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Development of A Green Packaging Assessment Tool for Manufacturing Industry

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Abstract: The fast growing of industrialization has leads to drastic growth of packaging waste issue. Although every product requires basic packaging before it could be shipped to the customer, but most of the time the packaging materials will end up turn into solid waste or become pollutants. For that reason, the demand for green packaging research is tremendously needed, but it is still considerable limited in the current studies. In this study, the green packaging criteria were extracted to develop an assessment tool to evaluate the green packaging performance. AHP approach was chosen for data collection and data analysis, particularly on the green criteria importance weightage before these criteria were used to develop the assessment tool. The assessment tool then was validated by two experts who are expert in eco design, sustainable product design. With the development of green packaging assessment tool, perhaps it could provide a quick assessment on packaging design on green performance aspect during product development phase.

Keywords: Green Packaging, Sustainable Packaging, Assessment Tool, AHP

1. Introduction

To date, an increasing number of manufacturing companies have raised the demands of materials for packaging. For that reason, a sustainable solution is needed such as the use of recyclable or green packaging. According to Orzan [1], green packaging is known as sustainable packaging, which is the use of low environmental impact materials and manufacturing methods for the packaging purposes. With the increase of environmental awareness, the demands of green packaging and the promotion of sustainable packaging in many industrialized countries has become a trend and legislative to follow [2]. The initial idea of green packaging is to use biodegradable and recyclable materials, and it is energy efficient process to create a packaging [3].

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In the manufacturing sector, the amount of industrial wastes, consumer wastes and other contaminants from the atmosphere is rising annually [4]. For that reason, designers need to rethink of their packaging design, which could balance the needs for consumer safety, production quality and reduce the environmental impacts [5]. This study is aims to investigate the green packaging criteria in manufacturing industry such as industry's packaging materials, packaging design and processes involved. In the end of the study, a green packaging assessment tool was developed to assist designer in designing their packaging.

2. Criteria of Green Packaging

2.1 Material Criteria to Influence Green Packaging

Materials are the basic resources for packaging. In green packaging aspect, the considerations of materials include renewable materials, reusable or returnable material, recyclable material, degradable or biodegradable material or compostable type of material. Renewable materials are natural materials based on non-petroleum that have harvest cycles of less than 10 years. The ideology to use renewable material is to save trees. Less forest means more greenhouse gasses entering the environment, since forests act as carbon sinks that absorb carbon dioxide. Although the renewable materials have the ability to grow back, the time needed to restore the ecosystem increases greenhouse gas emissions [6]. Thus, by using the renewable material for the packaging, it can help to save the environment.

Reusable materials mean the use of materials that have been reused, saved or refurbished. Obviously, this will reduce the need for the virgin materials from the markets. This not only reduces the waste, but also reduces the stress on the environment. Reuse of material is therefore different from recycled material. It is the material that is recovered or that is reused in its original form [2]. Reusable materials can help in reducing the waste and also the usage of the raw material. The selection of recycled materials should be expanded as far as possible to use low-power, low-cost, low-pollution raw materials as packaging materials, which can not only reduce environmental pollution but also save raw materials and are conducive to recycling resources such as recycled paperboard and plastic production [2].

Degradable is the ultimate packaging waste that cannot be reused, that should be capable of degrading, corrupting and not forming a permanent waste [2]. According to the Moses et al (2019), biodegradable plastics offer reduces carbon dioxide levels. More waste plastic produced today than ever before in human history [7]. These items are finding their way into our oceans and even contaminating our drinking water. Scientists estimate that by 2050 there could be more waste plastic in the ocean than fish, with up to 80 percent of the time containing tap water. Researchers at Bath University have created a plastic that uses only sugar and carbon dioxide, resulting in polycarbonates that are no longer required for refinement to use petrochemicals and their CO2 emissions.

The attribute of compostable is an important criterion for biopolymer materials because while recycling is bit energy expensive, composting allows the packages to be disposed of in the soil by transforming them into water, carbon dioxide and inorganic compounds. Composting biodegradable plastics together with traditional biodegradable paper products means that they can be transformed into rich humic material that can improve water and nutrient retention and help grow healthier plants with less chemical fertilizers and pesticides [8].

2.2 Design Criteria to Influence Green Packaging

The design criteria to influence green packaging are whether it is in flexible or deformable shape, lightweight design or exact-sized packaging. They are generally source reduction design to cut the usage of the raw material. It is to reduce the waste that come from packaging. Flexible packaging film promotes convenience and reusability [9]. Flexible packaging can be designed to include features that can fit many forms of product to fit in the same packaging. The flexible and deformable packaging can be used for more than one items with many types of size and shape. It can be molded into all kinds of shapes. This also helps in reducing space usage, so it helps in reducing the material waste of the packaging.

According to Zhang and Zhao [2], the development of packaging materials with high performance, lightweight, thin, fluorine-free, is an important direction for green packaging materials, especially in existing packaging materials. Light-weighting is a subset of source reduction achieved by designing with less material or lighter materials. Use light weighting strategies in packaging design to reduce energy and resource demand. Basically, the technique is source reduction of raw materials [10]. The packaging weight can be reduced in terms of size or thickness. Thus, lightweight design is also important as they can help in reducing the material usage and also material waste.

The packaging with proper or exact-sized packaging can helps in reduce material usage. The packaging size depends on the optimum product quantity and shape. If the packaging size is the exact sized of the product, then the usage of raw material can be reduced and also the material waste can be reduced [11]. Basically, if the material waste can be reduced, it will also affects the environment where the waste is not too much to be disposed [12]. It helps in source reduction of the materials.

More efficient use of transport for distribution will reduce the energy consumption significantly. Packaging must be built in ways that reduce weight, optimize space usage and, where possible, using bulk packaging. According to Glazer, more efficient transport utilization for distribution will significantly reduce energy consumption. Packaging must be constructed in ways that reduce weight, optimize the use of space and use bulk packaging, where possible. Bulk packaging helped in saving material consumption and reduce waste [13].

2.3 Manufacturing Processes Criteria to Influence Green Packaging

The criteria of the process involved in the manufacturing of the packaging to influence green packaging are whether less energy process is used, or renewable energy process is used or the process that is non-toxicity is used. These processes are basically environmentally friendly processes and do not cause pollution to the environment. Green processes include focusing on waste reduction and making more efficient operations with sustainable materials that go hand in hand with cost reduction and time savings [14]. Less energy process is also known as energy efficiency where the main purpose of energy efficiency is to reduce the amount of energy used in the process and carbon [14]. The examples include the microwave processing of materials and nanoceramic coatings, which show great potential for boosting the efficiency of industrial processes, according to National Academy of Sciences [15].

Another example use process that are cogeneration. Cogeneration is the simultaneous production of thermal and electrical energy, typically using significantly less energy resources than required in separate processes to produce the same thermal and electrical products, thus making a significant contribution to energy sustainability.

Toxic chemicals are defined on the basis of their effects; for example, toxic chemicals are defined by the National Transport Commission as 'substances that may cause death or serious injury or harm human health. According to [16], modern packages should be attractive and safe at the same time, not least because consumers require companies to adopt an environmentally friendly process and offer products that can be consumed without delay and without adverse health effects. In a chemical process, the use of toxic or hazardous substances should be avoided rather than disposed of [17].

Toxic and hazardous waste materials and the characteristic of toxic and hazardous waste in the process must be reduced before it is released from a business or activity by maximizing raw materials in the housekeeping process, substitution of substances, modification of processes, use of environmentally friendly technologies and other efforts to reduce them [18]. Toxic materials usually can cause pollution that is not good for the greenhouse and earth. Thus, the processes used to produce the green packaging must be less toxic involved or non-toxicity processes.

Environmentally friendly packaging is a packaging that minimizes the impact on the environment while preserving the quality of good inside. Manufacturers need to select material that is environmentally friendly so that the process involved will also be environmentally friendly that is not contaminating and cause pollution. This must be done without affecting the product's quality or lifespan and package goods in the right quantities to eliminate waste products [19].

Prevention of pollution refers to the use of materials, processes and practices that reduce or eliminate the production of pollutants by increasing efficiency in the use of raw materials, energy, water or other resources or by conserving natural resources. Pollution prevention is a multimedia approach that reduces waste generation and pollutant emissions to land, air and water without transferring pollutants from one medium to another [20]. The process involved in packaging manufacturing must not contaminate and not causing the pollution so that pollution can be prevented. This helps in overcoming the greenhouse effect and also save earth.

3. Methodology

In this study, it starts with credible literature study to extract green packaging criteria, followed by Analytical Hierarchy Process data collection, and lastly the development of green packaging assessment tool.

3.1 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 3 major categories of green packaging. These criteria are materials of packaging, design of packaging and process used to produce packaging. There is a total of 11 sub-criteria which categories under the criteria. A complete hierarchy structure framework in this study is shown in Figure 1 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.

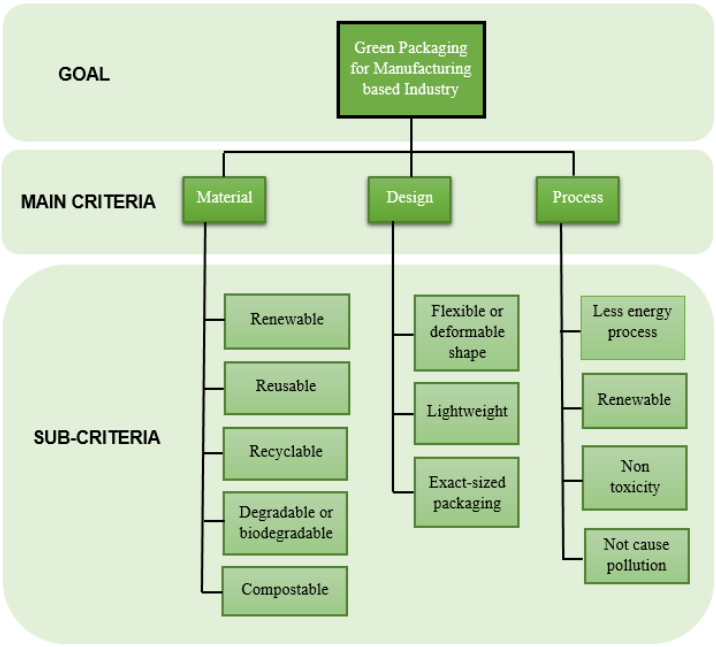

Figure 1: AHP framework for Green Packaging Criteria

The level of matrix consistency could be assessed employing consistency index CI [21] as follows:

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

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 [21] suggested another measure the consistency ratio (CR) that can be calculated as follow:

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

Where
RI = Random index

3.2 Development of Assessment Tool

The assessment tool can be developed from the data obtained from AHP analysis. This assessment tool was created by using a free website (https://www.tryinteract.com), The designed questions keyed into the assessment tool together with the answer. 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 idea to improve the packaging based on the result. Included with the result, the benefit of green packaging and examples of The summed weights will be categorized into several categories which give some corresponding suggestions in the performances of single-use plastics such as excellent (81-100%), good (61-80%), average or safe (50-60%), poor (<50%). For the development of assessment tool, as the output of Green Assessment Tool is the score percentage obtained base on the questions answered by the users in terms of criteria used by the users. The scoring formula used in this assessment tool is shown below.

Formula used,

$$GPP = [SO/1.792] \times 100$$

Where,

GPP = Green Packaging Performance for the user in percentage

SO = Score obtained from all parts

1.792= constant (Total highest score)

SO = S_Criteria+ S_Material+ S_Design+ S_Process

S_Criteria = The score of the main criteria
S_Material = The score for sub-criteria of green packaging material
S_Design = The score for sub-criteria of green packaging design
S_Process = The score for sub-criteria of green packaging process

The output of this Green Packaging Assessment Tool is the Green Packaging Performance (GPP) in unit percent (%). The score obtained (SO) is the total submission of score obtained from the main criteria and all sub-criteria answered by the users of the Green Packaging Assessment Tool. Those include the score of the main criteria, score for the green packaging material sub-criteria, score for the green packaging design sub-criteria and the score for the green packaging process sub-criteria. The constant, 1.792, is the total highest score from the main criteria and all sub-criteria for each criteria. The total result all rounded to the nearest ones.

4. Results and Discussion

4.1 AHP Results

The total of seven set of data obtained from the pairwise comparison survey were then transferred into a pairwise comparison matrix for AHP to obtain the consistency of the criteria, calculating the eigenvalue and eigenvector beside the consistency ratio. The AHP analysis was conducted by using Expert Choice software. The result from the AHP analysis shows that the material type of the packaging had the highest weight among all of the main criteria which its weightage is 0.563 followed by the design of the packaging which the weightage is 0.271 and the process used to produce the packaging has the least weightage which is 0.166. The comparison consistency ratio for all criteria were less than 10%. For the criteria of green packaging in terms of material, degradable or bio-degradable material was identified as the most important criteria need to be used by company with a score of 0.348 followed by compostable material which weighted 0.303, recyclable material that weighted 0.148, reusable material weighted 0.115 and lastly the renewable material that weighted 0.086.

Next, in terms of design of the green packaging, bulk packaging is the most focused criteria as the packaging design. Bulk packaging weighted 0.373 which the most important criteria. Second important after the bulk packaging is the flexible design which weighted 0.309 followed by lightweight design with weight 0.185 and the exact-sized packaging with weight 0.134. Lastly, the process used for producing the packaging focused more on using the non-toxicity process which weight 0.587, and then the process that not cause pollution with weight 0.229 followed by using the less energy process that weighted 0.184. The consistency ratio is less than 10 percent. The summary for the AHP result is shown in Table 1.

Table 1: Summary of AHP results

Main criteria	Weight of main criteria	Sub-criteria	Weight of sub-criteria	Global weight of sub-criteria
Material	0.563	Renewable	0.086	0.048
		Reusable	0.115	0.065
		Recyclable	0.148	0.083
		Degradable or bio-degradable	0.348	0.196
		Compostable	0.303	0.171
Design	0.271	Flexible	0.309	0.084
		Lightweight	0.184	0.050
		Exact-sized	0.134	0.036
		Bulk	0.373	0.101
Process	0.166	Less energy	0.184	0.031
		Non-toxicity	0.587	0.097
		Not cause pollution	0.229	0.038

4.2 Green Packaging Assessment Tool

Based on the AHP analysis, a green functional assessment tool was developed to suggest the idea to improve the packaging used in terms of green criteria. Figure 2 shows the home page of an assessment tool which have been developed using online tool development platform.

Figure 2: Online Green Packaging Assessment Tool

Figure 3 shows example question in the assessment tool. The assessment tool consists of 4 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 green packaging performance of the packaging the user use can be evaluated. Figure 4.3 shows an example of the result obtained in the assessment tool. The assessment tool will suggest the idea to improve the packaging in terms of green criteria with example of green packaging and the benefits of green packaging. If the green packaging performance is less than 50%, a recommendation will be given by the assessment tool to improve the performance of the product. The green packaging performance which less than 50% will be suggested to improve in terms of material performance. This is due to the material of packaging plays a major with a local criteria weight of 0.563. This showed that the material of packaging is a very significant factor to influence the green packaging performance.

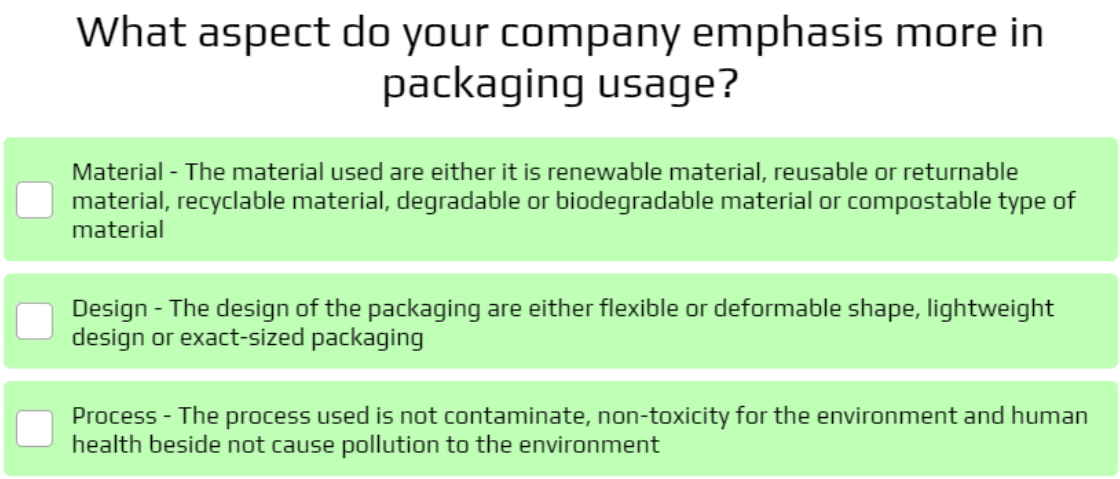

Figure 3: Example Question in Green Packaging Assessment Tool

Figure 4: Results displayed in the Green Packaging Assessment Tool

4.3 Discussion

4.3.1 Material of green packaging

The material of green packaging has the highest score obtained in AHP analysis in between the three main criteria. In other words, material of green packaging is the most important criteria for green packaging according to the respondents. In this study, the material used must have at least one of these criteria which are renewable, reusable, recyclable, degradable or bio-degradable or compostable. There are a few examples of material for the green packaging. One of them is starch-based biomaterial packaging. In the past decade or so, the packaging has seen a tremendous increase in value. Although it has many similar properties to plastic, corn starch-based packaging comes from corn and is much more environmentally friendly than plastic packaging. This is flexible in its applications, for example, this can be used by manufacturers to produce soda bottling or to create loose-fill packaging material. There are many more green material can be used to produce green packaging such as sugarcane-based biomaterials, mushroom-based packaging and organic fabrics. Those materials are degradable and easily to be composted. Material plays a major role in achieving green packaging for food industry [22].

4.3.2 Design of green packaging

The design of green packaging has the second highest score obtained in AHP analysis in between the three main criteria. Green packaging design is designing packaging of products with the primary purpose of doing as little harm as possible to the environment and human. The example of green packaging design is flexible or deformable shape, just like usual plastic packaging to reduce space used, lightweight to reduce material used, exact-sized packaging such as bubble wrap and bulk packaging which can help in reducing space used. The design of the green packaging is important to be weighted but material of the green packaging is more important. Moultrie, et al., 2018 stated that packaging material constitute 65 percent of solid waste globally. That shows the usage of material has major role more than the design.

4.3.3 Process in producing green packaging

The process in producing green packaging has the highest score obtained in AHP analysis in between the three main criteria. The criteria of the process involved in the manufacturing of the packaging to influence green packaging are whether less energy process is used or renewable energy process is used or the process that is non-toxicity is used. These processes are basically environmentally friendly processes and do not cause pollution to the environment. Green processes include concentrating on waste reduction and making recycled materials more effective, which go hand in hand with cost reduction and time savings [14].

5. Conclusion and discussions

Previous studies have shown the lack of assessment tool to evaluate packaging performance. Therefore, a green packaging assessment tool was developed to evaluate and measure the packaging of product. The developed green packaging assessment tool were validated and obtained positive feedbacks from the experts in fields. Perhaps, it can be used to assist and guide the designer, particularly to measure and continuously improve the designed green packaging.

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References

[1] Orzan, G.; Cruceru, A. F.; Bălăceanu, C.T.; Chivu, R. (2018) Consumers' Behavior Concerning Sustainable Packaging: An Exploratory Study on Romanian Consumers. Sustainability 2018, 10, 1787

[2] Zhang, G. and Zhao, Z. (2012). Green Packaging Management of Logistics Enterprises. Physics Procedia 24 (2012) 900 – 905.

[3] Guillard, V. Gaucel, S. Fornaciari, C. and Angellier-Coussy, H. (2018) The Next Generation of Sustainable Food Packaging to Preserve Our Environment in a Circular Economy Context.

[4] Minghua, Z.; Xiumin, F.; Rovetta, A.; Qichang, H.; Vicentini, F.; Bingkai, L.; Giusti, A.; and Yi, L. (2009) Municipal solid waste management in Pudong New Area, China. Waste Management 29 (2009) 1227–1233

[5] K. Vöröskői1, P. Böröcz1. (2016). Framework for the Packaging Supply Chain of an Automotive Engine Company. Vol. 9, No. 3, pp. 191-203, 2016

[6] Sheth, K. N. (2016). Sustainable Building Materials Used In Green Buildings. 9th International Conference on Engineering and Business Education (ICEBE) & 6th International Conference on Innovation and Entrepreneurship (ICIE)

[7] Bharathi, V.; Rohini, B.; Moses, J.A.; Chinnaswamy, A. (2019) Nanocomposite for Food Packaging: Principles and Applications.

[8] Ahmed, J. and Varshney, S.K. (2011). Polylactides—Chemistry, Properties and Green Packaging Technology: A Review, International Journal of Food Properties.

[9] Roberge, D. (2018). 5 Benefits of lexible Packaging and Flexible Films. Rosen, M.A. (2009). Energy Sustainability: A Pragmatic Approach and Illustrations. Sustainability ISSN 2071-1050. Sustainability 2009, 1, 55-80.

[10] Sustainable Packaging Coalition (2006). Design Guidelines for Sustainable Packaging.

[11] Grundey, D. (2010). Functionality of Product Packaging: Surveying Consumers' Attitude Towards Selected Cosmetic Brands, Economics & Sociology, Vol. 3, No 1, 2010, pp. 87-103.

[12] Sutton, A. (2019). 20 Sustainable Packaging Innovations. Board of Innovation. Xu, J.; Jiang, X.; Wu, Z. A Sustainable Performance Assessment Framework for Plastic Film Supply Chain Management from a Chinese Perspective. Sustainability 2016, 8, 1042.

[13] Glazer, J. (2007). Global Social and Environmental Responsibility Operations. Hewlett-Packard Development Company, L.P.

[14] Shove, E. (2017). What is wrong with energy efficiency? Building research & information. Volume 46, 2018- issue 7.

[15] National Academy of Sciences, National Academy of Engineering, and National Research Council. 2010. Real Prospects for Energy Efficiency in the United States. Washington, DC: The National Academies Press.

[16] Dellis, G. (2016). Green Packaging. A thesis submitted for the degree of Master of Science (MSc) ion Strategic Product Design. International Hellenic University.

[17] Fadel, C. and Tarabieh, K. (2019). Development of an Industrial Environmental Index to Assess the Sustainability of Industrial Solvent-Based Processes. Resources 8(2):155

[18] Setiawan, T.H. and Purwanto. P. (2018). Modification of processes, use of environmentally friendly technologies and other efforts to reduce them. ICENIS 2018.

[19] Saaty, T.L.; Vargas, L.G. Models, Methods, Concepts & Applications of the Analytic Hierarchy Process; Kluwer Academic Publishers: Norwell, MA, USA, 2001.

[20] Saaty, T.L. Decision Making for Leaders; RWS Publications: Pittsburgh, PA, USA, 2008

[21] J. Franek and A. Kresta, "Judgment Scales and Consistency Measure in AHP," Procedia Econ. Finance., vol. 12, no. December, pp. 164–173, 2014

[22] Geicu, M., Niculita, P. Mitelut, A., and Popa, M. E. (2011). Biodegradable Materials for Food Packaging Applications, Journal of environmental protection and ecology 12(4):1825-1834.