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DEVELOPING PRODUCT SUSTAINABILITY USING LIFE CYCLE ANALYSIS: CASE STUDY ELECTRIC COOKER PRODUCT

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Abstract:
Recently, sustainable development has emerged as a solution to environmental problems. It is widely recognized that individuals' choices in their daily purchases and consumption patterns significantly impact the environment. As such, it is incumbent upon everyone to adopt sustainable lifestyles and strive to preserve resources for future generations. One area where this can be achieved is through product development. Despite the importance of sustainable products, their availability remains limited. In this study, the analysis was performed on a popular electric cooker as a sample product. Various aspects of the product were examined, including the life cycle, the raw materials used, the processing stage, the usage phase, and the end-of-life. The goal of this study is to gain valuable insights and propose improvements for a more sustainable version of the product. The environmental impact of each stage of the product's life cycle was also analyzed. With this method, some practical approaches for specific steps can be proposed to make the product more sustainable and reduce the harmful impact on the environment. Overall, there were many opportunities to adjust the various stages of the product's life cycle to make it more sustainable.

Keywords: Life Cycle Analysis, Sustainable Product, Recycling, Eco Indicator 99, End of Life

INTRODUCTION

Environmental problems have greatly influenced the product development system. The industry must minimize the harmful impact of customer goods by applying sustainability concepts. Sustainable product development has three key factors: environmental friendliness, economic aspects, and social responsibility (Relich, 2023). Meanwhile, in processing, the term sustainability should be covered in four essential areas: materials selection, design and production, supply chain, organization structure, and policy management (Kalkanis et al., 2023).

Referring to the sustainable concept, a sustainable product must be produced with renewable resources, less waste, and low energy usage. Introducing sustainable products to society is essential for improving consumption behavior (Heinl et al., 2021). However, the availability of sustainable products is still limited (Weissmann & Hock, 2022). For instance, it is not easy to find green-labeled electric cookers on the market, as this product is a popular household appliance.

Most companies still adopt a linear life cycle or cradle-to-grave approach when developing products. It is defined as the linear sequence of a product from production, being used, and finally disposed of (Wilson et al., 2019). This philosophy is popularly known as the take-make-waste strategy (Morone & Yilan, 2020). Raw material for product making is initially obtained from the environment. Thus, a direct impact on the environment is negligible. In the product processing stage, energy consumption or released debris will hurt the environment. After production, a product will be packed in multilayer packaging and delivered to the market. The product is then used by customers for a couple of years until dumped after broken. Implementing a linear life cycle arouses

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environmental problems such as high volumes of trash accumulation in landfills (Wilson et al., 2019).

The product needs to be developed more sustainably to reduce its harmful impact. The current product life cycle analysis is necessary to find the adjustable steps. Every stage in the life cycle, including material selection, processing, packaging, usage phase, and end-of-life, will be adapted to make it more sustainable.

METHODS

The analysis started by observing and describing the product component after disassembling it. The product investigated in this research is an electric cooker by Midea (Figure 1) that has been used extensively for seven months. The general specifications of the electric cooker are listed in Table 1.

Figure 1. The electric cooker

Table 1. Typical Specifications of The Electric Cooker

Specification	Value
Dimension	415 x 239 x 216 mm
Net Weight	1.4 kg
Volume	3L
Rated Power	1200 W
Rated Voltage	220 V

The product's life cycle was then defined by drawing a schematic overview that mainly focused on material, processing, packaging, usage phase, and end-of-life scheme. After that, the weight of the material was measured, and the related processing of each component was determined in a functional unit. Indicator points of the whole stage in the product life cycle were calculated based on the Eco-Indicator 99 methodology. The indicator point resulting from the calculation shows the environmental impact. Based on the observation and calculation, a new type of life cycle was introduced and examined similarly. The analysis was performed by comparing the environmental impact between the current and proposed life cycles.

RESULT AND DISCUSSION

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Life Cycle Analysis. In this study, a life cycle analysis of an electric cooker is conducted to assess the product's environmental impact on waste management. The general life cycle of an electric cooker is illustrated in **Figure 2**. The current life cycle of this product is categorized as a linear life cycle. It begins with production, then the delivery process to customers as users, and ends up in the disposal stage. However, in this life cycle, it can be seen that any input in every stage, from the cradle to the grave, releases waste into the environment. There is no further step after disposal, thus contributing to waste accumulation on earth.

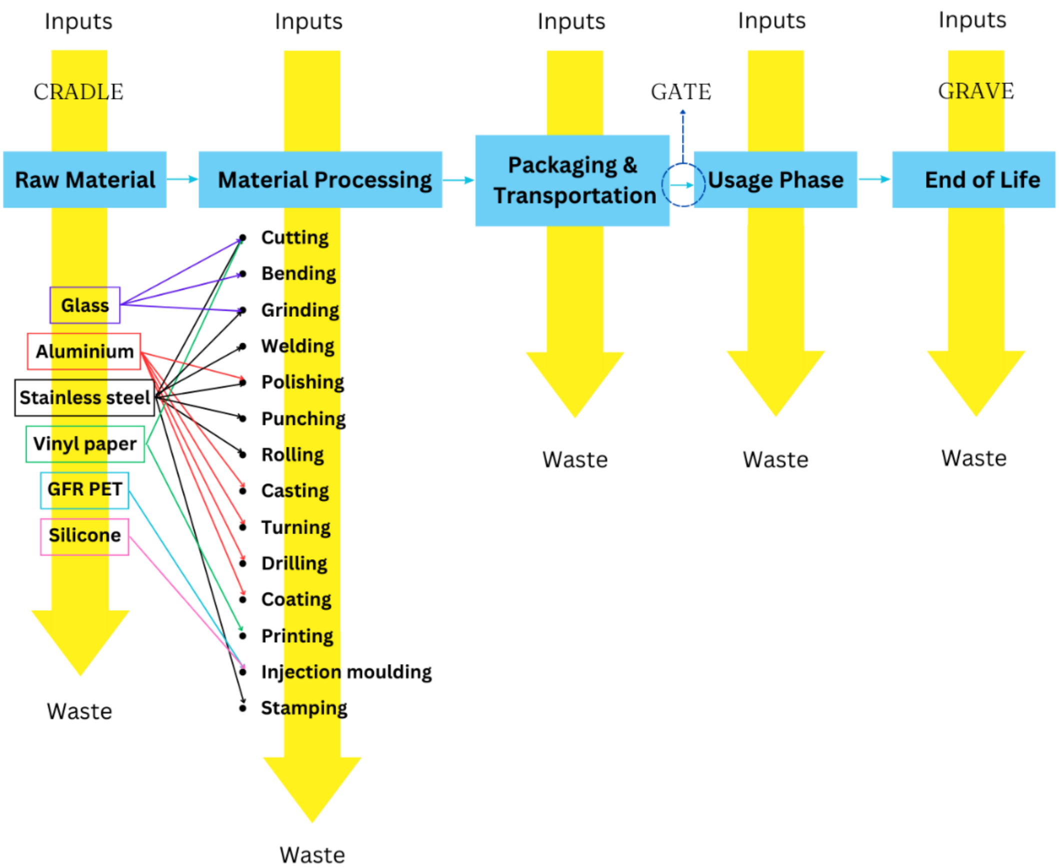

Figure 2. The typical life cycle of an electric cooker

A circular life cycle approach presented in **Figure 3** is proposed to tackle this problem. Recycle and reuse are introduced to replace the disposal scheme. The strategy focuses on increasing the possibility of recycled or reused products. Reducing the number of non-recyclable materials and minimizing material variations can be carried out to raise the recycling option. It is worth noting that using recyclable materials can improve the product's sustainability (Evode et al., 2021). Meanwhile, to increase the possibility of reuse attempts, the simple disassembly process of the product should be facilitated (Formentini & Ramanujan, 2023). Modifying the product to support recyclability and reusability will extend its life and prevent it from being dumped into the landfill.

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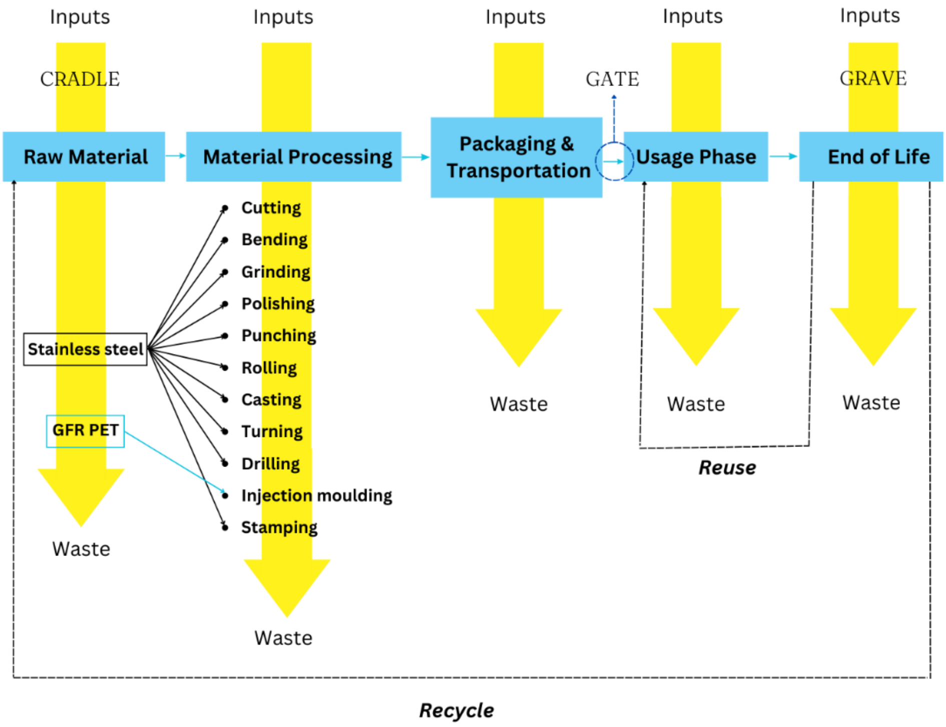

Figure 3. The circular life cycle of an electric cooker

Material Analysis. The electric cooker product is constructed of 6 materials listed in **Table 2**. The primary materials are aluminum and glass fiber (GF) reinforced PET. In this product, aluminum is used as the inner bowl material. Its properties, such as lightweight, quick and consistent heating, and affordable price, make aluminum cookware immensely popular. However, a study showed that the longer food is cooked or stored in aluminum cookware, the more metal is released into the food (Weidenhamer et al., 2017). This phenomenon can be dangerous, especially for people with chronic kidney disease (Charu Bansal et al., 2020). To reduce the harm of the aluminum cookware, the manufacturer applies a coating layer to the product. The coating can also provide a non-sticky feature on the cookware. Usually, the inner bowl is coated with different materials, such as the Teflon coating applied in this product. However, it is observed that the coating is easily scratched even after only seven months of usage (**Figure 4**). It means that the life expectancy of the inner bowl is short and may need to be replaced after specific years of use. Unfortunately, the inner bowl in this product is attached to the electronic parts and is difficult to disassemble, thus making it impossible to replace.

Table 2. Environmental impact of current product materials

No	Material	Parts	Total weight in kg (W)	Indicator (I)	Result (W*I)
1	Glass	Lid	0.4261	49	20.8789
2	Aluminium	Inner bowl	0.41	780	319.8
3	Stainless steel	Lid Screws, Steamer plate	0.1925	86	16.555
4	Vinyl paper	Labels	0.0004	178	0.0712

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5	GF reinforced PET	Body shell, Lid handle, Handle shell, Bottom shell, Cable holder	0.505	761	384.305
6	Silicone	Pad	0.0034	331	1.1254
Total impact of material production phase (in mpt) A = sum of all results in this phase					**742.7355**

Figure 4. Wear occurred in the inner bowl layer

The shell of the electric cooker is entirely made of GF-reinforced PET (**Figure 5**). This material is the modification of Polyethylene terephthalate plastic with glass fiber (5%-30%) as a reinforcing agent. The glass fiber is mixed to improve the durability of the plastic in terms of stiffness, strength, and water absorption (Asokan et al., 2009). GFR PET has been widely used in household ware, electronic devices, and other applications requiring lightweight components with high resistance (Rubio & Thielemans, 2022). On top of that, this material has high mechanical strength and enhanced heat and chemical resistance (Unterweger et al., 2014). GFR PET is classified as a composite material and thus has limited recyclability compared to pure PET because of its thermoset properties (Asokan et al., 2009). Although it cannot be melted, it can still be recycled using mechanical and chemical recycling (Rubio & Thielemans, 2022).

Figure 5. Electric cooker shell material

The comparison of the environmental impact of the material used in the current product and the proposed design is shown in **Table 2** and **Table 3**. In the proposed design, the environmental impact is minimized by reducing the material variations in the product. Glass, initially used as the

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lid component, can be removed. The lid component can alternatively be made of stainless steel. The silicone materials that build up the pad part can also be eliminated. The padded part can be merged with the bottom shell; thus, it will have a similar material to the shell. The information written on the sticker label can be alternatively printed directly on the packaging, thus minimizing the number of materials used.

Table 3. Environmental impact of proposed design materials

No	Material	Parts	Total weight in kg (W)	Indicator (I)	Result (W*I)
1	Stainless steel	Lid, Screws, Inner bowl, Steamer plate, electronic layer housing, U clamp	1.8343	86	157.7522
2	GF reinforced PET	Body shell, Lid handle, Handle shell, Bottom shell	0.4753	761	361.7033
Total impact of material production phase (in mpt) A' = sum of all results in this phase					**519.4555**

The inner bowl of the proposed design can be constructed of stainless steel without coating. The first reason is that stainless steel has a lower indicator of an environmental impact than aluminum (Goedkoop & Spriensma, 2001). Secondly, the coating will need extra steps and materials in the processing stage. Besides, coated components cannot be recycled. The coating material needs to be removed prior to the recycling process. An uncoated bowl is safe for cooking, health, and the environment. Although the bowl is not coated, preheating the bowl before adding oil and using sufficient oil while cooking will still perform a non-sticky feature.

Stainless steel is commonly found as cookware material because of its durability. Besides, it is also considered a strong material, has scratch-resistant characteristics, and has non-toxic behavior (Charu Bansal et al., 2020). Metals can migrate into foods in stainless steel cookware. However, it is reported that the amount of leached metal until the cookware is damaged is negligible, and there are no health risks (Fellows et al., 2022).

Processing Analysis. The product's processing phase involves around 25 steps of part processing. The analysis is limited to the processing of mechanical parts of the product, setting aside the electronic components because we assume that the company uses a finished product of electronic components in this product processing. **Table 4** shows the assessed parts and the environmental impact of parts processing.

Based on the calculation in **Table 4**, the inner bowl and lid processing have the most significant impacts (343.8 mPt and 76.28 mPt consecutively). The inner bowl is made of aluminum, which is a higher indicator of environmental impact on the machining process than steel (Goedkoop & Spriensma, 2001). Besides, a coating process is needed that contributes considerably to the impact (140.83 mPt).

The lid of the current product is made of glass, steel ring, and plastic handle. It can be noticed that the variation of material affects the processing process, making it longer. In addition, the initial product has ten types of screws. Meanwhile, the different sizes and shapes of the screw could also hinder the processing phase, as the setting of the machining should be settled differently for each size and shape. These situations may also be drawbacks in the production stage because the company must provide different production lines and extra assembly lines for different materials. Thus, reducing screw types is essential for the processing phase as well.

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Table 4. Environmental impact of current product processing

Component	Manufacturing Process	Unit (U)		Indicator (I)	Result (U*I)	Total impact per part
Lid	1. Cutting round glass from sheet	40487.0714	mm²	0.00006	2.4292	76.2852
	2. Bending glass	0.4260	kg	23.2	9.8832	
	3. Grinding the round glass	0.0980	kg	411	40.2698	
	4. Hole riling in glass	0.0121	kg	411	4.9672	
	5. Laser welding of rings	0.7134	m	19.3	13.7686	
	6. Polishing the rings	0.0121	kg	411	4.9672	
Screws	1. Wire cutting	0.0180	kg	252	4.5360	5.2524
	2. Punching	0.0180	kg	23	0.4140	
	3. Thread rolling die	0.0180	kg	16.8	0.3024	
Inner bowl	1. Casting	0.4100	kg	10.3	4.2230	343.8012
	2. Turning	0.0943	kg	1010	95.2430	
	3. Drilling hole	0.0064	kg	997	6.3740	
	4. Polishing	0.0943	kg	1030	97.1290	
	5. Coating	2.8741	µm/m²	49	140.8321	
Labels	1. Printing	0.0004	kg	386	0.1544	0.1551
	2. Cutting	0.0004	kg	1.81	0.0007	
Body shell	Injection molding	0.3221	kg	44	14.1724	14.1724
Lid handle	Injection molding	0.0532	kg	44	2.3408	2.3408
Handle shell	Injection molding	0.0603	kg	44	2.6532	2.6532
Bottom shell	Injection molding	0.0663	kg	44	2.9172	2.9172
Pad	Injection molding	0.0034	kg	44	0.1496	0.1496
Steamer plate	1. Plat stamping	36319.6429	mm²	0.00006	2.1792	30.1302
	2. Hole stamping	12106.5476	mm²	0.00006	0.7264	
	3. Edge grinding	0.0331	kg	411	13.6123	
	4. Polishing	0.0331	kg	411	13.6123	
Total impact of manufacturing phase (in mpt) B = sum of all results in this phase						**477.8573**

Lower-impact processing is an effective option for reducing the environmental impact in the processing stage. This research proposes reducing the processing step to 21 steps with a total environmental impact of 462.46 mPt, which is relatively smaller than the initial impact (477.85 mPt). The environmental impact of parts processing on the proposed design can be seen in **Table 5**.

Changing the glass lid into a stainless steel lid raises the potential to cut the processing step and reduce the number of impacts. Initially, the impact of glass lid processing is 76.28 mPt with six processing steps. It will be lowered to 63.71 mPt with four steps of processing. The inner bowl material has also been replaced with stainless steel. Although it has a higher density, it makes the product heavier; stainless-steel machining has a lower environmental impact indicator than aluminum processing (Goedkoop & Spriensma, 2001). The comparison can be seen between **Table 4** and **Table 5**. Producing a similar inner bowl dimension using stainless steel has a lower environmental impact (266.5 mPt) than aluminum (343.8 mPt). Besides, because the pad and handle

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can be merged into the shell part, and the removal of the label, the number of impacts by those parts is automatically minimized.

Table 5. Environmental impact of proposed design processing

Component	Manufacturing Process	Unit (U)		Indicator (I)	Result (U*I)	Total impact per part
Lid	1. Cutting round and hole	40487.0714	mm2	0.00006	2.4292	63.7146
	2. Bending	0.2890	kg	23	6.6470	
	3. Grinding	0.0665	kg	411	27.3192	
	4. Polishing	0.0665	kg	411	27.3192	
Screws	1. Wire cutting	0.0180	kg	252	4.5360	5.2524
	2. Punching	0.0180	kg	23	0.4140	
	3. Thread rolling die	0.0180	kg	16.8	0.3024	
Inner bowl	1. Cutting round	114965	mm2	0.00006	6.8979	266.5006
	2. Bending	1.2242	kg	23	28.1565	
	3. Grinding	0.2816	kg	411	115.7231	
	4. Polishing	0.2816	kg	411	115.7231	
Electronic layer housing	1. Casting	0.3031	kg	10.3	3.1223	75.9505
	2. Turning	0.0697	kg	1010	70.4180	
	3. Drilling hole	0.0064	kg	377	2.4102	
Body shell	Injection molding	0.2991	kg	44	13.1619	13.1619
Lid handle	Injection molding	0.0266	kg	44	1.1704	1.1704
Bottom shell	Injection molding	0.1496	kg	44	6.5809	6.5809
Steamer plate	1. Plat stamping	36319.6429	mm2	0.00006	2.1792	30.1302
	2. Hole stamping	12106.5476	mm2	0.00006	0.7264	
	3. Edge grinding	0.0331	kg	411	13.6123	
	4. Polishing	0.0331	kg	411	13.6123	
Total impact of manufacturing phase (in mpt) B' = sum of all results in this phase						**462.4615**

Packaging Analysis. After manufacturing, the product is packaged with different kinds of material. This electric cooker was initially wrapped with plastics and then put inside the box with Styrofoam as the partition (**Figure 6**). **Table 6** shows the environmental impact of the current packaging material. Styrofoam is made of polyester plastic, which is lightweight and formable (Hadiyanto et al., 2021). Besides, it is also low-cost and highly durable, making it widely used as a packaging material. However, Styrofoam is not a biodegradable material that can last centuries on land. Not only is it dangerous for the environment because of chemical leaching, but Styrofoam production and disposal release greenhouse gas emissions, which can lead to biodiversity loss (Abdullah & Osman, 2019).

On the other hand, although Styrofoam is labeled as recyclable plastic, its recycling attempt is minimal. Most recycling facilities refuse Styrofoam because it is hard to store and transport due to its lightweight volume and low economic value (Chun et al., 2020). Sterile foam recycling is also

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challenging. Despite the availability of technology, the market for recycled Styrofoam is tiny. Thus, most recyclers dispose of it in landfills (Chandra et al., 2016).

Figure 6. Product packaging

For the proposed design, our approach is to introduce degradable material such as paper as raw material (**Table 7**). We propose changing the whole packaging to a molded pulp, which has been used by BenQ company on their projector product (**Figure 7**). Molded pulp can be made of recycled paper compressed into a mold. Besides reducing cost, using recycled paper could decrease energy consumption by 27% compared to virgin pulp (Zhang et al., 2022). Molded pulp has many beneficial characteristics, such as biodegradability, inexpensiveness, and disposability.

Moreover, in manufacturing, the shape, features, and properties can be made as desired (Dislaire et al., 2021). Some additives like emulsion and alum can be added to provide unique properties such as waterproofing (Zhang et al., 2022). Besides its environmental benefit, molded pulp also has similar properties to Styrofoam, thus making it suitable as cushioning material (Perng & Wang, 2004).

Table 6. Environmental impact of current packaging

Component	Material	Total weight in kg (W)	Indicator (I)	Result (W*I)
Styrofoam	Polystyrene	0.015	370	5.55
Plastic	LDPE	0.005	360	1.8
Box	Corrugated box	0.05	145	7.25
Total impact of material production phase (in mpt) C = sum of all results in this phase				**14.6**

Table 7. Environmental impact of proposed packaging

Component	Material	Total weight in kg (W)	Indicator (I)	Result (W*I)
Moulded pulp	Recycled paper	0.1	104	10.4
Total impact of material production phase (in mpt) C' = sum of all results in this phase				**10.4**

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Figure 7. Example of molded pulp packaging (BenQ et al. Center, 2019)

Usage Phase Analysis. The product can operate at two power levels: 600W and 1200W. This assessment calculates the environmental impact based on the average power of 900W. Other quantity, such as usage duration, is assumed as 3 hours/day. Based on the database by Kushwah (2013), the life cycle of electric cookers, which belong to household goods, is around five years. After discovering the product life cycle, the quantity of electric power on the whole lifetime can be calculated by multiplying the average power by the total usage time. After that, the result is multiplied by the indicator point listed in the Eco 99 Indicator database. The total environmental impact by usage phase of the current product is shown in **Table 8**.

Table 8. Environmental impact of current usage phase

Material	Amount in kWh (A)	Indicator (I)	Result (A*I)
Electricity LV China	4927.5	146	719415
Total impact of usage phase (in mpt) D =			**719415**

The current product's operating power is slightly higher than that of other products in the market that operate at around 1000W or less. Based on the calculation, during the five years of usage phase, the current product will contribute to 719,415 mPt of environmental impact. It is critical to improve the design to reduce electric power consumption. Thus, for the proposed product, the power levels will be reduced to 500 W and 1000 W. Using a similar calculation method, **Table 9** shows how the number of impacts is significantly decreased (to 599,513 mPt) by applying lower power.

Table 9. Environmental impact of proposed usage phase

Material	Amount in kWh (A)	Indicator (I)	Result (A*I)
Electricity LV China	4106.25	146	599512.5
Total impact of usage phase (in mpt) D' =			**599513**

End-of-life analysis. Negative environmental impact can also be further reduced by examining the end-of-life (EOL) stage when the product can no longer fulfill the intended function and cannot be easily repaired by the user. Other than establishing proper disposal and recycling

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actions, it is also vital to ensure that the proposed plans do not cause inconvenience or loss to consumers and manufacturers involved.

Existing EoL management measures for the current product are limited to traditional and unsustainable options. Considering that the product is an affordable home appliance with long technology renovation cycles and expected usage terms, consumers typically dispose of the entire product once a malfunction occurs without attempting to troubleshoot or source a replacement for failed components. Such waste is categorized as household waste, collected and transported to incineration plants. In Singapore, the management of solid waste follows a hierarchical sequence. Society is expected to practice the 3R principle, namely "Reducing, Reusing and Recycling," to minimize waste, while incineration with energy recovery and landfill serve as secondary options (Bai & Sutanto, 2002).

Though waste-to-energy incineration conquers the limit of scarce land resources for landfill treatment, arbitrarily discarding products still leads to large amounts of solid waste that could have been recycled and reused. The manufacturer of the studied product, Midea, launched their "Green Strategy" in 2021, claiming that an old-for-new trading system has been well established since 2018, and replaced products are sent to designated facilities for disassembly and recycling (Zhou, 2021). However, this advertised strategy is not yet accessible to overseas customers, resulting in the inevitable waste of recyclable components. The eco-99 score on the current product disposal stage can be found in **Table 10**. Components of various materials are sent to different waste treatment facilities depending on the product's condition upon receipt.

Table 10. Environmental impact of current product disposal management

Material and type of processing	Used for	Amount	Indicator	Result
Incineration PET-GF	Shell	0.4753	-6.3	-2.99439
Incineration Aluminium	Inner bowl	0.41	-110	-45.1
Recycling Glass	Lid	0.4261	-15	-6.3915
Recycling ferro metals	Steamer plate	0.1445	-70	-10.115
Landfill Silicone	Supporting pads	0.0034	140	0.476
Recycling Cardboard		0.3	-3.3	-0.99
Landfill PE	Packaging	0.6	-19	-11.4
Landfill EPS foam		0.15	3.9	0.585
Total (mPt)				**-75.92989**

To reduce the negative impact caused by EoL disposal, a simple approach is to reduce the variation of materials involved and avoid damage to reusable components during disassembly. The environmental impact of the proposed product is calculated and shown in **Table 11**. The impact point recovered from material recycling is twice the original design, contributing to the lower overall Eco-99 score.

Table 11. Environmental impact of proposed product disposal management

Material and type of processing	Used for	Amount	Indicator	Result
Incineration PET-GF	Shell	0.4753	-6.3	-2.99439
Recycling ferro metals	Inner bowl, Lid	1.8343	-70	-128.401
Household waste, paper	Packaging	0.1	-0.13	-0.013
Total (mPt)				**-131.40839**

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Other than revising product design to reduce environmental impact, the proposed EoL strategies will mainly aim to reduce the quantity of waste heading to incineration plants and landfills and allow the product to be recycled properly and safely. Two approaches could address the issue that Midea's take-back policy has yet to be extended to overseas markets despite the company having a significant market share in east-south Asia for small home appliances. One is establishing a network to collect returned products from overseas customers and ship them back to the origin country for disassembly. However, for the proposed design in this project, more than the value gained from recycling stainless steel components and reusing the PET shell may be needed to offset the transportation costs and duty and tax incurred by importing metal from abroad. Meanwhile, this model of the electric pot, which is only equipped with the most basic functions, needs a valuable core to be put under remanufacturing and reusing.

Therefore, an alternative method is suggested to avoid overspending logistics and transportation. The method is collaborating with local home appliance manufacturers with a functioning product recycling chain to generate revenue from recycling, such as Mayer's trade-in program. However, this also imposes more restrictions on product design. Sourcing for collaborators requires the product to be sufficiently easy to disassemble and recycle at the EoL stage, and more limitations are enforced on the material grade to be used for the recycled components to comply with local regulations and be commercially viable.

As mentioned in the material analysis, the proposed material selection has emphasized its recyclability and reusability. The stainless-steel inner bowl can be recycled after being disassembled by simply grinding off the heat discoloration caused by prolonged exposure to high temperature and oxidation and melting down to remove impurities, followed by casting into stainless steel ingots or bar sections to be reused for various purposes. The exact process can be used to recycle the stainless steel lid. As for the plastic shell components made of PET-GF, though the presence of fiberglass enhances the strength and durability of the supporting structure, it can also introduce extra contamination and require processes to remove impurities, which is a class of highly recyclable but non-degradable plastic. PET used in bottles has been claimed to be recyclable, while the recycling processes of PET-GF are not as popular or well-developed (Cornier-Ríos et al., 2007)(Rorrer et al., 2019). While expecting improvements in recycling technologies, the practical approach is to allocate the PET-GF material to be reused.

CONCLUSION

In this study, a review of an electric cooker's life cycle is conducted regarding the material selection, processing, usage, and disposal stages. The life cycle analysis becomes a starting point for finding suitable adjustments to make the product more sustainable. Some improvements are proposed to enhance the sustainability of the product. Material adjustment is emphasized by minimizing the material variation, choosing materials with lower indicator points, and selecting recyclable or reusable materials. This method can reduce the environmental impact point from 742.73 mPt to 519.45 mPt. The processing stage is directly affected by the material selection. The lower number of material variations results in less processing that has to be carried out by the manufacturer. Thus, the impact can be reduced from 477.8573 mPt to 462.4615 mPt. The environmental impact of the usage phase of the product can be significantly minimized by applying a lower power level, from 719415 mPt to 599513 mPt. End-of-life management strategies such as recycling and taking a bake chain are also proposed to minimize the amount of unrecyclable waste generated upon disposal and reduce the environmental impact.

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