

Selecting sustainable packaging materials and strategies: A holistic approach considering whole life cycle and customer preferences

Devanshu Mudgal, Emanuele Pagone, Konstantinos Salonitis*

Sustainable Manufacturing Systems Centre, School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, MK43 0AL, United Kingdom

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ABSTRACT

With the increasing public awareness of packaging and the environmental impact caused by it, companies are driving their businesses to introduce and promote practices that help ease the negative impact of packaging on the environment. Studies done on consumer behaviour show that decisions nowadays are influenced by sustainability. Yet, companies struggle with changing practices and justifying adopting environmentally friendly packaging materials. The current paper presents a holistic approach, addressing the need for identifying, assessing, and selecting sustainable materials for packaging applications. The Kano model prioritises features that are then used with Ashby plots for identifying alternative materials. Life cycle assessment, as well as life cycle costing, are used for assessing the environmental and financial impact of the use of such materials. Automatically weighted Multi-Criteria Decision-Making Analysis (MCDA) is used to select the most appropriate packaging material. This methodology provides a combinatorial ranking for each criterion set by four pre-defined weight distributions for Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). The proposed methodology allows for a systematic and holistic design process when deciding on packaging materials for any product. The methodology is validated for the case of packaging weather-sensitive cast stone products and carbonated drinks. In cast stone, three packaging materials are ranked for pallets based on their attributes. Similarly, for carbonated drinks, three packaging materials are recommended at the end of the study.

1. Introduction

Packaging contributes to approximately 30–35% of the total municipal waste in developed nations and 15–20% in developing countries (Wiesmeth, Shavgulidze et al. 2018). In 2021, 36.8% of packaging went to landfills in the UK (Storr, 2023). The global packaging market is expected to grow from 1.10 trillion dollars to 1.33 trillion dollars by 2028, which could lead to more packaging waste (Mordor, 2023). To tackle such issues, one of the notable pledges includes two global soft drinks giants: PepsiCo pledged to use 50% recycled plastic in its European bottles by 2030, and Coca-Cola's European partners pledged to collect all packaging and utilise 50% recycled plastic in PET bottles in Western Europe by 2025 (Mordor, 2023). In response to criticism from campaigners, other major food producers are continuously reviewing their plastic packaging and joining groups like the European Plastics Pact, to minimise the use of virgin plastic by 2025 and achieve 100% recyclable or reusable packaging (Mordor, 2023). The new strict legislation around packaging such as the European Union's Directive on Packaging and Packaging Waste 94/62/EC aims to reduce

the environmental impact of packaging and encourage sustainable use of resources by minimising the waste generation (Hänsch and Kinkel, 1995).

Similarly, to achieve the net zero target by 2050, the UK government is developing new policies, such as plastic tax (Walker et al., 2020). India has banned the use of single-use plastic since 2022 to tackle climate change and other countries such as China, Kenya and Morocco have banned the use of thin plastic bags which are widely used in packaging (Harris, 2018). Complying with such government legislation is also one of the challenges the packaging industry faces.

Other direct challenges faced by the packaging industries include rising raw material costs, raw material shortages and labour shortages (Esaki et al., 2024). For example, an increase in the price of Petroleum-derived packaging has been observed in the global market due to the ongoing war in Ukraine. The war has led to volatility in the worldwide energy markets, pushing the price of petroleum-derived products up (Dube, 2022). One of the challenges the beverage packaging industry faces is the increase in demand for low-carbon aluminium to align with worldwide efforts, which is causing a shortage of it within

* Corresponding author.

E-mail address: k.salonitis@cranfield.ac.uk (K. Salonitis).

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the market (Moriera, 2023). Such issues must be addressed as packaging is the foremost element encountered by customers and plays an essential role in the decision-making process when purchasing an everyday product (Herbes et al., 2020). However, a predicament arises as the packaging transforms into a waste material once the product is shipped and unwrapped (Cheng, 2019). The studies on consumer behaviour show that sustainability progressively influences day-to-day purchases (Geels et al., 2015; Liu et al., 2016; Fischer et al., 2017).

1.1. Businesses and sustainable packaging

Businesses have begun comprehending this consumer behaviour and are gradually moving towards sustainable packaging (Wandosell et al., 2021). Nonetheless, this gradual shift poses challenges for the enterprises as they must substantiate the packaging cost, aesthetics, mechanical performance and green credentials to the stakeholders or decision-makers. On the bright side, the companies and decision-makers have responded positively to this increased customer demand in sustainable packaging initiatives based on the realisation of a needed shared value (Boz et al., 2020). A key challenge for companies is to analyse customer opinions about sustainable packaging and the needs that derive from their decisions to invest in it (Wandosell et al., 2021).

Another factor contributing to the failed launch of sustainable packaging in the market is translating customer needs poorly into technical specifications (Steenis et al., 2018). With a poor translation of needs, a company would launch a packaging product with poor customer acceptance (De Koeijer et al., 2017). To be competitive in the market by being customer-centric and economical, customer needs must be translated into technical requirements successfully so the decision-makers can select a sustainable packaging material. In some studies, complex and difficult-to-implement models such as Quality Function Deployment (QFD) translate customer requirements into engineering characteristics (Tontini, 2007; Porto De Lima et al., 2022). An easy-to-implement method is required to convert and prioritise customer needs into technical specifications.

1.2. Current decision making process

A decision such as selecting sustainable packaging requires 'experts' who use their experience for material selection. However, the level of expertise depends on the experience. In the case of multiple experts, a disagreement may occur due to differences in opinion. Also, not every company has an expert on sustainable packaging (Pagone et al., 2020). A packaging product can be manufactured using multiple materials; for example, a carrier bag, an efficient packaging product, can be produced using numerous materials and different thicknesses. Some materials are jute, recycled paper, corrugated paper, cotton, low-density and high-density polyethylene (Sengupta et al., 2022). The complexity arises when attributes such as customer needs, engineering requirements, cost and environmental impact must be considered.

The overarching aim of this paper is to propose a methodology that allows the selection of more sustainable packaging materials and, at the same time, address customer's needs. The paper's objectives include comprehensively understanding the customer's requirements for packaging material, which incorporates sustainability criteria, identifying the criteria and their impact, recognising the potential materials and providing decision-makers with a choice of materials to select from. To achieve this, firstly, within the methodology, identification of the diverse customer and engineering requirements for packaging material is required. Secondly, a method is needed to identify essential criteria from the customer and prioritise the vital ones. Prioritisation is the most significant and critical portion of the requirement analysis because it identifies desirable functionality as early as possible based on the importance of stakeholders' requirements (Hudaib et al., 2018). The material selection within the study could assist with a straightforward translation of customer requirements into technical specifications and

allow the comparison of different materials and their properties with no complexity. Lastly, the potential materials from the available materials must be identified. It will enable the decision maker to rank and select suitable packaging material alongside sustainability criteria. These steps provide a methodology that assists in material selection from many materials for packaging.

2. Literature review

The first key question explored in this section is whether a method exists for identifying and capturing customer needs and requirements. The second key question investigated is the translation of requirements into technical specifications. Thirdly, different criteria are used for selecting packaging materials and, lastly, for choosing a material available from many materials. All the studies included in this section are existing research that has answered aspects of these questions.

2.1. Voice of the customer (VoC)

An organisation that prioritises customer experience through its products and services is called a customer-centric organisation (Pardo-Jaramillo et al., 2020). It can also be defined as serving customers as individuals and delivering what they want with maximised efficiency and effectiveness (Sheth et al., 2000). Such an organisation's decision-making process deeply considers the output's effect on its customers. From a financial perspective, the literature has shown that customer-centric organisations are more profitable than non-customer-centric organisations as customers are satisfied with products and services (Kohli and Jaworski, 1990). This critical process captures precise information regarding customer requirements for a product or a service (Aguwa et al., 2012). The data obtained from the customers can then be translated into essential technical attributes that will ultimately be used to satisfy the customers and as input to a new product or a service. In VoC, there are two ways the information can be captured. The first is direct communication where data is captured through meetings, virtual conferences, surveys, and telephones (Guo, 2024). The second method is indirect communication, gathering information through market research, web analytics and product usage data (Aguwa et al., 2012). Companies need to choose a suitable VoC method to accurately understand customer input requirements and develop a correlation between new products or services. With VoC analysis, it is possible to prioritise the product outputs that are most important to customers. The decision to provide improved attributes depends on the cost and the feasibility of needs and their importance to the customer (Aguwa et al., 2012). Much research has shown that satisfying customer needs may increase customer happiness and loyalty (Boulding et al., 1993; Aguwa et al., 2012). A method is required that captures them efficiently and allows a company's efforts and resources to prioritise what is critical for the customer (Griffin, 2013).

As per Hudaib et al. (2018), several prioritisation methods have been developed to tackle different scenarios. A method can be selected based on the scale and complexity of the prioritisation problem. They can be classified into three main scales, i.e. Nominal, Ordinal and Ratio (Vestola, 2010). The Nominal scale prioritisation categorises the requirements into multiple classes based on their importance, assigning equal priority to the requirements within that category (Vestola, 2010). Methods such as MoSCoW, Kano and Numerical assignment are part of the Nominal scale (Hudaib et al., 2018). The second scale, i.e. the Ordinal scale, is used to show if one requirement is relatively more important than the other (Brahmam et al., 2024).

In contrast to the Nominal scale, the Ordinal scale assigns each attribute a particular rank, enabling understanding of their significance to one another. It encompasses the Priority group, Bubble sort, and minimal spanning tree methods (Castillo-Valdivieso et al., 2024). Lastly, the Ratio scale provides a relative difference between requirements. This scale includes methods such as the Analytical Hierarchy Process (AHP),

minimal spanning tree, Cumulative Voting (CV), and Hierarchical Cumulative Voting (HCV) (Bukhsh et al., 2020).

For this study, a nominal scale method is ideal as the packaging attributes defined by the customer can be categorised into distinct classes based on predefined criteria. This provides the stakeholders involved in the prioritisation process with an easy method to follow, resulting in an efficient decision-making process. Furthermore, equal priority is given to each attribute within the same category, preventing potential disagreements on each attribute's relative importance (Vestola, 2010, Hudaib et al., 2018).

As mentioned at the beginning of the section, MoSCoW is one method that comes under the nominal scale. In this method, the product requirements fall into four categories that are "Must have", "Should have", "Could have" and "Won't have" (MoSCoW) (Kravchenko et al., 2022). The MoSCoW technique offers a collaborative opportunity between the stakeholders and Business analysts (Tufail et al., 2019). Although this simplicity assists in speedy prioritisation and decision-making, it lacks a more detailed understating of customer satisfaction. However, it must also highlight that the categorisation in MoSCoW can be based on personal opinion and does not consider interdependency requirements (Tufail et al., 2019).

The second method that falls into the nominal scale method is the Numerical assignment. It is considered to be the traditional and popular prioritisation method (Hudaib et al., 2018). It involves categorising requirements into three different groups, three being the most common division (Cox et al., 2009). For example, the requirements can be classified as critical, standard and optional (Bukhsh et al., 2020). Each requirement is then assigned a priority on a scale of one to three, indicating its importance. Three are the highest priority, and one is the lowest. The requirements in each category hold equal weight. Therefore, no additional information is given to distinguish the importance of requirements within the same category. The third method is the Kano model, utilised to understand various attributes of a service or a product that might affect customer satisfaction (Kang et al., 2023). The Kano model prioritises the features based on customer needs and considers how these features will contribute towards customer satisfaction. It is a survey/questionnaire-based approach which is easy to implement. As per the methodology, the attributes are divided into five categories: Must-be, One-dimensional, Attractive, Indifferent, and Reverse. In addition to classifying the attributes, the Kano model also provides a standard structure for obtaining customer answers. Due to such customer-centricity and granularity of the analysis, the Kano method is ideal for this study compared to the MoSCoW and Numerical assignment method. Only the Kano method provides the satisfaction level of the customer.

As a versatile method, Kano's model has been used in several industries. A study related to packaging addresses questions regarding the practicality of packaging materials while also attempting to understand how specific packaging characteristics contribute to higher consumer satisfaction and creating a brand image. The paper assessed 14 different quality attributes of varying packaging using Kano questionnaires (Kovacević and Bota, 2021). In another study, researchers tried to find customer perception on 22 packaging attributes and 500 randomly selected respondents took part in the study. The questionnaires were structured around packaging on everyday commodities (Dash, 2021).

The combination of two prioritisation techniques has also been used in some studies. Since Kano is more customer-centric, it has been used in conjunction with the Ratio scale prioritisation technique, i.e. AHP, in studies to enhance the design of an existing product as well as to design a novel product based on customer feedback. For instance, in a study by Yuan and Guan (2014), a bespoke wheelchair design was proposed. In another study, a methodology combining life cycle thinking with the Kano was proposed for comparing various sustainable packaging designs in the food industry (Jagoda et al., 2023). In this study, QFD and Kano were combined for sustainable packaging design. The study focused on parameters such as Functional satisfaction, which deals with protecting,

communicating, and facilitating handling of the food packaging, life cycle impact, and environmental impact, followed by the cost of packaging. However, the study deals with the design rather than the material section for the design.

Overall, the studies in this section highlight using a customer-centric prioritisation method such as Kano or AHP to prioritise the design attributes in packaging. However, the studies presented have yet to use the prioritisation method to capture customer needs for sustainable packaging material. Studies selecting a packaging design mainly focus on aesthetics, design practicality rather than environmental attributes, and raw material transportation. However, these attributes must be considered in the material selection studies. This section's studies are more design-orientated than material from a customer perspective.

2.2. Capturing engineering requirements

As mentioned above, their needs and requirements must be converted to technical specifications for successful packaging to satisfy the customer. However, the absence of clearly established standards and customers with ambiguous requirements might make the journey to technical specifications arduous (Delghandi, 2018). The basic concept of QFD is to translate customer needs into engineering characteristics and, consequently, into parts characteristics, production plans and requirements. A matrix called the House of Quality (HOQ), is used for identifying customer requirements and establishing priorities of design requirements. QFD can be graphically represented as HOQ (Fung et al., 1996). To capture VoC, QFD has been used in multiple studies to translate customer requirements for sustainable packaging design to technical specifications (Fongsatitkul and Kainuma, 2021, Jagoda et al., 2023).

Another approach that can be used is the Axiomatic design approach, which uses matrix methods to translate customer needs into a set of independent requirements that characterise the functional needs of the products, design parameters and process variables (Kurniawan et al., 2004). The technique has been used for eco-designs in packaging (Morrison et al., 2013).

2.3. Sustainable packaging criteria

For a customer-centric approach, the criteria for sustainable packaging material must be understood from a customer's perspective. This section includes the relevant studies that assist in highlighting necessary criteria which are helpful for sustainable packaging from a customer point of view. A widely accepted definition of sustainable packaging was developed in confederation with companies from the Sustainable Packaging Coalition (SPC).

- "A: Is beneficial, safe & healthy for individuals and communities throughout its life cycle.
- B: Meets market criteria for performance and cost
- C: Is sourced, manufactured, transported, and recycled using renewable energy.
- D. Optimizes the use of renewable or recycled source materials.
- E. Is manufactured using clean production technologies and best practices.
- F. Is made from materials that are healthy throughout the life cycle.
- G. Is physically designed to optimise materials and energy.
- H. Is effectively recovered and utilised in biological and/or industrial closed loop cycles."

(SPC, 2011).

With the inclusion of the above criteria in mind from the definition of sustainable packaging, the companies should move towards sustainable packaging as customer purchases are highly motivated by sustainability (Geels et al., 2015). It will also help the business to increase the satisfaction level of their customers. Any improvements or changes to the

packaging should consider the customer's perception, environmental concerns and willingness to pay (Prakash and Pathak, 2017; Gustavo et al., 2018). Recent studies have highlighted that customers are willing to pay more for sustainable packaging (Mahmoud et al., 2022). However, the customer's perspective might vary based on the product (Geels et al., 2015). Multiple studies have been conducted to identify the attributes of sustainable packaging from a customer's perspective (Martinho et al., 2015; Herbes et al., 2018; Oloyede and Lignou, 2021; Branca et al., 2023). From the customer's perspective on sustainable packaging material, the questions were structured around a few criteria: cost, quality and environment (Branca et al., 2023). The attributes highlighted in those studies that fall into those criteria were packaging cost, packaging functionality (Martinho et al., 2015; Herbes et al., 2018), material (Branca et al., 2023), recycling (Herbes et al., 2018), biodegradability (Martinho et al., 2015; Herbes et al., 2018), reusability (Herbes et al., 2018), lightweight (Herbes et al., 2018), space-saving (Herbes et al., 2018) and service life (Herbes et al., 2018). The above-mentioned attributes can be grouped into three parts, i.e. quality, environment, and cost, and formulate the basis of the methodology which is proposed in this study.

2.4. Material selection

In today's world, where the packaging industry faces multiple challenges, such as legislation to reduce carbon emissions and material and labour shortages at the forefront of the global discourse (Esaki et al., 2024), material selection impacts such challenges directly throughout the product lifecycle. Considering all the challenges, a high-performance, sustainable material can be selected. Material selections are motivated by considering one of three ways: first, 'design-oriented', which is driven by functional demands and requires careful consideration of mechanical, physical and chemical properties; second, 'product oriented', which is motivated by the public market and the third is 'cost oriented' which aims to reduce the manufacturing costs (Edwards, 1994). A method is required to translate customer needs and requirements into technical specifications. As a measure against climate change, environmental properties have also been included in the product life cycle, where the material is selected with a conscious eye on the environment, which could be helpful to address sustainability considerations in packaging. It is called the 'environmentally conscious design' or eco-design (Ljungberg and Edwards, 2003; Zhao et al., 2012). In multiple studies, sustainable packaging materials have been selected based on Life Cycle Analysis (Almeida et al., 2010; Zhang et al., 2017), but LCA alone cannot determine the suitable packaging material. The method must also be design oriented. A further analysis must still be performed to compare other technical specifications.

A method called screening and ranking can be devised to select a material. This two-step method systematically evaluates candidate material based on specific criteria, such as Young's modulus, and screening materials that do not meet the essential requirements (Jahan et al., 2010). This approach narrows down the options to promising candidates (Farag, 2006). Being a two-step method, this approach has not been widely used. Furthermore, when dealing with complex problems of material and process selection, challenging optimisation issues occur due to the complex topology of the solution space (Ashby et al., 2004). In a few studies, the idea of sustainable material selection through neural networks (Jahan et al., 2010; Merayo et al., 2020).

Meanwhile, Ashby's diagram remains a popular technique for initial screening for material selection, as it plots multiple material properties together with environmental criteria and costs (Shah and Design, 2014). Using this technique, various materials can be compared for a specific constructive function using performance indices as a design criterion, making the material selection much more efficient. The technical requirements can be translated into technical specifications using an Ashby diagram. However, an expert's opinion might be required to narrow down the results (Gao et al., 2020). Ashby diagram has been

used in multiple studies to select the packaging material where technical and environmental aspects have been considered (Gao et al., 2020; Mifsud et al., 2023). In the study by Mifsud and Refalo et al. (2023), attributes such as biodegradability, flexural strength, shrink rate, carbon footprint, embodied carbon and cost were used in comparison from various materials. It has also been used along with Multi-Criteria Decision Analysis to select a material (Huang et al., 2011). In a critical study by Fuhrmann and Schwarzbauer et al. (2021), the author combines the Kano model and the Ashby diagram to develop a methodology for a new customer-centric material (Fuhrmann et al., 2021).

2.5. Decision making

In material selection, the problem arises when the decision maker has to select from a plethora of materials with multiple criteria, especially when choosing from a material database (Huang et al., 2011). Different methods have been proposed, such as the fuzzy set theory and multi-criteria Decision Support System for packaging material selection (Jarupan et al., 2004; Tamani et al., 2015). Excel sheet-based methods were developed using the "if-then" rule to select suitable packaging material for biobased food packaging (Sanyang and Sapuan, 2015). Similarly, Multi-Criteria Decision Analysis (MCDA) has been used to assess the packaging materials based on multiple criteria to select and rank them (Huang et al., 2011; Saidani et al., 2020). To choose a sustainable packaging material, the MCDA method, such as fuzzy AHP and Technique for Order Performance by Similarity to the Ideal Solution, have been used in the studies (TOPSIS) (Wang and White, 2014; ŞENYİĞİT and Demirel, 2017).

Similarly, Complex Proportional Assessment (COPRAS) has also been used to select a biodegradable plastic material for liquid containers (Kang et al., 2023). An MCDA method has also been employed to choose a packaging design for material selection and packaging design (Porto De Lima et al., 2022). In all the studies mentioned above, an expert must give weightage. Their experience constrains an expert opinion. Each expert will have a different weightage for each attribute, which could lead to disagreements. Also, not everyone has access to an expert. In a study by Pagone et al. (2020), an automatic weighted MCDA methodology is proposed where no expert is required. The method can be used in conjunction with any of the MCDA methods (Pagone et al., 2020). The study provides the decision makers with four distributions i.e. Uniform, 'Halving', 'Quadratic' and 'First two' to select from. The same method has been deployed with TOPSIS to assess the sustainability of traditional sand moulds compared to 3D-printed ones (Saxena, Pagone et al. 2021).

Although the studies in sections 2.1, 2.2, 2.3 and 2.4 contribute significantly to providing parts of the methodology, none of the studies has developed an integrated, structured, holistic approach for selecting a suitable packaging material from a plethora of materials that consider customer needs, translates them to technical specifications and helps in packaging material selection. Current approaches need more flexible integration to ensure that all the relevant attributes are adequately considered. Furthermore, most of the studies provide design options to the customers, and input from an expert is required. Such an example is demonstrated in the methodology mentioned by Fuhrmann et al. (2021) and Jagoda et al. (2023). However, the methodology is only valid for developing a new composite material rather than selecting a sustainable packaging material. The result may vary as each expert would have their own opinion and different weightage based on the experience. In addition, not everyone has access to an expert. Therefore, there is a pressing need for a holistic approach that bridges these gaps and provides a methodological pathway for sustainable packaging material that aligns with technical feasibility and customer requirements.

3. Methodology

The methodology presented in this paper is a straightforward three-step method for selecting packaging materials that are more sustainable

and address customers' needs. It consists of three modules, as shown in Fig. 1.

The overall flow of the process is shown in Fig. 2. For designing a customer-centric approach to selecting a sustainable packaging material, the first part of the methodology deals with capturing customer and engineering requirements. As mentioned in section 2.1, capturing the Voice of the Customer (VoC) is vital. The VoC can be captured via a direct or indirect method (Guo, 2024). Once the customer has answered the questionnaire, the customer's requirements can be prioritised based on a prioritisation method. By prioritising customer needs, a company can efficiently allocate resources to develop a new customer-centric product (Griffin, 2013). These requirements are then translated from customer needs to technical requirements using one of the methods mentioned in section 2.2. Based on the application, the technical team can specify the technical variables required for filtering within a material database for selection. It will allow the product design team to narrow options to a few from many materials. As mentioned in section 2.3, the choice of sustainable packaging material should be based on three criteria: quality, environmental, and cost. At a high level, the design team can select these materials.

Lastly, the list of packaging materials identified proceeds to a decision-making method. They can be ranked based on their quality, environmental and cost attributes for final selection and an appropriate decision is made.

3.1. Customer and engineering requirements

3.1.1. Kano

As mentioned in section 2.1, Kano's customer-centricity will benefit from this methodology in prioritising VoC. Based on the number of customers who agreed to answer the question, a suitable and efficient method to capture VoC can be employed. To capture the VoC, a direct or indirect communication method can be used (Guo, 2024). The customer sample size to whom the questions will be asked should represent an organisation's diverse customer segment, market segmentation and target marketing personas (Violante, Vezzetti et al. 2020). The questions to the customer are divided into two parts i.e. functional and dysfunctional. A response that determines the satisfaction level of the customer if the attribute is added to the product is functional, whereas a dysfunctional reaction from the customer is expected in case the attribute is not added to the product. The respondent is given five options to select from. As mentioned above, there are five attributes. However, there is a sixth attribute known as questionable, where the respondent selects the same response for both functional and dysfunctional (Sharif Ullah and Tamaki, 2011). Once the questionnaire is sent to the customers, it highlights what packaging attributes would satisfy them. For example, the packaging material must be waterproof if a product is kept in an open environment. Here, "waterproof" is an attribute of the packaging. The questionnaire contains a series of functional and dysfunctional questions. For each attribute, two questions are posed: one

negative question, which is dysfunctional, and one positive, which is functional. Predefined questionnaires minimise variability and ensure consistency in customer responses. The answer must fall into one of the five categories as explained in section 2.1. The combination of functional and dysfunctional will provide the classification for an attribute. In the Kano method, customer feedback falls into pre-defined categories as below (Sauerwein, Bailom et al. 1996).

- Must-be: These are requisite attributes; the absence of these attributes will cause customer dissatisfaction.
- One-dimensional: These are usually demanded by the customer explicitly.
- Attractive: The customer should actively anticipate these attributes. The absence of these attributes will not cause dissatisfaction.
- Indifferent quality: These attributes are distinguished by their neutrality, indicating that they have no observable positive or negative effect and that they neither elicit customer happiness nor discontent.
- Reverse quality: An attribute associated with substantial achievement may potentially cause dissatisfaction, and it emphasises the diversity of customer preferences and expectations.

3.1.2. Prioritisation of customer requirements

Once the customer response has been received, the attributes for the material can be prioritised using a pre-defined table from Kano that delineates the combination of customer responses based on the five attribute types mentioned earlier i.e., Must be (M), One dimensional (O), Attractive (A), In-different (I), Reverse (R) and Questionable (Q) attributes. For instance, if a customer opts for "I like it" from the functional and concurrently chooses "I can live with it" from the dysfunction type, the response means it is an attractive attribute.

3.1.3. Prioritising engineering requirements

Based on the same prioritisation method mentioned in 2.1.2, the overall technical attributes can also be prioritised from the product designer's perspective as each packaging design would have its technical requirements based on the application. For example, environmental criteria such as carbon emission will be under environmental criteria, similarly, Young's modulus will define the quality of the packaging material.

3.1.4. Mapping requirements into a technical specification

As mentioned in section 2.2, multiple methods can be used to translate requirements into technical specifications. For this step, the designers can use techniques such as QFD or Axiomatic design approach. For example, in the Axiomatic design approach, a matrix is used to map functional requirements to design parameters, visualising their relationship. If the matrix is diagonal or triangular, independence is maintained. The matrix allows the mapping of requirements into a technical specification. Axiomatic design has been used to design a beverage can

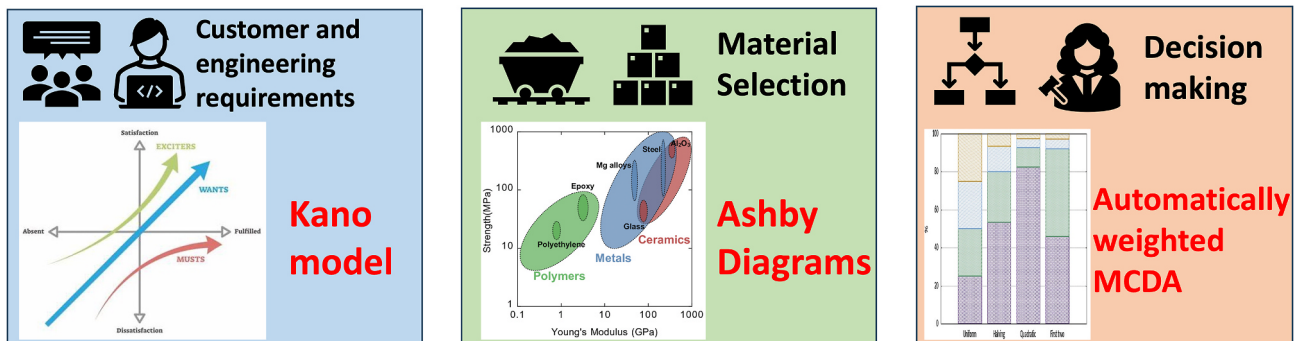


Fig. 1. Modules in the proposed methodology.

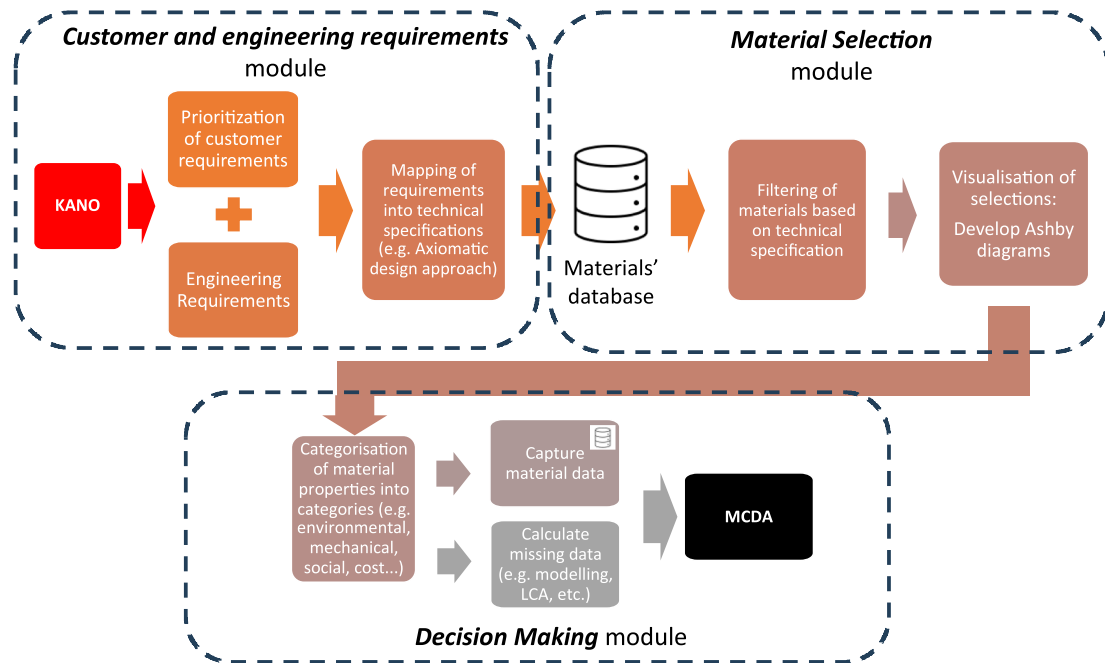


Fig. 2. The proposed methodology.

design (Suh, 2001).

If a company is already using a packaging material, the assumption can be made that the answers from the customer are in comparison with the existing packaging material. In that case, the filters can be applied directly within the database as in section 3.2.2.

3.2. Material selection

3.2.1. Material database

Multiple databases are available in the market such as IGDB, MASEA, ColePalmer, Spacer and CES Edu pack (Cambridge, 2024). However, environmental credentials must also exist within the database to find a suitable sustainable packaging material, such as recyclability and carbon dioxide emissions. For this study, Ansys CES Edupack, which already consists of Life Cycle Analysis (LCA) data, was used. The benefit of using a database is that it provides, the ability to plot Ashby diagrams within the database software and hold environmental and material cost-related data.

3.2.2. Filtering material based on the technical specification

As the customer specifications have now been translated to the technical requirements, filters can be applied to narrow the number of materials at a high level from many materials within the database.

3.2.3. Develop ashby diagram

The Ashby diagram allows easy visualisation of multiple materials, as explained in section 2.4. It also enables the characterisation of materials through several different variables. For high-level material selection, it is assumed that the company has the relevant attributes of the current packaging material. Based on requirements, the decision maker can plot materials on the Ashby diagram for a specific packaging attribute as shown in Fig. 3 where the Tensile strength vs Young's modulus for engineering and natural material has been plotted for different families. In high-level material selection, filters are applied to the material database, allowing the translation of quantitative to qualitative specifications. A qualitative specification is converted to a quantitative specification using a simple high-level material selection. For example, if cost is an important attribute and the customer asks for a cheaper

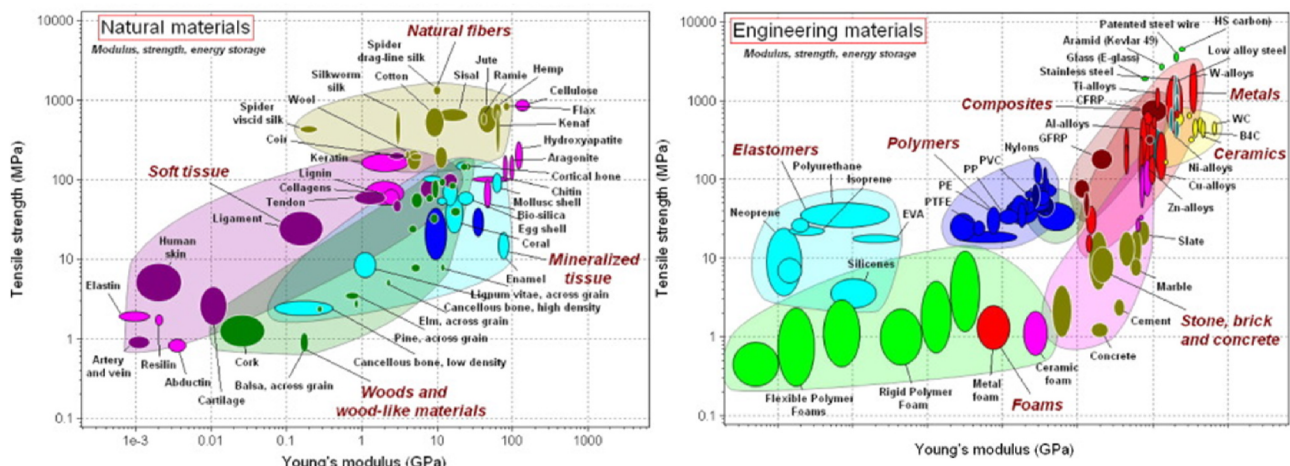


Fig. 3. Ashby diagram plotted between Tensile strength and Young's modulus for natural and engineering materials for different families (Ashby, 2008).

packaging material, the filters will be applied in the context of the existing packaging material. In other words, the material should be more affordable than the current packaging material. The material type required for packaging can be filtered using the material family. So, based on the material family, an array of potential materials can be plotted on the Asby diagram.

3.3. Decision making

3.3.1. Categorisation of material properties

In this step, a decision-making matrix is created using the data from the material database. To create this matrix, the criteria are divided into attributes, as shown in Fig. 4. As explained in section 2.2, the attributes are part of three criteria: quality, environment, and cost. The data is arranged in a decision-making matrix for automatically weighted MCDA, as shown in Table 1. In some cases, the database might provide a range of values.

3.3.2. Capture material data

The existing packaging material is also included in the matrix. This allows a comparison of the existing packaging materials with the alternatives. To capture information systematically, data tables are filled for each sub-criterion. Based on each category of packaging product, various data tables holding ‘n’ number of alternatives can be created. The attributes might change based on the packaging product, but as an example, a few attributes are shown in the “attributes” column in Table 1. Once the data is collected, as shown in Tables 1 and it is prepared for the automatic weighted MCDA. The positive and negative impact of each criterion is defined rather than asking decision makers (DMs) to provide weightage to each criterion (Pagone et al., 2020). To determine positive or negative impact “+” and “-” sign is used in the impact column. For example, in the first row, the negative impact shows that an alternative with the least “attribute 1” will have more influence than other alternatives, so, a “-” sign is used. In other words, the lower the “attribute 1”, the better the impact. Similarly, a positive sign implies that the higher the value is, the higher the influence on the materials chosen, as shown for “attribute 3”. The tables are then used as an input file for the automatically weighted high-resolution mapping MCDA (Pagone et al., 2020).

3.3.3. Calculate missing data

If the database is missing environmental, technical, or cost-related attributes, such data can be calculated using relevant methods such as Life Cycle Analysis (LCA) and put into the decision-making matrix for accurate material selection.

3.3.4. MCDA

TOPSIS is particularly suitable for this study because it simplifies complex decision-making by identifying solutions closest to the ideal

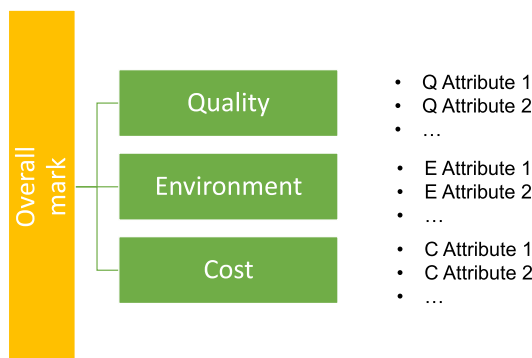


Fig. 4. The division of three main criteria i.e. quality, environment, and cost into attributes for the MCDA.

Table 1

The matrix shows the attributes and their impact on criteria. The value column contains data from n alternatives.

Attributes	Impact	Criteria	Values of n alternatives
Attribute 1	-	Financial	
Attribute 2	-	Environment	
Attribute 3	+	Environment	
Attribute n	+	Technical	

solution and farthest from the worst-case. It is considered a good choice because its compensatory aggregation nature determines its popularity in representing realistic engineering trade-offs. Multiple MCDM methods can be used to obtain a reliable ranking (Pagone and Salonitis, 2022).

The MCDA is run, and the results are plotted using the output files. The high-resolution mapping technique will plot four graphs based on the four laws described in the study (Pagone et al., 2020). The number of data points produced per graph will depend on the number of alternatives available. These graphs cover all the possible scenarios giving each criterion priority in all four laws, i.e., ‘First two’, ‘Halving’, ‘Quadratic’ and Uniform (Pagone et al., 2020). The equations for the four laws are explained below.

1. Equal importance is given to each criterion, resulting in uniformly distributed weights. As per Equation (1), for every successive jth position in the ranking, the weight ‘w’ is reduced by a factor $f_w(j)$. Where $w(j)$ represents the importance of each criterion for the DM.

Where.

- ‘w’ is the weightage
- f_w is the reduction factor per case
- n is the number of criteria
- j is the position of the criteria in the ranking

$$w(j) = \frac{1}{f_w(j)} \quad \forall j \in N \cap [1, n] \quad j \in [1, n] \quad (1)$$

2. In “halving”, the weight distribution w is decreased by a factor $f_w(j)$ at each successive jth place in the ranking. equation (2) is used:

- ‘w’ is the weightage
- f_w is the reduction factor per case
- n is the number of criteria
- j is the position of the criteria in the ranking

$$f_w(1) = 1f_w(j) = 2f_w(j-1) \quad \forall j \in N \cap [2, n] \quad j \in [1, n] \quad (2)$$

3. Each successive position in the ranking reduces the weight even further, resulting in a “Quadratic” distribution for which equation (3) below is used.

- ‘w’ is the weightage
- f_w is the reduction factor per case
- n is the number of criteria
- j is the position of the criteria in the ranking

$$f_w(j) = 2j^2 \quad \forall j \in N \cap [2, n] \quad j \in [1, n] \quad (3)$$

4. Weight distribution is analysed when the “First two” categories will dominate as shown in equation (4).

$$f_w(1) = f_w(2) = 1f_w(j) = j^2 \quad \forall j \in N \cap [3, n] \quad j \in [1, n] \quad (4)$$

- ‘w’ is the weightage

- f_w is the reduction factor per case
- n is the number of criteria
- j is the position of the criteria in the ranking

The entropy E is calculated for each criterion n using the elements normalised in the decision matrix R as shown in equation (5).

$$E_i = \frac{1}{\ln n} \sum_{n=1}^n n_{ij} \ln r_{ij} \forall i, j \in N : i \in [1, m], j \in [1, n] \quad (5)$$

- n is the number of criteria
- ' i ' is the position per entropy

5. The weights are calculated below using equation (6).

Where.

- $W_{s,i}$ are the resulting weights
- ' i ' is Entropy per criterion from equation (5)

$$w_{s,i} = \frac{|1 - E_i|}{\sum_{i=1}^n |1 - E_i|} \forall i \in N \cap [1, n] \quad (6)$$

6. Finally, combining with the weights provided by the distributions above in w_d as shown in equation (7).

Where.

- w_d is the weighted distribution
- ' i ' is the number of weights for equation (6)

$$w_i = \frac{w_{s,i} w_{d,i}}{\sum_{i=1}^n w_{s,i} w_{d,i}} \forall i \in N \cap [1, n] \quad (7)$$

The ranking from each case will allow the DM to pick the most suitable option based on the scenario. Ranking all the alternatives will help the decision-maker pick the best choice for the materials already used within the business. Furthermore, the high-resolution maps allow the DM to understand the drivers behind the ranking that make one option better than the other (e.g., cost, carbon footprint).

3.4. Novelty of the method

The novelty of this approach lies in integrating the three-step approach to select a sustainable packaging material. Most sustainable packaging products have not been launched due to a lack of acceptance from customers (Van Birgelen, Semeijn et al. 2009). Customer feedback would provide decision-makers with insight, which has been neglected in previous studies (Yuan and Guan, 2014, Jagoda et al., 2023). The second step of material selection connects the customer requirements and technical feasibility, missing in all the existing methodologies for sustainable packaging material (Almeida et al., 2010; Zhang et al., 2017). It also allows designers to choose sustainable packaging materials from various materials using a database based on pre-defined categories of cost, environment and environmental parameters. Finally, the decision-making step consolidates all the results, providing a fast, easy and streamlined process for selecting a packaging material. Combining all three steps allows a user to select a packaging material and provides flexibility to choose a technique based on the problem.

In the next section, two case studies from different industries highlight the practicality of the proposed methodology. The case studies show how methodology is used in a real-world industrial setup.

4. Case study – cast stone packaging (pallets)

To highlight the practicality of the suggested methodology, it has

been applied to select a sustainable material for pallets for a manufacturer of a cast stone company based in the UK. Cast stone (CS) is manufactured to look like carved natural stone (Mudgal, Pagone et al. 2021). The raw materials such as cement, sand and limestone are mixed to produce CS. It is made to resemble any shape, size or texture and is widely used to enhance the aesthetics of a landscape. This section explores alternative materials to a wooden pallet, which is a significant part of CS packaging. The primary factors contributing to finding an alternative to the current wooden pallets are the continuously increasing cost of pallets and the Limited supply (Al Suwaie et al., 2023). The timber industry heavily relies on the supply of wooden pallets. The disruption caused by logging due to bugs, transportation due to geopolitics, or labour shortages can disrupt the pallet supply, which causes a price increase (Prins, 2022). The secondary factors are the limited reliability and the need for weather-resistant material. As pallets are exposed to weather conditions, the wooden pallets start to degrade, causing damage to the goods (Tjumina, 2023). As this CS company uses wooden pallets during transportation, filters can directly be applied during the conversion to technical requirements based on the properties of wood.

4.1. Customer and engineering requirements

Based on these attributes, the Kano questionnaire was designed to reflect the functional and dysfunctional aspects of pallets. The decision-makers at the CS manufacturing company prepared the questionnaire based on the literature review performed for pallets, as shown in section 4.2. A total of 18 questions were sent to 10 loyal customers, where nine questions were functional and nine were dysfunctional. The answers received from the customers are translated into the technical requirements for the Ashby diagram, as one of the attributes mentioned in the questionnaire was cost, which is shown in Fig. 5. The questionnaire included attributes affecting packaging cost, service life, environmental impact and engineering specifications of a pallet.

4.2. Material selection

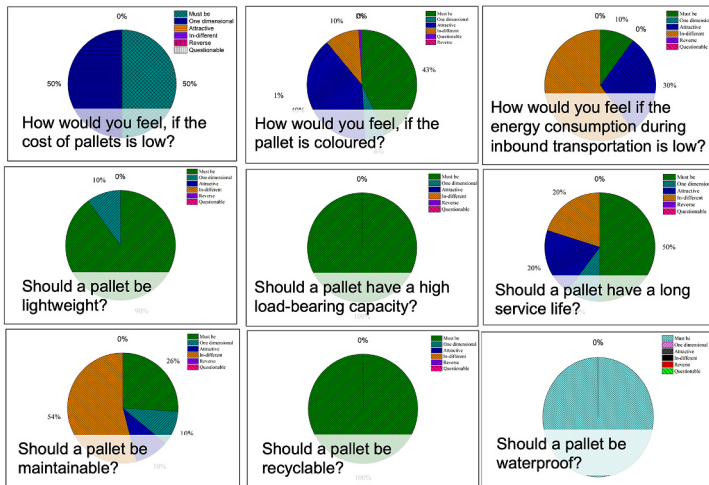
Wooden pallets have dominated the pallet industry since the beginning. In multiple studies dealing with pallets, the significant attributes have been highlighted which were used for this case study. Using the literature, a list of attributes was identified as essential for a pallet design. For instance (Masood and Haider Rizvi, 2006), it highlighted that a pallet must be light (density), it should have minimum deflection under load (Young's Modules, Tensile strength and Yield strength), and it should not be made from a brittle material (Hardness). A pallet must have a load capacity of at least 2.5t (Masood and Haider Rizvi, 2006) (Yield strength and fracture toughness).

Similarly, another study highlighted essential attributes such as recyclability and reusability. Other factors must be considered, as mentioned in section 2.2: factors such as biodegradability, recyclability, and service life. Wood is a cheap material for pallets. Some studies have suggested wood-plastic pallets, highlighting the cost of the material as an essential attribute (Soury et al., 2009). All the characteristics of each criterion are shown in Fig. 7. Attributes mentioned in these studies were added to the questionnaire for customers to answer.

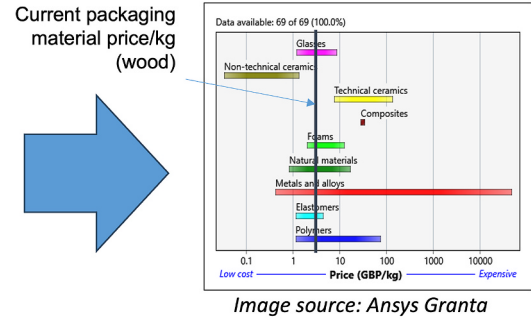
As shown in the Ashby diagram, 13 materials were selected at the high level to compare carbon footprint vs price in Fig. 6. For this case study, no LCA was performed as the data was already available in Granta's database.

Wood is one of the alternative materials. The database provided quantitative data on the alternatives. The material's properties for all the other options are classified into three categories, as shown in Fig. 7. The three categories are cost, environment, and quality. For environment, embodied carbon and the carbon footprint during processing are considered, whereas in the quality category, various mechanical attributes of the material are included.

Kano model implementation



High-level material selection



Ashby diagrams

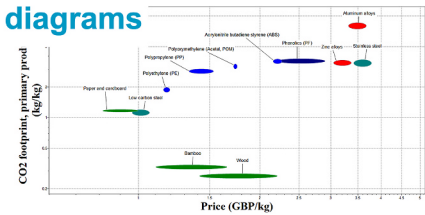


Fig. 5. Kano questionnaire responses and Ashby diagram for wooden pallets and high-level material selection for one of the attributes from the questionnaire (cost).

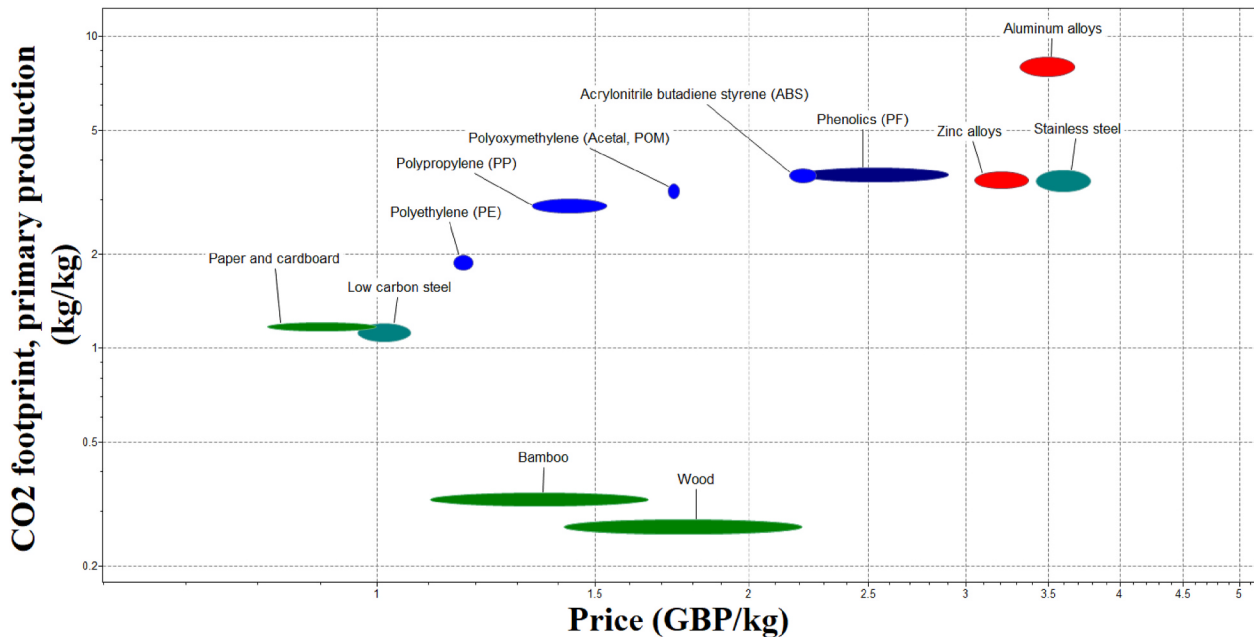


Fig. 6. Ashby Plot for Carbon Footprint vs Price for pallets.

4.3. Material selection

4.3.1. Uniform distribution

In Uniform distribution, when equal importance is given to each alternative, Low alloy steel outranks any other alternative, as shown in Fig. 8. The current material i.e. wood has a score between 0.6 and 0.5. ABS as an alternative, has ranked the lowest in the Uniform distribution. From the initial data, in the quality criteria, low alloy steel has the highest yield strength of 1034.5 MPa and tensile strength of 1249.5 MPa. High carbon steel is not far either, with a Tensile strength of 1055.5 MPa. However, the Yield strength is almost half of the Low alloy steel. Lead alloy is the densest material at 10,700 kg/m³ the heaviest of which is not suitable for pallet purposes, hence it ranked lowest. Under environmental criteria, all the metals have scored equal in recyclability. In the carbon dioxide footprint attribute, wood and bamboo have the

lowest values of 0.2675 kg/kg and 0.328 kg/kg respectively, making them greener.

4.3.2. Combinatorial ranking of each category by importance

When the cost criterion is given priority, followed by quality in 'cqe', high-carbon steel ranks the highest, followed by low-alloy steel in 'Halving', Quadratic and 'First two' distribution in Figs. 9–11. The reason is that High-carbon steel provides the strongest alternative with high Young's modulus, Yield strength, tensile strength hardness and fracture toughness with a lower price of 0.9985 GBP/kg in comparison to other high-performance alternatives. However, when cost and environmental criteria are given priority in 'coq' and 'eq', cardboard and paper pallets rank the highest due to their lower carbon footprint, as shown in Figs. 9–11.

The effect of entropy weighting from automatically weighted MCDA

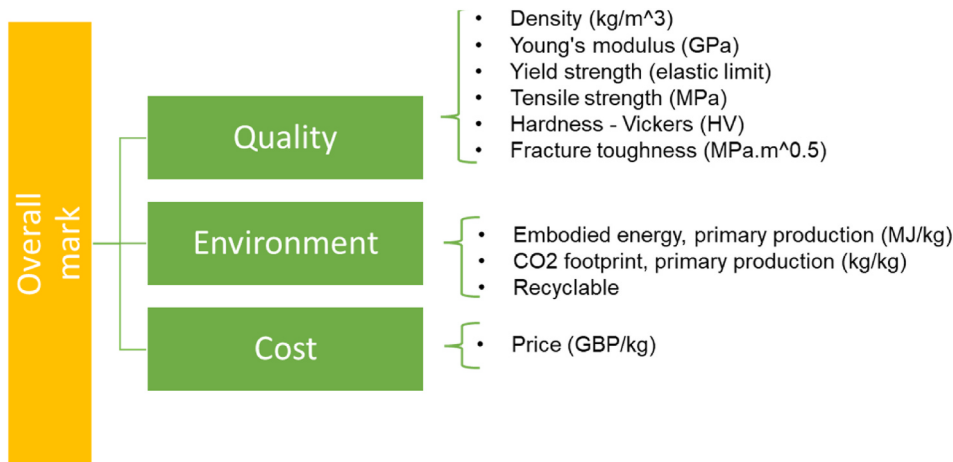


Fig. 7. The division of quality, environment and cost into subsequent attributes for the pallets.

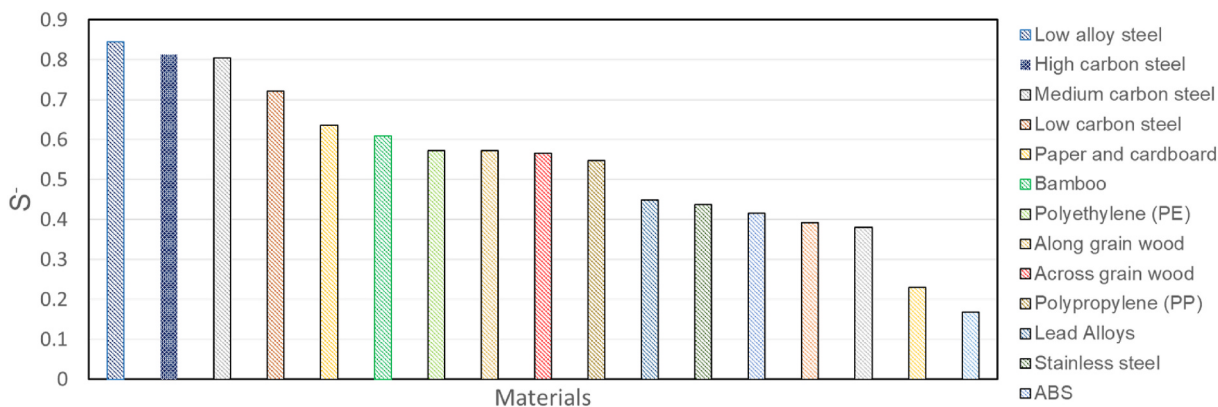


Fig. 8. Uniform distribution mapping for all 13 alternative materials.

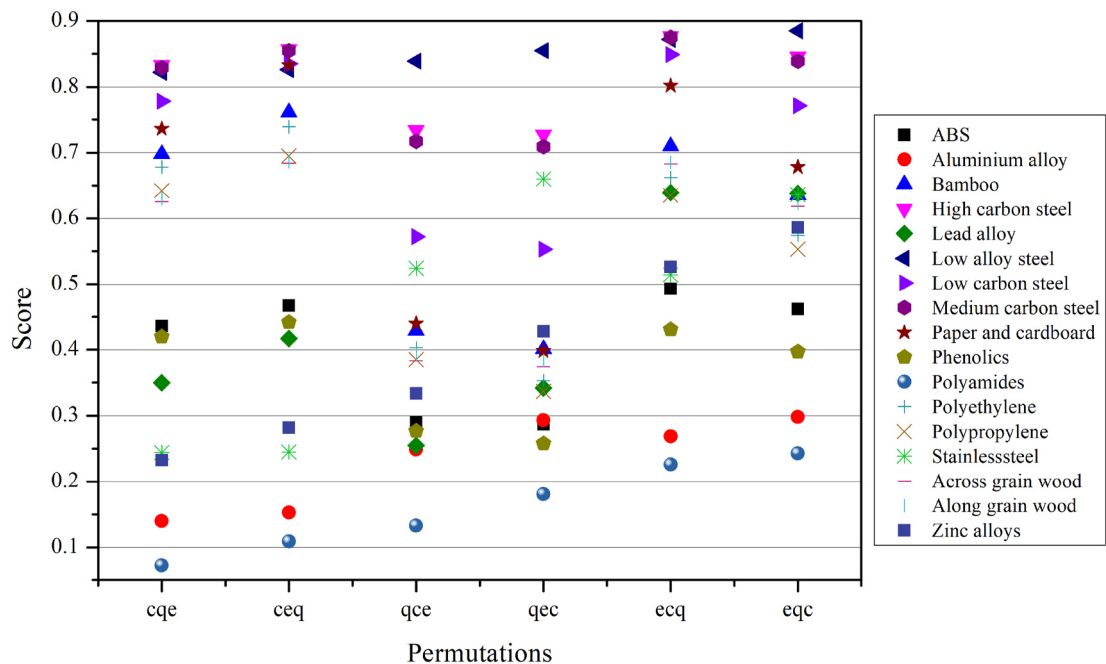


Fig. 9. Halving distribution for pallets.

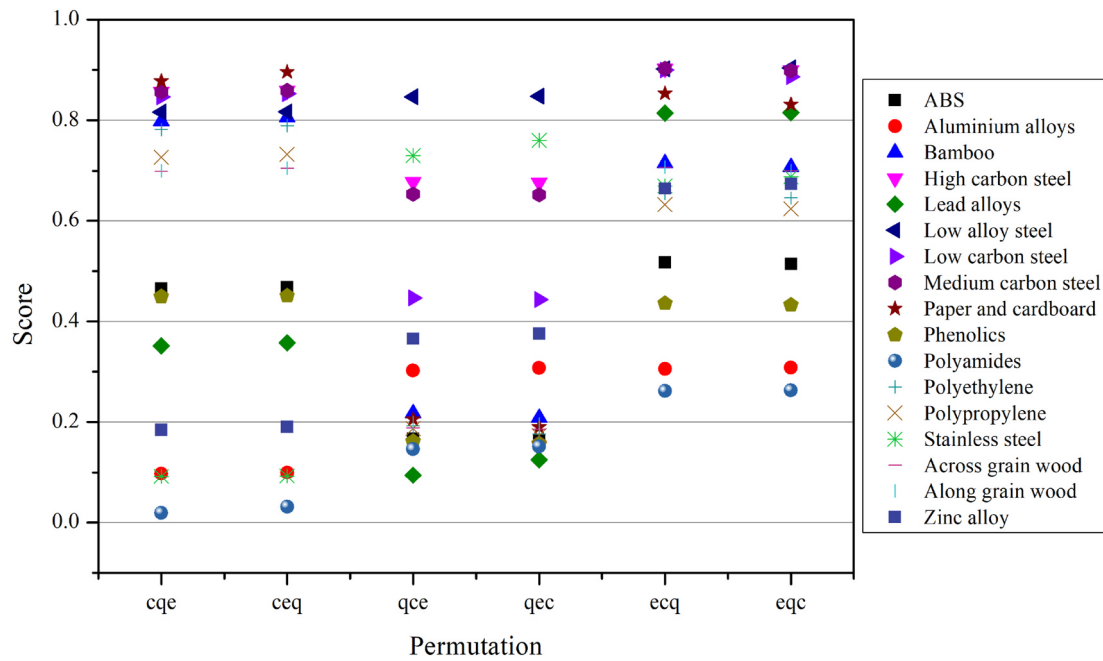


Fig. 10. Quadratic distribution for pallets.

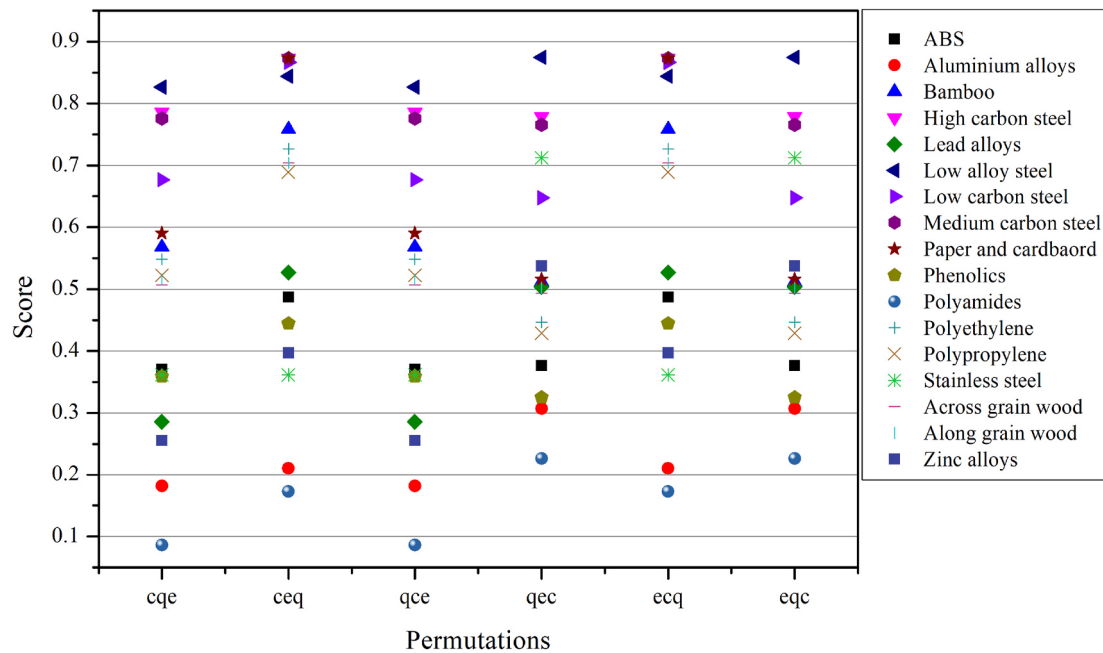


Fig. 11. 'First two' distribution for pallets.

is evident as the Polyamides and lead alloys are the low performers in each category in all distributions. Lead alloy is expensive at 2.655 GBP/kg with the highest density making it the heaviest, whereas Polyamides are expensive at 4.465 GBP/kg. Both types of wood, i.e. across grain and long grain, have scored similar in the first three categories. Paper and cardboard, being lower in cost, have scored the highest in criteria with cost as the priority.

4.4. Discussion- cast stone pallet case study

In cases where quality was the priority, low alloy steel had the highest ranking because it comprises Chromium, Nickel, Molybdenum and Manganese. These metals enhance mechanical properties, hence

making high-quality and durable steel. Where the environment was the priority, cardboard and paper pallets ranked most. Paper and cardboard pallets presented an excellent opportunity where cost and environment are a concern. They can be manufactured using recycled raw materials at low cost and produced with low embodied carbon, which is the driving factor behind such behaviour. However, they have load restrictions compared to low alloy and high carbon steel.

Furthermore, these pallets are prone to nature's elements. In this study, the transportation of the materials to the pallet manufacturing facility was not considered. Hence, low alloy steel and high carbon steel ranked highest. During the transportation process, more fuel would have been consumed to transport denser materials, which would eventually lower the ranking of the alternatives, such as low alloy steel and carbon

steel and paper and cardboard pallets would come on the top. In cases such as ‘ceq’, ‘qec’ and ‘ceq’ cardboard and paper would have ranked highest in all four categories i.e. Uniform, ‘Halving’, ‘Quadratic’ and ‘First two’.

In section 4.3, all the possible cases for four rules have been shown. Based on the driver attribute, each alternative material has scored differently. To find out which alternative has scored the highest the greatest number of times a cumulative graph would be required that would ease the decision-making process. Hence, by cumulating the best results for each alternative in all four cases, Low Alloy Steel ranked the highest in 56% of the cases, as shown in Fig. 10. Similarly, High Carbon Steel has ranked highest in 28% of the cases, followed by cardboard and wooden materials at 17%. The overall ranking would allow the decision maker to select a material from a high level shown in Fig. 12. A dashboard that offers a consolidated view of critical data points and will enable informed decision-making has been created as shown in Fig. 12. It will optimise operational efficiency, streamline decision-making, and foster collaboration among team members and stakeholders.

The material selection for a pallet depends on various factors such as load requirements, environmental considerations, and budget constraints as the Kano questionnaire in section 4.2 highlighted them. Low alloy steel pallets excel in quality-driven categories due to their superior strength and durability. In contrast, cardboard pallets are advantageous in terms of lightweight design, low cost, and lower carbon emissions. The high carbon steel pallets are favoured when cost is paramount, providing satisfactory strength and functionality at a slightly lower price point than Low alloy steel.

5. Case study – carbonated drinks packaging

5.1. Customer and engineering requirements

The methodology described in section 3 of this study was applied to find a sustainable carbonated drink container. For this case study, 20 questions based on the Kano method were sent to the 15 associates. Half of the questions were functional, and the other half were dysfunctional. The questions were based on the attributes of carbonated drinks packaging identified in a study by Korhonen et al. and Beuthner et al. (Boz et al., 2020; Herbes et al., 2020). In both studies, the author emphasised consumer behaviour towards sustainable packaging and the essential attributes of the packaging. The attributes were.

1. Cost
2. Appearance
3. Carbon footprint
4. Material type
5. Recyclability
6. Biodegradability

It was assumed that the company currently uses polyethylene terephthalate (PET) as the packaging material for carbonated drinks. Most of the responses were classed as “In-different”. However, a few attributes have been classed as “Must-be”. For instance, 70% of the colleagues agree that a container must have a lower carbon footprint, as shown in Fig. 13. Similarly, a container must be recyclable, says 90% of the response.

For this study, carbon dioxide emissions during transportation were not considered within the scope. Similar to pallets, the denser the material, the more energy is required to transport it to the manufacturing facility.

5.2. Material selection

After applying the filters to the database, a high-level material selection was performed, with 9 materials selected in total. The materials selected at a high level are shown in the Ashby Diagram in Fig. 14. For this case study, no LCA was performed as the data was already available in Granta’s database.

5.3. Decision making

5.3.1. Uniform distribution

When given equal importance to each alternative, Stainless steel grade AISI 205 has the highest score of 9.3, as shown in Fig. 15. Meanwhile, PEKK, which is a semi-crystalline thermoplastic, scored the lowest. PEKK does not have any fracture toughness, which is one of the reasons it has ranked the lowest. PET, which was assumed to be used currently by the carbonated bottling company, has scored 8.39. PET has the benefit of being the weakest in cost at 1.36 GBP/kg with average quality attributes, making it attractive to the bottling companies. It has a yield strength of 67.5 MPa and a Tensile strength of 72.5 MPa. All the alternatives have scored equally for recycling attributes, whereas PET has the lowest carbon footprint during production at 2.965 kg/kg, followed by stainless steel AISI 205 at 5.09 kg/kg.



Fig. 12. Dashboard displaying results from all four rules of Automatically Weighted MCDA with an overall ranking of materials for pallets.

Kano model

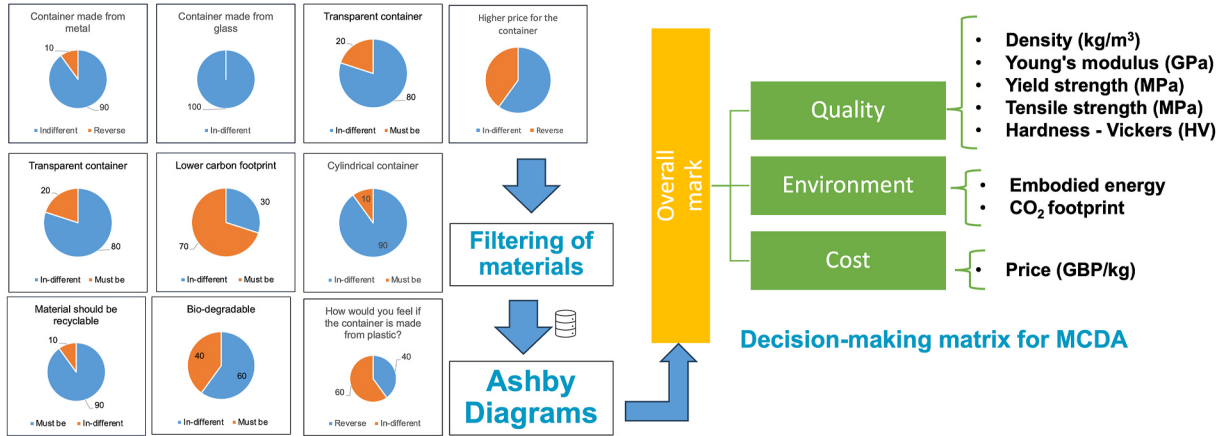


Fig. 13. Responses from consumers for the Kano questionnaire for carbonated drinks' container.

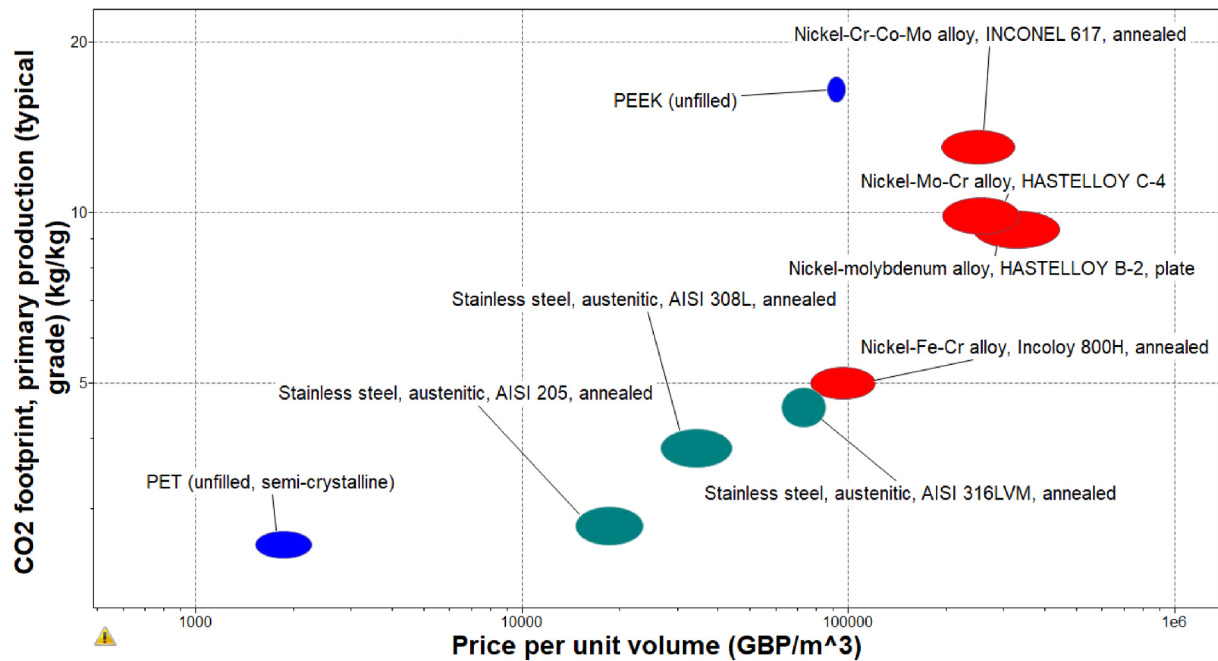


Fig. 14. Ashby plot for alternatives for carbon footprint vs price per unit volume for a carbonated drinks' container.

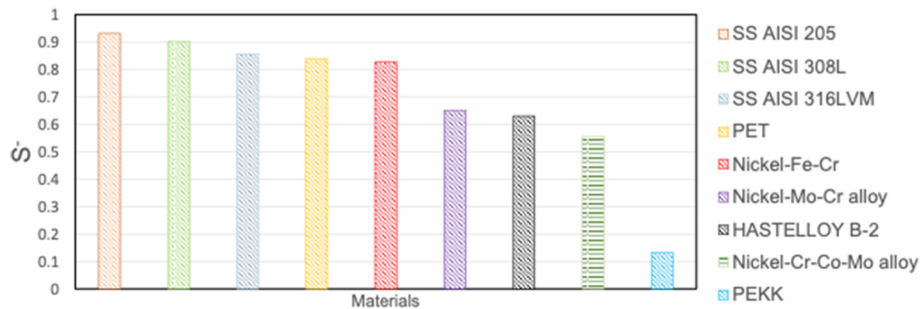


Fig. 15. Uniform distribution for carbonated drinks.

5.3.2. Combinatorial ranking of each category by importance

In the combinatorial ranking, when the environment is given first and the cost is given second priority ('ecq'), PET becomes the first choice in 'Halving', 'Quadratic' and 'First two' distributions in Figs. 16–18. In

those cases, the effect of weightage entropy can be seen as quality becoming the least priority and environment becoming the first. The driver behind such a result is PET's lowest carbon footprint and second lowest embodied energy.

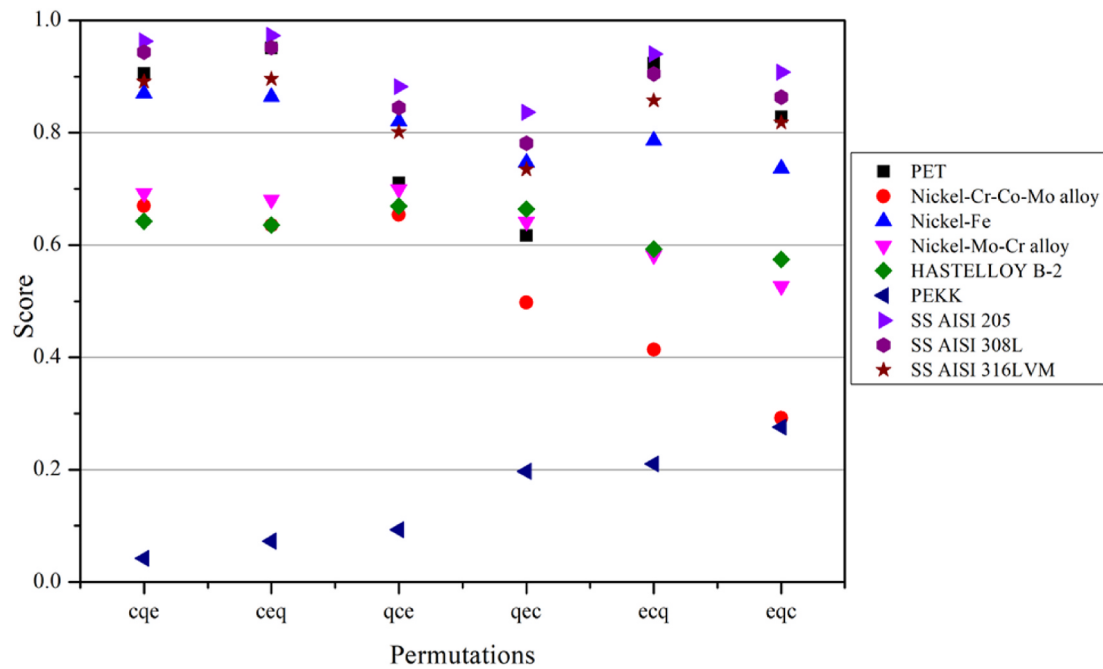


Fig. 16. Halving distribution for carbonated drinks.

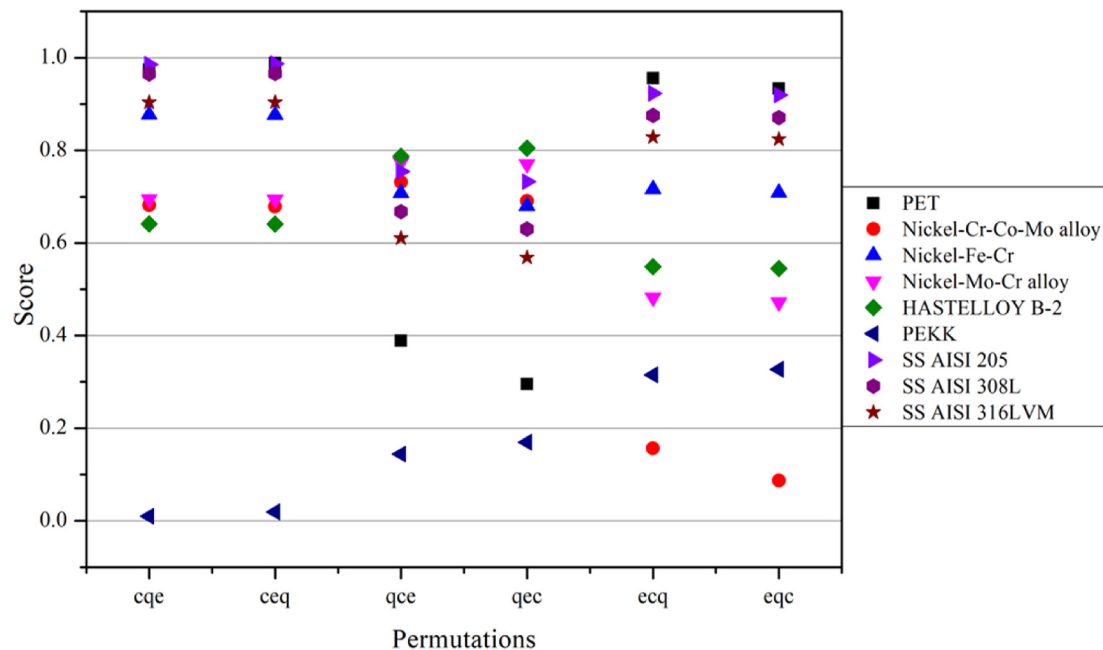


Fig. 17. Quadratic for the carbonated drinks.

It can also be noted that when quality is given priority over cost and environment ('qce' and 'qec' cases), stainless steel AISI 205 scores are highest, followed by PET. The reason for such behaviour can be pointed towards the superior quality of the stainless steel AISI 205, which provides a suitable alternative for packaging carbonated drinks. It has the highest Yield strength of 475 MPa and a tensile strength of 835 MPa. From an environmental perspective, it offers the second lowest carbon footprint during primary production at 5.09 kg/kg. PET has the lowest carbon footprint in production i.e. 2.965 kg/kg followed by stainless steel AISI 205.

As shown in Figs. 16–18, PEKK scored the lowest in all the cases. The driver for its low score is its high carbon footprint and high cost of 75.75

GBP/kg. Furthermore, PEKK's embodied energy is the second highest at 317.15 MJ/kg.

In the 'First two' cases, in 'ceq' category, PET scored the highest due to the lower price and better environmental attributes as shown in Fig. 18. But in most cases, stainless steel AISI 205 becomes the primary choice.

5.4. Discussion-carbonated drinks

In the above section, all the possible cases are shown, and all the distributions are mapped in high resolution. After calculating the best results for each alternative in all cases in this case study for the

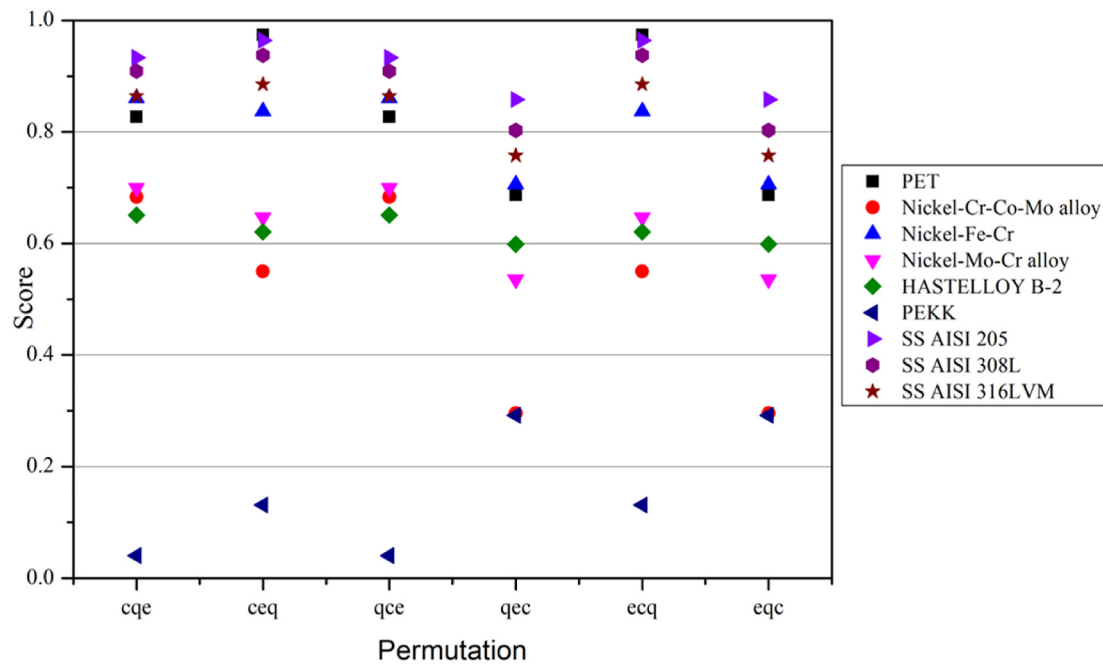


Fig. 18. 'First two' for the carbonated drinks.

carbonated drinks, it was found that the stainless steel AISI 205 occurred 56% of the time. In contrast, PET scored highest in 28% of the cases in all four distributions. This result is due to Stainless Steel's exceptional mechanical strength and longevity. Stainless steels are usually inert, eliminating the risk of any chemical reaction and maintaining high integrity over time. However, the initial cost of steel is higher than that of PET. The manufacturing method also differs for both, adding to the overall cost of the Stainless-Steel containers.

In contrast, PET offers competitive prices and mechanical properties. PET's recyclability further enhances its environmental ranking, making it greener. Furthermore, creating different shapes using PET is much easier than using stainless steel if customer requirements change in the future. Lastly, Hastelloy B-2 came third overall in the ranking, as shown in the dashboard in Fig. 19. The disadvantage is cost, and recyclability have outweighed its benefits for the carbonated drinks application. In

multiple scenarios, the lightweight PET has challenged the solid Stainless steel AISI 205 when the environment prioritises quality that conforms to the current industry trends within the carbonated drinks bottling industry.

As mentioned earlier, this case study does not consider transportation. Once transportation is included in the study, stainless steel might lose its first place in most cases. Based on this case study, Stainless steel AISI 205 is an ideal solution for carbonated drinks.

A balance between the mechanical performance, environmental impact and cost-effectiveness of the choice of material containing carbonated drinks should be considered aligning with the decision maker's objectives. The findings of this case study highlight the importance of considering different factors when selecting the material for bottling carbonated drinks. Stainless steel AISI 205 emerged as a top-ranking material due to its mechanical properties, followed by PET and

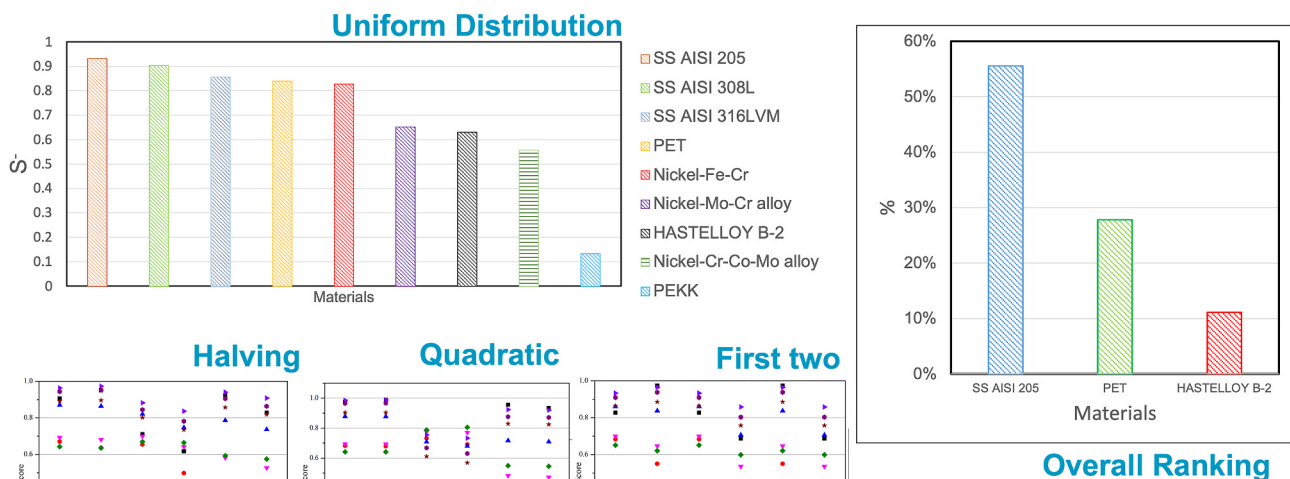


Fig. 19. Dashboard displaying results from all four laws of Automatically Weighted MCDA with an overall ranking of materials for Carbonated drinks packaging.

Hastelloy B-2. While Stainless Steel AISI 205 offers unmatched durability and reliability, PET presents a compelling competitive material with lower cost, easy manufacturability, and recyclability. While each set of materials has advantages and disadvantages, the final decision should be informed based on the decision maker's requirements. By carefully weighing these factors and the customer requirements, stakeholders can make informed choices prioritising mechanical performance, sustainability, and cost-effectiveness in carbonated drink packaging.

6. Conclusion

In this study, a holistic three-step customer-centric methodology to select a packaging material has been proposed. The first step of the methodology is capturing and prioritising customer and engineering requirements; the 'customer' part of this step is often overlooked or inadequately addressed in previous studies. This study ensures that the selected materials align with customer preferences and market demands. Furthermore, the VoC is translated to engineering requirements through a relevant method such as Axiomatic design. This allows for bridging the common disconnect between customer requirements and technical feasibility, a critical shortcoming in all the existing methodologies and frameworks. In this study, Kano method was used for the first step.

Secondly, these requirements are used to select a range of materials i.e. high-level material selection. The proposed approach allows a systematic selection process that evaluates a broad range of materials against these specifications, offering a more simplistic, robust and holistic solution than the fragmented methods found in the literature. Furthermore, using a material database provides the specification in a consolidated manner where all necessary data is available, reducing the time required for data collection, making the selection process more accessible, efficient and streamlined. The data is divided into quality, environment, and cost categories. Such division of attributes in material selection helps in thorough decision making which needs to be improved in the existing literature. Thirdly, the consolidated data is used for MCDA to rank and select materials in the decision-making step. MCDA enhances the robustness and transparency of the decision-making process. Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) has been used in this study for decision-making. The methodology provides the flexibility to use different techniques based on the scenario. For example, for material selection, another relevant database can be selected. This integrated approach not only enhances the accuracy and relevance of material selection but also demonstrates its practicality through its applicability in two real-world case studies, thereby showcasing the novelty and effectiveness of the methodology.

The proposed methodology has been validated with two case studies from two different manufacturing sectors. The underlying method assumes that a packaging material is currently being used, which gives a baseline for the material selection, which is one of the limitations of this study. It is ideal for an alternative rather than one for a new packaging product. Another limitation of this study is the carbon dioxide emissions

during transportation. As the raw material supplier location is company-dependent, it was assumed that they all exist at the same distance from the manufacturing site for this study.

The proposed methodology has been successfully applied and validated. It can be used for any other industry to identify sustainable packaging material. The benefits of using this methodology are.

- Customer-centric attribute preferences: By capturing the Voice of the customer in the material selection process for packaging. The customer becomes a part of the process, and they dictate the attribute preference. By including those attributes within the packaging material, the company can achieve a high customer satisfaction.
- Sustainability and environmental impact are included: When selecting sustainable packaging material, the criteria include environmental impact, which leads to greener packaging material. Within environmental impact criteria, carbon footprint and other environment-related attributes are included.
- Technical and cost considerations from a business's perspective are also included. The material selection also considers cost and technical attributes like the environment. With a customer-centric approach, the customer and businesses are in charge of dictating the cost of packaging material and its technical specifications.
- Provides the business with market competitiveness: This method allows for optimal material selection that would satisfy the customer, generating superior-quality products in comparison to other companies. The decision-making process in the proposed methodology provides detailed scenarios and the drivers behind each one, hence giving a broader picture to the decision-maker and providing market competitiveness.

The use of the three-step method provides flexibility to the user to include other techniques using the different methods within this study. So, for future work, other MCDA techniques such as COPRAS (Complex Proportional Assessment) and VIKOR (VIEkriterijumsko KOMpromisno Rangiranje) can also be implemented in the study. By using different methods, the methodology can be validated. Furthermore, the transportation distance for the raw material can also be included by performing a 'cradle-to-gate' LCA.

CRedit authorship contribution statement

Devanshu Mudgal: Writing – original draft, Investigation, Formal analysis. **Emanuele Pagone:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Konstantinos Salonitis:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. Appendix

8.1. Table showing an example of the Kano questionnaire sent to the customer which shows functional and dysfunctional questions

Table 8.1
An example of the Kano questionnaire with a functional and dysfunctional questionnaire

Kano question	Answer
Functional Example: How would you feel if the outside packaging of a product is waterproof?	I like it I expect it I am neutral I can live with it I dislike like it
Dysfunctional Example: How would you feel if the outside packaging of a product is not waterproof?	I like it I expect it I am neutral I can live with it I dislike like it

8.2. Pre-defined response template from Kano which is used to asses the response from a customer

Table 8.2
Pre-defined Kano response template for functional and dysfunctional questions

Packaging material 1						
Dysfunctional						
Functional	I like it	I expect it	I am neutral	I can live with it	I dislike it	
I like it	Q	A	A	A	O	
I expect it	R	I	I	I	M	
I am neutral	R	I	I	I	M	
I can live with it	R	I	I	I	M	
I dislike it	R	R	R	R	Q	

Data availability

All data are included in the manuscript.

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Mudgal, Devanshu; Pagone, Emanuele; Salonitis, Konstantinos

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