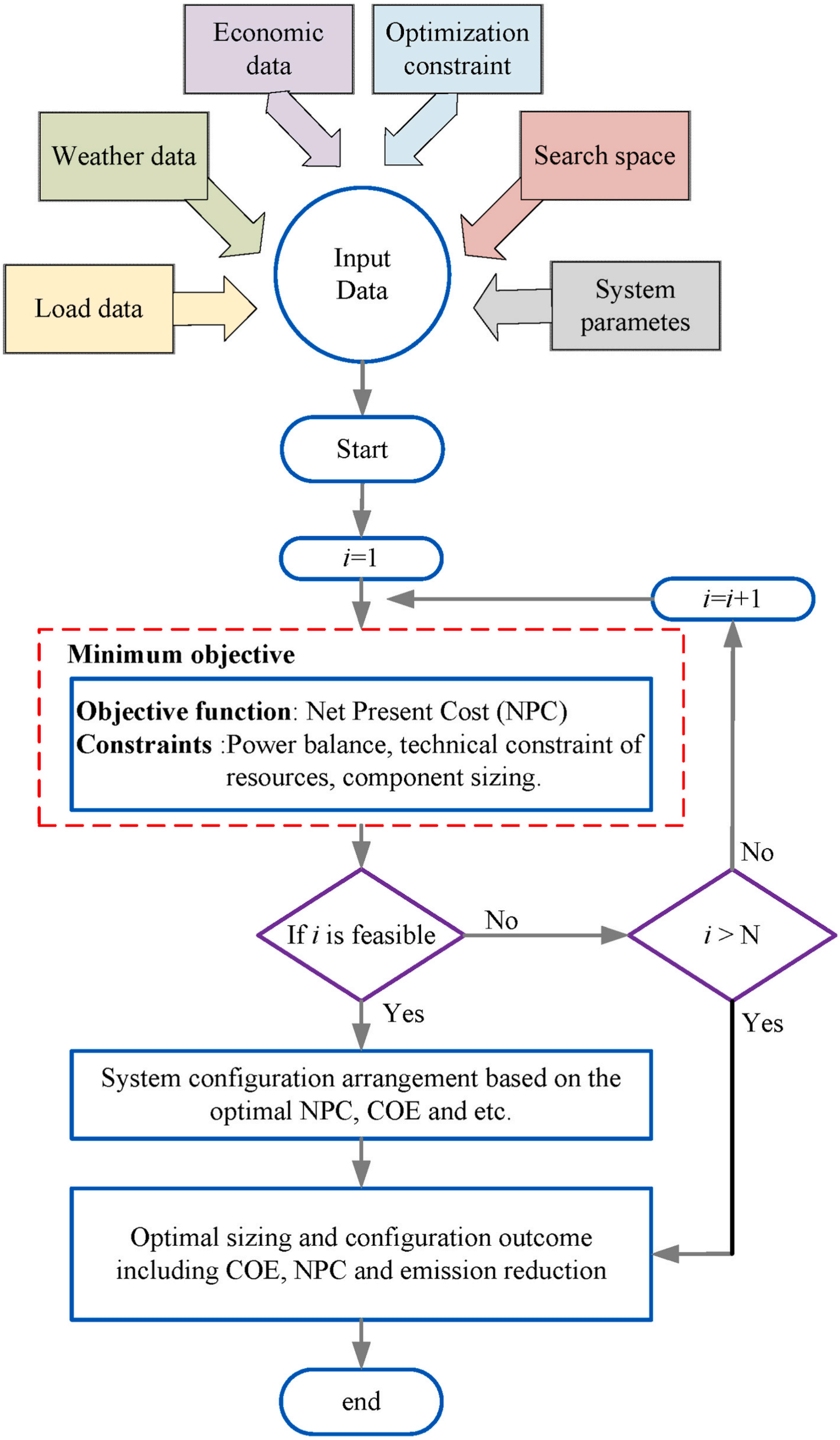


Fig. 8. A framework of the optimization procedure-based HOMER Pro tools optimization.

order to provide the requisite charging demand. The HOMER Pro-based optimization calculates both NPC and COE for a range of system combinations, sizes, and operational scenarios. The determination of the optimal feasible solution relies on assessing the configurations of NPC for each scenario. As presented in Fig. 9, the main variables of the optimization model are the economic aspect, environmental aspect, and sustainability aspect.

The proposed configuration of the EVCS is evaluated based on the lowest NPC. The COE is defined as the ratio of the average cost per kilowatt-hour (kWh) of the valuable electrical energy generated by the system. It is used as the primary indicator to evaluate the overall cost-effectiveness of the hybrid energy storage system which includes PV, WT, Li-ion battery and H_2 storage. For the purpose of this study, COE is defined to encompass all relevant costs over the system's lifetime

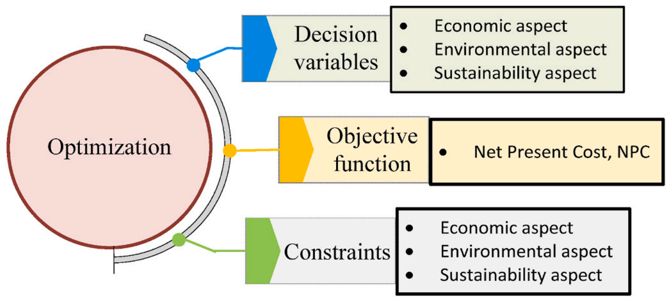


Fig. 9. The main parameter of the optimization process implemented in the HOMER Pro optimization model is to obtain an optimum configuration and operation of the system that is subjected to the constraints.

including initial capital, operation and maintenance, and other associated costs. The COE of the proposed system is calculated as follows [67]:

$$COE = \frac{NPC\ (\$)}{\sum_{h=1}^{h=8760} P_{EV}^{load}(h)(kWh)} \times CRF \tag{15}$$

where the *CRF* is the capital recovery factor and can be calculated as follows:

$$CRF_{(i,N)} = \frac{i(I+1)^{Y}}{\left((i+1)^{Y}-1\right)} \tag{16}$$

where *i* is the real interest rate in (%), and *Y* is the number of years.

The total annual cost (C_{total}) is the summation of capital cost, (C_c), replacement cost, (C_R), maintenance cost, (C_m), fuel cost, (C_F), salvage, (C_S), and other related costs, (C_o). Therefore, the total C_{NPC} of the present study that considering the total annual cost in the entire lifespan of the project is calculated as follows:

$$C_{NPC} = \frac{C_{total}}{CRF\left(i, R_{project}\right)} \tag{17}$$

where $R_{project}$ is the project's lifetime. The COE of the present study can be expressed as:

$$COE = \frac{C_{total}}{E_T} \tag{18}$$

$$E_T = E_P + E_{Def} + E_G^{sold} \tag{19}$$

where E_T is the total energy generation, E_P is the total primary load, E_{Def} is a total deferrable load, and $E_{G,sales}$ is the total energy sold to the grid.

In this study, an assessment of the environmental impact was considered in the analysis of the proposed hybrid energy storage system for EVCS. This examination aimed to quantify both the total CO_2 emissions from the grid and the Renewable Fraction (RF) of the system components. The calculation for CO_2 emissions originating from the grid is expressed as follows:

$$CO_2 = \sum_{t} P_G \times P_t \times CEF_t \tag{20}$$

where P_G represents the total output power supplied to the grid, P_t signifies the percentage contribution to the grid, and CEF_t stands for carbon emission factor. The RF represents the proportion of energy delivered to the load generated from RES generation and can be computed according to Eq. (21):

$$RF = 1 - \frac{E_{non\_RES}}{E_{L\_served}} \tag{21}$$

where the ratio of total non-RES load (E_{non_RES}) to total load served (E_{L_served}) is represented as $\frac{E_{non\_RES}}{E_{L\_served}}$. The LCOH production is calculated in the optimization model by dividing the difference between total annualized cost and yearly electricity cost by the total of annual H_2 production [68]. It is assumed that the PEM electrolyzer uses 100 % of electricity production by the RES generation. The LCOH of the H_2 production is expressed using Eq. (22) as follows:

$$LCOH = \frac{C_{annualized} - \left(V_{electricity} E_{Excess}\right)}{m_{Hydrogen}} \tag{22}$$

where $C_{annualized}$ represents the comprehensive annualized cost, encompassing capital, operational, maintenance, and replacement expenses of the system. The annual H_2 production denoted as $m_{Hydrogen}$ is quantified in kilograms per year (kg/yr). $V_{electricity}$ pertains to the selling price of excess electricity, measured in ($/kWh), while E_{Excess} signifies the surplus electricity generated by RES generation, quantified in (kWh/yr).

4.2. System's constraint

The constraint plays a crucial role in the optimization process to shape the operation of the system. It enables the optimization process to determine the objective within the predefined limit and restriction imposed on the system. The summation of the total power produced by each component should satisfy the load demands at any time (*t*). Thus, the load balance of the EVCS system can be obtained as follows:

$$\Delta P(t) = P_G(t) + P_{PV}(t) + P_{WT}(t) + P_{Battery}(t) + P_{FC}(t) - P_{EV}^{load}(t) \tag{23}$$

where $P_{FC}(t)$ is the FC output power. When the output power from RES exceeds the current load demand, several strategies are employed. Initially, the surplus power is directed towards charging the Li-ion battery. If there is still excess power beyond the battery's capacity, it's then utilized for H_2 production and storage. Any remaining surplus energy is subsequently exported to the grid for compensation. Conversely, when the load demand surpasses the power generated by RES, the stored energy within the Li-ion battery and H_2 systems is seamlessly dispatched to meet the load requirements. In cases of extreme demand or resource scarcity, a necessary power from the grid is needed to sustain the necessary power supply. Throughout the operational cycle, the stored energy within the Li-ion battery system should satisfy certain constraints, designed to prevent excessive discharging or overcharging. These constraints are mathematically represented as follows in Eq. (23) [69]:

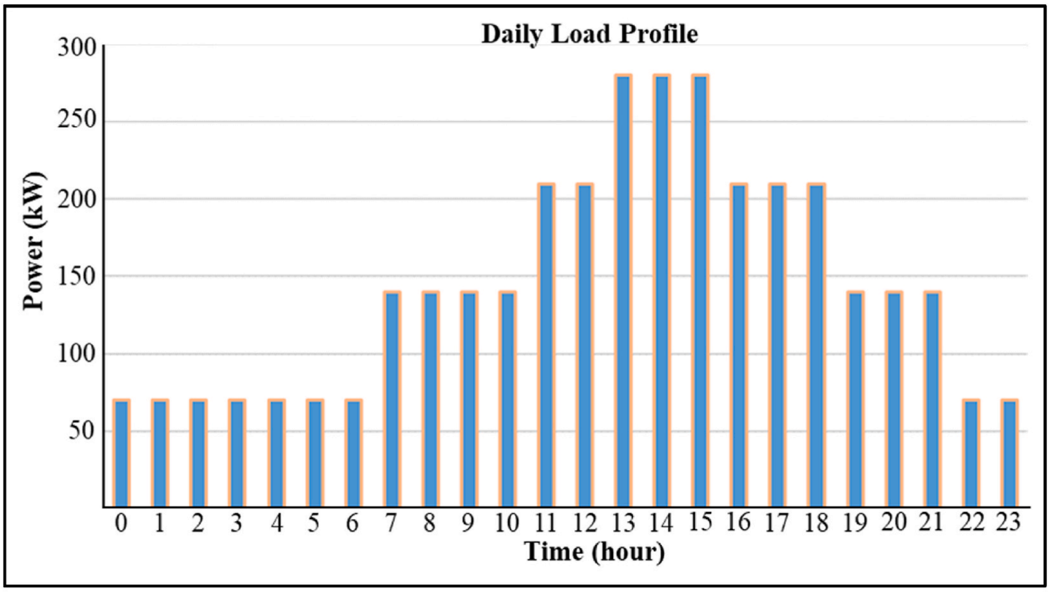
$$E_{Battery\_min}(t) \le E_{Battery}(t) \le E_{Battery\_max}(t), \tag{24}$$

where $E_{Battery\_min}(t)$ and $E_{Battery\_max}(t)$ are the minimum and maximum limits of energy stored in the battery system. Eq. (24) should be satisfied in each time interval according to a restriction that may exist on the charge and discharge rates of the battery system.

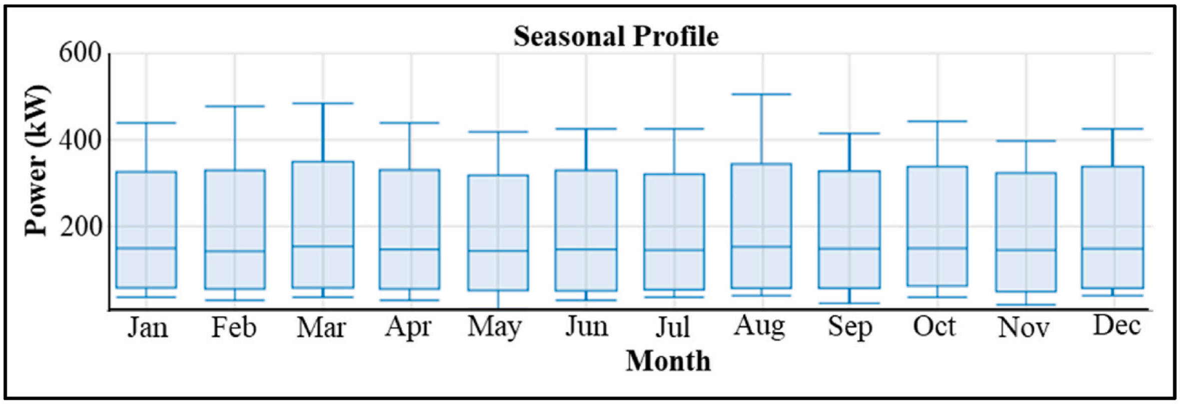
$$E_{Battery}(t) = E_{Battery}(t-1) + P_{charging} \times (\Delta t) \times \eta_{ch\ arg\ e} - {P_{discharging}}/{\eta_{discharge}} \times (\Delta t), \tag{25}$$

where $E_{Battery}(t)$ and $E_{Battery}(t-1)$ represent the energy storage levels within the battery at a time (*t*-1) and (*t*), respectively. $P_{charging}$ and $P_{discharging}$ denote the charging and discharging rates during a specified time interval Δt. The η_{charge} and $\eta_{discharge}$ signify the charging and discharging efficiencies of the battery. The sustainability analysis was conducted to achieve an optimal system characterized by reduced excess energy, enhanced system reliability, and cost-effectiveness within the proposed EVCS configuration. The low and high boundaries of the system component are constrained by

$$0 \le N_{PV} \le N_{PV}^{max} \tag{26}$$



(a)



(b)

Fig. 10. Daily load assessment for the proposed EVCS configuration. (a) daily load profile, (b) seasonal profile.

$$0 \le \theta_{PV} \le \theta_{PV}^{max} \tag{27}$$

$$0 \le N_{WT} \le N_{WT}^{max} \tag{28}$$

$$0 \le N_{Battery} \le N_{Battery}^{max} \tag{29}$$

where, N and N_i^{max} represent the number of components and high boundaries of the component, respectively. The θ_{PV}^{max} is the maximum tilt angle of the PV system. The optimization should satisfy each component's constraints to ensure that the system design remains within physical, economic, and operational limits, promoting efficient, cost-effective, and safe operation.

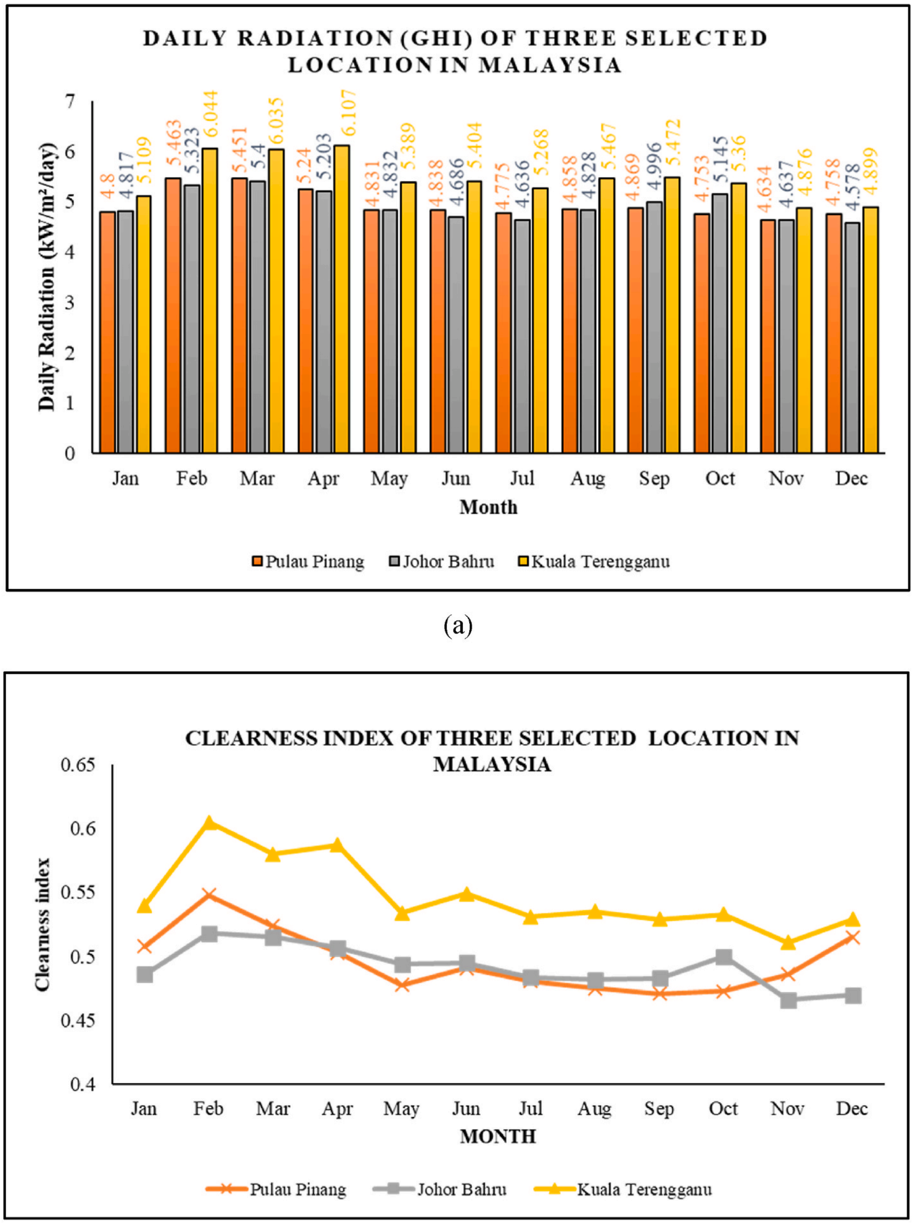
4.3. Decision variables

A system is regarded as reliable when enough power is used to meet the load requirement. In this study, the EV load demand in three locations such as Pulau Pinang, Johor Bharu, and Kuala Terengganu has been considered to evaluate the EVCS system. These demands are supplied by the RES generation which consists of PV and WT systems. Initially, the EV load demand is fulfilled by RES generation. During the output power from RES exceeds the current EV load demand, the excess power is used to charge the Li-ion battery. If there is still excess power beyond the battery's capacity, it's then utilized for H_2 production and storage. Any remaining surplus energy is subsequently exported to the grid for compensation. Conversely, when the EV load demand surpasses the power generated by RES, the stored energy within the Li-ion battery and H_2 systems is seamlessly dispatched to meet the load requirements. In cases of extreme demand or resource scarcity, purchased power from the grid is required to sustain the necessary power supply.

If the power produced by RES and hybrid energy storage is not sufficient, the shortage of power is fulfilled by borrowing from the grid ($P_G^{borrow}(t)$). Further to that, if enough power is available to satisfy load demand, it is fed back to the grid network ($P_G^{sold}(t)$). However, there are limits on purchasing and selling power to the grid, which is defined as the maximum purchase from the grid ($P_G^{borrow,max}(t)$) and the maximum sell to the grid ($P_G^{sold,max}(t)$). Energy cannot be borrowed from or sold to the grid outside these restrictions. Depending on the $\Delta P(t)$, the following conditions can be made.

- If $\Delta P(t) > 0$, the total power output gained from PV, WT, Li-ion battery and FC is enough to charge the EVs. Moreover, the extra power ($P_G^{sold}(t)$) is decided to sell to the grid that is calculated by:

$$P_G^{sold}(t) = \left(P_{PV}(t) + P_{WT}(t) + P_{Battery}(t) + P_{FC}(t) - P_{EV}^{load}(t)\right) / \eta_{Conv} \tag{30}$$



(a)

(b)

Fig. 11. Monthly average solar irradiation for three different potential locations, (a) monthly solar radiation, (b) clearness index for the selected location.

where η_{Conv} is the efficiency of the inverter.

- When the RES output power is enough to meet the load requirement while also exceeding the maximum selling capacity of the grid as $\Delta P(t) > 0$ and $\Delta P(t) > (P_G^{sold,max}(t))$, the surplus electrical energy is dump to load that calculated as:

$$P_D(t) = \left(P_{PV}(t) + P_{WT}(t) + P_{Battery}(t) + P_{FC}(t) - P_{EV}^{load}(t) - P_G^{sold,max}(t) \middle/ \eta_{Conv}\right) \tag{31}$$

- If $\Delta P(t) < 0$, the power produced by the EVCS system is not enough to fulfil the load requirement. Thus, the necessary electrical energy is obtained from the grid as follows:

$$P_G^{borrow}(t) = \left(P_{EV}^{load}(t) - P_{PV}(t) - P_{WT}(t) - P_{Battery}(t) - P_{FC}(t)\right) / \eta_{Conv} \tag{32}$$

- $\Delta P(t) = 0$, no power is exchanged from the grid and the EVCS power meets the EV load requirement.
- When the EVCS output and grid power are unable to satisfy the peak load requirement, a power deficit occurs which can be calculated as follows:

$$P_{def}(t) = P_G^{borrow}(t) - P_G^{borrow,max}(t) \tag{33}$$

- If the $P_{Battery}(t) > 0.8$, the excess power is used to generate the H_2 using electrolyzer that can be expressed as follows:

$$P_{EZ}(t) = \left(P_{PV}(t) + P_{WT}(t) + P_{Battery}(t) - P_{EV}^{load}(t)\right) / \eta_{Conv} \tag{34}$$

- When the $P_{Battery}(t) < 0.2$, the excess power used to charge the battery that can be presented as:

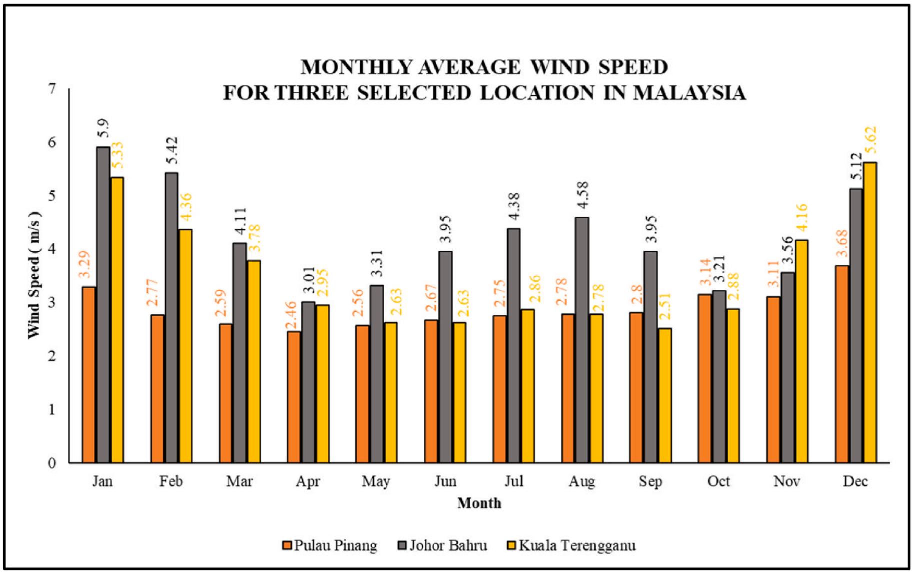


Fig. 12. Monthly average wind speed for the three different potential locations.

$$P_{Battery}(t) = \left(P_{PV}(t) + P_{WT}(t) - P_{EV}^{load}(t)\right) / \eta_{Conv} \tag{35}$$

The EVCS-based hybrid energy storage system that incorporates H_2 and BESS integrated with grid power is implemented to ensure a sustainable power supply and efficient operation of the EVCS system that provides a stable electricity supply and minimizes power quality issues for stable operation [70].

4.4. Load assessment

In this study, three potential different places in Malaysia were considered to evaluate the proposed EVCS namely, Johor Bharu, Pulau Pinang, and Terengganu. This approach aligns with the Malaysia 12th government's ambition to achieve net-zero CO_2 emissions by 2050, aiming for 38 % of the total vehicle fleet to consist of EV mobilities [71,72]. The CS functions continuously, operating around the clock with four distinct charging slots to assess its reliability. The daily and seasonal profiles of the cumulative daily load demand for 50 EVs amount to 3500 kWh, as depicted in Fig. 10. This synthetic electricity load profile was generated via HOMER Pro software, serving as a fundamental component of the analysis, aimed at obtaining optimal outcomes of the EVCS configuration system.

4.5. Resources assessment

The solar radiation data for the chosen location was calculated using the National Renewable Energy Laboratory database and National Solar Radiation Database. Fig. 11 (a) displays the monthly average solar irradiation. The annual average value for the selected location was 4.94 kWh/m^2/day for Pulau Pinang (5°24.8′N, 100°17.7′E), 4.92 kWh/m^2/day for Johor Bharu (1°29.6′N,103°44.5′E), and 5.45 kWh/m^2/day for Kuala Terengganu (5°19.8′N, 103°8.2′E), respectively. Meanwhile, Fig. 10 (b) presents the clearness index for each location with an average of 0.496 for Pulau Pinang, 0.491 for Johor Bharu, and 0.547 for Kuala Terengganu, respectively. Similarly, the average wind speed values were shown in Fig. 11 for different selected locations to examine the condition of the available wind in different locations based on the NASA prediction of Worldwide Energy Resource (POWER) database. Fig. 12 illustrates that, for each location, the wind speed varies and the pattern seems to be changing in a year. These data were used to configure the EVCS configuration for HOMER optimization as resource availability input parameters to fulfil the identical power demand at different states in Malaysia.

Table 4
Optimal component sizing for the EVCS configuration based on different location.

Component	Pulau Pinang	Johor Bharu	Kuala Terengganu
PV (kW)	402	214	363
Li-ion Battery (kWh)	400	400	400
WT (kW)	1000	1000	1000
Electrolyzer (kW)	100	100	100
FC (kW)	590	590	590
H_2 Tank (kg)	100	100	100
Converter (kW)	364	415	373

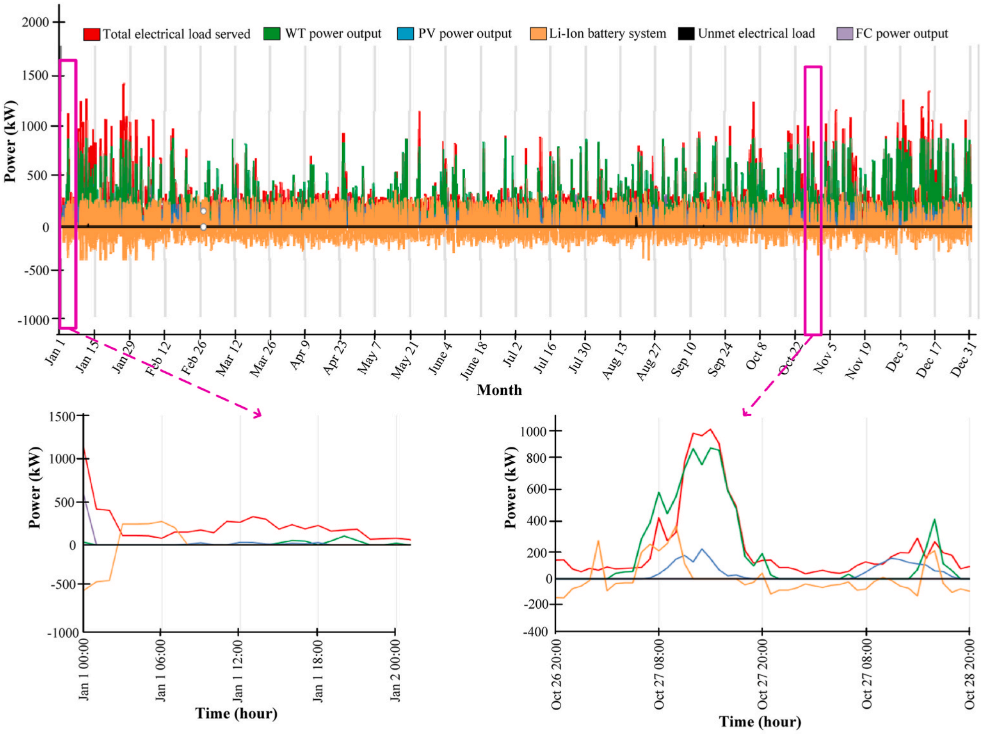
4.6. Validation condition

The validation of the proposed EVCS configuration-based hybrid energy storage system integrating H_2 with the grid mainly relies on detailed simulation using HOMER Pro software, location-specific meteorological data, precise technical specifications, and comprehensive economic analysis. By employing these validation conditions, the study ensures that the proposed system is both technically feasible and economically viable. To further validate the performance of the system in real world condition, in case of large-scale deployment, the future field trials and pilot project are suggested.

5. Results and discussions

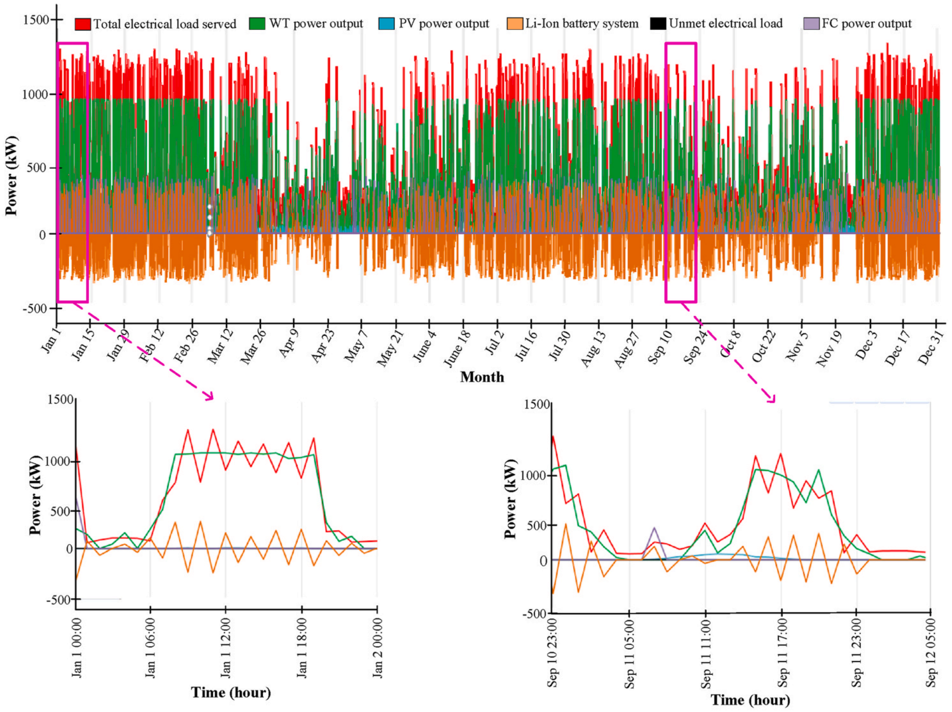
The result demonstrated the proposed EVCS configuration-based hybrid energy storage system of H_2 and Li-ion battery can achieve a stable electricity supply with a reduction in CO_2 emission and load peak condition. The optimized configuration and simulation for the three different locations are assessed to examine the technical and economic feasibility of the system. The obtained result explained the performance of the EVCS configuration on the different selected locations with detailed technical and economic analysis. After the system has been optimized following the above five processes, the performance of the EVCS system is examined and reported to obtain an optimum operation and configuration.

Table 4 summarizes the optimal sizing of each component for EVCS in Pulau Pinang, Johor Bharu, and Kuala Terengganu, optimized using HOMER Pro software. The PV capacity varies, with 402 kW for Pulau



(a)

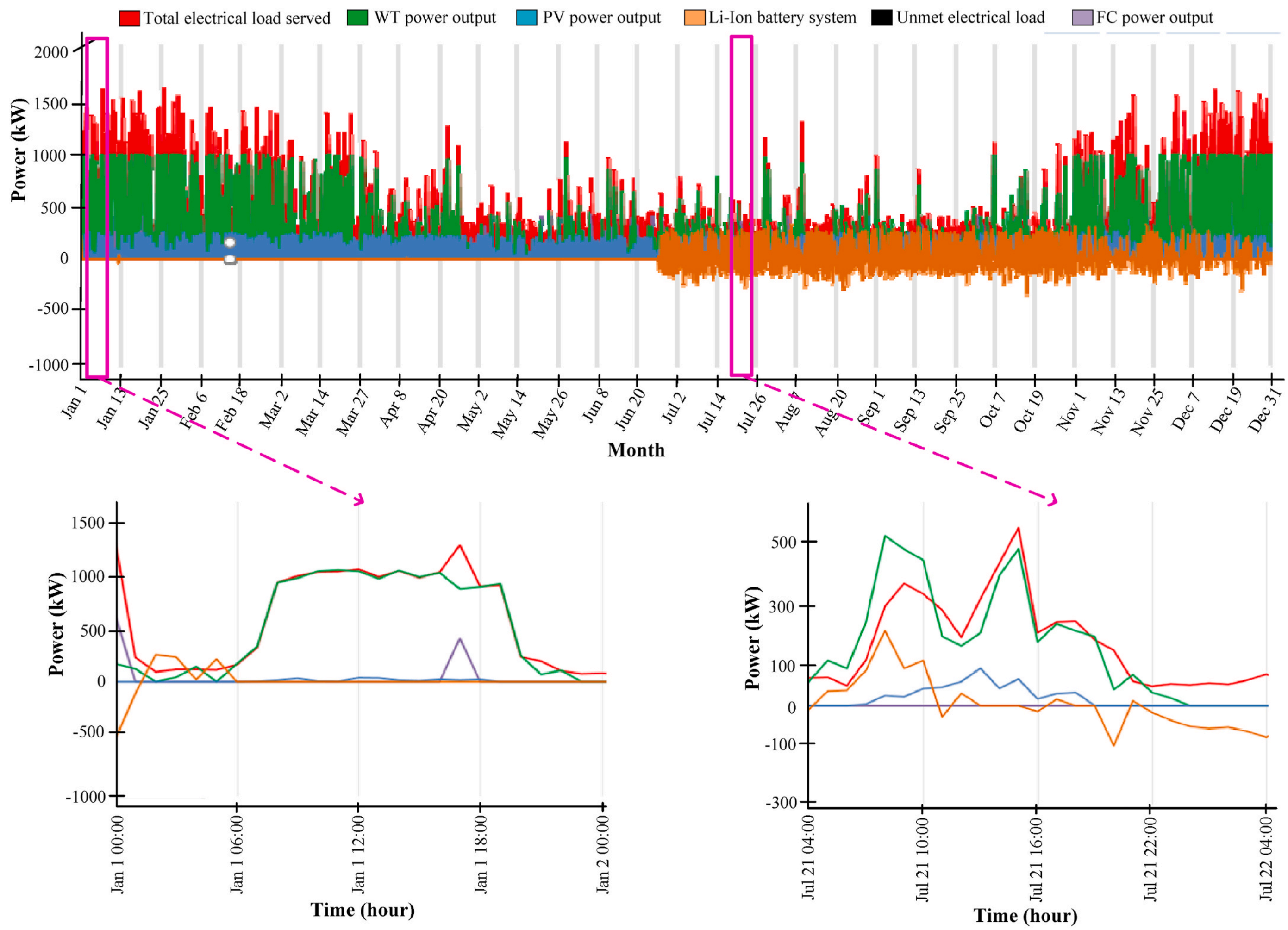
(a). Yearly power generation performance of optimal EVCS configuration based on Pulau Pinang locations.



(b)

(b). Yearly power generation performance of optimal EVCS configuration based on Johor Bharu locations.

Fig. 13. (a). Yearly power generation performance of optimal EVCS configuration based on Pulau Pinang locations.(b). Yearly power generation performance of optimal EVCS configuration based on Johor Bharu locations.(c). Yearly power generation performance of optimal EVCS configuration based on Kuala Terengganu locations.



(c)

(c). Yearly power generation performance of optimal EVCS configuration based on Kuala Terengganu locations.

Fig. 13. (*continued*).

Pinang, 214 kW for Johor Bharu, and 363 kW for Kuala Terengganu, reflecting the differing solar potentials of these locations. The Li-ion battery capacity is uniformly set at 400 kWh across all locations, indicating a standard storage requirement. Similarly, the WT capacity is consistently 1000 kW, and the electrolyzer, FC, and H_2 tank capacities are 100 kW, 590 kW, and 100 kg, respectively, for all locations, suggesting these components have similar needs and efficiencies across the different areas. This optimal sizing ensures efficient operation, grid stability, and economic viability of the EVCS in each location. The comprehensive analysis of both the EVCS configuration and the optimized system is reported in the following section.

5.1. Power generation

The total power generation for daily consumption of EVCS configuration on a typical day in January is highlighted in Table 4 and presented in Fig. 13. The hourly power produced and consumed over one day for charging the 50 EVs is shown in Fig. 13. As depicted in Fig. 13 (a), the highest power generation is supplied by the WT system with 3013.4 kWh/day which is equivalent to 60.3 %. The lowest power generation was revealed by H_2 FC generation at 22.2 kWh/day which is equivalent to 0.443 %. Meanwhile, a different performance of power generation was shown in Johor Bharu state as shown in Fig. 13 (b) which also shows the WT system provides the highest generation at 3013.4 kWh/day equivalent to 60.3 %. Similarly, for the Kuala Terengganu state was revealed that the WT system generated the highest power generation this month consisting of 3015.2 kW/day at 60.4 % generation. The differences in power generation across these locations are due to variations in weather characteristic.

Table 5
Power generation summary of various sources in different locations.

Locations	Power Summary			
	PV output power (kWh/yr)	H_2 FC (kWh/yr)	WT (kWh/yr)	Grid purchase (kWh/yr)
Pulau pinang	410,227	8088	1,099,890	307,289
Johor Bharu	421,401	8286	2,760,993	305,397
Kuala Terengganu	399,962	7831	1,860,883	313,022

The summary of the optimal power generation was calculated for

Table 6

Summary of power balance of EVCS configuration in different locations.

Locations	Excess Electricity (kWh/yr)	Unmet Electric Load (kWh/yr)	Capacity Shortage (kWh/yr)
Pulau Pinang	0	125	1027
Johor Bharu	6.4	131	1243
Kuala Terengganu	0	124	1242

yearly consumption to examine the power generation of each source as shown in Table 5. The highest power generation of PV output power was generated at Johor Bharu due to the relatively high solar radiation in the state compared to other remaining states. Due to the different weather characteristics for each location, the WT generation showed consistent power output across all locations. The optimization of the EVCS configuration using HOMER Pro ensures the optimal operation and technical and economic feasibility for each location. This optimization process effectively balances the power generation performance across different conditions.

The distribution of excess electricity exhibited notable variations among the three states, with Johor Bharu recording the highest surplus and Pulau Pinang and Kuala Terengganu having the least. In Johor Bharu, the system achieved a remarkable RF of 89.2 %, owing to power generation exclusively from PV output, the WT system, and H_2 FC, as detailed in Table 6. The maximum optimized renewable penetration rates were 1148 %, 1234 %, and 983 % for Pulau Pinang, Johor Bharu, and Kuala Terengganu, respectively. Notably, the lowest renewable penetration was observed in Kuala Terengganu, primarily attributable to variations in geographical characteristics and weather conditions. Unmet load is characterized by an electrical load that the power generation plant cannot fulfil, typically occurring when supply falls short of demand. Similarly, capacity shortages arise when there is an insufficient operating capacity to meet the required capacity [73]. Across the assessed locations, both unmet load and capacity shortages were evident. To address these challenges, the incorporation of supplementary storage systems, such as batteries, is recommended. These systems can store surplus electricity generated during daylight hours, subsequently bridging electricity demand during periods of peak consumption or unconventional hours.

The Li-ion battery system's performance is detailed in Table 7 across three distinct locations. As indicated in the table, the lowest annual throughput is observed in Johor Bharu, while the highest is recorded in Kuala Terengganu. This data reflects the energy capacity of the storage bank, calculated after accounting for charging losses and before discharging losses over a year. To further describe the battery storage performance in the EVCS configuration system, Fig. 14 shows the SOC performance of the Li-ion battery for different selected locations, respectively. The EVCS configurations were run and simulated randomly with different initial SOCs. The minimum and maximum limits of SOC were set between 20 % and 100 % for each Li-ion battery system. The Li-ion battery system was shown a different profile for each location after obtaining an optimum result. In Pulau Pinang, the SOC shows the device was in charging condition for the entire year as the system contains surplus energy to charge the Li-ion battery. This is because the system optimized the energy capacity of the device giving the decision to charge the battery according to SOC status and surplus energy from the system. Furthermore, the Li-ion battery showed a discharging mode profile for the entire year for the Johor Bharu location that utilized the device at an initial 81 % SOC. From February to April, the system utilized the Li-ion battery to supply the EV which shows a discharge mode of 42.8 %. The system optimized the availability of surplus power to charge the device until reached the threshold value in order to be used from August to November as shown in Figure. This proved that the Li-ion battery in

Table 7

Battery storage system performance of EVCS in different locations.

Location	Energy In (kWh/yr)	Energy Out (kWh/yr)	Storage Depletion (kWh/yr)	Annual Throughput (kWh/yr)
Pulau Pinang	408,858	368,043	75	387,952
Johor Bharu	403,315	363,086	108	382,726
Kuala Terengganu	410,707	369,718	86	389,717

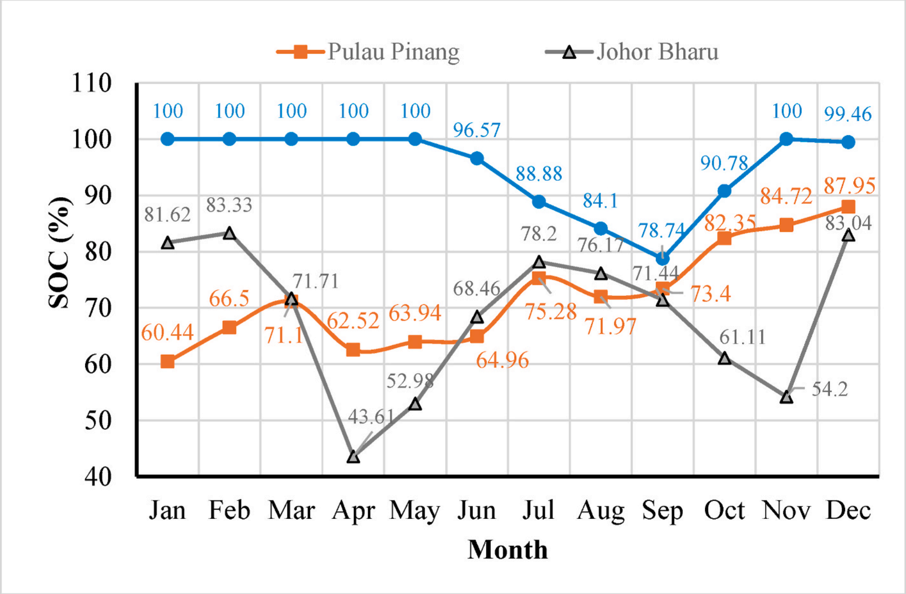


Fig. 14. Yearly average optimal charging discharging performance of Li-ion battery system in the EVCS configuration based on the different selected locations (a) Pulau Pinang, (b) Johor Bharu, and (c) Kuala Terengganu.

Table 8
Summary of the cost analysis for EVCS configuration in different locations.

System	Grid + RE + Hydrogen		
Location	Pulau Pinang	Johor Bharu	Kuala Terengganu
COE ($/kWh)	0.1659	0.03766	0.08674
NPC ($/kWh)	3,490,361.00	1,400,082.00	2,513,846.00
Operating Cost ($/yr)	56,464.8	−66,778.83	−110,937.54
RF (%)	81.1	89.2	87.5

EVCS configuration is optimally operated to fulfil the EV demand to compensate for the fluctuation power that occurred from the RES generation. However, the Li-ion battery shows constant status at Kuala Terengganu on average. The Li-ion battery device started to discharge its power from July until September to support the EVCS system. This is because the Li-ion battery was set as 100 % of the initial SOC and it maintains its energy to be used during a shortage of power in the system.

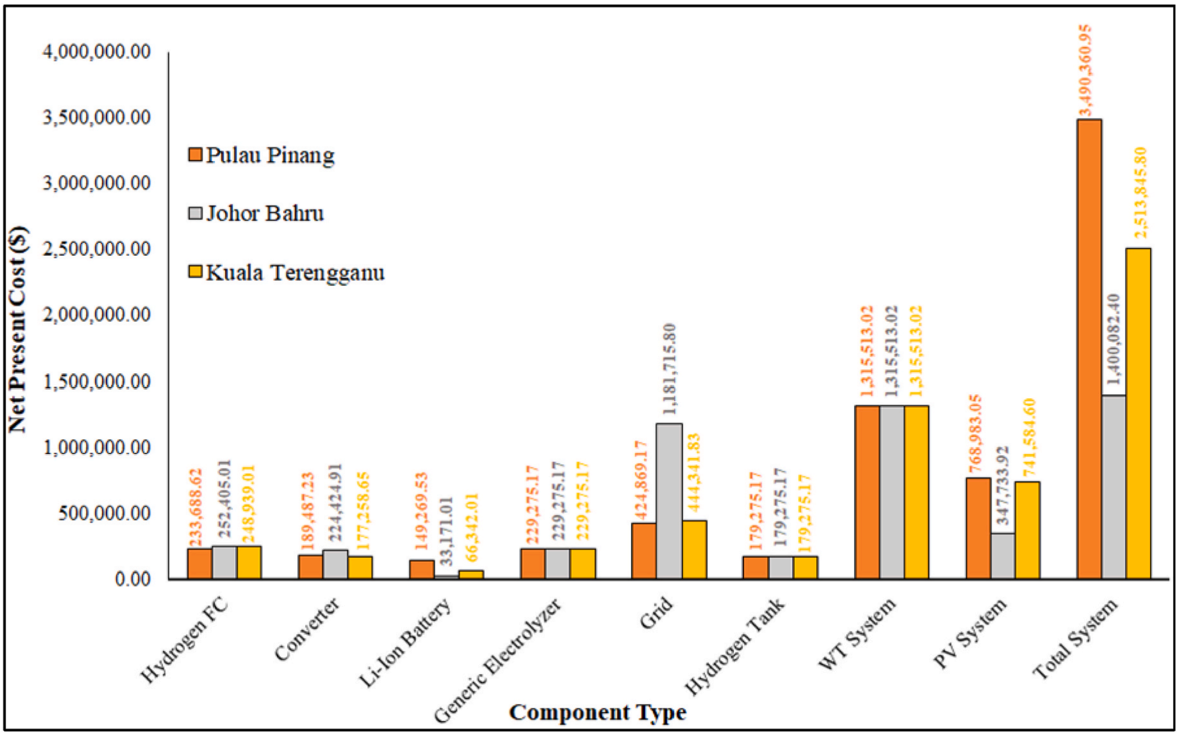


Fig. 15. The optimal NPC performance for different sources at different selected locations.

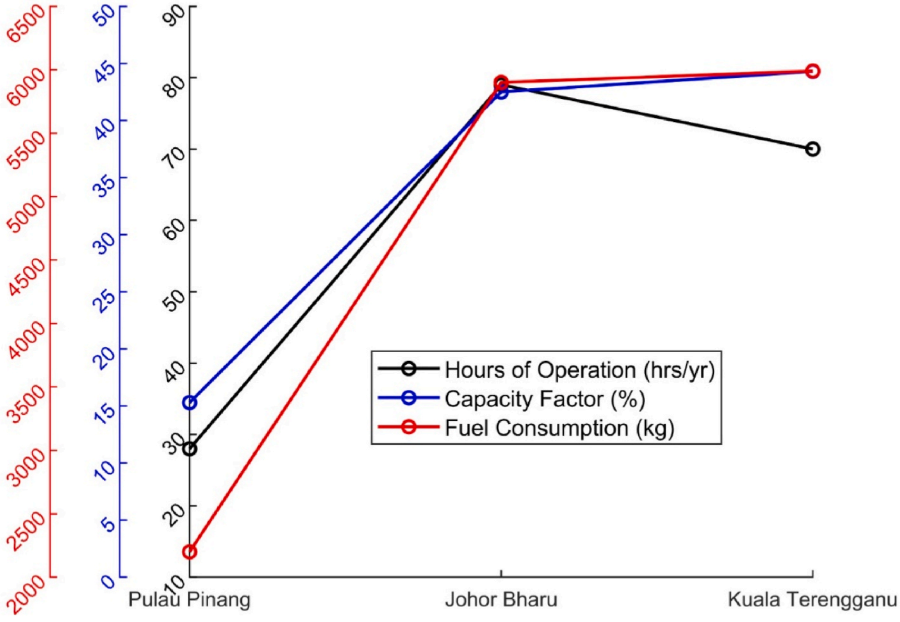


Fig. 16. An optimal performance of FC operation based on different selected locations.

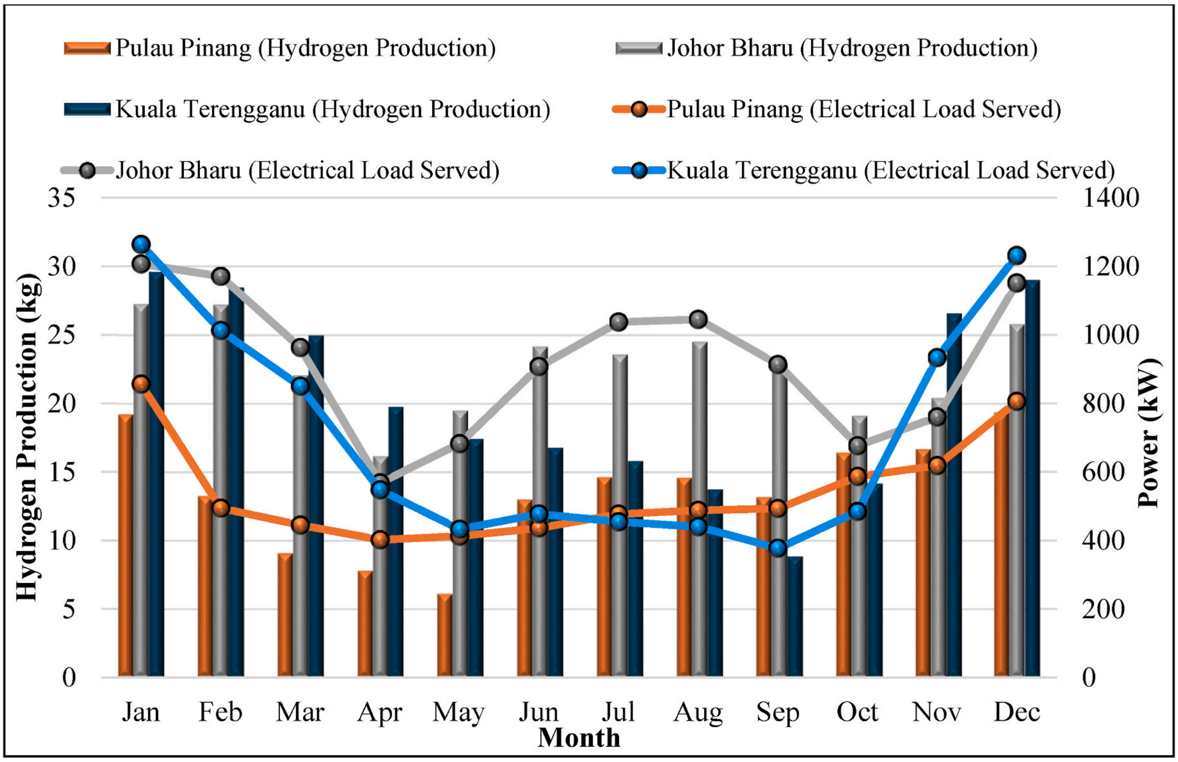


Fig. 17. Monthly average of the stored H_2 production for a year and the relation with electrical load serves at different selected locations. (a) Pulau Pinang, (b) Johor Bharu and (c) Kuala Terengganu.

5.2. Economic analysis

The economic evaluation summary is presented in Table 8 for different selected locations. Pulau Pinang exhibits the highest COE at 0.1659 $/kWh due to lower electricity generation in that region coupled with higher demand. This higher COE may be influenced by factors such as dense population, rapid urbanization, and intensive industrial activity. Conversely, the lowest COE was revealed by 0.03766 $/kWh in Johor Bharu state and followed by 0.08674 $/kWh in Kuala Terengganu, respectively.

The determination of the optimal configuration for the hybrid energy storage system in the EVCS relies on the identification of the lowest NPC and COE among all possible options. This calculation is based on the Net Present Value (NPV) method, which considers factors such as capital investments, associated costs over the component lifespan, and the project's salvage value at the end of its lifetime while accounting for predefined inflation and discount rates. As a result, Fig. 15 visually compares the optimal NPC performance across various locations, highlighting their economic viability.

The WT system incurred the most substantial cost within the overall NPC for each EVCS configuration location, closely followed by the PV system. Conversely, the Li-ion battery component carried the lowest cost. The elevated NPC associated with the PV system may be attributed to the comparatively higher life cycle costs of PV modules when compared to other system components [38]. Similarly, the initial investment and environmental impact factor contribute to the higher NPC of the WT system.

5.3. Hydrogen production

Fig. 16 shows the operational aspects of the FC, including fuel consumption, capacity factor and operation duration. Johor Bharu recorded the longest FC operation period with a 43.2 % capacity factor, while Pulau Pinang had the shortest at 15.3 %. This demonstrates that the FC effectively uses H_2 from the H_2 tank to supply electricity, ensuring high efficiency and reliability of the EVCs configuration. Fig. 17 illustrates the H_2 production level relative to the electrical load throughout the year for the three locations. The data shows varying H_2 production performances based on power generation availability. Pulau Pinang experiences peaks in electrical load from March to May, resulting in decreased surplus energy and lower H_2 production. In contrast, Johor Bharu and Kuala Terengganu show more consistent H2 production due to additional excess energy utilized for H2 generation and storage.

The substantial solar radiation received during the early part of the year has a notable impact on the H_2 tank levels across all locations. Among these, Kuala Terengganu stands out with the highest H_2 production, totaling 5994 kg/yr. Following closely, Johor Bharu and Pulau Pinang recorded H_2 production rates of 5964 kg/yr and 2219 kg/yr, respectively. Based on the optimum result of EVCS configuration, the highest H_2 consumption by the FC was recorded at Kuala Terengganu with 5988 kg/yr representing 99.8 % of the H_2 production. Furthermore, the second highest consumption was recorded at Johor Bharu with 5948 kg/yr (99.7 %) followed by Pulau Pinang with 2187 kg/yr (98.5 %), respectively. This demonstrates the system's capability to harness excess energy for H_2 production through the use of an electrolyzer, subsequently employing this generated H_2 to meet the EV charging load requirements. To assess this production process, the LCOH was calculated, revealing the relationship between the annualized cost, annual electricity cost, and total annual H_2 production. Notably, Johor Bharu exhibited the lowest LCOH at 18.6 $/kg, while Pulau Pinang recorded the highest LCOH at 122 $/kg, followed by Kuala Terengganu with 29.6 $/kg. These findings underscore the cost-effectiveness of H_2 production in comparison to previously reported H_2 costs [67,74], and [75]. Table 8 in other literature provides a comparison of H_2 production costs for various configuration approaches.

While the cost of H_2 production in this configuration may appear somewhat elevated in comparison, it's important to note that the system achieved the lowest COE, NPC, and operating cost among all system

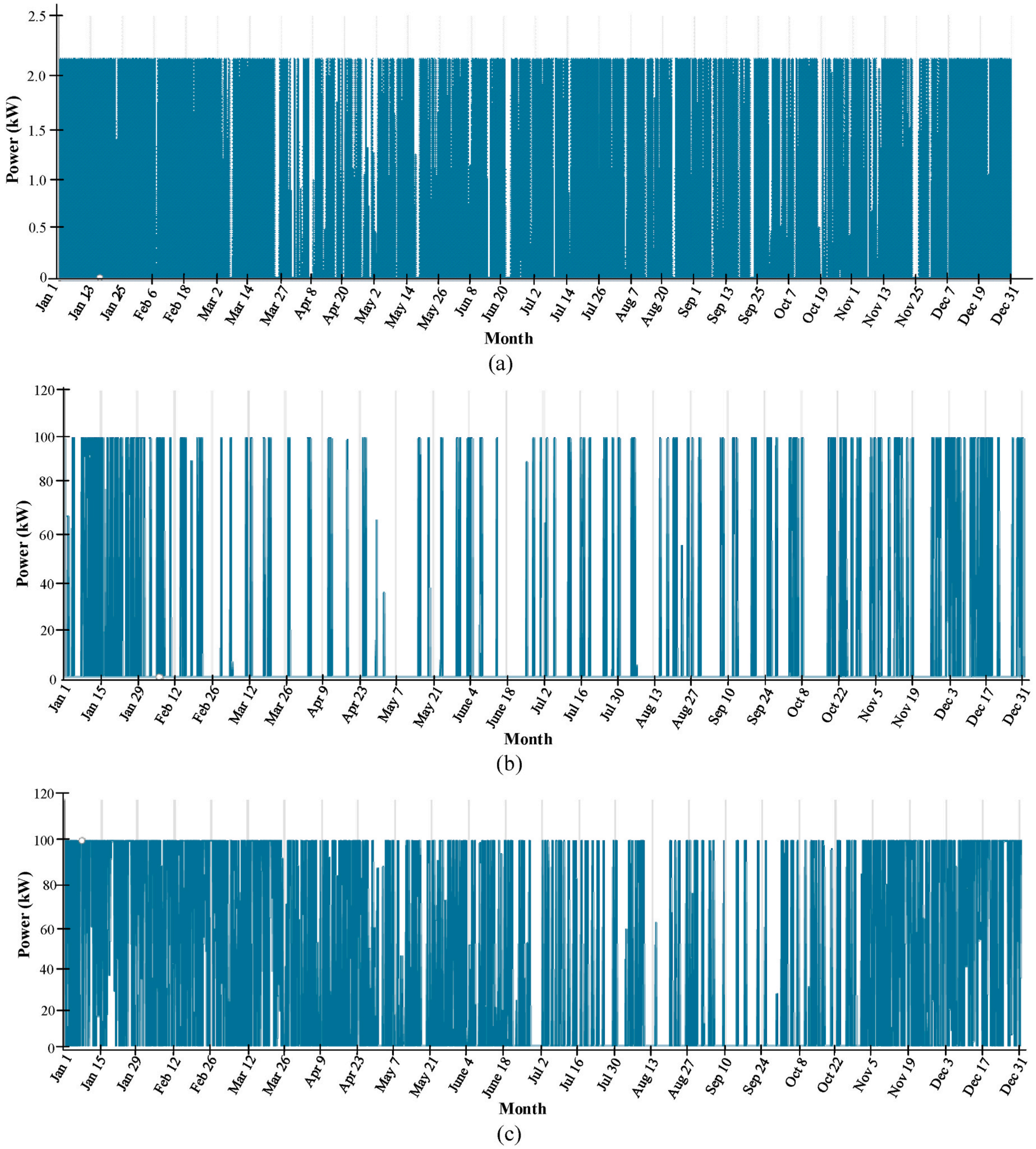


Fig. 18. Monthly average H_2 production-based electrolyzer system in the EVCS configuration from optimal decision using HOMER Pro optimization model for different selected locations. (a) Pulau Pinang, (b) Johor Bharu, and (c) Kuala Terengganu.

components when utilizing the proposed EVCS configuration. This suggests that the system, while potentially having higher H_2 production costs, presents a relatively cost-effective and economically viable overall solution. The monthly electricity generation pattern of H_2 production by the electrolyzer system for different selected locations is shown in Fig. 18.

5.4. Environmental analysis

In the process of converting energy through the combustion of fossil fuels, numerous pollutants including CO_2, CO, SO_2, NOX, particulate matter, and unburned H_2 are emitted. These emissions have detrimental effects on our daily lives, contributing to air pollution that can disrupt atmospheric conditions [76]. The gaseous emission obtained from the optimization for different locations is shown in Fig. 19. The figure presented the different dissemination of the emission with respect to the system with grid-only configuration and with grid and EVCS configuration, respectively. Fig. 19 (a) shows the performance of emission for the grid-only configuration as for the EVCS system. It shows that the three locations have similar emissions for CO_2 emissions as the lines are close to each other. Furthermore, the NOX and SO_2 extend farther between each other for the three locations. Meanwhile, the emission of particulate matter seems to be fairly consistent across the three locations, respectively. From the analysis, it is concluded that the total emission for all types of pollutants is 855200 kg/yr similar for the three locations. This is because the total operation of the EVCS system for the three locations mainly depends on the grid power consumption which generates huge pollutants from the fossil fuel generation. Furthermore, the result reported in Fig. 19 (b) indicated that Johor Bharu and Pulau Pinang produced the highest levels of total emission for all types of

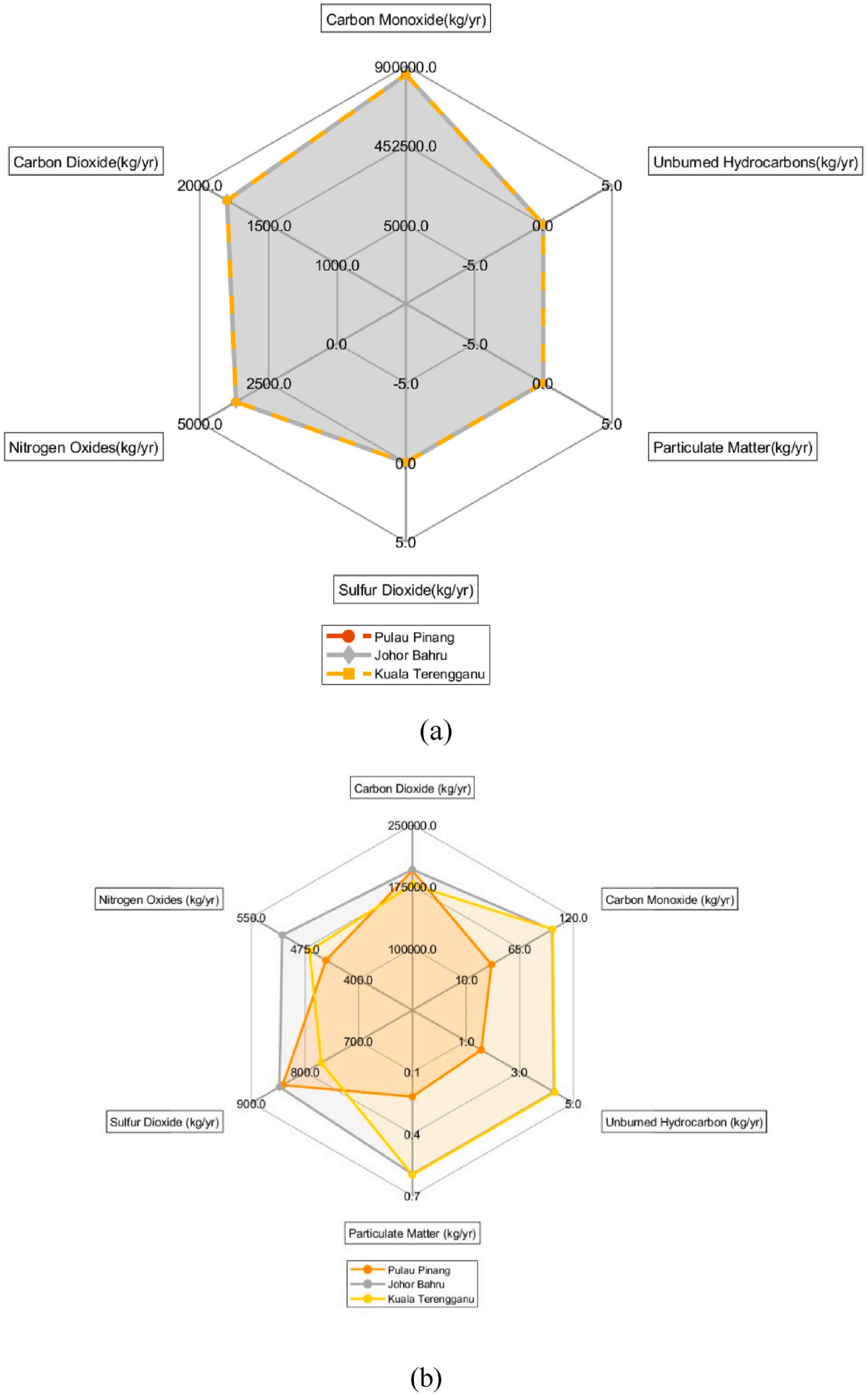


Fig. 19. Pollutant emission comparison for the EVCS configuration based on different locations. a) with grid only. b) with grid and EVCS system.

Table 9
Comparative analysis with other report studies.

Ref	Yr	Location	Configuration	COE ($/kWh)	NPC ($)	LCOH ($/kg)
[74]	2022	Saudi Arabia	PV/WT/Batteries/H_2 tank.	0.593	–	36.32
[10]	2022	Qatar	PV/WT/Batteries/Electrolyzer/H_2 tank.	0.285–0.329	2.53 M–2.92 M	–
[77]	2021	Turkey	PV/WT/Battery	0.064	1.04 M	–
[25]	2022	India	PV/Hydrogen/FC/Electrolyzer	0.41–0.48	–	3.00–3.22
[75]	2017	Sarawak, Malaysia	PV/Battery/FC	0.35	369,603	99.9
Proposed	2023	Johor Bharu, Pulau Pinang, Kuala Terengganu, Malaysia	PV/WT/Battery/Electrolyzer/H_2/FC	0.03–0.16	1.4 M–3.4 M	18.6–122

Table 10
Summary of benchmark for hybrid energy storage system based EVCS configuration with existing conventional EVCS configurations.

Parameter	Proposed Hybrid Energy Storage System based EVCS	Conventional EVCS system	References
Cost	Lower COE and NPC: 0.03–0.16 $/kWh, 1.4M–3.4 M $/yr.	Generally higher COE and NPC: e.g. 0.593 $/kWh in Saudi Arabia, 0.35 $/kWh in Sarawak, and 0.285 $/kWh in Qatar.	[74,78, 79]
Complexity	Higher, due to the integration of PV, WT, Li-ion batteries, electrolyzer, H_2 tank, and FC	Lower, typically included simpler configurations like PV/Battery or WT/Battery.	
Reliability	High, optimized for low unmet load and capacity shortage (e.g. 125–131 kWh/yr unmet load)	Variable, depending on system and backup capabilities.	
Smooth Power Supply	Improved, with integration ensuring power balance and continuous supply with minimized grid power consumption and maximized RES utilization.	Less consistent, dependent on single storage or integration sources. normally, the system depends on the PV and WT generation and utilized grid power for shortage supply.	
Environmental impact	Lower CO2 emissions, environmentally friendly.	Generally higher emissions, especially if reliant on fossil fuel based electricity.	
Efficiency	High, due to advanced optimization and multiple energy sources utilization.	Moderate, efficiency varies with system components and configuration.	
Technical viability	High, supported by detailed optimization models and case studies.	Moderate to high, depending on specific technology and deployment conditions.	

pollutants are 195465 kg/yr and 194150 kg/yr, respectively. This is due to the intensive industrial activity which produced a total fuel consumption of 5987 kg/yr and 2187 kg/yr representing the highest amount compared to Kuala Terengganu. Meanwhile, Kuala Terengganu state is considered the most cost-effective location for EVCS configuration which was found to have a CO_2 emission of 177342 kg/yr which is 9.2 % lower than Johor Bharu state.

5.5. Comparative analysis

The rapid proliferation of EVs on a global scale has raised questions about the capacity, installation, and dimensions of EVCS. In response, the proposed optimized EVCS-based hybrid energy storage system presents noteworthy technological, economic, and environmental benefits. Notably, the system exhibits the lowest COE and NPC while also contributing to reduced CO_2 emissions over the year. A comparative assessment of the proposed system against existing configurations is detailed in Table 9. The results indicate that the proposed EVCS configuration boasts the lowest COE, ranging from 0.03 to 0.16 $/kWh when compared to other existing systems. Additionally, the NPC for all locations falls within the range of 1.4 M $/yr to 3.4 M $/yr. This substantiates the cost-effectiveness and economic feasibility of implementing the proposed EVCS configuration for EV charging applications.

Table 10 compares a hybrid energy storage system for EVCS with conventional EVCS configurations. The configuration demonstrates lower costs, higher complexity, and improved reliability due to its integration of various renewable energy sources. It also offers a smoother power supply and lower environmental impact, making it more efficient and technically viable. Conversely, conventional EVCS systems, while simpler and less complex, tend to have higher costs, variable reliability, and greater environmental impacts, often depending on fossil fuel-based electricity.

6. Conclusion

This paper presents a detailed investigation that integrates the RES with the hybrid energy storage system, composed of the H_2 technology and the Li-ion batteries for the EVCS in Malaysia. The research has been conducted by modelling and optimization using HOMER Pro software and illustrates that the proposed hybrid energy storage supplies a feasible, renewable and economic solution to alleviate the increasing energy withdrawal requirements of EVCSs as well as improve the network grid support and reduce the CO_2 emissions. This new methodology mitigates the limitations of conventional organic storage strategies and represents a remarkable environmental and economic opportunity and helpful policymaker-orientated insights to enable global sustainability targets. The environmental benefits of the proposed configuration are significant with a 76.9–79.1 % reduction in CO_2 compared to the grid. The RF achieved in the results varies between 81.1 % and 89.2 %.

The potential suggestions and future recommendations for EVCS infrastructure incorporating hybrid energy storage system technology are as follows.

- Investigate the impact of integrating demand side management and deferrable loads with advanced methods to balance production and demand effectively, achieving further cost reductions.
- Integrate advanced optimization methods into the EVCS model is necessary for EVCS configuration in which the limitation of this study to ensure optimal operation and accurate outcomes, enhancing system reliability and efficiency.
- Extend future research by employing load forecasting algorithms on charging/refueling data to conduct multiyear analyses.
- Explore the potential of combining or using other resources such as biomass and hydro as standalone sources for electricity generation and H_2 production.
- Investigate the feasibility of FC technology, which can help strengthen power grids and address energy shortages in remote areas. A hybrid energy storage system with distributed generation

and FC technology can provide green and clean energy to meet base-hour energy demand or mitigate peak-hour energy demand.
- Introduce artificial intelligence-based techniques to investigate grid-connected EVCS systems for energy trading, considering different tariff schemes.

However, the proposed system may exhibit a certain limitation in terms of grid instability during ultrafast charging sessions due to substantial spikes in power demand. Additionally, the EV charging congestion during peak hours may result in power quality issues and can result in voltage fluctuations, and increased harmonic and potential overload on the grid. Some additional limitations may include high initial capital cost, complexity in integrating multiple energy sources and logistical challenges across diverse geographical locations. The enhancement of efficiency and cost-effectiveness through technological advancements such as improved battery technologies, the advanced control algorithm for better power quality management, improved integration methodology, incorporation of adaptive virtual admittance, and conducting comprehensive field trials to validate the performance of the proposed system, integrating smart grid technologies along with demand respond strategies for improvement of adaptability and reliability of the system to ensure sustainable EVCS infrastructures can be the future potential of this work.

CRediT authorship contribution statement

M.F. Roslan: Data curation, by, Formal analysis, by, Methodology, by, Writing – original draft, by. **Vigna K. Ramachandaramurthy:** Funding acquisition, by, Supervision, by, Writing – review & editing, by. **M. Mansor:** Funding acquisition, by, and, Visualization, by, and. **A.S. Mokhzani:** Resources, by, Validation, by. **Ker Pin Jern:** and, Software, by, Validation, by, and, Writing – review & editing, by. **R.A. Begum:** Investigation, by, and, Visualization, by, Writing – review & editing, by. **M.A. Hannan:** Roles in preparing the manuscript are as follows, Conceptualization, by, and, Project administration, by, Supervision, by, Writing – review & editing, by.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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