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Techno-economic analysis for using hybrid wind and solar energies in Australia

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ABSTRACT

Hybrid energy production from available resources such as wind and solar are identified as an environmentally friendly alternative for power production. Australia, as a developed country, possesses the potential to use renewable energies. Motivated by the lack of comprehensive research dedicated to the economic analysis of hybrid systems in Australia, the objective of the present work is to propose an optimal integrated renewable energy system model in order to fulfill the electrical energy demands in five major Australian cities, namely, Perth, Adelaide, Melbourne, Sydney, and Brisbane. To compare the studied cities, ten types of buildings (hospital, hotel, office, mall, clinic, retail, apartment, supermarket, school, and warehouse) have been analyzed in different climatic zones of Australia. The results have revealed that different viable scenarios for the investigated case studies are obtained. Furthermore, the optimal configuration, along with the cost and carbon emission that is obtained in the study, can be applied as a guideline for designing power systems (with a minimized cost) for the considered communities and other cities with similar characteristics (population and climatic conditions).

1. Introduction

Renewable energy requirements have been focused on in developed countries as the global economy is developing rapidly. The major types of renewable energy sources include biomass, hydropower, geothermal, wind, and solar generation. In addition, fossil fuels are finite and possess negative impacts that lead to changes that are not desirable, while using renewable energy results in a slowdown of global warming. Renewable energies are essential sources of energy and can be considered as alternative options because of environmental protection; therefore, they have the potential to replace fossil fuel resources [1].

Nowadays, many countries in the world use renewable energy, and it is expected that the growing renewable energy markets will continue and improve powerfully in the future [2,3]. Solar energy and its technologies, as an essential source of renewable energy, have huge longer-term benefits, which enhance sustainability and reduce pollution [4–6]. Australia, as a developed country, possesses the potential to use renewable energies; furthermore, solar energy has been known as a sound source of renewable energy in Australia [7–10].

As for solar energy, hot water could be generated by solar energy using solar photovoltaic (PV), in which the systems are operated well, and their efficiency has been approved across the world over the last few years [11,12], in this regard, a PV system is used to convert solar energy into electricity [13]; and a CSP technology is applied to generate electricity and also is conducted to be applied in a downstream process to generate electricity [12]. Furthermore, solar thermal heating and cooling provide thermal energy from sunrise and are applied in commercial applications [14]. Regarding solar energy, solar panels are strongly dependent on weather, which means the produced energy by the PV is dependent on sunlight. So to be able to gather solar energy effectively, rainy and cloudy days may have an obvious consequence on the power of the system [15].

Furthermore, wind energy is mostly the use of wind turbines to generate electricity and possesses the most negligible negative impact on the climate compared to other energies, such as fossil fuels. Although Australia uses some fossil fuels, clean energy, such as solar and wind energy, has a significant share in producing energy and electricity due to the fact that these types of energies own several positive impacts on the environment compared to fossil fuels [8,16,17]. In Australia, the wind is recognized as one of the most significant sources of renewable energy, as wind speeds are generally measured above average in some specific areas [18,19]. Wind turbine, as a technology of wind energy, is used to

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generate electricity and is popular as a sustainable renewable energy source, which has a much smaller negative impact on the environment than fossil fuels [20]. Consequently, it would be reliable to establish wind farms to generate power and electricity [5].

Conversely, there are lots of disadvantages to using wind energy; for example, wind power is still used for pumping water and grinding food grains in addition to the generation of electricity [21]. Moreover, weather data such as wind speed [22] and load requirements for a specific site are essential, and it is one of the difficulties of using wind energy; also, in order to measure the performance of a current system, suitable weather data is necessary [23].

The main weakness of using solo renewable energy is that those energies cannot continuously supply energy because the systems depend on the weather. Therefore, a hybrid of these two sources is recommended to improve the overall energy output. Hence, to find the optimum system in terms of the number of PV and wind turbines, an appropriate optimization system is necessary to be applied [24,25]. Additionally, as another advantage of the hybrid system, the hybrid of PV and wind turbine results in reducing the battery bank and diesel requirements [26,27]. Using hybrid renewable energies has benefited economically as well, in which many scholars have addressed hybrid renewable energy systems [28,29]; Q [30,31]. Budak & Devrim [32] conducted a comparative study in which they compared the use of water and methanol electrolysis to produce H2 to feed FC as a part of the photovoltaic system. Ren et al. [33] proposed an optimization model developed for the PV/Fuel Cell/Battery based residential energy system. For the proposed model, the evaluated results show that the PV system contributed to the environmental performance, while the BT unit contributed to the economic point of view. Hassan et al. [34,35] studied using fuel cells as an energy storage unit to increase renewable energy self-consumption in microgrid energy system applications. The results obtained demonstrate that the proposed photovoltaic fuel cell energy system provides a viable option to run semi-autonomous or fully autonomous applications. In the other two studies [34,35], the utilization of an ultra supercapacitor as an energy storage unit was evaluated, effectively increasing the energy self-consumption in applications using microgrid renewable energy systems.

Therefore, the renewable counterpart, hybrid renewable energy, is the optimal solution for reducing energy demands. Hybrid renewable energy systems usually contain more than two types of renewable energy used together to increase system efficiency as well as maintain an outstanding balance in energy supply. Feasibility assessment and study of using hybrid renewable energies have been addressed vastly in literature (e.g., Refs. [36–39]). Sinha & Chandel [40] reviewed the recent trends in optimization methods for a hybrid PV-wind energy system. Khare et al. [41] have conducted a valuable review of state-of-the-art approaches and analyzed the pre-feasibility sizing, modeling, control, and reliability features of solar PV and wind energy hybrid systems. Weschenfelder et al. [42] reviewed the state-of-the-art methods to understand the complementarity between grid-connected solar and wind power systems. Furthermore, other works reviewed numerous techno-economic approaches and models for hybrid renewable energy systems applied in different sectors, for example, rural areas [43], cities [44,45] or buildings [46]. [47] addressed a techno-economic of a hybrid solar–wind–battery system along with a sensitivity analysis to evaluate the robustness of the economic analysis.

Arul et al. [48] addressed the control strategies for the hybrid of renewable energy based on the wind-PV power system. From the above-mentioned study, results showed that the appropriate interfacing power conversion approaches were vital for the hybrid system. Balleh et al. [49] addressed a comparative study and analyzed the efficiency of energy production from solar PV, wind turbine and hybrid systems. Moreover, they evaluated the production quantity and the profitability of the proposed energy supply systems. Malik et al. [50] studied the techno-economic-environmental feasibility analysis of grid-integrated hybrid renewable energy systems, and a case study was conducted in the western Himalayan region. Baruah et al. [51] addressed a feasibility analysis of a hybrid renewable energy system for the electrification of an academic township, and the East District of Sikkim in India was selected as a case study. Also, there are some works in the field in some special parts of Australia (e.g. Ref. [52]), or some general studies in the field (e.g., Ref. [53]; G [54,55]).

This work is the first comparative study in the Australian context and is focused on identifying the best combinations of renewable energy resources in five major Australian cities. Moreover, ten types of buildings were considered, in which we conducted a feasibility study of using a hybrid of wind and solar energies as two core sources of renewable energies in Australia.

The remainder of the study is ordered as follows. Motivation is introduced in Section 2. Sections 3 and 4 present the study's research methodology and data collection. Sections 5 and 6 show input data and the results, respectively. The findings and conclusion are provided in the final sections of the paper.

2. Motivation

Our study is directed at supplementing major cities within Australia with clean energy produced by a distributed system of hybrid renewable energy plants.

Even though major cities in Australia have adequate energy connectivity and transmission, the provided electricity is generated from predominantly non-renewable resources, namely fossil fuels, including coal, gas, and oil.[1] This study aims to promote the implementation of hybrid renewable energy sources at optimal locations to replace all electricity being provided to potential locations, ultimately reducing Australia's impact on climate change and levels of greenhouse gas emissions. The locations of our case study have been identified as a research gap in the field of hybrid renewable energy optimization. Each location dramatically affects the performance of renewable energy systems. Many articles focus exclusively on the performance and limitations of the installed energy system but exclude details on how these systems benefit surrounding populations, specifically the economic benefits associated with renewable energy systems, such as no electricity fees, reduced maintenance costs, and no greenhouse gas emissions.

Although Australia uses some fossil fuels, clean energy (such as solar and wind energy) has a significant share in producing energy and electricity. Assessing the potential locations for the installment of the renewable energy system for some specific cities in Australia has been investigated in some studies (e.g. Refs. [56–61]), however, to the best our knowledge, this is the first study in Australi, which have investigated assessing the feasibility the installment of a distributed hybrid renewable energy generation system in major cities of Australia, specifically.

This study was motivated by the lack of comprehensive research dedicated to the economic analysis of hybrid systems in Australia. This work is the first comparative study in the Australian context and is focused on identifying the optimal configuration of the hybrid systems in five major Australian cities, which conducts the feasibility study of using a hybrid of wind and solar energies as two core sources of renewable energies in Australia. Five big cities in Australia, namely Perth, Adelaide, Melbourne, Sydney, and Brisbane, have been selected, and different configurations of renewable energy installations have been proposed to evaluate the feasibility of using the energies in the cities. In the proposed cities, ten types of buildings, including hospital, hotel, office, mall, clinic, retail, apartment, supermarket, schools, and warehouses, have been measured. The studied cities in this research are industrial zones and touristic areas. This paper shows a comparative study on a feasibility study of using hybrid renewable energies considering

[1] Australian Government: Department of Industry, Science, Energy and Resources. (2020). Electricity generation. Retrieved from https://www.energy.gov.au/data/electricity-generation.

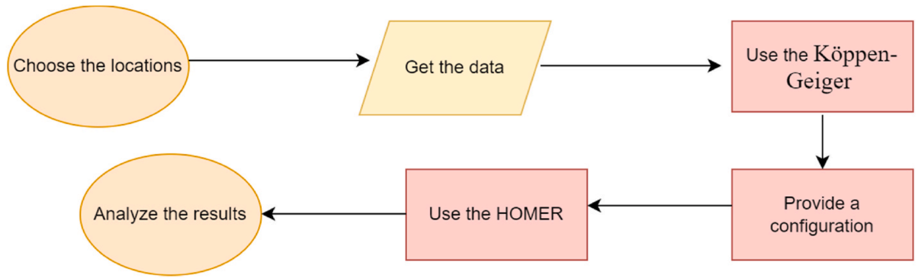

Fig. 1. Flowchart of research methodology.

Table 1
Details of the buildings in the cities.

Id	Type of Building	Size (Square feet)	Number of floor/s
1	Hospital	241,351	6
2	Hotel	110,120	6
3	Supermarket	73,960	1
4	clinic	52,628	3
5	school	52,045	1
6	Office	45,000	3
7	Apartment	33,740	4
8	Warehouse	32,946	1
9	retail	24,962	1
10	Mall	22,500	1

different configurations in Australia.

3. Research methodology

Australia owns the potential to use clean energy; renewable energy in Australia has been a major part of the country's electricity production. In this study, five locations in the south, east and west of Australia, namely Perth, Brisbane, Adelaide, Melbourne, and Sydney, have been studied. The above-mentioned cities own significant impacts on Australia in terms of economy, education, tourism, etc. Hospital, hotel, office, mall, clinic, retail, apartments, supermarket, school, and warehouse have been simulated to analyze the feasibility of utilizing renewable energy in the cities. Also, the Köppen-Geiger, climate classification system has been used to simulate similar climates in the US locations. HOMER software, as a free trial version, has been applied to measure the feasibility of installing different hybrid energy systems (Fig. 1). Table 1 shows the details of the buildings, as ten different buildings have been considered and simulated.

4. Data collection

In this section, profile loads for the studied areas, along with a brief introduction of the considered cities, have been addressed. According to the geographical locations, different cities in the west (Perth), east (Brisbane), and south of Australia, including Sydney, Brisbane, Perth, Melbourne, and Adelaide, have been studied (Fig. 2). Table 2 presents the geographical locations of the cities in Australia.

Fig. 2. The location of the studied cities (Source: Google map, 2022).

Table 2
Cities with the location.

City	Geographical location	Location
Perth	31° 57′ 12.6432″ S, 115° 51′ 25.3728″ E	Western state
Melbourne	37°48′50″ S 144°57′47″ E	South
Adelaide	34.9287° S 138.5986° E	Southeast
Sydney	33°52′04″ S, 151°12′26″ E	Southeast
Brisbane	27°28′04″ S, 153°01′41″ E	East state

5. HOMER software input data

HOMER software, as a trial version, has been used for all analyses in this study. The National Renewable Energy Laboratory (NREL) has generated this software in the U.S., and climate data, sun radiation, wind speed, and temperature have been extracted by HOMER. In HOMER, for the simulation, the average 24-h load profile and daily load profiles for the whole year are calculated. Also, scaled data are used for calculations, which refers to changing the magnitude of the data.

On the other hand, real load data almost always have some “noise”, but by specifying daily load profiles, HOMER proposes the option of adding random variability, and in this case, HOMER’s addition of random variability usually makes the load data more realistic.

5.1. Hybrid power system

Figs. 3 and 4 present the solar radiation and wind speed across Australia (April 11, 2022), indicating the selected locations as good wind and solar sources in Australia. Several configurations have been designed for this project, and all data, including solar and wind data, have been provided by HOMER, which is monthly solar radiation and monthly wind speed (Figs. 5–7). Perth owns the most solar radiation and wind speed among the other cities, followed by Adelaide in some cases and while Brisbane possesses the most solar radiation in June, July, and August (Fig. 5). From Fig. 6, Brisbane owns the most temperature values (average) for the year compared to other cities during the year. There is a significant difference between the wind speed (Perth) as the first rank and the lowest wind speed (Sydney), as shown in Fig. 7.

Furthermore, Table 3 displays HOMER input data, and all the cost values have been calculated according to the U.S. dollar. Also, Table 4 shows the technical data used in this study. It is noteworthy to mention that the presented data in this study (Tables 3 and 4) were generated by the NREL and were proposed by the HOMER software.

6. Result analysis

The discussions shown in the following subsections are the results of illustrations of the simulated load profiles.

6.1. Simulated load profile

For the simulation, HOMER calculates the average 24-h load profile for the whole year. For this aim, HOMER uses scaled data for calculations. The load profile of the studied cities in Australia in different buildings is illustrated in Fig. 8. As expected, the hospital possesses the most load values among the case studies since it has the largest size among the others, followed by hotels, supermarkets, and clinics (refer to the building size in Table 1). It is assumed that in the case of hospitals, hotels, supermarkets, and clinics, appliances such as a refrigerator for storage were considered, while in the case of school, people attend the class between mornings and afternoons. In the apartment case, since people spend most of their day outside the house, most energy consumption occurs at night.

6.2. Carbon emission results

Fig. 9 describes the distribution of released dioxide carbon in the cities compared to other cities. As shown in Fig. 9, case of an apartment, Adelaide owns the most emissions among all cities, followed by Brisbane (the emission for other cities for this case small). Furthermore, in the hotel case, Adelaide has the most released carbon compared to other cities with a huge amount of released carbon dioxide. Moreover, as can be seen from Fig. 9, Adelaide possesses the most released carbon dioxide in all cases, excluding supermarkets, hospitals, offices, and warehouses. For the warehouse case study, Brisbane and Melbourne produce the most carbon dioxide among the other cities. It is concluded, from Fig. 9, that there is no common trend for all cases and all cities.

Figs. 10 and 11 show the cost summary (total NPC and operating

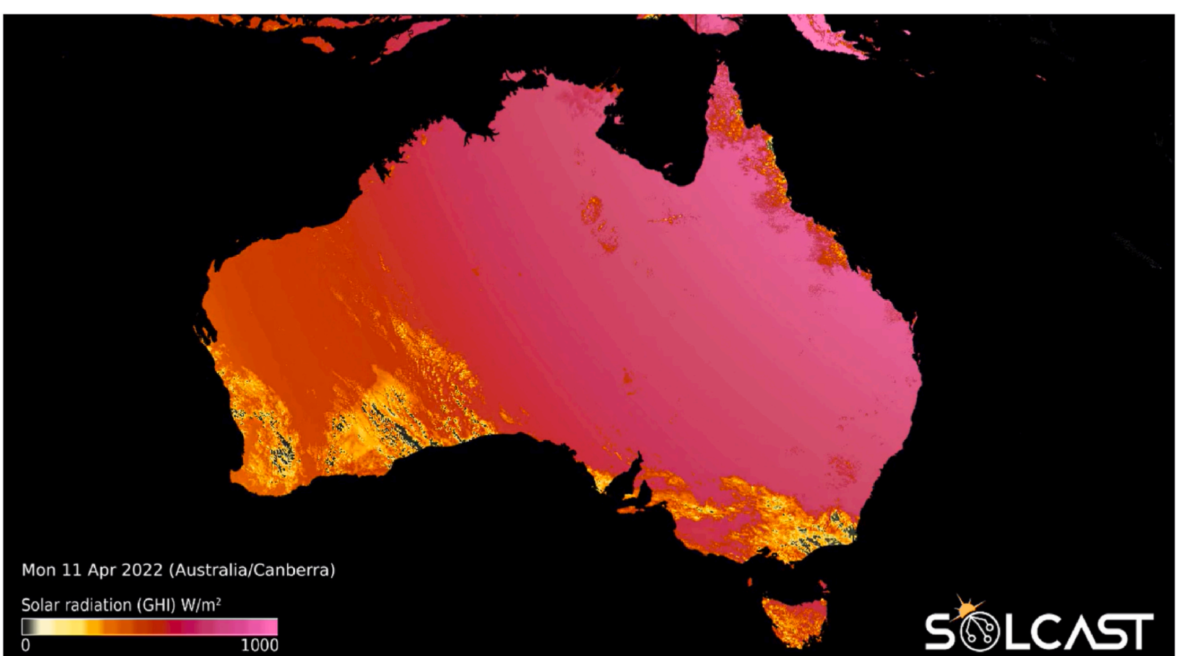

Fig. 3. Solar radiation (source: solcast.com, 2022).

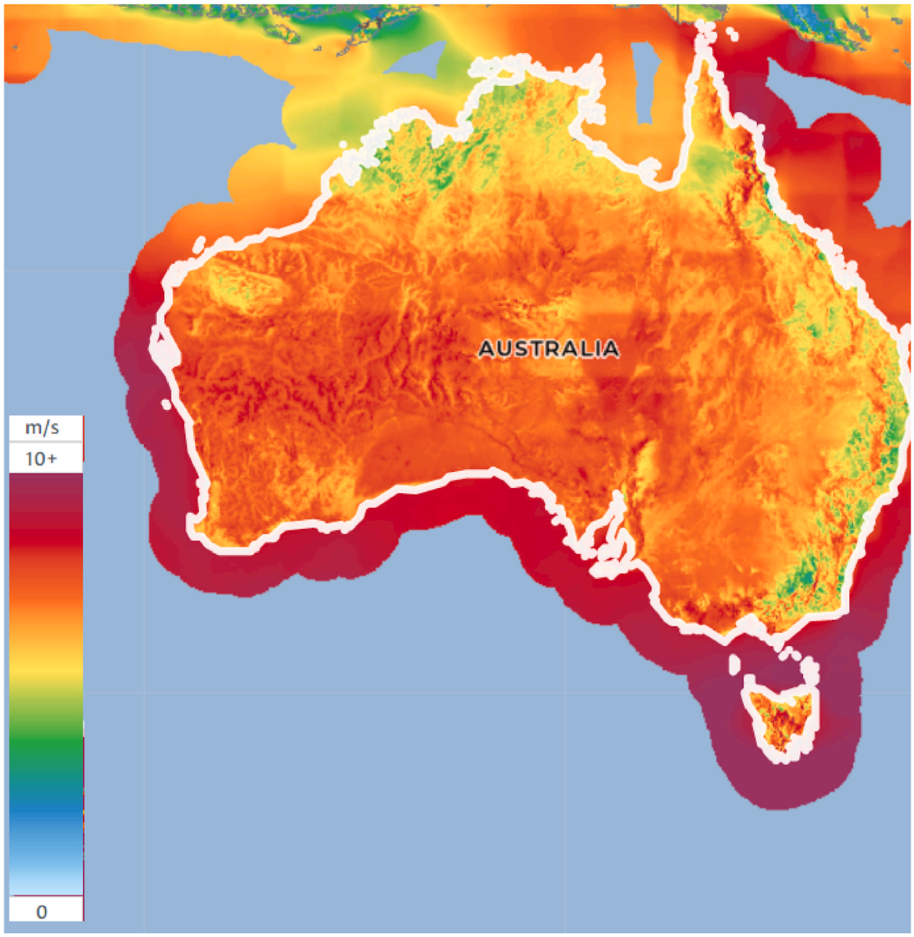

Fig. 4. Wind speed (Source: globalwindatlas.info, 2022).

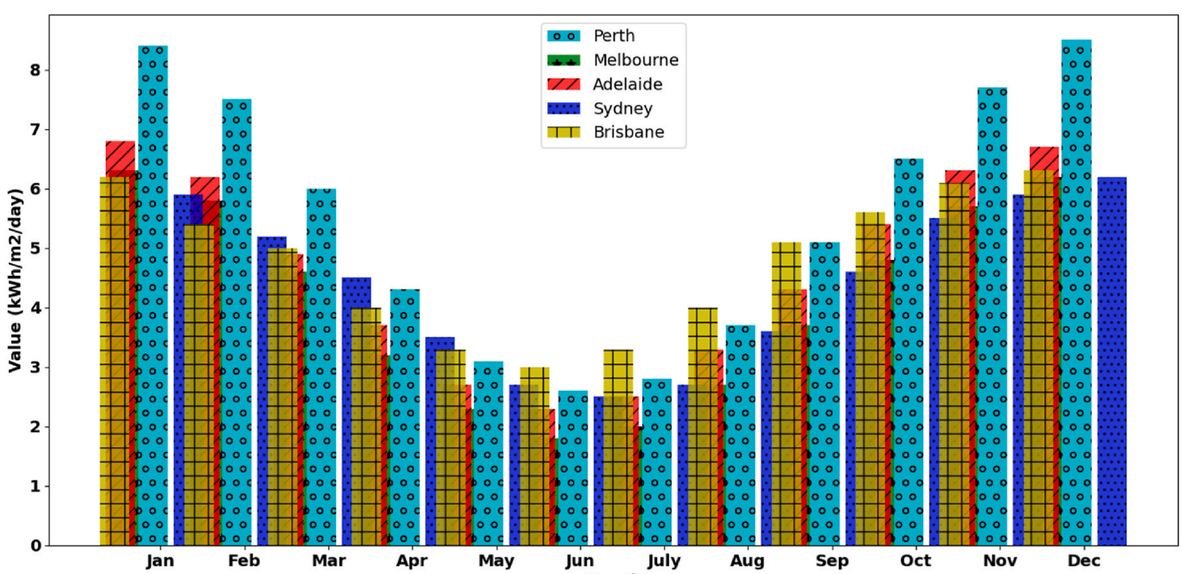

Fig. 5. Solar radiation considering a full year.

cost, respectively) of the studied cities in different buildings. In comparison to these figures, the optimum cost changes from city to city when the case is changed. As an example, considering the mall case, Melbourne uses PV as the main source of energy and owns the minimum NPC and operating costs, and Brisbane utilizes the most contribution of wind turbines compared to other cities and owns the maximum NPC and operating costs among the other cities.

As another instance, for the hospital case, in Sydney, both PV and wind turbines contribute to energy production while Sydney uses wind turbines as the most contribution compared to other cities and resulting

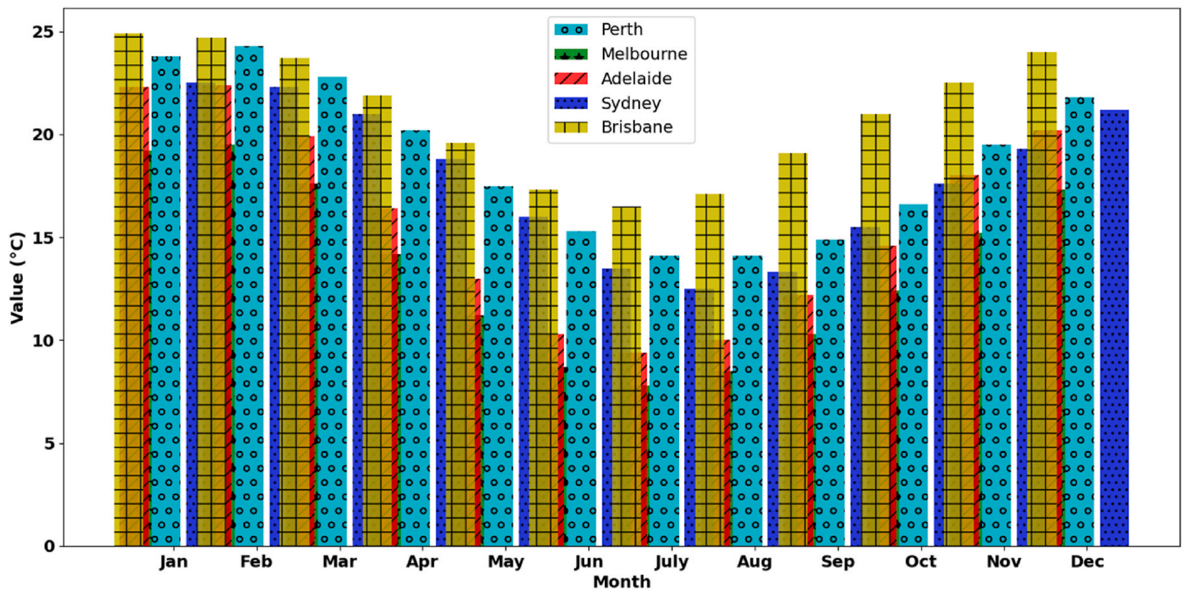

Fig. 6. Temperature resource considering a full year.

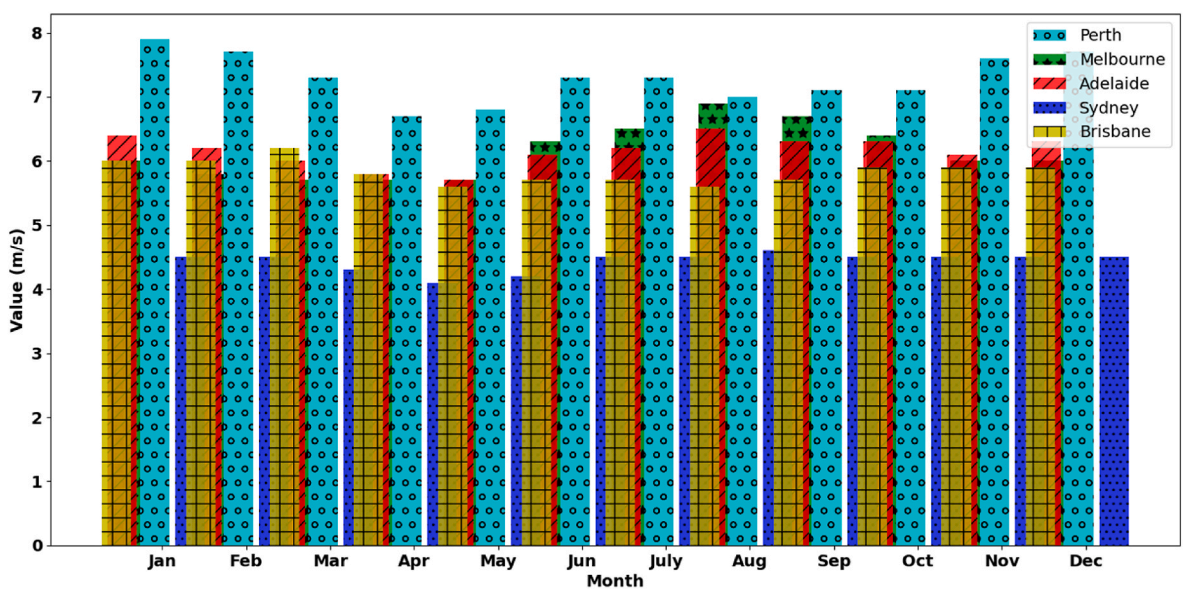

Fig. 7. Wind speed considering a full year.

Table 3
HOMER input data.

Component	Model	Life time	Initial cost (U.S. dollar/kW)	Replacement cost (U.S. dollar/kW)	Maintenance cost (U.S. dollar/kW/yr)
Diesel generator	Generic 10 kW fixed Capacity genset	15000 h	5000	5000	0.3
Battery bank	Idealized (729 (V))	2,767 kWh	155.66	15.56	2.37
PV module	Studer VarioTrack VT-65	25yr	2700	2500	180
Wind turbine	Generic 3 kW	20yr	18000U.S.$/turbine	18,000 U S.$/turbine	180 U S.$/turbine/yr
Power convertor	–	15yr	300 U S.$/kW	300 U S.$/kW	0 U S.$/kW/yr

in minimum NPC and operating costs. Moreover, in the clinic case, the wind turbine is recognized as the main energy source in Brisbane, causing the highest NPC and operating costs among the other cities. For the retail case, wind turbine possesses the minimum utilization for Melbourne among the other cities, and Melbourne possesses the minimum NPC cost compared to other cities.

From Figs. 12–14, some of the optimal costs for different configurations have been presented. Although for the “PV, Diesel, Wind,

Table 4
Technical data.

Power converter efficiency	90%
Wind turbine data:	
cut in	3.5 m/s
cut out	24 m/s
lifetime	25yr
fuel price	0.39 and 0.98U.S.$/L
K*	2
Diurnal pattern strength of wind	0/25
Autocorrelation factor for wind	0/85

K*: Weibull shape parameter.

Battery, and Converter", Perth owns the highest cost of NPC and initial capital (close to Brisbane), for two other configurations (i.e., PV, Diesel, Battery, and Converter; and PV, Battery, and Converter) Perth has the highest costs along with a significant difference with the second rank (Brisbane). Melbourne possesses the minimum initial capital and NPC costs for all the above-mentioned configurations. Moreover, it is concluded that considering various types of building in the cities results in different outputs in terms of cost the geographical location, population distribution, solar radiation, wind speed, and temperature are considered as some of the factors that affect the optimum solution found by the HOMER [2]. Also, the number of technologies (PV and wind turbine) contributing to energy production can affect the NPC and operating costs. The supplementary file (Excel dashboards) presents the findings of the other cases.

7. Summary of findings

A brief summary of the findings are:
Regarding carbon dioxide emission:

- Although load profiles in the cities are in the same range for the studied cases, there is a slight difference in some cases. For example, for the hospital case, the load profile in Adelaide is slightly higher than the others, followed by Melbourne, while for the clinic case, Sydney and Perth own the highest load profile.
- The amount of dioxide emission was measured, and the following results were found:
  - o For apartments, hotels, and retail, Adelaide owns the most emissions among all cities.
  - o Brisbane possesses the most emissions among all cities in the case of a supermarket.
  - o For office cases, Perth generates the most emission, followed by Brisbane.
- The cost results are summarized as follows:
  - o Considering the mall cases, the minimum NPC and operating cost belong to Melbourne, while Brisbane owns the maximum costs.

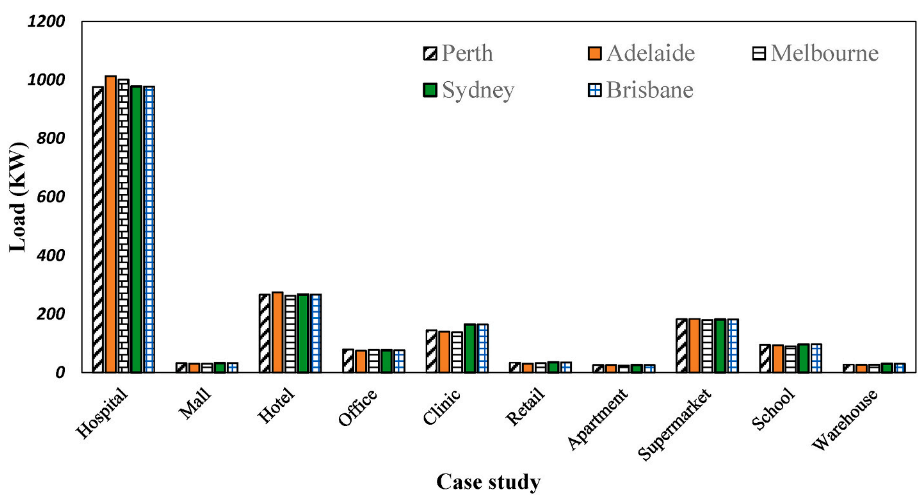

Fig. 8. Load profile data considering various types.

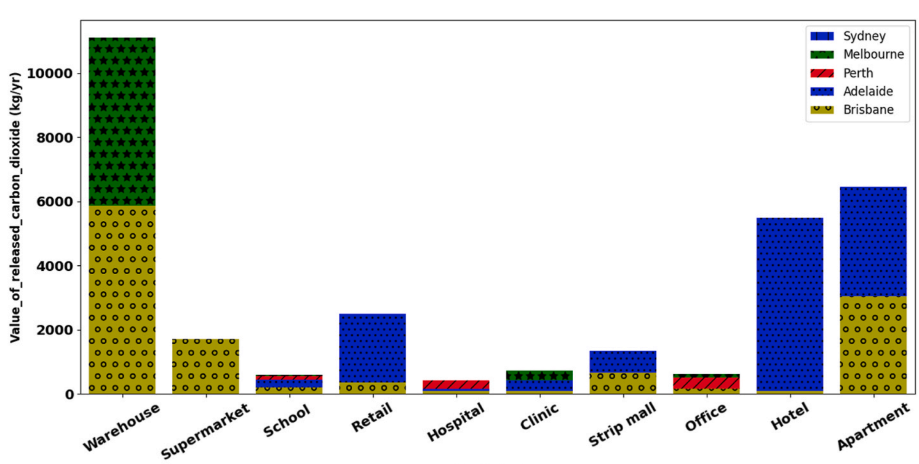

Fig. 9. Dioxide Carbon emissions in the cities.

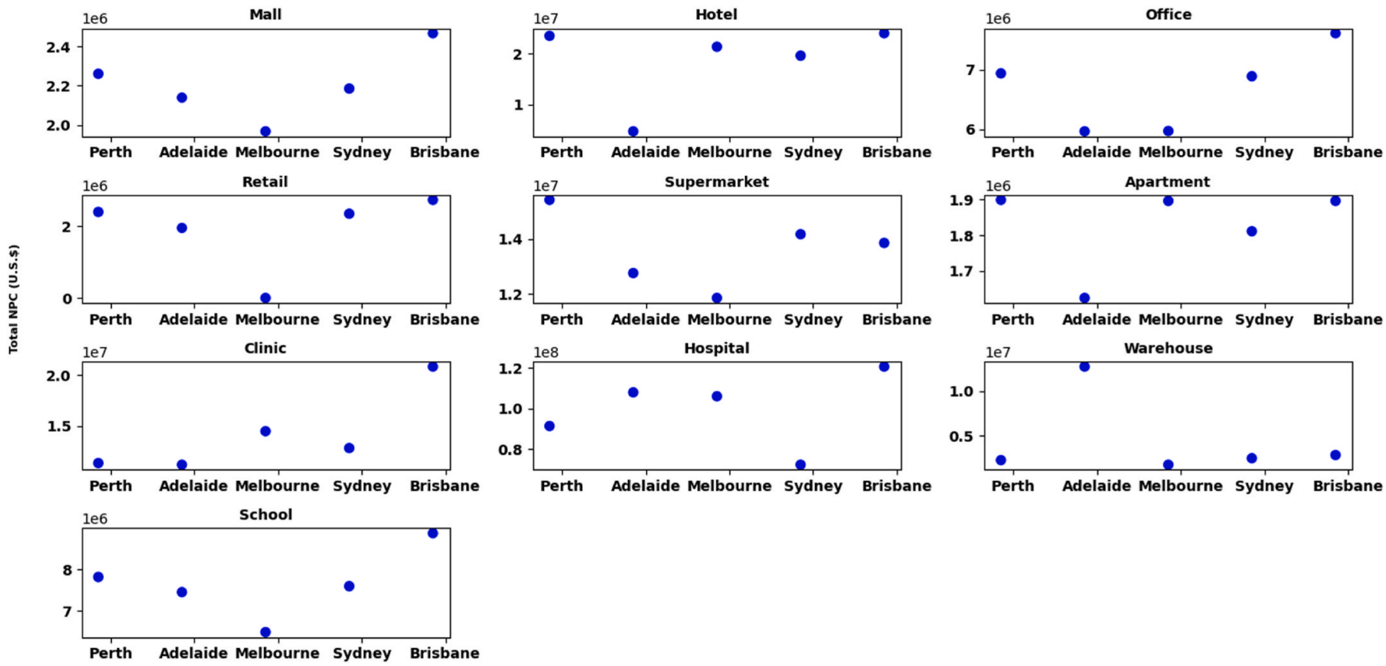

Fig. 10. Cost summary (total NPC).

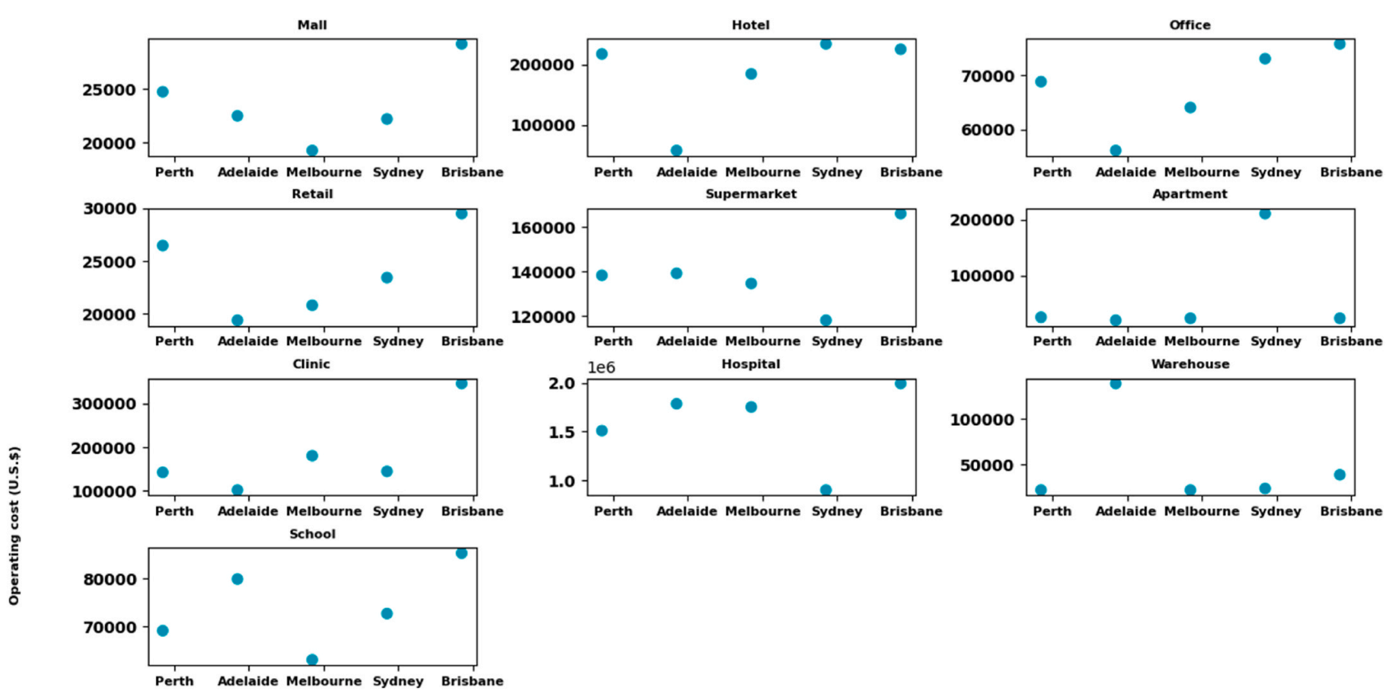

Fig. 11. Cost summary (operating cost).

o Although there is no significant difference among costs in the cities for the mall case, considering hotel, a significant difference between the highest and the lowest cost in the cities can be found.

Several configurations were considered in the study (refer to supplementary file (excel file)):

o For apartment case:

- For PV- Diesel-wind-Battery-Converter: Perth owns the highest NPC, and Operating cost, while Melbourne possesses the lowest NPC, Operating cost, and initial capital. It is worth mentioning that Perth has the highest initial capital and NPC (Close to Brisbane) with the above-mentioned configuration.

o For clinic case:

- For PV-Diesel-wind -Battery-Converter: Sydney owns the highest NPC, Operating cost, and initial capital, while Adelaide possesses the lowest NPC, COE, and initial capital.
- For PV-Diesel-Battery-Converter: Sydney owns the highest NPC, COE, Operating cost, and initial capital, while Melbourne possesses the lowest COE and operating cost, and Adelaide has the lowest NPC and initial capital.

o For hospital cases:

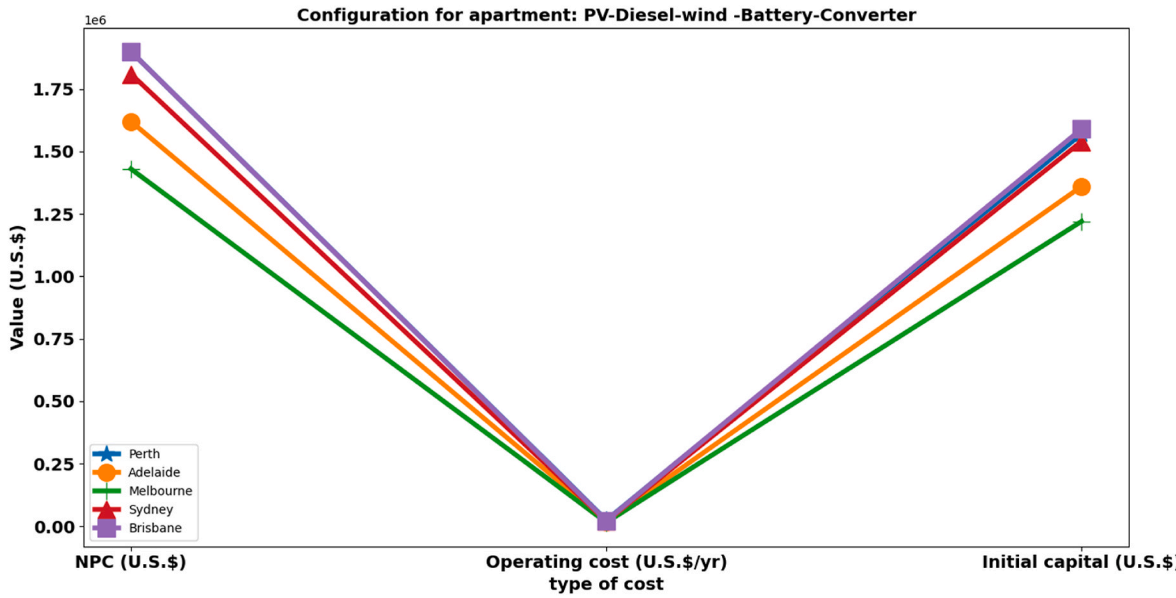

Fig. 12. Optimum cost for configured case (apartment).

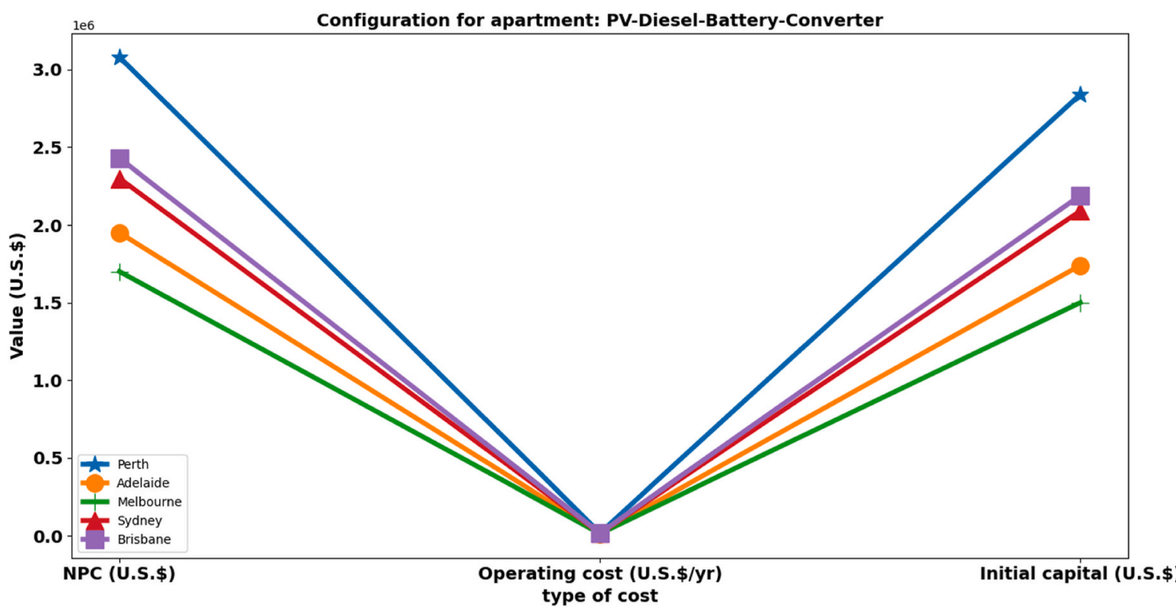

Fig. 13. Optimum cost for configured case (apartment).

- For PV-Diesel-Wind-Battery-Converter: Brisbane owns the highest NPC, COE, and Operating cost, while Sydney possesses the lowest NPC, COE, and Operating cost, and Perth has the lowest initial capital.
- For Wind-Diesel-Battery-Converter: Brisbane owns the highest NPC, COE, Operating cost, and initial capital, while Perth possesses the lowest NPC, COE, Operating cost, and initial capital.
- For Wind-Battery-Converter: Brisbane has the highest NPC, COE, Operating cost, and initial capital, and Perth owns the lowest costs.

o For hotel case:

- For PV-Diesel-wind -Battery-Converter configuration: Brisbane owns the highest NPC, COE, and Operating cost, while Adelaide possesses the lowest NPC, Operating cost, and Melbourne has the lowest COE.
- For PV-Diesel-Battery-Converter configurations: Perth owns the highest NPC, COE, and initial capital, and Brisbane possesses the highest Operating cost, while Adelaide possesses the lowest NPC, COE, Operating cost, and initial capital.

o For mall case:

- For Wind-Diesel-Battery-Converter: Perth owns the highest NPC, and Operating cost, and Adelaide has the highest COE cost, while Melbourne possesses the lowest NPC, Operating cost, and the lowest COE.
- For Wind-Battery-Converter: Brisbane has the highest NPC, Operating cost, and initial capital, while Melbourne owns the lowest costs of NPC, Operating cost, and initial capital, and Sydney has the minimum cost of COE.

Also, load profiles for each studied case are different, and it is supposed that for the case of a hospital, hotel, supermarket, and clinic, appliances such as refrigerators for storage were considered, while for the case of school, people attend the class between mornings and

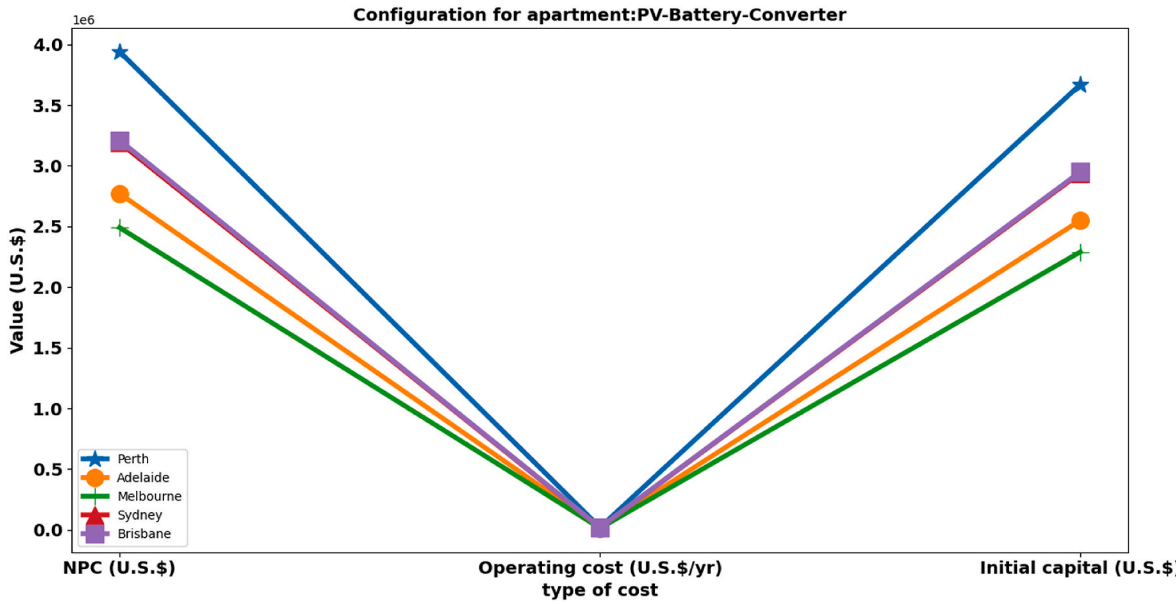

Fig. 14. Optimum cost for configured case (apartment).

afternoons. Furthermore, in the apartment case, since people spend most of their day outside the house, most energy consumption takes place at night.

More details about the configurations and the optimal costs have been presented in the supplementary file (excel file).

8. Limitation

One key limitation of this study is using HOMER software. This software has a detailed economic calculation that takes account of all economic factors, but the detailed calculation (mathematical modeling) is not revealed and it is just a black box with limited flexibility in changing the input data without the capability to check and change the economic calculation method.

9. Conclusion

This project presented a feasibility study of using a hybrid of renewable energies in five cities of Australia located, namely, Sydney, Brisbane, Perth, Melbourne, and Adelaide. This study aimed to measure and analyze the possibility of using wind and solar energies in the cities, comparing ten types of buildings, including hospital, hotel, office, mall, outpatient clinics, stand-alone retail, apartment, supermarket, school, and warehouses. Moreover, considering the load profiles of chosen buildings in the cities, the optimum solution for various configurations for the hybrid of energies, along with a cost summary identifying NPC and operating costs, were obtained. This work was motivated by the lack of comprehensive research related to the economic analysis of hybrid systems in Australia. The aim of this study was to promote the use of hybrid renewable energy sources at studied locations to replace all electricity being provided to potential places, which results in reducing Australia's impact on climate change and levels of greenhouse gas emissions.

- The results have discovered that different practical scenarios for the investigated case studies are gained.
- Also, the optimal configuration, along with the cost and carbon emission obtained in the study, can be applied as a guideline for designing power systems.

As a future direction, it is recommended to use a data mining approach for finding the optimum location for installed capacities in the cities considering the hybrid systems. Also, it is interesting to compare the other types of renewable energies in the studied cities. Moreover, comparisons with other existing installations are suitable.

Credit author statement

Iman Rahimi: Conceptualization, Methodology, Formal analysis, Software, Writing – original draft, Data curation, Investigation. **Amir H. Gandomi**: Supervision, Methodology, Validation, Writing – review & editing, **Mohammad Reza Nikoo**: Revising, Review & Editing, Visualization.

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esr.2023.101092.

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