RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING VOL.2 NO.1 (2021)35–47

RPMME

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Development of A Product Green Functional Assessment Tool to Improve Resources Sustainability

See Toh Jun Xin[1], Ho Fu Haw[1*]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.01.005
Received 05 March 2021; Accepted 01 April 2021; Available online 15 April 2021

Abstract: Single-use plastics waste is one of the major problems found in developing and developed countries. This study aims to evaluate the influencing factors for next functional life performance of single-use plastics. In this study, an assessment tool which gives a performance index for the next functional life of single-use plastics was developed. This study applied Analytic Hierarchy Process (AHP) in data collection and synthesis from the selected experts from plastics industry. Seventeen factors were generated from a questionnaire and were then ranked by priority using the AHP method. There are six participants ranged from engineer to manager level were involved in answering the questionnaire, particular in evaluating the importance level among the determined next functional factors of plastics. Next, the extracted results from AHP analysis is used to develop an assessment tool which suggests the next functional of single-use plastics. Two university experts were chosen to validate the assessment tool, and the results are found acceptable. The findings of this study could be used as a guideline for plastics industry companies in designing the green product and improve resource sustainability especially in the rethinking of plastics lifecycle performance during its end of life.

Keywords: Analytic Hierarchy Process, Assessment Tool, Single-use Plastics

1. Introduction

In the past century, plastics have been saturating our world and changing the way we live. Unfortunately, the majority of the produced plastics are used to manufacture the disposable item for packaging purpose or other short-lived products. Besides, the durability of the polymers involved result in a huge amount of plastics accumulate as debris in the world's landfills and natural habitats. In Malaysia, environmental issues related to plastics waste have become a major problem. Fast-growing of plastics lead to a poor solution to reduce the plastics pollutants. Most of the time, plastics recycling is the only solution. However, the plastics waste growing rate is far faster than the recycling rate, which ends up with landfill of the plastics product.

*Corresponding author: fhho@uthm.edu.my

Hence, a study was proposed focussing on introducing second functional use evaluation for plastics product to improve the function of plastics before disposal. At the same time, the assessment tool will be used as a guideline for the user to determine its functionality before send for recycling or disposal. This study aims to develop an assessment tool to evaluation plastics products during its end of life. The tool enables the user to give inputs based on the plastics criteria. Next, the user will be guided on what to be the next use for the single-use plastics to improve resources sustainability. For the researcher, this project will help them to uncover the critical criteria that affect the next functional uses of plastics that are not able to explore.

2. Literature Review

2.1 Plastics material

According to the research by the European Commission, material selection is essential in the redesign of plastics products to facilitate the reuse, sorting, collection and recycling [1]. In the case of plastics, encouraging scientific breakthroughs in the production of products that can be commercially reused, recycled, or composted must be a key pillar of such a political ambition [2]. Combinations of different types of plastics should be avoided to maximise the recyclability of plastic products. Plastic materials which unable to recondition or repair with the main material will reduce reprocessing yields and significantly reduce process efficiency and introduce unreasonable costs [3]. Based on the study of PRAG, plastics bottle which made by PET and HDPE is most preferable for recycle, monolayer PP, PVC or PS and multi-layer single material bottles is less preferable for recycling while avoiding multi-material, multi-layer, PLA or other biopolymer bottles for plastics recycling. Sleeve material also will affect the recyclability since the PVC sleeve on the bottle may contaminate the PET recycling stream and cause black spots in the recycled polyethylene terephthalate (rPET). On the other hand, when the technology and infrastructure become more advanced in the future, it encourages high-value recyclate and closed-loop recycling [4].In short, materials of plastics will be a factor that needs to be considered due to the different type of material have varieties of properties which affect the next functional use of single-use plastics. Table 1 shows the list of factors that influence the next functional of sing-use plastics.

Table 1: List of Factors that influence the next functional of single-use plastics

Criteria	Sub-criteria
Material of plastics	Polyethylene Terephthalate (PET) High Density Polyethylene (HDPE) Low-density polyethylene (LDPE) Polypropylene (PP) Polyvinyl chloride (PVC) Polystyrene (PS) Other (Other)
Quality of plastics	Contamination Chemical Substance Environment factors
Colour of plastics	Transparent Semi-transparent Opaque
Thickness of plastics	Bigger or equal to 0.05mm Smaller than 0.05mm
Green recycling labelling	Recycling code Hazard communication labelling

2.2 Quality of Plastics

In reconditioning and remanufacturing periods, quality of PET bottle is often reduced that leads to the closed-looping cycling obstruct its looping to return to the market. Materials, components and products (MCPs) Manufacturers of plastics are hesitant to repair products, use recycled components or recycled materials normally due to their sensed lower quality compared to new materials and components. Another basic value variable which needs to be considered when determining the residual usability and recovery possibilities of MCPs is degradation. For instance, chemical and morphological modifications that alter mechanical and rheological properties. Although plastics are theoretically reusable or repaired plastic bottles such as those used as drinks container have a limit which they can be recycled safely until releasing chemical substances such as di(2-ethylhexyl) phthalate (DEHP) and bisphenol A (BPA) into the fluid they collect which will damage to the human health by the frequency of their use [5].

However, environmental factors like temperature, moisture and ultraviolet need to be considered. When plastics bottle expose to the environment over some time such as from disposal to collection, transport and sorting that possibly lead to uncontrollable deterioration of their chemical and physical properties [5].According to the research conducted by Wenzel [6], the present case of single-use bedpan plastics indicates that the recycling route interrupted by impurity contamination of the material of goods that may have a significant impact on the measurement and environmental priorities defined. Before reuse or repairing the bedpan, cleaning process generally suggests the flow of impurity is converted from solid waste treatment to water waste treatment [6].

2.3 Colour of Plastics

Andrady [7] stated that plastics can be coloured by either dyes or pigments technique. Dyes provide clear colours and opaque pigments. By using a naturally transparent substance such as acrylic, a very wide range of colours can be achieved from translucent to dark black [7]. Iacovidou [5] despite that colour is a domain factor that affects the recyclability of plastics. Figure 2.8 indicates the different colour of the plastics container. For instance, clear plastics and translucent are considered better quality. Packaging Resources Action Group (PRAG) [4] state that the colour of plastics will affect the recycling of plastics. For instance, clear plastics are most suitable for recycling, pale tints of blue or green colour plastic are less suitable for plastics recycle while dark, opaque and black colours are least suitable for recycling. This is due to the clear plastics is easy to be recycled while the black colour is difficult to be detected by the sorting system and may to the contaminations problem. Clear plastics are always preferred in the recycled materials market due to its highest material value. This is because transparent plastic can be dyed into other colours with greater flexibility.

However, the coloured plastics are often limited to become darker shades of the original dye, or black. For this reason, some recycling facilities consider certain pigmented plastics contaminants to the recycler stream and subsequently dispose of them instead of recycling them. Hence, the clear plastics have a high value compare to the dark colour of plastics due to the recycling convenient. In conclusion, colour classification of plastics in Figure 2.9 is a significant aspect to influence the next functional life of single use plastics. For instance, transparency of plastics bottle is essential when it use for aquarium which use to enjoy the beauty of fish.

2.4 Thickness of Plastics

Based on the research conducted by Amazonas, there are wide variations in weights of the water bottle and product volumes. Some premium brands prefer to use heavier package while others continue to lower their bottle weights. However, the performance was not directly correlated to the weight of the package. although finish size did have some impact wall thickness generally tracked with bottle weight since wall thickness was traded for a larger finish [8]. A study conducted by [9] has been undertaken to determine whether there is a minimum thickness rigid plastic packaging should be for it to be recycled effectively. Light weighting through the reduction in material usage has a positive impact as less raw material is used, however, there are concerns that some packaging may be so thin that it cannot be recovered and recycled labels [9]. The result of the study shows that recovery of PET flakes <0.05 mm is not effective, and to be recycled material should be 0.05 mm or thicker [9]. Although there was no perceived issue for polyolefin recyclers, it is suggested the same minimum thickness to be used [9].

2.5 Plastics Recycling Labelling

Green labelling such as recycling labelling is an important system that can provide a lot of information to the user or plastics recycling industry. Plastics New Zealand Association [10] encourages all the plastics industry companies to clearly label their plastics products by using the number in the chasing arrows with the letters on the plastics including packaging, construction or agriculture plastics. This international identification code is developed with consistent and uniform which can apply worldwide to help plastics industry to identify the plastics easily for remanufacture, repair, reuse and recycling. Plastics identification code is introduced by the Plastics New Zealand in the early 1990s [10].

3. Methodology

In this study, three main stages of research activities involved such as literacy study for factors that affect the next functional life of single-use plastics, AHP design and development of assessment tool. The flow of the methodology is shown in the flow chart in Figure 1.

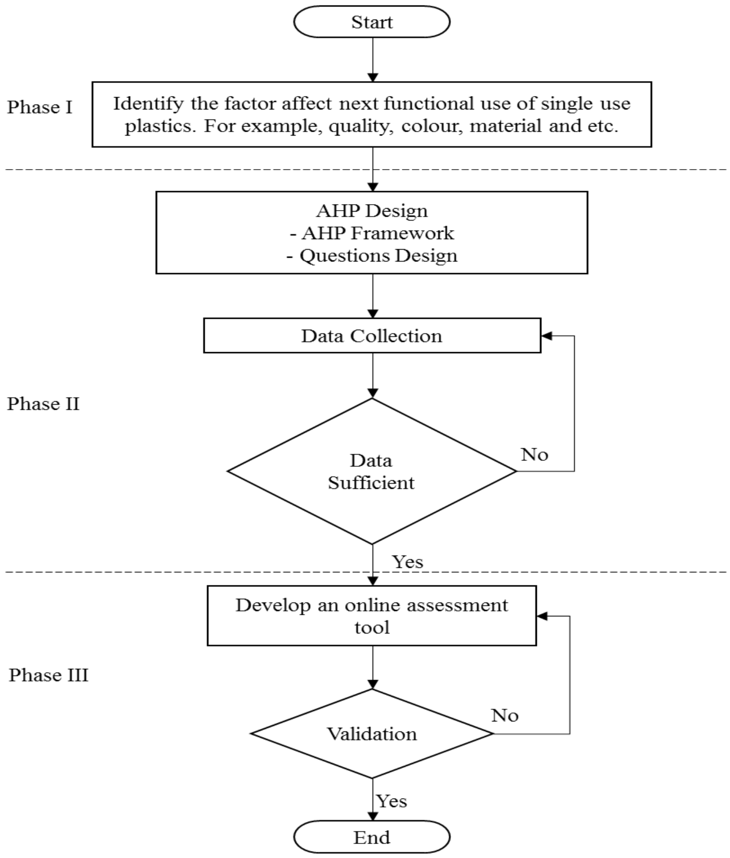

Figure 1: Research flow chart

3.1 Questionnaire Design

After the factors have been determined from the literacy study, a questionnaire designed based on pairwise comparison. Then, collection of data was performed by sending the questionnaire to the plastics expert by the email to gain adequate data. To collect sufficient data which was consistent, consistency ratio must less than 0.1. Data collection was done by the respondents who fulfilled the requirement such as 4-5 year working experience, at least degree in engineering (plastics or mechanical preferred), any achievement in the plastics industry and familiar with recycle/reuse/redesign/recondition/repair of plastics. The details of the respondents were shown in Table 2.

Table 2: Details of respondents

Respondents	Position	Type of company	Country of Origin, size	Response on the criteria
AHP 1	Production Engineer	Consumer goods	Malaysia, small	All criteria
AHP 2	Production Engineer	Consumer goods	Malaysia, small	All criteria
AHP 3	Production Engineer	Consumer goods	Malaysia, small	All criteria
AHP 4	Production Manager	Consumer goods	Malaysia, small	All criteria
AHP 5	Production Engineer	Consumer goods	Malaysia, small	All criteria
AHP 6	Program Manager	Consumer goods	Malaysia, small	All criteria

3.2 AHP Framework

AHP methodology was used for data collection to assess the priority weight of the factors collected during phase one of the determination of the factors. In this study, the criteria consist of 5 major categories. There are the material of plastics, quality of plastics, the thickness of plastics, the colour of plastics and plastics recycling labelling. There is a total of 17 sub-criteria which categories under the criteria. A complete hierarchy structure framework in this study is shown in Figure 2.

Next, a pairwise comparison of the factors was performed. The AHP used pairwise comparisons of elements to pair off all individual criteria and compiled the result into a decision matrix. There are 4 steps for the analysis to conduct before obtained the final result:

1. Conduct the pairwise comparison matrix for each of the respondents
2. Assess the consistency ratio of the pairwise judgment. (Data accepted for consistency ratio less than 0.1 if not respondents need to redo the questionnaire for consistency ratio > 0.1.
3. Construct the geometric mean analysis.
4. The result of the priority of the criteria is shown.

The level of matrix consistency could be assessed employing consistency index CI as follows: firstly the λ_{max} (the highest eigenvalue of the matrix) has to be calculated like [12],

$$\lambda_{max} = \sum_{j=1}^{m} \frac{(S.v)_j}{m.v_j} \qquad Eq. 1$$

Where
λ_{max} =Highest eigenvalue of the matrix
m = Number of independent rows of the matrix
S = Pairwise comparison matrix
v = Matrix eigenvector

Then the consistency index can be calculated as follows:

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad Eq.2$$

If the matrix was perfectly consistent then consistency index=0. When dealing with a rising number of pair-wise comparisons the possibility of consistency error was also increased. Thus, Saaty suggested another measure the consistency ratio (CR) that can be calculated as follow [12]:

$$CR = \frac{CI}{RI} \quad Eq.3$$

Where
RI = Random index

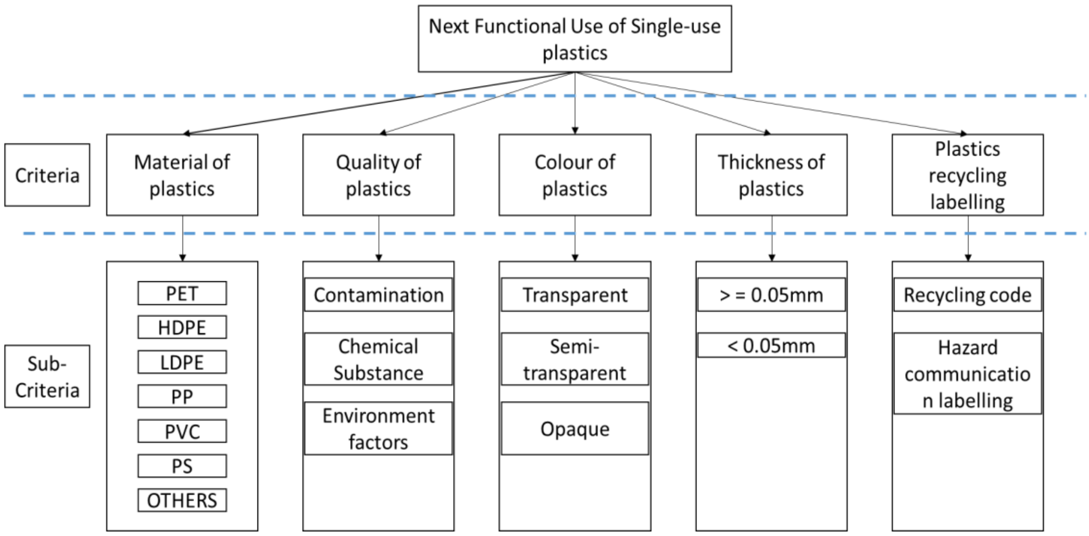

Figure 2: Hierarchy structure framework

3.3 Assessment tool development

After AHP analysis, an assessment tool developed using a free web-based platform (Proprof). The designed questions keyed into the assessment tool together with the answer. The criteria acted as the questions while sub-criteria acted as the answer. Hence, there are only 5 questions in the assessment tool. Each of the sub-criteria represented a specific global weightage obtained from the AHP result. The points for each of the question was the highest weight of the respective answer. After summing up all the marks from the user's answers, the assessment tool would suggest the next functional life for single-use plastics container based on the result. The summed weights will be categorised into several categories which give some corresponding suggestions in the performances of single-use plastics such as excellent (85-100%), good (70-84%), average (50-69%), poor (<50%).

From the weightage of the questions and answers designed in the assessment tool. The total highest score was 40.7 marks which were the constant. The formula used to calculate the performance of the product is shown below.

$$Performance = \frac{a+b+c+d+e}{40.7} \times 100\% \quad Eq.4$$

Where
a = Score obtained in criteria material
b = Score obtained in criteria quality
c = Score obtained in criteria thickness
d = Score obtained in criteria colour
e = Score obtained in criteria recycling labelling

3.4 Validation

After the assessment tool was developed, assessment validation was conducted by email the assessment tool to two experts together with the validation. The details of the university experts were shown in Table 3.

Table 3: Details of university expert

Details	Expert 1	Expert 2
Designation	Associate professor in mechanical engineering	Senior lecturer in manufacturing
Area of Expertise	Eco-design, sustainable manufacturing	Sustainable product design
University	University of Nottingham Malaysia	Universiti Teknikal Malaysia Melaka

4. Results and Discussion

4.1 AHP Results

An AHP analysis was conducted to enhance the quantitative findings by evaluating the priority weight for the factors that influence the next functional use of single-use plastics. From the AHP result, the classification of the priority weight was made according to the criteria level. First of all, the results of the main criteria were obtained. These consisted of the material of plastics, quality of plastics, the colour of plastics, thickness of plastics and green recycling labelling. A total of 10 pairs of criteria are evaluated to determine the priority. Then, the sub-criteria for each group were categorized under 5 majors of criteria. There is a total of 21 pairs of sub-criteria for the material of plastics, 3 pairs for quality of plastics and colour of plastics, 1 pair for the thickness of plastics and green recycling labelling. All of the sub-criteria are undergoes the evaluation to identify the priority.

Next, compute the eigenvectors, consistency index and consistency ratio. The analysis was performed for the criteria and sub-criteria without the alternatives were assessed in the AHP framework. The analysis of the AHP framework was conducted using the Expert Choice software. Table 4.1 showed the priority factors that influence the next functional use of single-use plastics. Results showed that the material of plastics had the highest weight of 0.428 while the lowest are green recycling labelling and colour of plastics with 0.055. Moreover, the quality of plastics had a weight of 0.346 followed by the thickness of plastics with 0.115. All of the 5 criteria fulfil the comparison consistency ratio with less than 0.1.

For the material of plastics, low-density polyethylene (LDPE) was determined as the most important factor with the score of 0.269 followed by the high density polyethylene (HDPE) with a local weight of 0.264. The remaining factors were polypropylene (PP) with 0.262, polyethylene terephthalate

(PET) with 0.094, polystyrene (PS) with 0.063. Polyvinyl chloride (PVC) and other (Other) both obtained the lowest local weight with 0.024. For the quality of plastics, all of three sub-criteria (contamination, chemical substance and environment factors) obtained equally weight with 0.333. For the colour of plastics, transparent obtained the highest weight with 0.608 followed by semi-transparent with 0.295 and opaque with 0.096. In the thickness of plastics, plastics with bigger or equal to 0.05mm obtained 0.841 local weight which is more important than the plastics with smaller than 0.05mm (0.159). In green recycling labelling, the highest local weight with 0.848 obtained by the recycling code while the lowest is hazard communication labelling with 0.152. The overall ranking of the criteria can be determined by using the global weight as showed in Table 4.

The material of plastics was found most important factor to affect the next functional life of sing-use plastics because the material selection is essential to affect the recondition, reuse or repair of plastics which is inclined with the previous study [1][3]. The colour of plastics and plastics recycling labelling is the least important because the colour of plastics and plastics recycling labelling didn't directly impact the next functional life of single-use plastics. Some of the colour of plastics are reusable and recyclable, some are less desirable for reuse or recycle which was consistent with the past study done by Packaging Resources Action Group [4]. In plastics recycling labelling, recycle label helped user to identify which type of plastics product was reusable which was in agreement with the past study by Plastics New Zealand Association [10].

Table 4: Priority Factors That Influence the Next Functional Life of Single-use Plastics

Criteria	Local weight of criteria	Sub-criteria	Local weight of sub-criteria	Global weight	Rank
Material of plastics	0.428	Polyethylene Terephthalate (PET)	0.094	0.040	9
		High Density Polyethylene (HDPE)	0.264	0.113	5
		Low-density polyethylene (LDPE)	0.269	0.115	1
		Polypropylene (PP)	0.262	0.112	6
		Polyvinyl chloride (PVC)	0.024	0.010	14
		Polystyrene (PS)	0.063	0.027	11
		Other (Other)	0.024	0.010	14
Quality of plastics	0.346	Contamination	0.333	0.115	1
		Chemical Substance	0.333	0.115	1
		Environment factors	0.333	0.115	1
Colour of plastics	0.055	Transparent	0.608	0.033	10
		Semi-transparent	0.295	0.016	13
		Opaque	0.096	0.005	17
Thickness of plastics	0.115	Bigger or equal to 0.05mm	0.841	0.097	7
		Smaller than 0.05mm	0.159	0.018	12
Plastics recycling labelling	0.055	Recycling code	0.848	0.047	8
		Hazard communication labelling	0.152	0.008	16

4.2 Green Product Assessment Tool

Based on the AHP analysis, a green functional assessment tool was developed to suggest the next functional life of single-use plastics refer. Figure 3 shows the home page of an assessment tool which have been developed using online tool development platform (Profprofs). In the homepage of the assessment tool, the user needs to fill in the name and email to access the assessment tool.

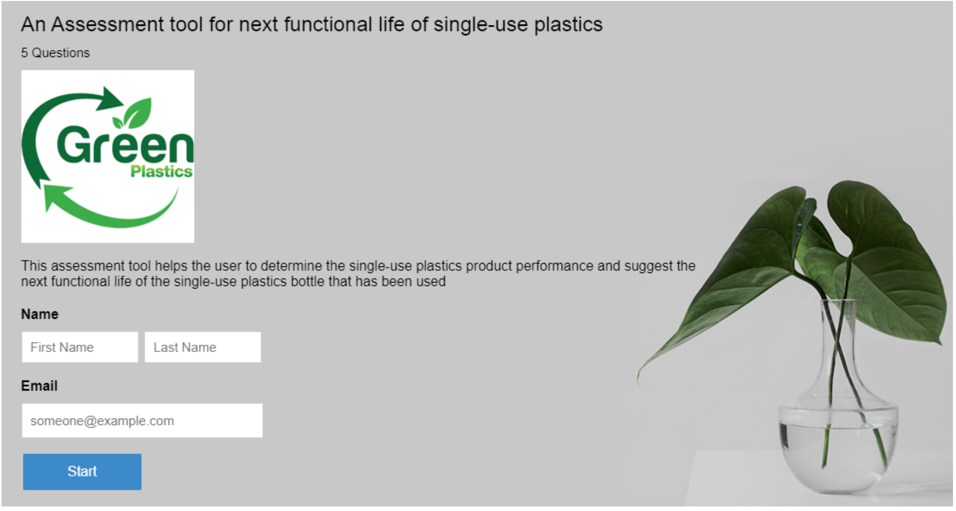

Figure 3: Homepage of the Assessment Tool

Figure 4 shows a list of questions in the assessment tool. The assessment tool consists of 5 questions. Only one answer can be chosen for each of the questions. After the user has been answering all of the questions and submitted. A result of the product functional performance after its end of life can be evaluated. Figure 5 shows an example of the result obtained in the assessment tool. The assessment tool will suggest the next functional life of single-use plastics. All of 3 alternatives of the next functional of single-use plastics have been reviewed by the respondents during the quantitative study. If the product functional performance is less than 50%, a recommendation will be given by the assessment tool to improve the performance of the product. The product functional performance which less than 50% will be suggested to improve the material performance. This is due to the material of plastics play a major with a local criteria weight of 0.428. This showed that the material of plastics is a very significant factor to influence the product functional performance.

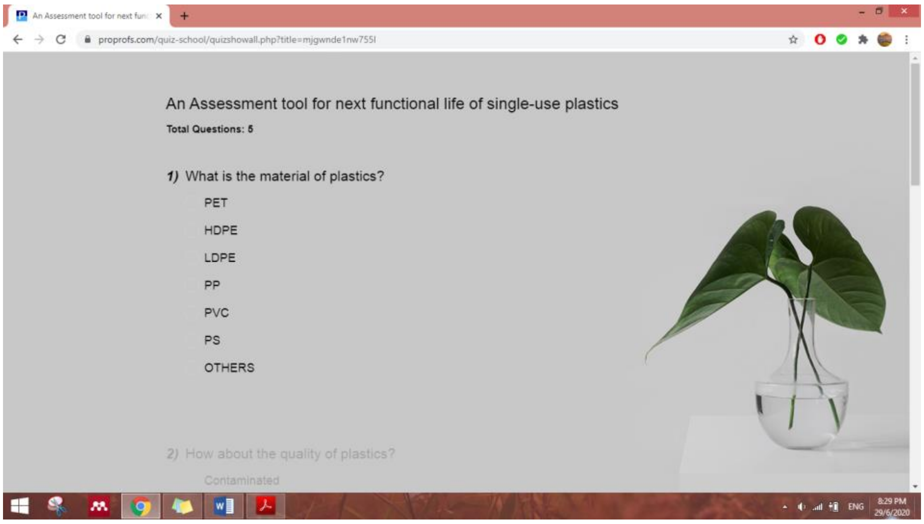

Figure 4: List of question in the assessment tool

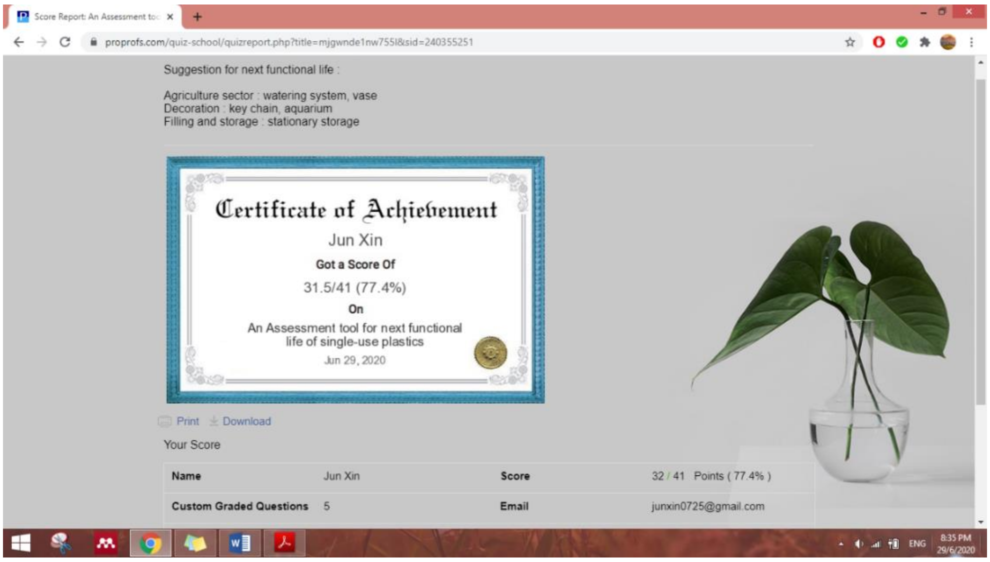

Figure 5: Example of the result shown in the assessment tool

4.3 Discussion

Past empirical studies have shown that understanding the factors that influence the next functional use of single-use plastics is significant to help the plastics industry to formulate a suitable design solution. The detailed discussions related to the factors provided in the following section.

4.3.1 Material of Plastics

From the results, it shows the material of plastics obtained weightage of 0.428 which is the highest. This may due to the different material of plastics having a different type of physical properties such as corrosion resistance, density and strength. For example, density is a very important parameter because it reveals information about the intrinsic strength of the construction that is supposed to be created, as in the case of flax reinforcement when HDPE, PP and LDPE are the best choices (because of their low density) since its purpose is to produce a composite that is as light as possible [13]. From this explanation, it's the reason why LDPE, HDPE and PP obtained local weight of sub-criteria with 0.269, 0.264 and 0.262 respectively. While PET, PS, PVC and OTHER only obtained a small portion of weightage with 0.094, 0.063, 0.024, and 0.024 respectively.

4.3.2 Quality of Plastics

From the results, it shows that quality of plastics obtained second highest in the local weight of criteria but the sub-criteria of quality of plastics (contamination, chemical substance and environment factors) are equally important with a local weightage of 0.333. When plastics expose to the environment, plastic can be degraded by four mechanisms: photo-degradation, thermo-oxidant degradation, hydrolytic degradation, and microorganism degradation. Natural plastic degradation starts with photo-degradation due to the sun's UV light, which provides the triggering energy required to activate the induction of oxygen atoms into the polymer, leading to thermo-oxidant degradation [13]. The reused plastics can be contaminated with contaminants and the contaminants can move into the packaged products in the next functional life. Contamination can be of a chemical or microbiological nature [13] [14]. The finding with the past study by John N Hahladakis [15] mentioned that chemicals present in plastics can probably migrate from the plastic product to the medium in contact with the product, and may also gradually migrate within the plastic to the surface.

4.3.3 Colour of plastics

It is found that the colour of plastics also plays a role to influence the next functional life of single-use plastics with 0.055 in local weightage of criteria. Transparent plastics score the highest with 0.608 of the local weight of sub-criteria follow by semi-transparent plastics 0.295 and opaque plastics with 0.096. This result is in agreement with the previous study conducted by the Eleni Iacovidou [5]. On the other hand, the semi-transparent and opaque plastics are not suitable to use as an aquarium compares to the transparent plastics which is more practical in this study. Hence, it can be concluded that, if the transparency of the plastics is higher, the value of the plastics is also higher. This is because transparent plastics have more option for the next functional life compare to the semi-transparent plastics and opaque plastics.

4.3.4 Thickness of Plastics

In this study, plastics with bigger or equal to 0.05mm is more important with 0.841 in local weight of sub-criteria compare to the thickness less than 0.05mm with only 0.159 in local weight of sub-criteria. This may due to the thickness with 0.05mm is too thin and which normally used in the manufacturing of plastics bag. In this case, the plastics bag is low-value to propose the next functional life for it. On the other hand, plastics with the thickness bigger or equal to 0.05mm can be transformed into a suitable thickness which is more suitable for the next functional life.

4.3.5 Plastics Recycling Labelling

Plastics recycling labelling obtained 0.055 in local weight of criteria which is equally important to the colour of plastics. In plastics recycling labelling, recycling code is more important than hazard communication labelling with a local weight of sub-criteria of 0.848 and 0.152 respectively. This is because recycling code is referred to the type of plastics used to manufacture that product and not all plastics can be recycled or reused [16]. On the other hand, the hazard communication labelling normally refers to the type of hazardous chemical that has been contained such as flammable, corrosive or even explosion. Hence, the recycling code is explained about the plastics material while hazard communication labelling refers to the content which content in that container.

4.4 Assessment Tool Validation

Assessment tool validation was done by 2 university experts. Table 5 shows the result of the validation of the assessment tool. Based on the results of validation, it showed a consistent result which most of the aspect achieved fair performance or good performance. From the feedback of the experts, the expert commented on the user interface is easy to assess but the presentation of the score used for decision analysis is not clear. Besides, the expert also mentioned that the factors that affect the next functional life of single-use plastics should be increased to enhance the accuracy of the result and the detail explanation for the material of plastics could improve by providing the image or figure.

Table 5: Result for Assessment Tool Validation

Aspect	Expert 1	Expert 2
User interface	Good	Good
Graphical modelling approach	Good	Fair
Quality result estimation	Fair	Good
Knowledge-based system	Fair	Fair
Decision analysis model	Fair	Good
Presentation of result	Good	Very Good
Usefulness level	Fair	Good
Informative level	Fair	Good

5. Conclusion

In conclusions, all the stated objectives of study have been achieved according to the completion of development of the assessment tool to suggest the next functional life of single-use plastics after its end of life. The first objective was to identify factors that influence the product functional use after its end of life. The developed product green functional assessment tool able to provide a quick evaluation on a product functional performance based on five main factors namely plastics material, quality of plastic, thickness, colour, and green labelling. Perhaps this tool could be used as one of the option to help practitioner in designing a plastic product with extra functional value of during its end of life rather than considering thrown for recycling.

Acknowledgement

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] European Commission, *A CIRCULAR ECONOMY Insights from research*. 2019.

[2] D. E. MacArthur, “Beyond plastic waste,” *Science (80-.).*, vol. 358, no. 6365, p. 843, 2017.

[3] P. East, *Plastic packaging recyclability by design*. 2017.

[4] Packaging Resources Action Group, “An introduction to Packaging and Recyclability,” *Prag*, no. November, pp. 1–23, 2009.

[5] E. Iacovidou, A. P. M. Velenturf, and P. Purnell, “Quality of resources: A typology for supporting transitions towards resource efficiency using the single-use plastic bottle as an example,” *Sci. Total Environ.*, vol. 647, pp. 441–448, 2019.

[6] B. L. Sørensen and H. Wenzel, “Life cycle assessment of alternative bedpans - A case of comparing disposable and reusable devices,” *J. Clean. Prod.*, vol. 83, pp. 70–79, 2014.

[7] A. L. Andrady, “An Introduction to Plastics,” *Plast. Environ. Sustain.*, pp. 55–82, 2015.

[8] M. Amazonas, G. Fisher, and W. Zhang, “Research Shows Which PET Water Bottle Design Attributes Impact Recycling,” 2018.

[9] R. McKinlay, “Minimum thickness of plastic bottles to be recycled – research findings,” no. October, 2018.

[10] Plastics New Zealand Association, “The Plastic Identification Code - Label your plastics,” 2005.

[11] V. Goodship, “Plastic recycling,” *Sci. Prog.*, vol. 90, no. 4, pp. 245–268, 2007.

[12] J. Franek and A. Kresta, “Judgment Scales and Consistency Measure in AHP,” *Procedia Econ. Financ.*, vol. 12, no. December, pp. 164–173, 2014.

[13] M. Grigore, “Methods of Recycling, Properties and Applications of Recycled Thermoplastic Polymers,” *Recycling*, vol. 2, no. 4, p. 24, 2017.

[14] K. Pivnenko, L. G. Jakobsen, M. K. Eriksen, A. Damgaard, and T. F. Astrup, “Challenges in

plastics recycling," *Proc. Fifteenth Waste Manag. Landfill Symp. Sardinia 2015*, no. October, 2015.

[15] J. N. Hahladakis, C. A. Velis, R. Weber, E. Iacovidou, and P. Purnell, "An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling," *J. Hazard. Mater.*, vol. 344, pp. 179–199, 2018.

[16] The City Bin Co., "Recycling symbols & what they mean ? A handy reference guide Process 2017 Effective : What Does It Mean ?," 2017.