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DESIGNING A SUSTAINABLE ENERGY MODEL FOR SMART GRIDS USING CIRCULAR ECONOMY CONCEPT

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Abstract

The global energy system nowadays is experiencing rapidly rise in global demand for energy which causes the climate crisis to increase. This study is to design a sustainable energy model for smart grid using circular economy concept which also combining the PV generator, biogas, battery energy storage system and energy management controller. These implementations can improve the sustainability, efficiency and economic performance of energy system in Malaysia. This model is implemented in Simulink and MATLAB is used to run the simulations. The main thing in this model is the controller as it is used to manage the energy flow by prioritizing renewable energy generation. The biogas will be used when the sunlight is insufficient to supply the PV generator. Battery charging and discharging is based on the peak and off-peak load demand. A simulation is carried out to evaluate the system performance under three different design such as conventional model, CE-reuse model and the proposed CE-cVPP model. The outputs showed that the proposed model has highest renewable energy penetration and lowest emissions of CO_2 which indicates the optimization of energy reuse. This research has concluded that smart grid integrated with CE concept can provide a sustainable, cost effective and resilient energy solution for the development of energy system in Malaysia.

Keywords: Battery energy storage system, Biogas generator, Circular economy concept, PV generator, Smart grid.

1. Introduction

In recent times, there is urgent need to decarbonize, decentralised and digitalized the global energy system because the global demand for energy is rising rapidly which has make the climate crisis to increase. The use of traditional power grid is uncertain in the future because the use of coal and gas are shifting to solar and wind. The opportunity for bidirectional electricity flows will increase as more affordable and efficient batteries are brought into the market and the open loop system is where the power transmits from the generating plant to the consumer will become less common [1]. Traditional power system is relying on the large-scale centralized generation and facing challenges such as high electricity demand, depletion of natural resources and emissions of greenhouse gases. Hence, smart grids are implementing few ways such as two-way energy flows, distributed generation and storage to address these challenges [2].

Besides that, the main objective of smart grid systems is to integrate renewable energy resources, enhance the reliability of grid and regulating energy flows within the system [3]. In terms of efficiency, the smart grid systems have improved over the conventional grid although they ignore the wider resource and material lifecycle consequences of their components. The integration of renewable energy sources such as solar, wind, and biogas into the grid to reduce the emission of greenhouse gases and use of fossil fuels. In Malaysia, there is approximately 4-5 kWh/m^2 of solar irradiance per day which is known as one of the highest rates in Southeast Asia. Hence, solar energy is highly recommended to be used in Malaysia for sustainability energy system [4]. Smart grids are operating within a largely linear energy and material framework. According to Circular Economy Integration in Smart Grids: Reindl et al. [5] highlighted that smart grids, while improving the efficiency of power systems, still face challenges related to the disposal of electronic components and the recovery of critical materials such as lithium and cobalt. As a result, a circular economy framework is necessary to address their material, energy, and lifecycle sustainability limitations.

In addition, circular economy is an innovative sustainability paradigm that transform the conventional linear production into a closed loop system to emphasize the concept of resource efficiency, waste minimization and reuse of materials. Based on the 3R principles, CE is operated through reduce, reuse and recycle to preserve the value of materials [6]. In energy sector, circular economy concept includes the entire lifecycle of material and processes that recover waste energy and enable resource circularity throughout the generation, storage and consumption stages. For instances, the second-life lithium-ion batteries from those electric vehicles can be rebuilt for stationary energy storage. This closed-loop method has improved the overall resilience and sustainability of energy systems which reduces the environmental impact of component production. Hence, integrating circular economy concept into smart grid system is important as it enhances long term energy efficiency and lifecycle optimization [7].

In the modern energy system nowadays, the integration of circular economy concept into the smart grid technologies is a critical way to achieve long-term sustainability. For example, the integration of circular economy concept within smart grids can achieve optimization of energy use, reduction of waste and the recovery of materials by converting grids into regenerative systems from linear energy consumers [8]. Similarly, another research showed that integrating CE-based resource recovery which include biogas produced from organic waste and reuse of thermal energy can increase lifecycle energy efficiency and decrease the greenhouse gas emissions by over 60% [9]. This integration supports a systematic change from separated energy production to a complete model that combines recovered waste energy, second-life batteries and renewable resources to form an intelligent control network. The circular economy integrated smart grid ensures that material and energy flows can be optimized throughout the whole value chain and achieving the goal of net-zero energy.

Smart grid and circular economy concept are individually popular around the world because smart grid improves the energy efficiency and support renewable energy integration while CE concept promotes the sustainable industrial practices. However, their integration is still on research stage especially developing in Southeast Asia [5]. There are smart grid studies emphasizing on improving the energy efficiency while circular economy studies focus on reducing waste and reusing of materials. Therefore, this project is bridging this research gap by implementing a circular economy-based smart grid model that combines renewable energy generation and reuse of resources to improve the sustainability in energy sector of Malaysia.

In addition, the model integrates a biomass waste-to-energy generator to provide electricity when the sunlight is insufficient. The biogas generator uses anaerobic digestion process to convert the organic waste produced from the residential area into electricity to cover the residential load. The model creates a reliable hybrid energy system by combining the output of solar irradiance with this predictable power source. Based on the Malaysia context, the biogas generator serves as an essential buffer against low sunlight normally happened during cloudy day.

In this project, the objective is to design a sustainable energy model for smart grids by integrating circular economy concept. The proposed model has combined PV generator, battery energy storage system, biogas generation and energy management controller within a community-based framework. This model is implemented and compared with conventional smart grid and CE-reuse smart grid to evaluate overall system sustainability of the circular economy integrated smart grid. MATLAB and Simulink will be used to build and simulate the model for result comparison. After that, the comparison between CE model and the other models are performed based on their annual operational cost, annual carbon emissions, self-sufficiency ratio and annual energy flow. Through this research, it demonstrates that smart grid integrated with circular economy concepts can produce a low-carbon, resilient and resource-efficient energy system which is aligned to the sustainability goal of Malaysia.

2. Research Methodology

2.1. Project overview

Figure 1 shows the overall methodology of the project by starting to design the system. In this project, PV generator and biogas generator will be the main power supply for the system. The PV generator will be used when there is sunlight as it cannot operate during low sunlight conditions. Hence, biogas generator will operate during the time PV generator is not operated to ensure that there is still energy production for the consumer. Other than that, energy management controllers, battery energy storage systems and power grid are also built in this model to ensure the continuous power supply. Next, this model will be implemented using MATLAB and runs through Simulink where the testing process is performed. Scopes are connected to grid and the battery storage system to visualize the result for evaluation. There will be 3 scenarios being simulated and compared such as conventional, half CE-integrated and full CE proposed model. Then, the output of the proposed model will be compared with two other models because this can show the energy flow and reliability of the proposed model. Performance of 3 models are being compared in terms of their annual operational cost, annual carbon dioxide emission, self-sufficiency ratio and annual energy flow. Lastly, results are evaluated and future work for the model will be discussed.

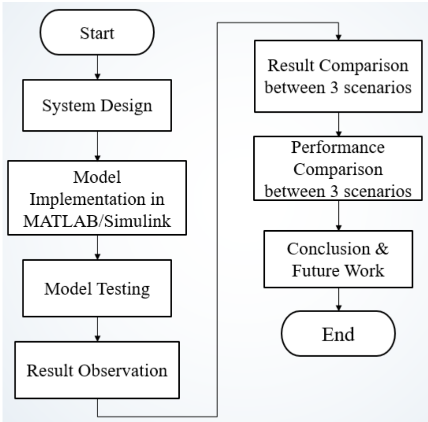

Fig. 1. Methodology flowchart of project.

2.2. Model setup

Based on Fig. 2, this is a smart grid model that is integrated with circular economy (CE) concept and is implemented in Simulink. The model has combined PV generator, biogas generator and battery energy storage system together coordinated by energy management controller to minimize the grid import. There are 3 inputs used to run the system such as solar irradiance, load demand and hour of the day. Solar irradiance drives the PV generator hourly and converted into electrical power, load demand will be the hourly consumption of electricity demand based on the Malaysia residential load, and the hour is to control the peak or off-peak hour for the battery operation. Biogas generator is used to generate electricity when solar irradiance is low especially during nighttime or cloudy days.

In the energy management controller block, there are 5 inputs such as power from PV generator and biogas generator, load demand, feedback loop from battery and peak hour settings. This controller will manage the energy flow and the charging time for the battery storage system based on the peak and off-peak hours. The battery energy storage system will be charged by the excess renewable energy produced by PV generator during off-peak hours and discharged during peak hours to meet the demand. Additionally, the controller imports energy from grid to address energy shortages problem when all the renewable resources are insufficient. Other than that, scopes are used to visualize the outcomes and each of them relates to a gain block so that the result looks clearer in smaller value. The simulation outputs like PV and biogas generation, battery energy storage system and net grid usage are analysed to assess the effectiveness and performance of smart grid in applying CE concept to optimize the use of renewable energy.

Based on the graph shown in Fig. 3, we can see both the solar irradiance and load profile used during the model simulations. These two graphs are plotted based on the realistic Malaysia data for 1 week time. The value for solar irradiance graph is showing highest during noon time and zero during nighttime [10]. It has a lower level on day 3 as I set a cloudy day so that the result is able to see the model operates under both normal day and cloudy day. For the residential load, they are separated into weekday and weekend loads which have peak load of 170 kW and 194 kW.

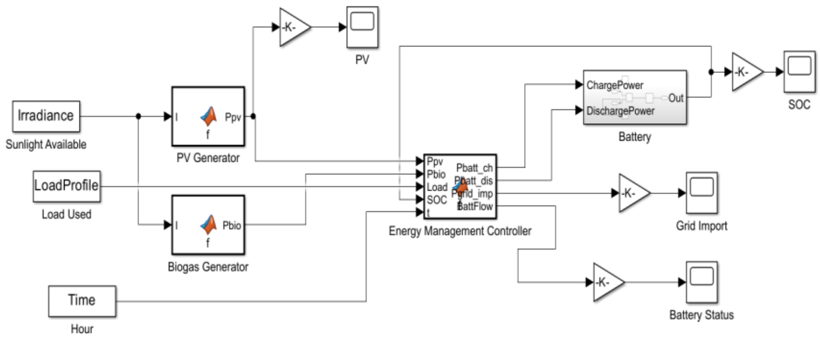

Fig. 2. Model implementation in Simulink.

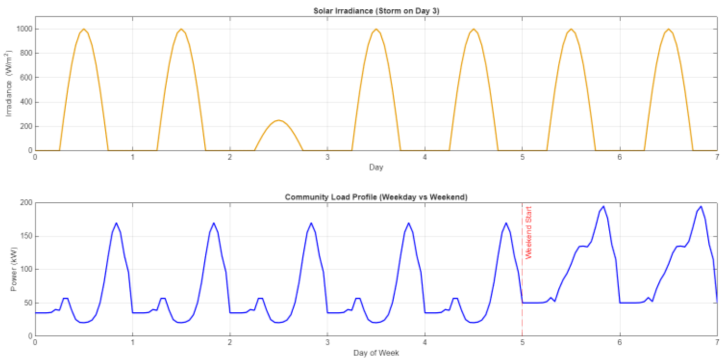

Fig. 3. Residential load profile and solar irradiance.

As shown in Table 1, they are the parameters used in simulating the model for Malaysia residential area. A smart grid model integrated with circular economy concept is developed to simulate the energy flow of a residential area that comprises 100 households. The period of simulation will be 1 week, which is equivalent to 168 hours, and the hourly setting is inputted through the time workspace. The PV system is set to have 500 kW of PV capacity which correspond to the average rooftop capacity permitted for residential use under Malaysia's Net Energy Metering (NEM 3.0) program [9]. Normally, the PV capacity used in a single house is 4 kW so 400 kW will be used for 100 houses and the performance ratio of the PV system is set at 0.8 for PV capacity of 500 kW. Next, the biogas capacity used in my model is 20 kW which only operates when the irradiance level is lower than

0.3 to prevent further discharge of the battery storage system. For battery capacity, it was sized at 1 MWh to provide enough electricity for 100 houses because the load demand for a house is estimated at around 10 kWh between sunset and sunrise. Load peaks for weekdays and weekends are 170 kW and 194 kW because people will normally stay at home during weekends more than weekdays so the use of electricity will be higher.

Table 1. Data generation.

Parameters	Values
No. of Houses	100 Houses
Time Simulated	168 Hours (1 Week)
PV Capacity	500 kW (500 000 W)
Performance Ratio of PV Generator	0.80
Biogas Capacity	20 kW (20 000 W)
Battery Capacity	1000 kWh (1 000 000 Wh)
Load (Weekday Peak)	170 kW (170 000 W)
Load (Weekend Peak)	194.98 kW (194 980 W)
No. of Houses	100 Houses

2.3. Operation of energy management controller

As shown in Fig. 4, the main component of this model is the energy management controller and it is implemented to optimize the energy management by controlling PV generator, biogas plant, battery energy storage system and the grid interaction. The controller is operated based on the real-time energy supply, load demand and hour of the day by setting in workspace. From the flowchart above, total supply from PV generator and biogas plant are summed together and compared with load demand. The irradiance set in biogas plant block is 0.3 as the threshold which means that the sunlight intensity is at least 30% of the peak value. If the value is lower than 0.3, this controller will switch the PV generator into biogas plant acts as the main power supply. On the other hand, the PV generator maintains as the main power supply when sunlight is enough to generate at least 30% of its rated power.

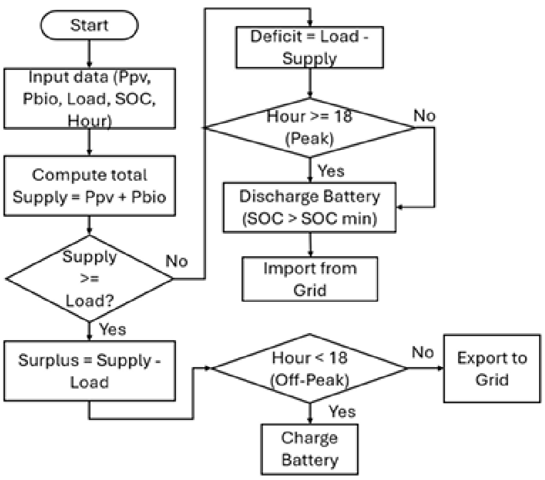

Fig. 4. Flowchart of energy management controller.

Next, surplus is indicating the extra power got from generation after supplying to current load demand. The surplus energy will be directed to charge the battery up its maximum capacity and the excess energy exported to the grid during off-peak hour which is from 6am to 6pm every day. If the power supply is not enough to handle the load during peak hours which is from 6pm to 6am, the battery will be discharged to overcome the deficit and ensure that the state of charge stays higher than the minimum threshold. Any remaining deficit will be imported from the grid as well. The controller implements the circular economy concept of optimal energy reuse by maintaining the limits of battery state of charge to prevent overcharging and ensuring an efficient balance between the local renewable consumption and grid dependency.

2.4. Biogas generator capacity selection

The capacity of biogas generator is set at 20 kW to supply sufficient electricity for the Malaysia residential area based on the amount of waste generation. According to the U.S. International Trade Administration, Malaysia have generated more than 39000 tons of solid waste daily which equivalent to approximately 1.17 kg of municipal solid waste per capita per day with 30% being food waste [10]. Within a community of 100 households, the number of occupants from each home is estimated at 5 which results in a total daily waste generation of around 585 kg. Crucially, Zakaria et al. identify that residential areas are the primary generators of solid waste in Malaysia, with organic waste such as food scraps and landscape waste can constitutes approximately 45% to 50% of this volume and that means there is 250 kg of organic waste are produced daily [11]. According to Chen et al., the anaerobic digestion of the Organic Fraction of Municipal Solid Waste (OFMSW) in Malaysia has a high methane potential due to the tropical moisture content [12]. By aggregating this community waste, the 20 kW biogas generator capacity is not suitable for continuous baseload because it is insufficient to supply large amount of load but can provide critical backup during the specific low sunlight conditions.

2.5. Comparison and evaluation

To objectively compare the three scenarios such as conventional, half CE-Integrated, and Full CE model, the annual operational cost, annual carbon emission, self-sufficiency ratio and annual energy flow are formulated and calculated over the simulation period.

In Eq. (1), the self-sufficiency ratio shows the percentage of the total energy demand met by on-site generation such as PV and biogas rather than the grid, as follows:

$$SSR\ (\%) = \left(1 - \frac{\sum_{t=1}^{T} Egrid\ (t)}{\sum_{t=1}^{T} Eload\ (t)}\right) \times 100 \tag{1}$$

where $E_{grid}(t)$ is the energy imported from the grid at time step t, and $E_{load}(t)$ is the total residential load demand at time step t.

Annual carbon dioxide emissions are calculated based on the grid import and the specific carbon concentration of the Malaysia grid, as shown in Eq. (2).

$$\mathrm{CO}_{2,\mathrm{emission}} = \left(\sum_{t=1}^{T} E_{grid}(t)\right) \times EF_{grid} \tag{2}$$

where EF_{grid} is the grid emission factor for Malaysia which is equivalent to 0.585 kg CO_2/kWh, and it is the SEDA Malaysia Baseline.

The economic performance is evaluated based on the cost of electricity purchased from the grid and the calculation is using the Tenaga Nasional Residential Tariff B, as shown in Eq. (3).

$$\mathrm{CO_{annual}}\ (\mathrm{RM}) = \left(\sum_{t=1}^{T} E_{grid}(t)\right) \times Tariff\ TNB \tag{3}$$

where TariffTNB used is set at RM 0.571/kWh.

3. Result and Discussion

The simulation is simulated over 168 hours which is 1 week, representing a typical Malaysian week with a cloudy introduced on Day 3 (Hours 48-72) to stress-test the reliability of system. The simulation will be run for a residential area consisting of 100 households. The proposed model is compared with the conventional model and half-CE integrated model where the conventional model is using electrical grid for power supply while the half-CE integrated model is using a PV generator and battery storage system. The comparison was simulated through Simulink by modifying the value of PV capacity and biogas capacity. For the conventional model, the performance ratio of PV generator and biogas capacity is set to zero then the grid will be required to supply electricity to cover the load demand. While for the half-CE integrated model, only the biogas capacity is set to zero which shuts off the biogas generator even during low sunlight conditions. The scope results of each model are shown in the following sub-sections.

3.1. Comparison and evaluation

The power generation from PV generator is based on the solar irradiance input every day and there is a cloudy day simulated on day 3. In Fig. 5, the PV scope results show zero results because only grids are used in the conventional model. I have disabled the PV generator, biogas generator and battery to simulate conventional model. While for half CE and CE proposed model, they are both using PV generators as the main power supply. In Fig. 6, the PV scope result shows that the power generation on day 3 has the lowest peak which is 100 kW and other peak is 400 kW because cloudy days have lower solar irradiance.

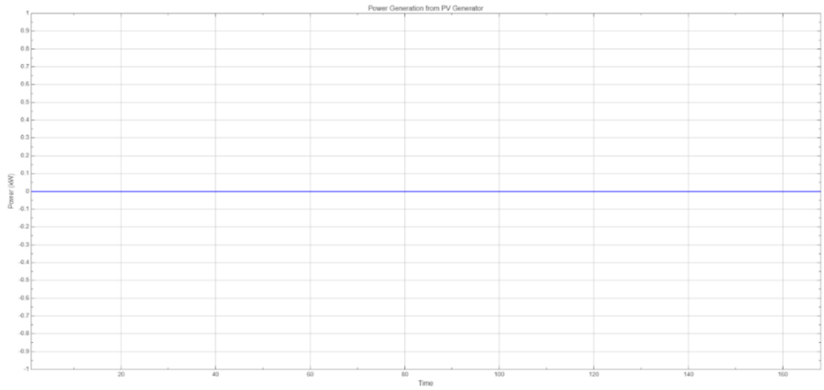

Fig. 5. PV scope result for conventional model.

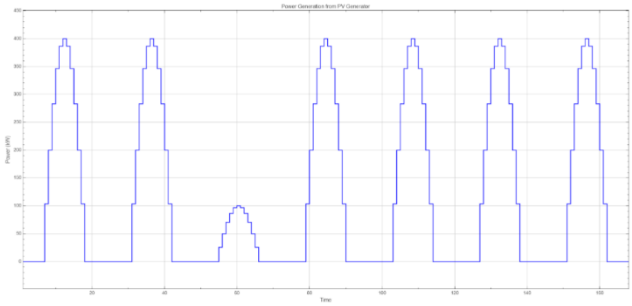

Fig. 6. PV scope for half CE and CE model.

3.2. Battery state of charge

There is no result for conventional model because I have disabled the use of battery in this mode. In Fig. 7, we can see that the curve is going up to high peak at 100% which is 1MWh and going down to low every day except for day 3 only reaches a small peak at around 450 kWh. The curves on weekends show that the battery is fully charged slower than on weekdays because more electricity is used and longer time to charge the battery. Figure 8 illustrates the state of charge of the battery for CE model and provides a “sawtooth” pattern of graph. In the charging phase, the SOC increases to its peak at 100% from 8am till 2pm because the 500 kW PV generator is generating surplus energy. While in the discharging phase, we can see that the graph is declining steadily during nighttime from 6pm to 7am. In this CE-integrated proposed model, the biogas generator helps in supplying electricity during low sunlight conditions.

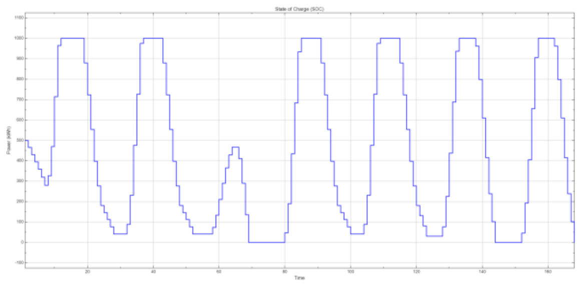

Fig. 7. SOC scope for half CE model.

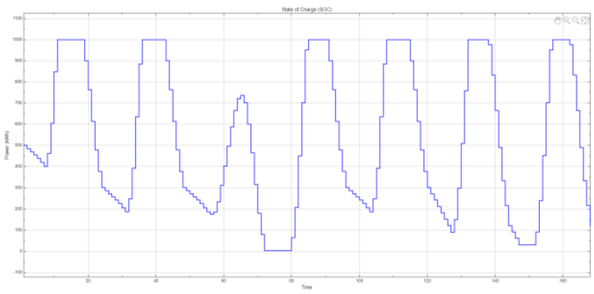

Fig. 8. SOC scope for CE model.

3.3. Grid import

In Fig. 9, the graph is perfectly mirrored of the load profile because only the grid is supplying electricity in the conventional model. The shape of the graph never goes to zero because I set a base load which represents the permanent use of home appliances. The graph also shows a higher peak on weekends compared to weekdays which indicates weekends have higher demand. In Fig. 10, scope of grid import for half CE model has a few sudden spikes shaped curves at daily night because the PV generator cannot fully charge the battery, especially during cloudy days with a solar irradiance of 0.25. At night, there is no biogas generator that helps with supplying electricity so the battery drains quickly and will stop at its limit. Then, the grid will start supplying the full load until the sun rises. Figure 11 showing the power imported from the grid for CE proposed model is zero over 168 hours but supplying on day 3 and Sunday because the electricity generated from PV generator is insufficient and load demand is higher on weekends. The grid will only be used when the power generated from PV generator and biogas generator are insufficient.

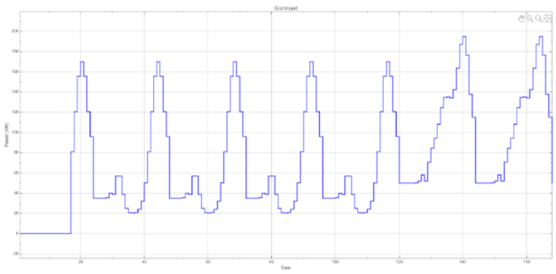

Fig. 9. Grid imports for conventional model.

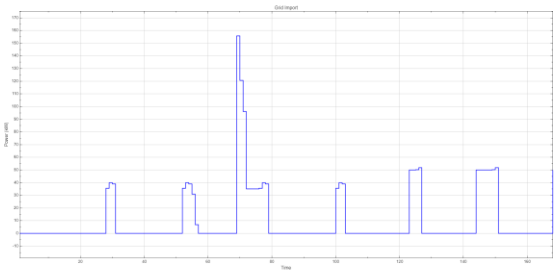

Fig. 10. Grid import for half CE model.

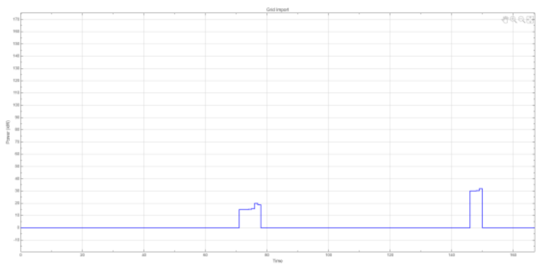

Fig. 11. Grid import for CE model.

3.4. Battery status

As mentioned above, there is no battery in conventional model, and the result does not exist. In Fig. 12, the battery status for half CE model is shown depends on the charging and discharging phase of the battery. The graph shows that the charging of the battery reaches 250 kW to indicate the absorption of surplus solar energy. The discharging level is nearly 170 kW on weekdays and 190 kW during weekends. In Fig. 13, it shows the bidirectional power flow of battery for CE proposed model. The peak charging power has reached approximately 250 kW around noon time in the positive region. The discharging level is nearly 150 kW on weekdays and 175 kW during weekends.

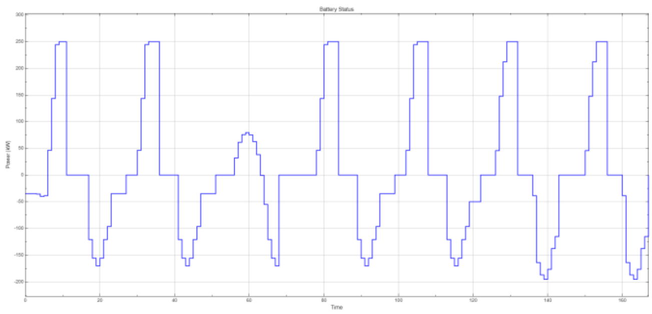

Fig. 12. Battery status for half CE model.

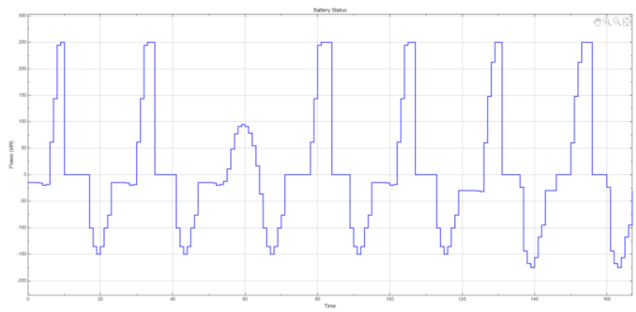

Fig. 13. Battery status for CE model.

3.5. Result comparison of proposed model with conventional and half CE

There are four results such as annual operational cost, annual carbon emissions, self-sufficiency ratio and annual energy flow shown in Fig. 14. These results are compared for the 3 different models such as conventional, half CE and CE proposed. In the annual operational cost result, the cost for conventional model is RM 372 824, half CE model is RM 53 642 and CE model is RM 7756. The cost is calculated based on the TNB rate of RM0.571 per kWh. The conventional model has highest cost because it uses 100% of its power from the grid, often during peak tariff hours when electricity is at most expensive period. The half CE model is using PV generator to supply electricity which has reduced around RM 310k compared to the conventional model. The proposed CE model has the lowest operational cost because the biogas generator supports the model by supplying electricity during low sunlight conditions. By covering the base load using waste converted energy, it prevents the battery from emptying, ensuring that the community never needs to purchase electricity from TNB, even during the monsoon simulation.

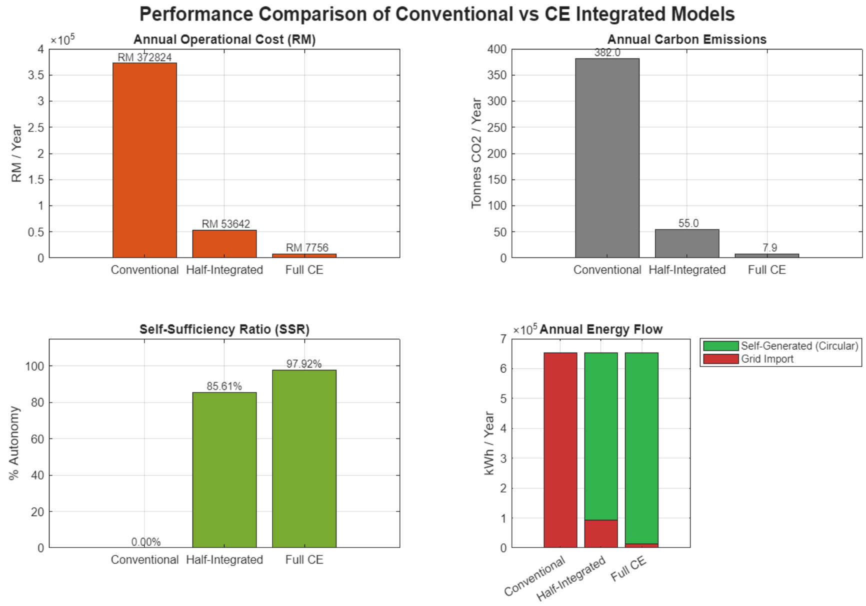

Fig. 14. Performance comparison result of 3 different models.

Next, the graph for annual carbon emissions for conventional models has 382 tons, half CE model has 55 tons, and the CE model has 7.9 tons of emissions per year. The high footprint of conventional model is directly tied to the grid emission factor of 0.585 kg CO_2/kWh which represents the burning of fossil fuels at power plants to meet residential demand. The half CE model failed to reach zero emissions because whenever the solar charged battery ran dry, the system reverted to the dirty grid. The full CE model has the lowest emissions because it substitutes the grid backup with biogas generator, effectively decoupling the residential area from the national carbon footprint completely [13, 14].

For self-sufficiency ratio result, this is the most critical engineering findings as it represents the reliability of the model. The 12.31% difference between the half CE and full CE models represents the reliability gap caused by solar intermittency. Although 85.61% is high, the missing 14% corresponds to blackout periods or grid reliance during the night and cloudy day. The integration of biogas generator is to bridge this gap. As shown in the SOC scope results, the Biogas injection prevented the battery from dropping into the critical "Deep Discharge" zone between 5 to 15%, keeping it healthy at 30-40% and ensuring continuous uptime.

In the annual energy flow result, conventional model has a full red bar which indicates that 100% of grid is used in this mode. Half CE model has larger green bar compared to red bar and CE model has larger green bar which indicates that the organic waste is almost fully utilized to generate the power that solar PV cannot provide. This validates the waste-to-energy hypothesis.

4. Conclusions

In this study, it has successfully shown that integrating circular economy concepts into smart grids can improve sustainability, efficiency and economic benefits compared to the conventional and half CE-integrated model. The proposed model is implemented with a PV generator, biogas generator, battery energy storage system and energy management controller. This model is operated based on the controller by managing renewable energy during peak hour and off-peak hour. There are three different systems being analysed such as conventional, half CE-integrated and proposed model. The conventional model is simulated by disabling both the PV generator and biogas generator while the half CE-integrated model only disables the biogas generator. The simulation results have used realistic irradiance and load profiles to confirm that smart controllers are effectively managing the surplus generation by charging and discharging batteries during off-peak hours and peak hours. The result analysis has proved that the integration of biogas generator can transform residential waste into electricity is the main factor to stabilize the grid during normal day and simulate cloudy day, especially the performance of half CE-integrated model. Next, the performance comparison between 3 models has summarized that CE model is achieving sustainability and the objectives of the project. In conclusion, this research demonstrates that a circular economy concept integrated smart grid can improve system sustainability and acts as a highly effective solution for future energy systems in Malaysia.

Nomenclatures

EF_{grid}	Grid emission factor
$E_{grid}(t)$	Energy imported from the grid at time step *t*.
$E_{load}(t)$	Total residential load demand at time step *t*.

References

1. Dkhili, N.; Eynard, J.; Thil, S.; and Grieu, S. (2020). A survey of modelling and smart management tools for power grids with prolific distributed generation. *Sustainable Energy*, *Grids and Networks*, 21, 100284.
2. Campana, P.; Censi, R.; Ruggieri, R.; and Amendola, C. (2025). Smart grids and sustainability: The impact of digital technologies on the energy transition. *Energies*, 18(9), 2149.
3. Bhatia, R. (2024). The role of smart grids in enhancing energy efficiency and sustainability. *International Journal of Advanced Control and System Engineering*, 2(2), 10-18.
4. Koons, E. (2023). Solar energy in Malaysia: A bright future or dim prospect? Retrieved January 22, 2026, from https://energytracker.asia/solar-energy-in-malaysia
5. Reindl, K.; Dalhammar, C.; and Brodén, E. (2024). Circular economy integration in smart grids: A nexus for sustainability. *Circular Economy and Sustainability*, 4, 2119-2145.
6. Elroi, H.; Zbigniew, G.; Agnieszka, W.-C.; and Piotr, S. (2023). Enhancing waste resource efficiency: Circular economy for sustainability and energy conversion. *Frontiers in Environmental Science*, 11, 1303792.

7. Alqahtani, M.F.; and Afy-Shararah, M. (2025). Integrating circular economy practices into renewable energy in the manufacturing sector: A systematic review of the literature. *Sustainability*, 17(16), 7301.
8. Munonye, W.C. (2025). Circular economy meets smart energy grids: Designing systems for resource optimization and carbon reduction. *Frontiers in Sustainability*, 6, 1568254.
9. Xie, H. et al. (2024). Eco-energetical analysis of circular economy and community-based virtual power plants (CE-cVPP): A systems engineering-engaged life cycle assessment (SE-LCA) method for sustainable renewable energy development. *Applied Energy*, 365, 123191.
10. International Trade Administration. (2024). Malaysia waste management. U.S. Department of Commerce. Retrieved January 22, 2026, from https://www.trade.gov/market-intelligence/malaysia-waste-management
11. Zakaria, A.A. et al. (2024). Strategic domestic solid waste management in urban areas. *MAEH Journal of Environmental Health*, 6(1), 1-5.
12. Khairuddin, N.; Manaf, L.A.; Hassan, M.A.; Halimoon, N.; and Karim, W.A.W.A. (2015). Biogas harvesting from organic fraction of municipal solid waste as a renewable energy resource in Malaysia. *Polish Journal of Environmental Studies*, 24(4), 1477-1490.
13. Xie, H. et al. (2025). Prosumer full lifecycle sustainable footprint painting for circular economy and community-based virtual power plant: A multi-objective optimization research. *Process Safety and Environmental Protection*, 202, 107728.
14. Goh, H.H. et al. (2025). Sustainable development through the balancing of photovoltaic charging facilities and agriculture for energy harvesting. *Applied Energy*, 377, 124463.