

Sustainable Practices in Healthcare Facilities: A Case Study of Hospital Pulau Pinang's Waste Management and Energy Efficiency Initiatives

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Abstract: Nowadays, hospitals generate significant waste, contributing to pollution and landfill overload, as well as high energy consumption, leading to substantial carbon dioxide (CO₂) emissions. The objective of the reduce, reuse, and recycle (3R) program at Hospital Pulau Pinang is to minimise landfill waste and reduce the environmental footprint, while aiming for significant reductions in electrical consumption and CO₂ emissions through the Energy Management Program (EMP). From 2020 to 2024, Hospital Pulau Pinang demonstrated the 3R program significant advancements in waste management, with annual increases in recycled materials. In 2020, the hospital successfully recycled 121,943.06 kilograms of waste, valued at RM 34,713.92, primarily consisting of mixed paper. Subsequent years continued this positive trajectory, with 2021 witnessing the recycling of 146,042.70 kilograms (RM 85,907.89), mainly comprising cardboard. In 2022, 2023 and 2024 sustained robust efforts, recycling 143,274.55 kilograms (RM 92,569.75), 134,877.83 kilograms (RM 60,941.47) and 136,818.66 kilograms (RM 67,140.53) respectively, with cardboard as the predominant material recycled. Meanwhile, the EMP initiative at Hospital Pulau Pinang, spanning from 2017 to 2024, has consistently delivered substantial electrical savings and significant reductions in CO₂ emissions, shows steadfast dedication to sustainability. Beginning with a 10.93% reduction in 2017, the program achieved annual savings of 8.15% in 2018 and 7.76% in 2019, followed by remarkable leaps to 17.95% in 2020, 21.89% in 2021, 22.74% in 2022, 22.50% in 2023, and 20.44% in 2024. This progression correlates with a steady decline in CO₂ emissions, notably reducing by thousands of tonnes each year, from 2,194.58 tonnes in 2017 to 26,001.27 tonnes in 2024. In conclusion, the 3R program not only reduces landfill waste, saves costs, generates revenue, and enhances sustainability practices, demonstrating a commitment to efficient waste management beneficial to the Ministry of Health (MOH). Simultaneously, EMP efforts have notably reduced electrical consumption and CO₂ emissions, shows a proactive approach to sustainable healthcare practices.

Keywords: Reduce, Reuse and Recycle (3R), Energy Management Program (EMP), Waste, Environmental, Footprint, Healthcare, Sustainability

INTRODUCTION

Rising resource costs and the urgency of climate change mitigation are driving the need for interdisciplinary, international research on sustainable practices in healthcare facilities, particularly in waste management and energy efficiency (McGain & Naylor, 2014). Hospital activities consume substantial financial, energy, and material resources, requiring a thorough evaluation of their environmental impact including buildings, energy use, transport, procurement, waste management, and staff behaviour to promote sustainable healthcare practices (UK National Health Service (NHS) Sustainable Development Unit, 2012). Using Building Information Modelling (BIM) and tools like Green Building Studio (GBS), energy efficiency in healthcare facilities enhanced by optimizing parameters such as orientation, materials, glazing, and HVAC systems, significantly reducing energy costs, CO₂ emissions and electricity consumption (Khahro et al., 2021).

The study supports healthcare administration and pollution control in creating checklists for monitoring healthcare waste management practices, contributing to sustainable environmental development and preventing infection spread from healthcare waste in the long term (Thakur et al., 2021). Healthcare facilities should implement sustainability strategies, including responsible medical waste management, energy and medicine consumption, and carbon footprint reduction, by forming unit-based "Green Teams" of doctors, nurses, and paramedics, providing training, and raising awareness to minimize energy use from heating, lighting, ventilation, and air conditioning (Sürme et al., 2024). Personal perspectives from patients, carers, and advocates are crucial in assessing how sustainability initiatives in healthcare impact care quality and the overall patient experience (Knagg et al., 2024). Excessive electricity consumption in hospitals addressed through optimized lighting, heating, and cooling designs, coupled with energy

optimization training, technical audits, and inspections, to achieve economic benefits and reduce environmental pollutants (Mahmoudi et al., 2024). The 3R Program at Hospital Pulau Pinang (HPP) aims to minimize landfill waste through recycling and responsible waste segregation, enhance recycling efforts to increase the value of recycled materials, and foster a culture of sustainability by engaging staff in waste reduction initiatives. In parallel, the Energy Management Program (EMP) seeks to reduce electrical consumption and CO₂ emissions through energy-efficient practices (Odunayo et al., 2025) while achieving cost savings and establishing sustainable energy management for long-term benefits (Nwankwo et al., 2024).

2. BACKGROUND

Hospital Pulau Pinang (HPP) also known as Penang General Hospital, is a prominent public healthcare institution located in George Town, Penang, Malaysia. As one of the largest hospitals in the northern region, it serves as a critical tertiary referral centre for Penang and neighbouring states such as Kedah and Perlis, offering comprehensive medical services to a diverse population (Segarmurthy et al., 2024). HPP is a leading medical centre offering specialised care, emergency services, medical education, public health initiatives, and advanced diagnostic and treatment facilities to ensure high-quality, patient-centred healthcare (Muhamad et al., 2024). HPP is a major healthcare facility with a capacity of 1,163 beds (Faisal et al., 2023). This hospital has a Gross Floor Area (GFA) for energy use totalling 119,383.77 square meters. With a workforce of 4,600 hospital staff, it provides extensive medical services, supported by 16 operation theatres to cater surgical needs. HPP has two blocks under the C2 tariff and five blocks under the B tariff. The C2 tariff are receiving electricity at a higher voltage to meet higher energy demands (Qu et al., 2025). Meanwhile, the B tariff is categorised as lower voltage reflecting lower energy consumption requirements. HPP is committed to sustainability, actively implementing programs such as reduce, reuse and recycle (3R) Program and the Energy Management Program (EMP) to minimise its environmental footprint while promoting eco-friendly practices. Through its comprehensive services, educational contributions and sustainability efforts, HPP continues to a cornerstone of Malaysia's healthcare system (Lee et al., 2025). The 3R program at HPP is an essential component of sustainability efforts. It strives to reduce waste generation, stimulate material reuse, and promote recycling among hospital employees, patients, and visitors (Ahlawat et al., 2025). This program is consistent to incorporate sustainable practices into healthcare operations while reducing our environmental footprint. It also helps the Ministry of Health's (MOH) in Sustainability Program, which launched in 2015 and focuses on waste reduction and environmental conservation in healthcare facilities across Malaysia (Ram & Bracci, 2024). The primary objectives of the 3R program at HPP focus on fostering environmental sustainability and community health through the principles of the 3R concept, which is particularly relevant to its waste management initiatives. This program aims to achieve a minimum 5% waste reduction by actively minimising the volume of waste generated within the hospital premises, effectively reducing the amount sent to landfills and curbing environmental pollution. Additionally, it seeks to enhance recycling practices and improve the segregation of recyclable materials to ensure effective waste management (Moh & Abd Manaf, 2016). The 3R program actively promotes recycling efforts, resulting in significant increases in the quantity and value of materials recycled annually, such as paper and cardboard, which not only generate revenue and reduce operational costs but also align with global sustainability goals (Zorpas, 2024). HPP promotes environmental responsibility among staff and visitors, fostering sustainability and reducing its ecological footprint to support public health. Figure 1 shows that the 3R material collected at HPP.



Figure 1: The 3R material collected at Hospital Pulau Pinang
 HPP focus on energy efficiency through its EMP complements the 3R concept by emphasizing resource conservation. By reducing electricity consumption and optimising energy usage, HPP achieves sustainable energy practices while decreasing its reliance on non-renewable resources. These combined efforts highlight how HPP can adopt the 3R principles alongside energy-efficient strategies to create a holistic approach to sustainability. This case study serves as a model for other institutions, showing how sustainable practices in healthcare significantly contribute to environmental preservation, operational efficiency and long-term resilience (Sharma & Alshatshati, 2024). The EMP at HPP serves as a prime example of sustainable practices in healthcare facilities to environmental and operational efficiency. By adopting energy-efficient technologies such as LED lighting, optimised HVAC systems, and automated controls, the EMP has successfully reduced electricity consumption, minimised CO₂ emissions, and lowered operational costs, all while maintaining high-quality healthcare services (Dion & Evans, 2024). The 3R Program reduces waste and generates revenue, while the EMP optimizes energy, together making the hospital a model of sustainable healthcare.

3. METHODOLOGY

The methodology employed by HPP demonstrates an integrated approach to sustainability by combining effective waste management and energy efficiency initiatives. These strategies emphasize practical and scalable solutions such as waste segregation, recycling incentives, and energy optimisation programs and monitoring systems. This approach reduces environmental impact, fosters a culture of sustainability among staff, and delivers economic benefits through cost savings and revenue generation. Figure 2 illustrates the flowchart of sustainable practices at Hospital Pulau Pinang.



Figure 2: Flow chart of the Sustainable Practices in Hospital Pulau Pinang
 HPP implements a structured 3R segregation and storage system, requiring staff to use designated recycling bins, while the Concession Company (CC) ensures proper bin placement, compliance with government standards, and efficient collection and transportation of materials. Segregation and storage of 3R materials implemented by requiring staff to separate these materials into dedicated recycling bins at the source of generation. The Concession Company (CC) in HPP determine the specific locations for recycle bins, and the CC must ensure that the bins comply with Government specifications. For the collection of 3R materials, the CC is responsible for collecting these materials from the designated 3R bins throughout the HPP, ensuring that the collection devices also meet Government standards. After

collected, the CC transport the 3R materials to the collection centre. Finally, CC responsible for transporting all 3R materials out of the collection centre and manage the transportation process to ensure compliance and efficiency in waste management.

HPP's waste collection system is managed by a dedicated team, ensuring efficient handling of recyclable materials across multiple collection points. The total manpower allocated for waste collection at HPP consists of 2 personnel, who are responsible for managing 32 collection points. The types of 3R waste collected at the HPP include various materials: mixed paper, cardboard, plastic, iron scrap, tin scrap, aluminium cans, plastic bottles, plastic wrappers, pallets, and lead/plumbum.

Aligned with the Energy Management Program (EMP), HPP's energy efficiency initiatives focus on optimizing consumption through advanced technologies, real-time monitoring, and sustainable practices to reduce costs, lower carbon emissions, and enhance overall hospital sustainability. HPP implements energy-saving measures such as retrofitting lighting systems with LEDs, optimizing HVAC systems with smart controls, and adopting renewable energy sources. Real-time energy management systems monitor progress and track CO₂ emissions, promoting transparency and accountability. The EMP utilises regular evaluations and feedback to ensure continuous improvement, lowering operational costs and carbon footprints while enhancing patient care and hospital sustainability.

4. RESULTS AND DISCUSSIONS

Reduce, Reuse and Recycle (3R) Program

From 2020 to 2024, the 3R Program successfully diverted 671,898.10 kg of recyclable materials from landfills, generating RM 335,789.60 in revenue. The highest collection occurred in 2021 (146,042.70 kg), while the lowest was in 2023 (81,055.23 kg) before rebounding in 2024 (136,818.66 kg). Cardboard consistently contributed the most revenue, peaking in 2022 (RM 68,617.78), though its value fluctuated. Plastic bottle collection declined significantly from 36,921.52 kg (2020) to 5,737.16 kg (2024), while tin/iron scrap and aluminium cans showed strong growth. Table 1 displays the annual recycling data and revenue trends for the years 2020 to 2024. Lead/plumbum collection dropped drastically after 2020, and pallet recycling remained stable. Revenue did not always correlate with weight due to market price fluctuations, emphasizing the need for strategic waste management. Despite some declines, the 3R program remains effective, and strengthening recycling, optimising collection methods and increasing public participation can further enhance sustainability efforts. Figure 3 illustrates the trends in recyclable material collection and revenue from 2020 to 2024.

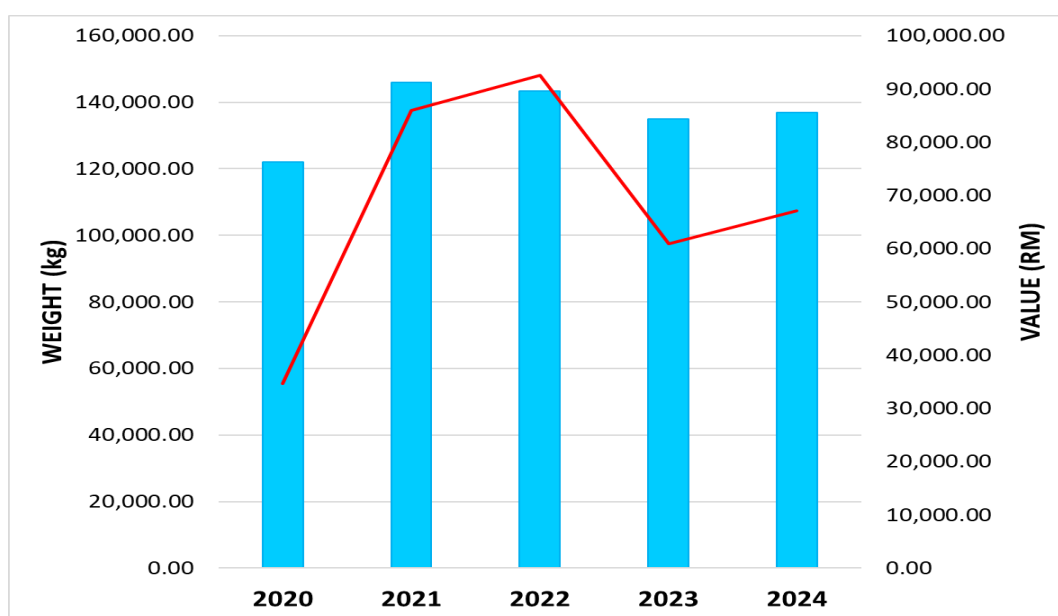


Figure 3: Trends in Recyclable Material Collection and Revenue (2020–2024)

Table 1: Annual Recycling Data and Revenue Trends (2020–2024)

Types of Materials	2020		2021		2022		2023		2024	
	Weight (kg)	Value (RM)	Weight (kg)	Value (RM)	Weight (kg)	Value (RM)	Weight (kg)	Value (RM)	Weight (kg)	Value (RM)
Mixed Paper	8,474.05	2,394.83	14,281.00	4,556.45	8,133.60	4,047.88	8,121.80	3,238.51	6,332.70	2,684.76
Cardboard	55,217.64	17,488.37	89,094.60	61,418.30	90,515.50	68,617.78	72,524.78	35,970.16	92,480.80	50,311.80
Plastic	1,288.20	1,112.28	1,806.00	1,040.55	2,497.90	968.80	1,171.00	705.95	1,501.00	843.33
Iron Scrap	384.20	179.30	2,492.00	2,639.00	44.30	54.77	962.80	1,079.08	127.40	145.52
Tin/ Iron Scrap	202.20	133.73	78.50	99.58	261.80	222.20	611.60	676.72	1,149.80	1,132.92
Aluminium can	202.20	133.73	8.00	14.45	35.80	110.12	7.60	25.08	415.20	392.92
Plastic Bottle	36,921.52	6,924.80	6,334.40	13,258.88	6,917.65	13,721.60	5,152.55	7,846.89	5,737.16	7,638.20
Plastic wrapper	104.00	98.17	933.00	547.98	771.60	968.80	750.80	594.00	926.60	741.28
Pallet	1,831.25	1,878.92	30,509.20	1,624.30	33,072.40	1,771.80	23,763.00	1,435.00	27,412.00	1,925.00
Lead/Plumbum	17,312.00	4,368.04	506.00	708.40	1,024.00	2,086.00	415.00	830.00	736.00	1,324.80
PVC	5.80	1.75	-	-	-	-	-	-	-	-
Total	121,943.06	34,713.92	146,042.70	85,907.89	143,274.55	92,569.75	81,055.23	36,651.30	136,818.66	67,140.53

Energy Management Program (EMP):

From 2017 to 2024, the Energy Management Program (EMP) successfully saved 37,009,215.89 kWh, reducing CO₂ emissions by 25,684.40 tonnes and generating RM 18,837,690.89 in cost savings. Figure 4 illustrates the annual energy savings (kWh) and savings percentage trends from 2017 to 2024. The highest energy savings occurred in 2022 (6,370,608.00 kWh, 22.74%), with notable reductions in CO₂ (4,421.20 tonnes) and cost savings (RM 3,242,639.47). However, a slight decline in efficiency was observed in 2023 and 2024, possibly due to increased energy demand. The baseline energy consumption for HPP from January 2016 to December 2016 was recorded at a total of 27,496,731.00 kWh, amounting to RM 11,445,531.70. Figure 5 presents the graph of annual energy consumption from 2016 to 2024. Despite this, the EMP has consistently delivered financial and environmental benefits, emphasizing the need for continuous optimization and investment in energy-efficient solutions. Table 2 presents the trends in energy consumption, costs, and CO₂ reduction from 2017 to 2024.

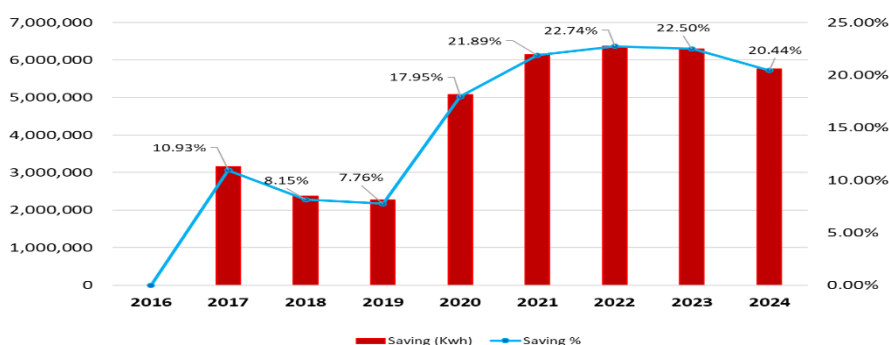


Figure 4: Annual Energy Savings (kWh) and Saving (%) Trends (2017–2024)

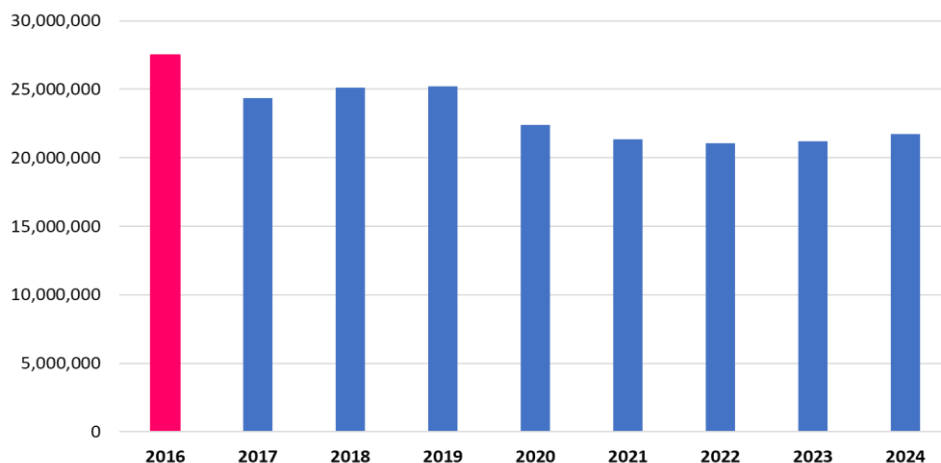


Figure 5: Graph Annual Energy Consumption (2016–2024)

Table 2: Energy Consumption, Costs and CO₂ Reduction Trends (2017-2024)

	2017	2018	2019	2020	2021	2022	2023	2024
Energy Consumption (Kwh)	3,162,216.00	2,372,759.10	2,273,324.00	5,084,111.00	6,150,668.00	6,370,608.00	6,295,495.79	5,756,642.00
Percentage (%)	10.93	8.15	7.76	17.95	21.89	22.74	22.50	20.44
*RM	1,609,567.94	1,207,734.38	1,157,121.92	2,587,812.50	3,130,690.01	3,242,639.47	3,204,407.36	2,930,130.78
**CO ₂ Reduction (Tonne / Year)	2,194.58	1,646.69	1,577.69	3,528.37	4,268.56	4,421.20	4,369.07	3,995.11

* Savings (RM) based on Hospital rates (RM0.509/kWh) at baseline 2016 including Imbalance Cost Pass-Through (ICPT), Kumpulan Wang Tenaga Boleh Baharu (KWTBB), and related charges

**CO₂ emission factor for Malaysia kg 0.694(CO₂/kWh) -source <http://www.greentechmalaysia.my/carboncalculator/index.php>

The total savings of 37,009,215.89 kWh of energy from 2017 to 2024, equivalent to RM 18,837,690.89, reflect a strong commitment to energy efficiency and sustainability. This substantial energy reduction aligns with the annual CO₂ emissions reductions, totalling 25,684.40 tonnes, achieved through effective energy-saving measures, particularly notable in 2021 and 2022. Additionally, the environmental benefit of saving 1,167,472 trees highlights the significant ecological impact of these efforts, as this figure represents the amount of CO₂ that trees can sequester over their lifetimes. Overall, these achievements demonstrate how ongoing energy management not only delivers financial savings but also contributes positively to environmental stewardship and climate change mitigation. The energy-saving initiatives not only enhanced operational efficiency and cost savings but also contributed significantly to sustainability by reducing its environmental footprint. By lowering energy consumption and CO₂ emissions, these efforts align with national and global sustainability goals, particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) (Raman et al., 2024). The reduction in carbon emissions supports climate change mitigation, while improved resource efficiency reflects responsible energy

management in healthcare operations (Braithwaite et al., 2024). These initiatives demonstrate a commitment to sustainable development, reinforcing the HPP's role in environmental stewardship and long-term ecological preservation.

7. CONCLUSION

The sustainability initiatives at HPP, particularly the 3R Program and the EMP demonstrated significant environmental and economic benefits. The 3R Program has successfully reduced landfill waste, enhanced recycling efforts, and generated revenue, with a total of 671,898.10 kg of recyclable materials collected between 2020 and 2024, yielding RM 335,789.60 in revenue. Despite fluctuations in waste collection and revenue due to market price variations. The EMP has also achieved remarkable outcomes, saving 37,009,215.89 kWh of energy, reducing CO₂ emissions by 25,684.40 tonnes, and generating RM 18,837,690.89 in cost savings from 2017 to 2024. The highest energy savings occurred in 2022, with 6,370,608.00 kWh saved, although a slight decline in efficiency was observed in 2023 and 2024 due to increased energy demand. The 3R program at HPP exemplifies the commitment to environmental sustainability and community health by focusing on reducing waste, promoting reuse, and enhancing recycling practices. The aim is to maximise environmental benefits and inspire similar practices across other healthcare facilities, ultimately contributing to a greener future and improving the health of the communities HPP serve. The 3R Program has successfully minimised landfill waste while generating revenue, showcasing the potential for financially viable waste reduction strategies in HPP. Simultaneously, the EMP has achieved substantial energy savings, significantly reducing carbon emissions and operational costs, reinforcing the role of energy-efficient strategies in sustainable healthcare management. HPP serves as a model for healthcare facilities, demonstrating how strategic waste management and energy efficiency initiatives can contribute to environmental conservation, cost savings, and overall hospital sustainability. Moving forward, continuous improvements, policy support, and expanded engagement with hospital staff and the public was essential to further enhance the impact and scalability of these initiatives in the broader healthcare sector.

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