# Assessing sustainable consumption practices on cruise ships

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## Abstract

**Purpose** – This study aims to examine a hierarchical framework for sustainable consumption (SC) for cruise ships and identify the causal relationships and decisive attributes of cruise ship operation practices that allow cruise organizations to achieve a higher level of sustainable performance.

**Design/methodology/approach** – This study applies a hybrid of the Delphi method and a fuzzy decision-making trial and evaluation laboratory (DEMATEL). DEMATEL methodology helps to construct complex causal relations through digraphs, which depict interrelationships among attributes. The fuzzy set theory assesses experts' perceptions of attributes given in linguistic preferences. The Delphi method has been previously used to validate attributes and determine the validity and reliability of the construct from qualitative information.

**Findings** – A set of three aspects containing 21 criteria were defined based on previous literature and expert consultations. The analysis results show that waste minimization and recycling and recovery are causal aspects that influence efficient resource use. Emission controls on ships, cruise ship alternative energy sources, ballast water treatment systems, water purification systems and nanofiltration systems are also prominent criteria for the improvement of SC during cruise ship operation.

**Originality/value** – This study contributes to the literature by offering a hierarchical framework for SC literature and confirming the role of this issue in improving the cruise industry sustainability. In practice, as such results provide key attributes for successful performance, the implications are offered for companies developing new activities, either in ensuring compliance with business goals or in decreasing the environmental impact.

**Keywords** Sustainable consumption, Fuzzy set theory, Cruise ship industry, Decision-making trial and evaluation laboratory (DEMATEL), Sustainable consumption practices

**Paper type** Research paper

## 1. Introduction

During the past decades, sustainable consumption (SC) has arisen as a key aspect of sustainable development (Fischer *et al.*, 2017). It is not only involved in sustainable product consumption but also in numerous actions undertaken by different processes, from the primary manufacturing procedures to the final consumption (Liu *et al.*, 2016). Changes in consumption, especially the desire for sustainable consumer products and services, have influenced environmental improvements through the demand for cleaner and more efficient production processes. However, SC still faces challenges (Luthra *et al.*, 2016). There is an urgent need to emphasize the necessity for more intelligent consumption as an essential requirement for environmental sustainability (Kilbourne and Mittelstaedt, 2012). Additionally, an embedded challenge is the need to understand the role of environmental concerns (Leary *et al.*, 2014). The cruise industry is no exception in that it also shares its own challenges in this context. As the cruise industry runs global operations, it is clear that




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measures are needed to ensure sustainable operation abroad (Véronneau *et al.*, 2015). However, the prevailing focus in the operative literature is on visible consumption, with few references to environmental stewardship. There is an urgent need to investigate SC to encourage positive environmental changes for sustainable development.

In previous studies, sustainable economies have been built based on SC, which comprises sustainable production processes. Manzoor *et al.* (2014) investigated optimal policies for a fundamental manager focused on the utility maximization of renewable resources. Pandey *et al.* (2018) explored linkages between SC and the usual green performance in household waste reuse and recycling to reduce the volume of waste generated. However, the performance of SC practices tends to be outweighed by the consequences of consumption: growth in consumption causes unsustainable patterns (Leary *et al.*, 2014). In particular, the characteristic of the cruise industry is that the end consumption is not a product but a service. Additionally, the consumption scale of cruise ships is beyond comparison to other industries. With a large increase in accommodation capability, there is an even greater burden from absorbing natural resources and the production of associated pollutants (Véronneau*et al.*, 2015). Furthermore, SC is not consuming less, but consuming in a different, more effective way, which improves the quality of life (UNEP and CDG, 2000). The previous frameworks for SC may not be suitable for this industry. Still, there are few examples of literature specific to the cruise industry (Bonilla-Priego *et al.*, 2014). Therefore, this study will explore a framework and identify the attributes that influence cruise ship SC, such that the sustainable performance of cruise lines can be enhanced.

The SC is indicated by the mutual level, not just by a single element, that the harmful magnitudes of untenable consumption can be alleviated. The formation of a hierarchical framework of SC is necessary for a company to achieve a competitive advantage. Shao *et al.* (2016) established a configuration hierarchy model for the automobile industry using the knowledge of Italian experts. Luthra *et al.* (2016) identified and assessed barriers to the application of SC in the supply chain. However, the most critical character of human insights, which is the capacity to extract information from a large amount of data, has not been well used (Tseng and Bui, 2017). An analytical methodology and appropriate design approach are necessary. In terms of conceptual development, SC problems are too complex for individual business organizations to handle (Jonkutė and Staniškis, 2016). Here, a multi-criteria decision-making method constructed by collecting experts' opinions and related literature resources is proposed. A hybrid method combining the Delphi method and a fuzzy decision-making trial and evaluation laboratory (DEMATEL) is used in the present study to seek a valid and reliable hierarchical framework for analyzing SC attributes, as well as for the evaluation of driver attributes for cruise ship performance improvements.

In particularly, DEMATEL methodology helps to construct complex causal relations through digraphs, which depict interrelationships among attributes (Pai, 2014). However, it is difficult to define the uncertainty and potential imprecision in practice (Luthra *et al.*, 2016). Since SC has become multi-dimensional in nature,most previous studies have used qualitative assessment and most attributes were evaluated using linguistic preferences (Luthra *et al.*, 2017). The fuzzy set theory assesses experts' perceptions of attributes given in linguistic preferences. The Delphi method has been previously used to validate attributes and determine the validity and reliability of the construct from qualitative information (Lim and Antony, 2016). The objectives of this study are as follows:

- to create a hierarchical framework for the cruise industry SC using qualitative information; and
- to understand the causal interrelationships among the SC attributes.

This study contributes to the literature by offering a hierarchical framework for SC literature and confirming the role of this issue in improving the cruise industry sustainability. In practice, as such results provide key attributes for successful performance, this study also has many implications for companies developing new activities, either in ensuring compliance with business goals or in decreasing the environmental impact.

The rest of the study is organized as follows. Section 2 presents the literature related to SC and the cruise industry, proposed methods and measured attributes. Section 3 explains the methods used in detail. The results are revealed in Section 4. Section 5 discusses the study's implications. Finally, the conclusion, limitations and future research areas are mentioned in Section 6.

## 2. Literature review

This section discusses the theoretical background of prior SC studies, SC practices in the cruise industry and the proposed method and measures.

### *2.1 Sustainable consumption*

According to OECD (2002), SC refers to the products and services consumed to meet basic demands and quality of life without risking future generations' needs. Haron *et al.* (2005) proposed that SC is a process of obtaining, disposing of and using the products and services, while being aware of the environmental and social welfare. Michaelis (2003) indicated that the issue was the consumption pattern subsequent from the stakeholders' interrelating interests to enhance sustainable performance. Leary *et al.* (2014) claimed that SC could be regarded as a behavior intended to satisfy the current generation's requirements, while benefiting the environment and without threatening the demands of future generations. SC has become a fundamental objective in national and international situations (Seyfang, 2004). However, current natural resource consumption levels and practices are unsustainable (Lim, 2017).

Another standpoint of SC is therefore required. Liu *et al.* (2016) argued that SC is not only about sustainable product consumption but also consists of numerous accomplishments, from the first stage of production to the final consumption. Peattie and Collins (2009) suggested that SC should not be regarded as only a purchasing activity but as decisions and actions, including purchasing, use of the product or services and disposing of any tangible remains after use. Tseng *et al.* (2013) stated that SC involves a number of obstacles and challenges in developing strategies to endorse the efficient use of natural resources and technological innovation for better processes and quality as well as solving the socioeconomic opposition. Demand for recycled products, economic situations, weight lessening, product reuse, consumption behavior and developing social or legal systems also indirectly influence SC (Fujii *et al.*, 2014).

Still, consumption increase is not always driven by positive social influences such as augmented income progression, and unsustainable consumption patterns keep placing high pressure on the environment (Liu *et al.*, 2016). This generates a challenging circumstance because the understanding of sustainability in any consumption form necessitates a comprehensive knowledge of all potential effects that could occur during the entire production and consumption cycle. Some issues have not been solved, such as ecological efficiency and effectiveness, share of environmentally friendly products/services markets or sustainability awareness or serving ownership and brand promotion. The current consumption pattern has become a driving factor for unsustainable production and resource degradation (Govindan, 2018; Liu *et al.*, 2016).

Michaelis (2003) presented three dimensions of business contributions to SC:

(1) the development of new technologies and practices;
(2) changes to economic incentives; and
(3) changes to the culture within the influence network.

However, increasing attention should be directed to environmental issues due to resource scarcity and environmental pollution (Eleftheriou and Iyanna, 2016). Pandey *et al.* (2018) proposed a number of aspects to support SC, including waste minimization, recycling and resource efficiency measures. Liu *et al.* (2016) used the infrastructure supply or perspective system to develop an analytical tool by considering consumer alternative packages provided by ordinary suppliers to utility infrastructure in the areas of water, energy, transportation and waste. Hence, this study considers SC practices as the development of new technologies and environmentally friendly operation practices that help companies to recycle used material, minimize waste and consume resources more efficiency.

*2.2 Sustainable consumption practices on cruise ships*

The notion of SC has become a problematic issue for both scholars and in practice. Biswas and Roy (2015) indicated that unsustainable consumption practices consisting of inappropriate resource use are substantial contributors to environmental degradation. This is the main reason for environmental problems, such as environmental contamination, global warming and biodiversity reduction (Liu *et al.*, 2016). Copeland (2008) considered cruise ship tourism to be not only an important transportation pollution issue but also a new effluence phenomenon in small port cities or tourism destinations. Carić and Mackelworth (2014) stated that tourists have a significant negative influence on local societies and economies when tourism exceeds the capacity of the host environment and thus threatens natural and cultural heritage. Carić (2016) confirmed there are many negative effects such as emissions, wastewater and biocides that significantly reduce resource values, creating essential risks for natural capital use in the future. SC has thus been derived to prevent extreme consumption and material arrangement (Quoquab and Mohammad, 2016).

Although work has been done to understand and modify unsustainable practices, those practices still exist and are being intensified by the unrelenting development of the global economy. In terms of cruise ship SC performance, Parnyakov (2014) has addressed the fact that advanced technology can affect the comfort level in cruise ships. Rivas-Hermann *et al.* (2015) developed a conceptual framework of innovation in products and services for ballast water treatment systems in the shipping retrofit. Strazza *et al.* (2015) investigated a potential innovative pattern of recycling food waste for cruise ships in terms of environmental sustainability. Vairo *et al.* (2017) developed a consequence-based model integrating environmental effects, hazardous distances and the response time scales related to fuel spills and fires with widespread smoke. This is evident from the promising determinations of SC on understanding how changes in sustainability might be embarked on (Lim, 2017).

The literature has debated the consideration of different traits of cruise tourism, such as the destination cultures and resources, labor rights, passenger and crew safety, ethics, crime, ecology problems and corporate profits (Carić, 2016). However, most cruise ships currently have none of the skills needed to successfully adopt SC practices, as these practices are not yet well organized, defined or implemented (Vergragt *et al.*, 2015). Additionally, cruise ship operation requires five times the standard energy used by most luxury hotels per visitor night, while providing many similar amenities, such as gymnasiums, swimming pools, restaurants and casinos (Howitt *et al.*, 2010). Although studies and practical experiences show there are a number of tools available to the industry to ensure sustainable development, there is still confusion regarding how to apply them in the best possible manner. Hence, a systematic approach integrating the use of these technologies is needed to deliver a more complete understanding of SC performance in cruise ship operation.

*2.3 Proposed method*

A few studies have proposed SC frameworks in the literature (Shao *et al.*, 2016;Luthra *et al.*, 2016). However, a valid and reliable multi-level framework is still lacking. The problems are too complex for an individual company to handle alone (Jonkutė and Staniškis, 2016). SC is still unclear or unfamiliar in different industrial applications. In this context, the assessment of both qualitative and quantitative factors, as well as ensuring the validity and reliability of the development framework is necessary. To allow for this, the Delphi method evaluation and the hybrid fuzzy DEMATEL are used in this study. The DEMATEL method has been amended for use in various areas, such as decision-making problems, environmental assessment, industrial planning, as well as sustainable development. Previously, Bacudio *et al.* (2016) identified critical barriers to instigating industrial symbiosis systems using DEMATEL. Luthra *et al.* (2017) constructed an operational model for SC and production implementation based on this approach.

However, DEMATEL has limitations in setting the framework reliability and validity. Hence, this study combines fuzzy DEMATEL with the Delphi method to observe the responses of experts and validate the proposed attributes (Lim and Antony, 2016). Tseng *et al.* (2015) proved that the Delphi method is suitable to identify, select and validate factors and indicators in a proposed framework. Ahmad and Wong (2019) confirmed that this technique is appropriate for the comprehension of indicator reliability by applying the cultivated selections of experts. Hence, as the problems of SC are complicated, this hybrid methodology is the most suitable tool to address actual situations encountered during cruise ship operation in the SC performance field.

*2.4 Proposed measures*

To approach SC, reduction of both consumption and wastage, as well as consideration of the sources of the materials and gorging water used, will be needed. Environmental impacts are defined as the effect of production and consumption on the natural systems that redistribute biophysical wealth (Liu *et al.*, 2016). Consumption is unavoidable and therefore resources such as gas, oil and other fossil fuels can be depleted or exhausted. Renewable resources offer the possibility of SC, as the supply of resources can be held at an adequate level, even during a surge in consumption (Manzoor *et al.*, 2014). Previous studies have approved the requirement for reducing resource consumption as part of SC (Kotler, 2011). Still, there is a lack of compromise present regarding how consumption should be abridged or altered and how consumers need to be contributing to resource preservation (Banbury *et al.*, 2012). This study proposes that some attributes important for the cultivation of SC include waste minimization, resource efficiency and recycling and recovery (Pandey *et al.*, 2018).

The SC of products and services is essential to satisfy needs and guarantee the quality of life, while minimizing waste (A1) produced through the whole product or service life cycle, without causing harm to future generations (Jonkutė and Staniškis, 2016). In terms of cruise ships, ballast water treatment systems (C1) are one of the primary solutions for reducing or preventing the spread of non-indigenous species, with an instant recompense in fuel savings (Fernandes *et al.*, 2016). Emission controls on ships (C2) refer to a technological mechanism that radically decreases the smog-forming $SO_2$,$NO_x$ and PM2.5

coming from ship smokestacks throughout activities of moving, maneuvering and hoteling (Maragkogianni and Papaefthimiou, 2015). In practice, carbon emissions reduction (C3) tends to reduce $CO_2$ emissions for cruise ships by reducing luxury amenities and space (Howitt *et al.*, 2010; Strazza *et al.*, 2015; Stefanidaki and Lekakou, 2014). Hull-fouling treatment (C4) denotes antifouling coatings and paints that help to control ships hulls bio-fouling from non-indigenous species that affect fuel consumption (Fernandes *et al.*, 2016). Biological diversity conservation (C5) goes beyond how humans affect ecosystems and include how society can be influenced by, or benefit from, ecosystem services (Roos and Neto, 2017). In addition, hazardous waste handling (C6) ought to be executed by licensed shoreline amenities (Carić, 2016). Turbo-drying technology (C7) refers to the food waste stream treated by plummeting its humidity, making it easy to store and dispose of pounded products, complying with public health regulations onboard when deprived of cold room usage (Strazza *et al.*, 2015).

Accomplishing SC requires increasing consumption efficiency and changing consumption patterns, which involves improving technology and customer perceptions to mend resource efficiency (A2) (Tseng *et al.*, 2015). Energy-efficient lighting systems (C8) install light-emitting diode lighting and motion sensors to respond to the movement of people to alter the light intensity. Energy-saving technology (C9) is mentioned with regard to the design of the engine, devices and cruise ship structure to save energy (Parnyakov, 2014). Lillebø *et al.* (2017) proposed using alternative energy sources (C10) such as wind, wave and solar energy resources. Bailey and Solomon (2004) and have also suggested several solutions to abolish extra effluence by plugging cruise ships into a shore-side power system (C11) while docking instead of using diesel-fueled auxiliary engines to operate onboard systems, such as pumps, fans and lights. Cleaner diesel fuel (C12) choices are available for current diesel engines, including diesel emulsions, low sulfur and biodiesel. Idling limits (C13) can save huge amounts of fuel consumption and are a cost-effective solution that markedly reduces diesel emissions from automobiles and ship engines while at the port for long periods. Older, highly polluting engines can be powered by retrofitting the locomotives (C14) with low-emission engine possibilities, such as hybrid electric batteries and natural gas. Moreover, a berth allocation system (C15) is a technique for planning ship arrivals and monitoring cruise passenger numbers to avoid overcrowding (Stefanidaki and Lekakou, 2014).

Under the demand for recycling and competitive economic circumstances, recycle and recovery (A3) emphasizes the incorporation of reuse processes (Tseng *et al.*, 2013; Fujii *et al.*, 2014). The aspect contains waste heat recovery systems (C16), whereby waste heat is recovered from exhaust gases and engines' fresh cooling water (Nguyen and Tenno, 2016). Nanofiltration systems(C17)are a grey wash water treatment that recycles 80 per cent of washing machine inlets by generating wastewaters containing organics loads (food), grease, oil and cleansing chemicals, as well as deferred materials like hairs, fibers or bacteria (Guilbaud *et al.*, 2012). Water purification systems (C18) process drinking water using reverse osmosis and a high-desalination method to refine water after use, as well as to absorb rain or stormwater (Parnyakov, 2014). Waste reception facilities (C19) designate the ability of a destination to treat ship wastes (Stefanidaki and Lekakou, 2014). Absorption refrigeration systems (C20) use flue gases, jacket water and air-cleaning processes as sources of energy, in which temperature is optimized for different refrigerant temperatures using different sources of waste heat (Salmi *et al.*, 2017). Aquaculture feeding (C21) recycles leftover food from cruise ships and uses it to nurture aquaculture (Strazza *et al.*, 2015). After collecting examples from the existing literature, this study proposes using these three perspectives – including three aspects and 21 criteria – under the cruise ship environmental practices operations for SC performance (Table I).

## 3. Methods

### *3.1 The Delphi method*

The Delphi method is a methodical technique that collects the sentiments of experts for decision-making purposes and is effective in attaining compromises in scenarios with uncertain evidence or a lack of empirical data (Carrera and Mack, 2010). Hsu and Sandford (2007) used this technique for several different purposes, including determining, exposing or exploring conventions within different judgments, constructing compromises and instructing respondents. This method is appropriate for exploratory qualitative studies and is applied to gain expert assessment of a set of ideas or problems by conducting several questionnaires using controlled responses. This is branded as a cost-effective and sensibly efficient way to use the knowledge and understanding of experts in forming a comprehensive set of attributes (Ahmad and Wong, 2019).

This study used face-to-face interviews for data collection. The attributes were derived from literature and then proposed to the experts. A group of 12 experts, including 5 experts from academic sector, 4 supervisory managers from the cruise companies and 3 experts from related government agencies with more than seven years of experience on working and researching in the field of cruise ships management, were invited to confirm the validity of the attribute using a nominal YES/NO scale. The inclusion of the indicator was based on a 75 per cent or higher consensus score (Chang *et al.*, 2011).

| Aspects | | Criteria | | References |
|---|---|---|---|---|
| A1 | Waste minimization | C1 | Ballast water treatment systems (BWTS) | Fernandes *et al.* (2016) |
| | | C2 | Emission controls on ships | Maragkogianni and Papaefthimiou (2015) |
| | | C3 | Carbon emissions reduction | Howitt *et al.* (2010), Strazza *et al.* (2015); Stefanidaki and Lekakou (2014) |
| | | C4 | Hull-fouling treatment | Fernandes *et al.* (2016) |
| | | C5 | Biological diversity conservation | Roos and Neto (2017) |
| | | C6 | Hazardous waste handling | Carić (2016) |
| | | C7 | Turbo-drying technology | Strazza *et al.* (2015) |
| A2 | Resource efficiency | C8 | Energy-efficient lighting systems | Parnyakov (2014) |
| | | C9 | Energy-saving technologies | |
| | | C10 | Cruise ship alternative energy sources | Lillebø *et al.* (2017) |
| | | C11 | Shore-side power | Bailey and Solomon (2004) |
| | | C12 | Cleaner diesel fuels | |
| | | C13 | Idling limits | |
| | | C14 | Repowering locomotives | |
| | | C15 | Berth allocation system | Stefanidaki and Lekakou (2014) |
| A3 | Recycling and recovery | C16 | Waste heat recovery system (WHRS) | Nguyen and Tenno (2016) |
| | | C17 | Nanofiltration system | Guilbaud *et al.* (2012) |
| | | C18 | Water purification system | Parnyakov (2014) |
| | | C19 | Waste reception facilities | Stefanidaki and Lekakou (2014) |
| | | C20 | Absorption refrigeration systems | Salmi *et al.* (2017) |
| | | C21 | Aquaculture feeding | Strazza *et al.* (2015) |

**Table I.**
Proposed attributes and criteria

### 3.2 Fuzzy DEMATEL

The method used the defuzzification of fuzzy numbers technique to translate the experts' linguistic judgments into triangular fuzzy numbers (TFNs). Based on the application of fuzzy set theory, crisp values can be generated (Opricovic and Tzeng, 2004). From the fuzzy minimum and maximum values, the TFNs are converted into crisp values by determining the left and right values. The average crisp values based on fuzzy membership functions $\tilde{d}_{ij}^{k} = \left(\tilde{d}_{1ij}^{k}, \tilde{d}_{2ij}^{k}, \tilde{d}_{3ij}^{k}\right)$ are adopted to generate the total weighted values. The crisp values are formed into a total direct relation matrix. The DEMATEL visualizes a diagram for tackling the analytical results and simplifying the problems. The attributes are categorized into cause and effect groups, representing their interrelationships and the influential effects. These groups offer an advanced evaluation that structures the interrelationships among the attributes. Thus, DEMATEL proficiently unravels complex interrelationship problems.

In detail, the interrelationships between cause and effect attributes are determined by the DEMATEL. If a set of attributes are collected as $F = \{f1, f2, f3, \cdots, fn\}$, particular pairwise interrelations are used to modify the mathematical relations. The analytical measures are defined below:

- *Step 1:* Aggregating the crisp values.

The comparison scale was designed using five linguistic preferences, from no influence to very high influence (Table II), to compute the fuzzy direct relation matrix. Presume that there are $k$ evaluators in the expert group. Then, the assessments $\tilde{d}_{ij}^{k}$ are made to indicate the fuzzy weight of the $i$th attribute affecting the $j$th attribute assessed by the $k$th evaluator.

Then the fuzzy numbers are normalized using:

$$F = \left(f\tilde{e}_{1ij}^{k}\ ,\ f\tilde{e}_{2ij}^{k}, f\tilde{e}_{3ij}^{k}\right) = \left[\frac{\left(e_{1ij}^{k} - mine_{1ij}^{k}\right)}{\Delta}, \frac{\left(e_{2ij}^{k} - mine_{2ij}^{k}\right)}{\Delta}, \frac{\left(e_{3ij}^{k} - mine_{3ij}^{k}\right)}{\Delta}\right] \quad (1)$$

where $\Delta = maxe_{3ij}^{k} - mine$

The left ($lv$) and right ($rv$) is computed by:

$$\left(lv_{ij}^{n},\ rv_{ij}^{n}\right) = \left[\frac{(fe_{2ij}^{k}}{\left(1 + fe_{2ij}^{k} - fe_{1ij}^{k}\right)}, \frac{fe_{3ij}^{k}}{\left(1 + fe_{3ij}^{k} - fe_{2ij}^{k}\right)}\right] \quad (2)$$

The total normalized crisp values ($cv$) are generated from:

$$cv_{ij}^{k} = \frac{\left[lv_{ij}^{k}\left(1 - lv_{ij}^{k}\right) + \left(rv_{ij}^{k}\right)^{2}\right]}{\left(1 - lv_{ij}^{k} + rv_{ij}^{k}\right)} \quad (3)$$

| Scale | Linguistic variable | Corresponding TFNs |
|---|---|---|
| 1 | No influence | (0.0, 0.1, 0.3) |
| 2 | Very low influence | (0.1, 0.3, 0.5) |
| 3 | Low influence | (0.3, 0.5, 0.7) |
| 4 | High influence | (0.5, 0.7, 0.9) |
| 5 | Very high influence | (0.7, 0.9, 1.0) |

**Table II.**
TFNs linguistic scale

The synthetic values are adopted to aggregate the subjective judgment for $k$ evaluators:

$$\tilde{e}_{ij}^{k} = \frac{\left(cv_{ij}^{1} + cv_{ij}^{2} + cv_{ij}^{3} + \cdots + cv_{ij}^{3}\right)}{k} \tag{4}$$

- *Step 2:* Arranging the pairwise comparisons into the initial matrix (*IM*) of direct relation.

The *IM* of direct relation is an $n \times n$ matrix that is acquired by pairwise comparisons. In this matrix, $\tilde{e}_{ij}^{k}$ is indicated as the level of impact of attribute $i$ on the attribute $j$ and can be amended as $IM = \left[\tilde{e}_{ij}^{k}\right]_{n\times n}$.

- *Step 3:* Creating the normalized direct relation matrix.

The normalized direct relation matrix ($U$) is created using:

$$U = \tau \otimes IM$$
$$\tau = \frac{1}{\underset{1ik}{max} \sum_{j=1}^{k} \overset{1 \le i \le k}{\tilde{e}_{ij}^{k}}} \tag{5}$$

- *Step 4:* Obtaining the interrelationship matrix.

Then the interrelationship matrix ($W$) is obtained from the normalized direct relation matrix using:

$$W = U(I - U)^{-1} \tag{6}$$

where $W$ regards to $[W_{ij}]_{n\times n}, i, j = 1,2, \cdots n$

- *Step 5:* Mapping the cause–effect interrelationships diagram.

The values of the driving power ($\alpha$) and dependence power ($\beta$) are obtained to be the sum of row and column values of the interrelationship matrix as:

$$\alpha = \left[\sum_{i-1}^{n} w_{ij}\right]_{n\times n} = [w_i]_{n\times 1} \tag{7}$$

$$\beta = \left[\sum_{j-1}^{n} w_{ij}\right]_{n\times n} = [w_j]_{1\times n} \tag{8}$$

The causal interrelationships diagram is illustrated by locating the attributes in the ($\alpha + \beta$), ($\alpha - \beta$) vectors in turn of horizontal and vertical axes. The ($\alpha + \beta$) represents the importance level of attributes, the higher the values of ($\alpha + \beta$) are, the more important function the attributes have. In addition, ($\alpha - \beta$) assists in separating the attributes into cause and effect areas by considering if ($\alpha - \beta$) is positive or negative. If the $\alpha - \beta$ value is positive, the attributes are classified as causal, if not, they move to the effect group.

## 4. Results

This section presents the data analysis procedure and empirical results. The experts' evaluations for the interrelationships between aspects were obtained using a linguistic scale (Table II). The evaluations were interpreted into TFNs, as shown by one specific example in Table III.

These TFNs were then converted into crisp values using equations (1)-(4). The vague denotations as specific crisp values are shown in Table IV.

Then the crisp values were acquired into an interrelationship matrix and aspect grouping using equations (5)-(6). The DEMATEL was used to examine the interrelationships and the driving and dependent powers and the aspects; the result of interrelationship matrix is shown in Table V.

A cause–effect diagram was then generated by mapping the dataset onto $[(\alpha+\beta), (\alpha-\beta)]$. Waste minimization (A1) and recycling and recovery (A3) were in the cause group with the $[(\alpha+\beta), (\alpha-\beta)]$ value in turn as (32.648, 0.094) and (33.367, 0.821), whereas the effect group consisted of resource efficiency (A2) (33.321, (1.178)) (Figure 1). Specifically, recycling and recovery (A3) had the strongest effect on resource efficiency (A2) with the important value $(\alpha+\beta)$ as 33.367 and was the main aspect of driving SC.

Repeating the above process, the crisp values and the total interrelationship matrix for the criteria were obtained and the results are presented in Tables VI and VII. Table VIII addresses the causal interrelationships among the criteria. Figure 2 shows the cause–effect diagram that was generated. The results revealed that C1, C2, C3, C4, C8, C9, C10, C16, C20 and C21 were the cause criteria and that C5, C6, C7, C11, C12, C13, C14, C15, C17, C18 and C19 belonged to the affected group. Emission controls on ships (C2) $(\alpha+\beta = 15.019)$, cruise ship alternative energy sources (C16) $(\alpha+\beta = 14.957)$, ballast water treatment systems (C1) $(\alpha+\beta = 14.457)$, water purification systems (C10) $(\alpha+\beta = 14.077)$ and nanofiltration

**Table III.** Transferred TFNs of respondent 1 for the three aspects

| | A1 | | | A2 | | | A3 | | |
|---|---|---|---|---|---|---|---|---|---|
| A1 | [1.000 | 1.000 | 1.000] | [0.100 | 0.300 | 0.500] | [0.100 | 0.300 | 0.500] |
| A2 | [0.700 | 0.900 | 1.000] | [1.000 | 1.000 | 1.000] | [0.700 | 0.900 | 1.000] |
| A3 | [0.300 | 0.500 | 0.700] | [0.500 | 0.700 | 0.900] | [1.000 | 1.000 | 1.000] |

**Table IV.** Crisp values for aspects

| | A1 | A2 | A3 |
|---|---|---|---|
| A1 | 0.726 | 0.497 | 0.497 |
| A2 | 0.546 | 0.733 | 0.551 |
| A3 | 0.444 | 0.456 | 0.731 |

**Table V.** Interrelationship matrix and cause-and-effect interrelationships among aspects

| | A1 | A2 | A3 | $\alpha$ | $\beta$ | $\alpha+\beta$ | $\alpha-\beta$ |
|---|---|---|---|---|---|---|---|
| A1 | 5.534 | 5.299 | 5.616 | 16.371 | 16.277 | 32.648 | 0.094 |
| A2 | 5.788 | 5.803 | 6.033 | 16.072 | 17.250 | 33.321 | (1.178) |
| A3 | 5.049 | 4.971 | 5.445 | 17.094 | 16.273 | 33.367 | 0.821 |

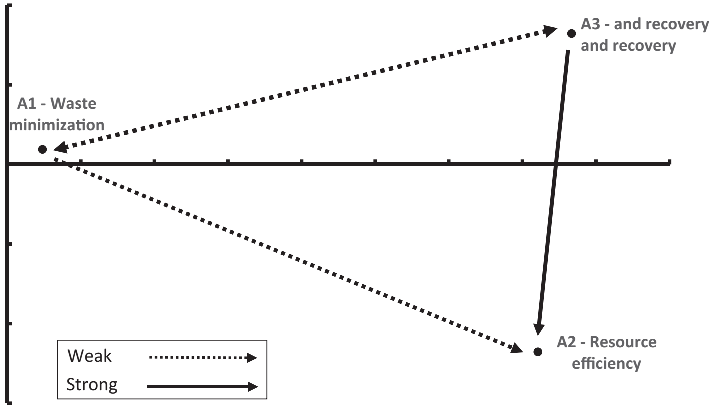


**Figure 1.**
Cause–effect diagram for aspects

systems (C9)($\alpha + \beta = 13.790$), which had the highest importance in the cause group, were identified as critical attributes for the improvement of SC in cruiseship operation practices.

## 5. Implications

### *5.1 Theoretical implications*

The results show that recycling and recovery is the principal aspect for conceptions of SC. The demand for recycled products, reuse, weight reduction, economic conditions, quantity, consumption behavior, types of competition and social or legal system development directly influence the SC (Fujii *et al.*, 2014). Initiatives under sustainable development have had an extreme focus on SC, with more efficient and "green" operations shifting to more environmentally friendly resources and localism. The incorporation of recycling and recovery of used products has been emphasized (Tseng *et al.*, 2013). However, it has not been politically acceptable to follow in transport and travelling. Mobility is considered decisive for economic growth and social freedom; economic instruments that need to be applied effectively. Materials recycled to recover economically significant amounts of certain precious waste material and energy consumption include all the applicability of the requirements.

The role of waste minimization on disposal is also revealed in this study. This aspect focuses on avoiding and minimizing waste, promoting reuse, recycling and recovery while carrying out the safe transport and treatment of disposal waste with a focus on maximizing efficient resource use (Pandey *et al.*, 2018). The preservation of resources through waste minimization can be reached under the influence of governing authorities through effective policy implementation. Still, waste minimization might present as little use as it comes with an emerging cost on essential remunerations gained by consumption (Manzoor *et al.*, 2014). When waste-produced onboard cruise ships areappropriately classified, stowed and preserved, the risk is ordinarily minimalized. This can entail waste stream management programs for combination into SC management systems.

### *5.2 Managerial implications*

Ballast water treatment systems, water purification systems and nanofiltration systems are critical attributes for improving SC in cruise ship operation practices. These technologies can be placed throughout ships to segregate the infrastructure for minimizing waste streams as well as for increasing the volume and types of salvaged resources. A challenge is the lack

**Table VI.**
Crisp values for criteria

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.772 | 0.551 | 0.366 | 0.425 | 0.371 | 0.404 | 0.300 | 0.446 | 0.405 | 0.505 | 0.516 | 0.537 | 0.450 | 0.538 | 0.425 | 0.495 | 0.424 | 0.365 | 0.337 | 0.449 | 0.443 |
| C2 | 0.484 | 0.754 | 0.436 | 0.460 | 0.357 | 0.374 | 0.546 | 0.367 | 0.455 | 0.391 | 0.402 | 0.503 | 0.500 | 0.525 | 0.490 | 0.420 | 0.426 | 0.404 | 0.342 | 0.404 | 0.281 |
| C3 | 0.364 | 0.355 | 0.754 | 0.243 | 0.260 | 0.230 | 0.358 | 0.370 | 0.326 | 0.345 | 0.354 | 0.328 | 0.383 | 0.363 | 0.348 | 0.388 | 0.394 | 0.339 | 0.344 | 0.404 | 0.267 |
| C4 | 0.364 | 0.240 | 0.536 | 0.765 | 0.538 | 0.311 | 0.360 | 0.352 | 0.346 | 0.281 | 0.340 | 0.349 | 0.400 | 0.477 | 0.444 | 0.369 | 0.372 | 0.288 | 0.270 | 0.386 | 0.267 |
| C5 | 0.382 | 0.322 | 0.340 | 0.396 | 0.787 | 0.442 | 0.321 | 0.335 | 0.345 | 0.363 | 0.357 | 0.393 | 0.317 | 0.313 | 0.315 | 0.290 | 0.390 | 0.338 | 0.267 | 0.354 | 0.379 |
| C6 | 0.349 | 0.255 | 0.273 | 0.279 | 0.342 | 0.787 | 0.427 | 0.419 | 0.443 | 0.442 | 0.390 | 0.395 | 0.367 | 0.379 | 0.315 | 0.471 | 0.480 | 0.421 | 0.340 | 0.419 | 0.446 |
| C7 | 0.240 | 0.386 | 0.371 | 0.378 | 0.358 | 0.423 | 0.748 | 0.268 | 0.409 | 0.247 | 0.423 | 0.411 | 0.417 | 0.450 | 0.400 | 0.423 | 0.330 | 0.290 | 0.297 | 0.208 | 0.331 |
| C8 | 0.349 | 0.336 | 0.302 | 0.440 | 0.373 | 0.328 | 0.450 | 0.776 | 0.347 | 0.426 | 0.371 | 0.393 | 0.333 | 0.298 | 0.283 | 0.272 | 0.293 | 0.353 | 0.373 | 0.303 | 0.331 |
| C9 | 0.417 | 0.521 | 0.306 | 0.313 | 0.342 | 0.377 | 0.400 | 0.400 | 0.765 | 0.415 | 0.438 | 0.397 | 0.417 | 0.429 | 0.477 | 0.406 | 0.408 | 0.421 | 0.344 | 0.366 | 0.315 |
| C10 | 0.353 | 0.488 | 0.269 | 0.280 | 0.342 | 0.392 | 0.352 | 0.287 | 0.362 | 0.765 | 0.440 | 0.492 | 0.467 | 0.394 | 0.379 | 0.423 | 0.496 | 0.440 | 0.372 | 0.402 | 0.511 |
| C11 | 0.370 | 0.488 | 0.288 | 0.313 | 0.390 | 0.426 | 0.380 | 0.337 | 0.448 | 0.459 | 0.750 | 0.442 | 0.417 | 0.381 | 0.383 | 0.473 | 0.479 | 0.489 | 0.372 | 0.340 | 0.315 |
| C12 | 0.290 | 0.473 | 0.207 | 0.328 | 0.294 | 0.375 | 0.352 | 0.352 | 0.430 | 0.426 | 0.451 | 0.763 | 0.417 | 0.363 | 0.348 | 0.453 | 0.398 | 0.488 | 0.312 | 0.352 | 0.331 |
| C13 | 0.272 | 0.440 | 0.221 | 0.296 | 0.276 | 0.326 | 0.337 | 0.187 | 0.361 | 0.427 | 0.356 | 0.410 | 1.000 | 0.400 | 0.348 | 0.392 | 0.363 | 0.405 | 0.344 | 0.373 | 0.248 |
| C14 | 0.401 | 0.458 | 0.222 | 0.280 | 0.310 | 0.327 | 0.337 | 0.269 | 0.379 | 0.409 | 0.354 | 0.297 | 0.367 | 0.743 | 0.444 | 0.498 | 0.411 | 0.453 | 0.405 | 0.340 | 0.315 |
| C15 | 0.501 | 0.407 | 0.173 | 0.182 | 0.260 | 0.311 | 0.205 | 0.171 | 0.280 | 0.293 | 0.306 | 0.345 | 0.267 | 0.396 | 0.743 | 0.531 | 0.395 | 0.406 | 0.358 | 0.292 | 0.315 |
| C16 | 0.433 | 0.575 | 0.434 | 0.502 | 0.452 | 0.553 | 0.471 | 0.368 | 0.380 | 0.457 | 0.404 | 0.472 | 0.400 | 0.396 | 0.475 | 0.754 | 0.332 | 0.385 | 0.290 | 0.436 | 0.379 |
| C17 | 0.368 | 0.502 | 0.269 | 0.372 | 0.279 | 0.409 | 0.387 | 0.337 | 0.396 | 0.509 | 0.436 | 0.312 | 0.400 | 0.398 | 0.350 | 0.406 | 0.765 | 0.450 | 0.374 | 0.388 | 0.429 |
| C18 | 0.401 | 0.521 | 0.388 | 0.376 | 0.325 | 0.426 | 0.423 | 0.383 | 0.360 | 0.395 | 0.471 | 0.347 | 0.383 | 0.331 | 0.300 | 0.340 | 0.549 | 0.754 | 0.419 | 0.354 | 0.381 |
| C19 | 0.401 | 0.221 | 0.271 | 0.313 | 0.361 | 0.345 | 0.323 | 0.318 | 0.298 | 0.297 | 0.406 | 0.346 | 0.267 | 0.283 | 0.265 | 0.340 | 0.341 | 0.399 | 0.718 | 0.402 | 0.381 |
| C20 | 0.282 | 0.370 | 0.401 | 0.428 | 0.393 | 0.457 | 0.314 | 0.367 | 0.442 | 0.326 | 0.420 | 0.361 | 0.317 | 0.348 | 0.392 | 0.401 | 0.361 | 0.354 | 0.370 | 0.754 | 0.381 |
| C21 | 0.369 | 0.356 | 0.521 | 0.513 | 0.377 | 0.442 | 0.406 | 0.274 | 0.231 | 0.330 | 0.405 | 0.461 | 0.217 | 0.398 | 0.333 | 0.384 | 0.343 | 0.406 | 0.390 | 0.386 | 0.737 |

**Table VII.** Interrelationship matrix of criteria

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.402 | 0.416 | 0.323 | 0.352 | 0.342 | 0.375 | 0.352 | 0.334 | 0.365 | 0.389 | 0.400 | 0.401 | 0.383 | 0.395 | 0.369 | 0.404 | 0.389 | 0.378 | 0.333 | 0.365 | 0.351 |
| C2 | 0.362 | 0.428 | 0.322 | 0.347 | 0.332 | 0.362 | 0.371 | 0.317 | 0.362 | 0.366 | 0.378 | 0.388 | 0.379 | 0.385 | 0.368 | 0.386 | 0.380 | 0.373 | 0.325 | 0.351 | 0.324 |
| C3 | 0.287 | 0.315 | 0.303 | 0.264 | 0.262 | 0.282 | 0.288 | 0.262 | 0.285 | 0.297 | 0.306 | 0.302 | 0.301 | 0.301 | 0.289 | 0.315 | 0.310 | 0.300 | 0.268 | 0.290 | 0.264 |
| C4 | 0.303 | 0.320 | 0.294 | 0.337 | 0.310 | 0.308 | 0.304 | 0.275 | 0.304 | 0.306 | 0.321 | 0.321 | 0.320 | 0.331 | 0.316 | 0.331 | 0.325 | 0.312 | 0.275 | 0.304 | 0.279 |
| C5 | 0.297 | 0.320 | 0.265 | 0.289 | 0.329 | 0.315 | 0.292 | 0.266 | 0.295 | 0.307 | 0.315 | 0.318 | 0.302 | 0.304 | 0.293 | 0.312 | 0.318 | 0.309 | 0.267 | 0.292 | 0.285 |
| C6 | 0.317 | 0.340 | 0.278 | 0.300 | 0.303 | 0.378 | 0.328 | 0.297 | 0.331 | 0.342 | 0.345 | 0.344 | 0.333 | 0.337 | 0.318 | 0.360 | 0.354 | 0.344 | 0.298 | 0.324 | 0.316 |
| C7 | 0.283 | 0.329 | 0.269 | 0.288 | 0.283 | 0.314 | 0.340 | 0.259 | 0.304 | 0.295 | 0.323 | 0.321 | 0.315 | 0.321 | 0.305 | 0.329 | 0.313 | 0.305 | 0.271 | 0.277 | 0.280 |
| C8 | 0.292 | 0.320 | 0.259 | 0.293 | 0.282 | 0.300 | 0.305 | 0.313 | 0.294 | 0.313 | 0.315 | 0.316 | 0.303 | 0.301 | 0.288 | 0.309 | 0.305 | 0.309 | 0.277 | 0.285 | 0.278 |
| C9 | 0.334 | 0.380 | 0.289 | 0.311 | 0.310 | 0.341 | 0.333 | 0.302 | 0.374 | 0.347 | 0.359 | 0.353 | 0.348 | 0.352 | 0.345 | 0.362 | 0.355 | 0.353 | 0.306 | 0.326 | 0.308 |
| C10 | 0.328 | 0.377 | 0.287 | 0.309 | 0.311 | 0.345 | 0.330 | 0.290 | 0.332 | 0.387 | 0.361 | 0.366 | 0.355 | 0.349 | 0.335 | 0.365 | 0.367 | 0.357 | 0.310 | 0.331 | 0.332 |
| C11 | 0.331 | 0.379 | 0.290 | 0.314 | 0.318 | 0.350 | 0.334 | 0.298 | 0.343 | 0.356 | 0.396 | 0.362 | 0.351 | 0.349 | 0.337 | 0.372 | 0.367 | 0.364 | 0.312 | 0.326 | 0.311 |
| C12 | 0.304 | 0.357 | 0.265 | 0.298 | 0.290 | 0.325 | 0.313 | 0.283 | 0.323 | 0.333 | 0.344 | 0.377 | 0.332 | 0.328 | 0.315 | 0.350 | 0.338 | 0.344 | 0.288 | 0.309 | 0.295 |
| C13 | 0.286 | 0.336 | 0.252 | 0.279 | 0.273 | 0.303 | 0.295 | 0.250 | 0.299 | 0.316 | 0.317 | 0.322 | 0.381 | 0.316 | 0.299 | 0.326 | 0.317 | 0.319 | 0.277 | 0.296 | 0.271 |
| C14 | 0.310 | 0.348 | 0.260 | 0.286 | 0.286 | 0.313 | 0.304 | 0.268 | 0.310 | 0.324 | 0.326 | 0.319 | 0.319 | 0.363 | 0.319 | 0.348 | 0.332 | 0.333 | 0.292 | 0.301 | 0.287 |
| C15 | 0.293 | 0.311 | 0.229 | 0.248 | 0.253 | 0.281 | 0.260 | 0.231 | 0.270 | 0.281 | 0.290 | 0.293 | 0.277 | 0.295 | 0.322 | 0.320 | 0.299 | 0.298 | 0.260 | 0.267 | 0.260 |
| C16 | 0.358 | 0.410 | 0.325 | 0.354 | 0.345 | 0.385 | 0.364 | 0.319 | 0.355 | 0.375 | 0.380 | 0.386 | 0.370 | 0.372 | 0.368 | 0.425 | 0.371 | 0.373 | 0.320 | 0.356 | 0.337 |
| C17 | 0.324 | 0.373 | 0.282 | 0.314 | 0.299 | 0.341 | 0.328 | 0.291 | 0.330 | 0.353 | 0.355 | 0.339 | 0.341 | 0.344 | 0.326 | 0.357 | 0.390 | 0.352 | 0.306 | 0.324 | 0.317 |
| C18 | 0.330 | 0.377 | 0.298 | 0.317 | 0.307 | 0.345 | 0.335 | 0.299 | 0.328 | 0.343 | 0.361 | 0.346 | 0.342 | 0.339 | 0.323 | 0.352 | 0.369 | 0.387 | 0.313 | 0.323 | 0.314 |
| C19 | 0.284 | 0.292 | 0.243 | 0.266 | 0.268 | 0.288 | 0.276 | 0.250 | 0.275 | 0.284 | 0.304 | 0.296 | 0.280 | 0.284 | 0.272 | 0.301 | 0.296 | 0.299 | 0.302 | 0.283 | 0.270 |
| C20 | 0.302 | 0.343 | 0.286 | 0.308 | 0.301 | 0.333 | 0.307 | 0.284 | 0.323 | 0.320 | 0.339 | 0.331 | 0.319 | 0.325 | 0.319 | 0.343 | 0.332 | 0.328 | 0.294 | 0.352 | 0.300 |
| C21 | 0.313 | 0.343 | 0.302 | 0.319 | 0.301 | 0.333 | 0.319 | 0.275 | 0.300 | 0.321 | 0.339 | 0.344 | 0.309 | 0.332 | 0.313 | 0.343 | 0.332 | 0.335 | 0.297 | 0.313 | 0.340 |

Table VIII.
Cause-and-effect interrelationships among criteria

| | $\alpha$ | $\beta$ | $\alpha+\beta$ | $\alpha-\beta$ |
|---|---|---|---|---|
| C1 | 7.818 | 6.639 | 14.457 | 1.179 |
| C2 | 7.604 | 7.414 | 15.019 | 0.190 |
| C3 | 6.092 | 5.921 | 12.013 | 0.171 |
| C4 | 6.495 | 6.395 | 12.891 | 0.100 |
| C5 | 6.287 | 6.305 | 12.592 | (0.018) |
| C6 | 6.886 | 6.918 | 13.804 | (0.032) |
| C7 | 6.325 | 6.680 | 13.005 | (0.354) |
| C8 | 6.257 | 5.964 | 12.221 | 0.293 |
| C9 | 7.088 | 6.702 | 13.790 | 0.386 |
| C10 | 7.123 | 6.954 | 14.077 | 0.169 |
| C11 | 7.159 | 7.175 | 14.335 | (0.016) |
| C12 | 6.709 | 7.146 | 13.855 | (0.436) |
| C13 | 6.330 | 6.958 | 13.288 | (0.628) |
| C14 | 6.551 | 7.025 | 13.576 | (0.474) |
| C15 | 5.838 | 6.739 | 12.577 | (0.900) |
| C16 | 7.648 | 7.309 | 14.957 | 0.338 |
| C17 | 6.988 | 7.156 | 14.144 | (0.169) |
| C18 | 7.049 | 7.072 | 14.122 | (0.023) |
| C19 | 5.912 | 6.190 | 12.102 | (0.278) |
| C20 | 6.690 | 6.594 | 13.285 | 0.096 |
| C21 | 6.723 | 6.318 | 13.041 | 0.406 |

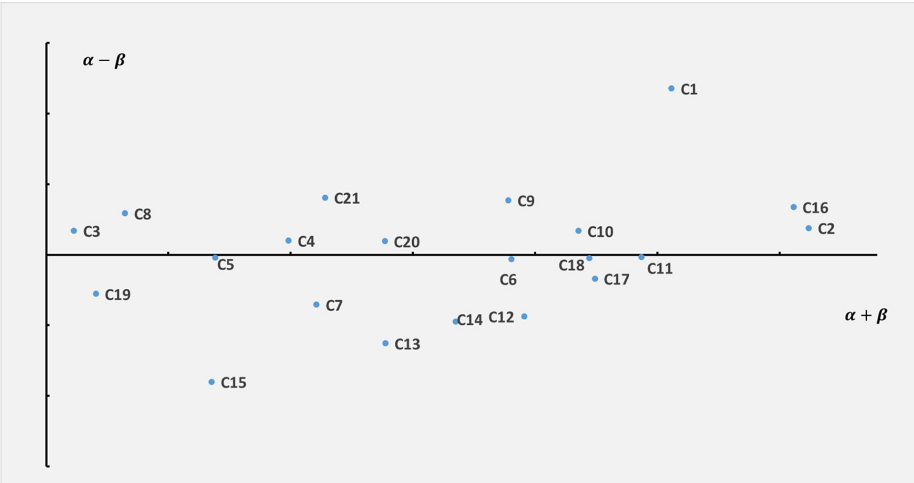


Figure 2.
Causal diagram for criteria

of modern infrastructure availability at certain ports worldwide. As part of an overall strategy, encouraging stakeholders to assist cruise operators with SC efforts can be encouraged by enhancing their awareness of the available onboard options. Accordingly, there should be a management strategy that entails a multi-level approach fitting with regulatory requirements and in many instances exceeding regulations and including waste ashore, incinerating waste onboard and discharging liquid and food waste. Cruiseship operators should invest in the identification of new solutions for facilities, sourcing, products and service selection by working with onshore suppliers using the proposed alternatives to avoid inefficient consumption and to reduce toxicity from the cruise ship.

Furthermore, the energy and exergy problems on existing cruise ships need to be improved by enhancing the operation of emission controls currently on ships and by looking into alternative energy sources. From a thermal perspective, the current energy and exergy flow rates potentially obtainable for recovery advocate for improving the system's efficiency and lessening fuel consumption. Energy savings and alternative solutions found from this study should be improved by setting up energy-efficient standards and mandatory labels and by providing increased energy efficiency subsidies. Communication campaigns should be carried out to advocate for ecofriendly technology, purchasing non-toxic products, controlling material flow and replacing older equipment with new equipment.

## 6. Conclusions

Over the past decades, SC has emerged as a key priority area in research and policy-making related to sustainable development. While the SC business trends may prove to be a powerful measure, they are challenging as well. The overriding emphasis within the main operators' literature addresses conspicuous consumption, with little or no mention of environmental stewardship. It is urgent to pursue SC as an agent for positive environmental change for sustainable development. Previous frameworks for SC may not be suitable to the cruiseship industry. As there was no literature specifically targeting the cruise industry, this study was conducted to explore a framework and identify attributes that influence cruiseship SC for enhancing the sustainable performance of cruise lines. A multi-criteria decision-making method based on collecting expert opinions and related literature resources is proposed. A hybrid method of the Delphi method and fuzzy decision-making trial and evaluation laboratory (DEMATEL) was used in the present study to seek a valid and reliable hierarchical framework for analyzing the cruise ships SC, understanding the causal effects of the attributes, as well as evaluating the attributes that drive improvements in cruise ship performance.

The proposed set of attributes included three aspects and 21 criteria. The results showed that waste minimization and recycling and recovery were causal aspects that influenced resource efficiency. Specifically, recycling and recovery had the strongest effect on resource efficiency and is the main aspect of driving SC. Furthermore, criteria including emission controls on ships, alternative energy sources, ballast water treatment systems, water purification systems and nanofiltration systems were also identified as critical attributes for the improvement of SC in cruiseship operation practices.

Hence, this study contributes to the literature by providing both theoretical insights and empirical findings. It not only offers a hierarchical framework for SC, but also confirms the role of this issue in improving the cruise industry sustainability. In practice, emission controls on ships, cruise ship alternative energy sources, ballast water treatment systems, water purification systems and nanofiltration systems provide the key elements for successful performance and offer targets for companies developing new activities for either ensuring compliance with business goals or decreasing environmental impacts.

Still, limitations do exist. This study focused on technical aspects and attributes were proposed from the literature and using expert evaluation, which might limit the framework comprehensiveness and affect the generalizability of this study. Future studies should expand the number of related attributes and consider other dimensions of SC to extend the current work. Additionally, the number of expert respondents was limited to 12, which could have generated a bias in the results due to subjective viewpoints, experience and knowledge in the sector. Enlarging the pool of respondents in future studies may overcome this problem. As the top important attributes are identified in this study, which will obviously increase the cost of the cruiseship industry, exploring the effect of these attributes to the cruiseship industry are recommended for future studies.

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