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ORIGINAL PAPER

Sustainable supply chain management in construction industry: a Turkish case

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Abstract

In the construction industry, social, environmental and economic concerns are increasing in recent years. Sustainability approach is gaining wide interest to solve these concerns. Sustainable supply chain management ensures environmentally and socially pleasant practices, and provides economic gains. We propose a sustainable supply chain management model for the construction industry in Turkey context, which considers all levels of construction process. The proposed model is based on the life cycle assessment of buildings and employs triple bottom line sustainability dimensions—environmental, social and economical. We utilize the analytic network process methodology to evaluate the sustainability level of construction sustainable supply chain management in Turkey by employing the principles of the green buildings performance rating system (LEED). The contribution that lies in this paper provides the importance of sustainable supply chain management elements in construction, reasons for insufficient sustainability and a framework to improve sustainability integration.

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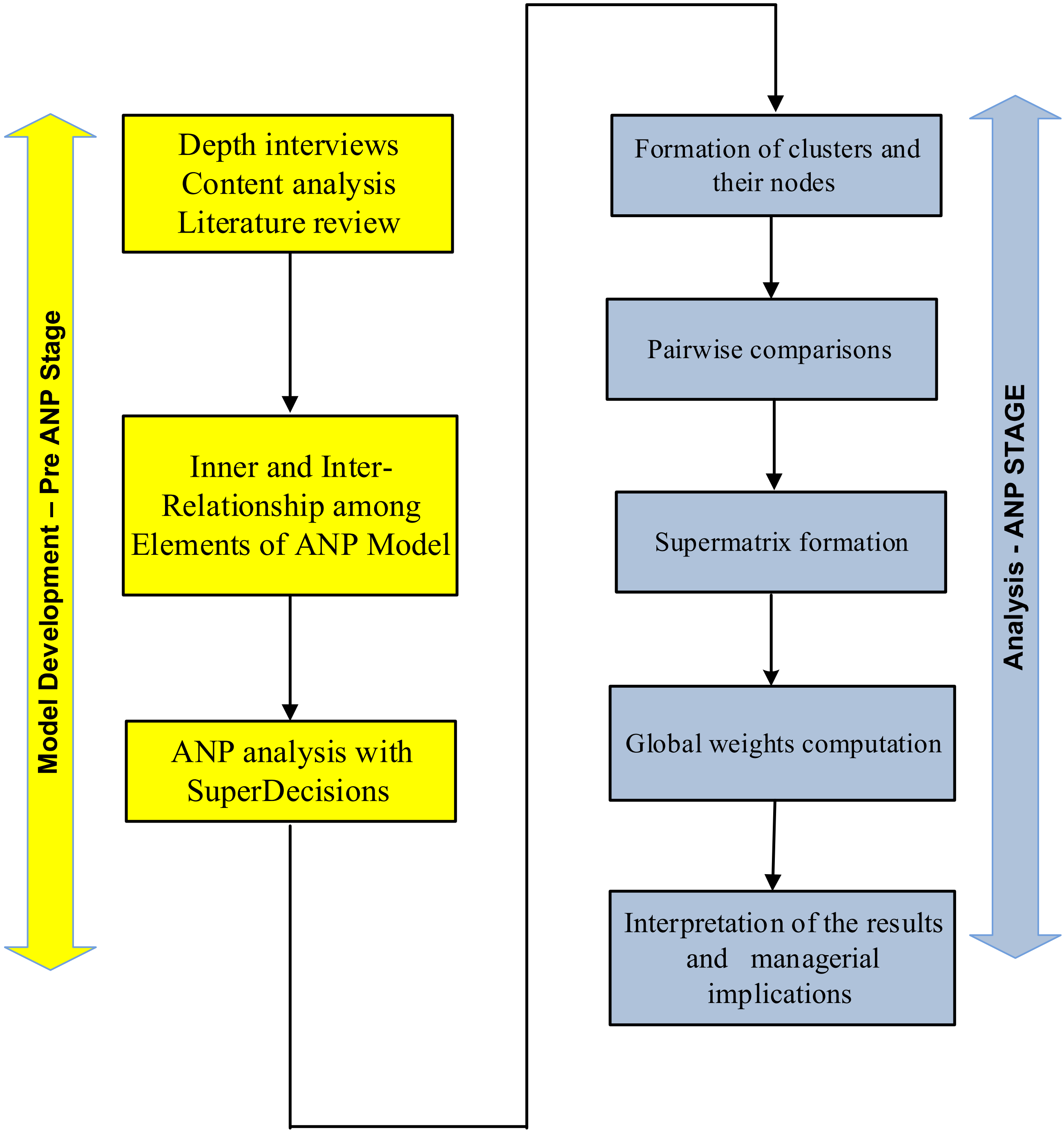
Graphic abstract



Keywords Sustainability · Sustainable supply chain management · Sustainable construction · ANP · Turkey

Introduction

The extensive growth in the global economy and population created a large demand of natural resources. Thus, organizations search for cheaper and easier methods to procure natural resources. However, these actions often may cause adverse effects on both environment and society in the long term. For example, asbestos is widely used in isolation of buildings, since it is easily mined, inexpensive, durable to heat, electricity and chemical corrosion (Feric et al. 1997).

However, asbestos is a highly pathologic material that may cause cancer (Craighead et al. 1982). Another arising problem followed by increased demand for products is excessive usage of natural resources. Due to the increase in population and utilization of natural resources per individual, humanity is in danger of facing a lack of natural resources problems in the near future. Also, pollution and waste problems occur because of the shortened usage time of goods, which increases waste management and waste storage problems. Therefore, handling the waste of products is another problem that needs to be carefully considered.

Fortunately, there has been a noticeable increase in awareness of sustainability concerns since the late 1990s (Rajeev et al. 2017). This awareness leads to a change in production methods and consumption behaviors. People are more sensitive to use products that are manufactured with environmentally friendly materials and processes. Environmental considerations also affect the manufacturers' business model. They need to take into account environmental concerns in design, production, delivery of the final product and end-of-life management of the product after its useful life (Srivastava 2007).

The construction industry also has a significant impact on the environment. It is a major consumer of natural resources and energy (Badi and Murtagh, 2019). The construction industry is also accountable for 30–40% of the world's total carbon emission (Huovila, 2007) and 30% of solid waste in the European Union (2015). Thus, governments introduce strict regulations to reduce the negative environmental impacts of the construction industry.

This study proposes a sustainable supply chain management (SSCM) for the construction industry in a key emerging country, Turkey. The proposed model is based on the life cycle assessment of buildings. All three sustainability dimensions defined as the triple bottom line (TBL) by Elkington (1998) are included in the model. The extant literature shows that most of the studies on SSCM employ multi-criteria decision-making (MCDM) methods on the firm level (Khan et al. 2021). We evaluate sector-level sustainability of the Turkish construction industry using the analytic network process (ANP) methodology, which is one of the conventional MCDM methods. The principles of green buildings performance rating system (LEED) are considered in the evaluation to find the best alternatives. Also, an extensive analysis of ANP results presents which alternatives need improvement to increase the sustainability level of the Turkish construction industry.

Section 2 of this paper presents an extensive literature review on the sustainable supply chain management, Dimensions of SSCM and SSCM in the Construction Industry. Then, Sect. 3 discusses the methodology of ANP. Section 4 presents the application of the ANP method to the Turkish construction industry. Section 5 presents computational results and analysis. Finally, the last section discusses the conclusions from our work and presents some directions for future research.

Literature review

In this section, we first review the relevant literature to provide a concise definition of SSCM and explain its role in the construction industry. We then present a brief coverage of the underlying dimensions of SSCM used in this study.

Sustainable supply chain management

Sustainability has gained much more attention and actuated policymakers and enterprise managers after the Rio Conference on Environment and Development in 1992 (Seuring and Müller, 2007). It becomes a point of interest for all parties globally, such as the governments, non-governmental organizations (NGOs), academic communities and businesses in recent years due to global warming, climate change, environmental pollution and diminishing natural resources. Sustainability's primary goal is to protect natural resources to provide livable conditions for future generations using eco-friendly materials in production, manufacturing recyclable products and providing efficient waste management. Since sustainability involves stages of raw materials acquisition, production, manufacturing, packaging, distribution, reuse, operation, maintenance and disposal of products and services, the supply chains within a sustainable perspective have crucial importance in achieving this goal.

Sustainability is expressed as TBL consisting of environmental, social and economic dimensions. The TBL states that a system must reach at least minimum economic, environmental and social requirements to be sustainable (Jeurissen, 2000). In order to achieve a sustainable supply chain, each part of it should have environmentally friendly procedures, including product design, manufacturing, usage, recycling and transporting among suppliers, manufacturers and customers (Linton et al. 2007).

SSCM is defined by (Seuring et al. 2008) as "*the management of material and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, and stakeholder requirements into account.*"

Companies and organizations are required to contribute to social welfare and decrease their environmental impact while being profitable (McWilliams et al. 2016). SSCM deals with issues like environmental-friendly production and fair labor conditions, beyond reaching economic objectives (Seuring, 2013). Dubey et al. (2017) classify the critical drivers of SSCM from the result of literature review, and they found twelve themes: strategic supplier collaboration, green warehousing, continuous improvement, logistics optimization, environment conservation, enabling information technologies, internal pressures, institutional pressures, ethics and social values, economic stability, commitment and corporate strategy and green product design. Sharma et al. (2020) introduced a hybrid multi-criteria decision-making method to identify key factors effecting sustainability of supply chain networks of manufacturing companies. Their findings show that external barriers such as lack of regulations have more influence than internal barriers. Carter and Rogers (2008) present a comprehensive literature review of the SSCM. They frame a starting point to develop SSCM practices in organizations and listed some sustainability activities such as decreased packaging use and disposal, shorter lead times and better working conditions.

Assessment of SSCM policies according to a TBL, including social responsibility, environmental performance and economic aspects, also has been extensively studied (Eskandarpour et al. 2015). TBL requires integrating health, safety and environmental concerns with green product design, green and lean operations, and closed-loop supply chains (Kleindorfer et al. 2005). Zsidisin and Siferd (2001) present a study that is one of the first literature reviews and theoretical studies in this field, and they discussed the environmental purchasing concept. Narimissa et al. (2020) introduce a work that identifies the important aspects of sustainability aspects which are crucial for assessing and the supply chain.

Zailani et al. (2012) study the magnitude of SSCM implementation (such that sustainable packaging and environmental purchasing) and investigate through the outcomes of these SSCM practices on the performance of sustainable supply chain with a questionnaire. According to the survey results applied among manufacturing firms in Malaysia, environmental purchasing has a positive effect on the economic, social and operational outcomes, whereas sustainable packaging has a positive effect on economic, environmental and social outcomes. Egilmez et al. (2014) study on SSCM assessment in the US food manufacturing industry by using economic input–output life cycle assessment and data envelopment analysis. They indicate that supply chains in food manufacturing sectors are heavily responsible for the impacts, with 80% for water, energy and carbon footprint, fishery and grazing categories.

Marshall et al. (2015) investigate the factors that drive the adoption of different social sustainability supply chain practices in Ireland from different industries. The social sustainability practices that they use are: basic (social monitoring and social management systems) and advanced (social new product and process development, social supply chain redefinition). According to their findings, sustainability culture is positively related to all the practices they addressed. Seuring et al. (2019) present a study using content and contingency analysis on the base-of-the-pyramid (BoP) projects. They interview with professionals from an export-oriented pineapple supply chain (SC) in Uganda (34 interviewers) and the local dairy SC Kenya (11 interviewers). Their findings show that customer demands and pressure are the main drives for sustainability developments when 3rd parties (NGOs, middlemen or certification agents) are involved in monitoring and auditing suppliers. Paulraj et al. (2017) research the relationships among the SSCM practices, corporate motives and firm performance on using survey method to 259 supply chain firms in Germany. They find that relational and moral motives are key drivers, and that firms exhibit moral obligations in high levels of tend to outperform those primarily driven by amoral considerations. Goni et al. (2020) present important aspects of sustainable implementations. In particular, their findings indicate that sustainability is one of the key drivers in sustainable business model.

Gardas et al. (2019) identify and analyze the influence of determinants of SSCM on the operational and business performance (OPR) of the case supply chain in the Indian oil and gas industry. They use interpretive structural modeling (ISM) and structural equation modeling (SEM) to analyze the research data and find that the "Regulatory Pressure (RP)" has the highest driving power and "Collaborative Green Logistics" has a significant influence on the OPR. Saumyaranjan & Lokesh (2020) explore the impact of dimensions of green supply chain management to organizational performance.

Dimensions of SSCM

A sustainable supply chain can be achieved if three sustainability dimensions are combined with supply chain management (Linton et al. 2007). The first dimension, combined with the supply chain, is the economic dimension. In applying the economic dimension to the supply chain, some key points must be handled carefully. First of all, sustainability implementation should not be conflicted with the company's interests (most of the time net profit) (Krajnc and Glavič, 2005). Secondly, cost and expenditure need to be decreased in regards to the sustainability principles. In order to accomplish this, first, all elements of the supply chain need to be observed, and then, the steps that result in waste are handled with special care. An organization needs to observe all supply chain steps from raw material procurement to production and delivery to customers.

The environment is the second dimension combined with supply chain management. The objective is to manage natural resources and their by-products throughout the supply chain. A resource enters supply chain leave as the final product, by-products and/or waste at some point. Sustainable supply chain management handles this flow by respecting environmental concerns. Management takes actions such that recycling, solid waste management, energy conservation, water and air purification, and usage of electric vehicles, renewable energy and resources, solar and wind power (Shi et al. 2012).

The social dimension takes care of working conditions, worker rights, social projects, the effect of layoffs, working hours, training and education, child labor, diversity and equal opportunity, health and safety, etc. (Massaroni et al. 2015). The most crucial element of the supply chain is humans (workers and society). The social dimension of sustainable supply chain conventionally focuses on working conditions to improve employees' satisfaction and life standards by providing a safe working environment, low rate of accidents (or no accident), well-defined workers' rights and privileges (Seuring and Müller, 2008). Recently, some new subjects such as social equity, diversity, social quality of life and integrated governance are included to the social dimension of sustainability (Talan et al. 2020).

The social dimension of the sustainable supply chain is also interested in the effects of companies' activities on society. For example, noise, dust, waste, etc. decrease the quality of society's life conditions (Seuring and Müller, 2008). In order to decrease the harmful effects of the supply chain on society, a suitable grievance mechanism should be created, and complaints must be handled properly, such that providing prompt answers and feedback and solving problems as soon as possible. Although many companies still have some shortcomings in implementation of SSCM practices, adaptation of clear environmental management policies is growing (Alves et al. 2020).

Dimensions of the supply chain have crucial importance in the designation of sustainable supply chain management objectives. Figure 1 presents a supply chain model that takes into account all dimensions of sustainability. Particularly, we demonstrate the interaction among all dimensions of a sustainable supply chain.

SSCM in the construction industry

Construction supply chain management (CSCM) is an emerging area of practice. CSCM involves the whole process of construction, including plan, design, construction and acceptance. The partners in CSCM are owners, general contractors, subcontractors, designers and suppliers Li et al. (2010). Due to the construction industry's different characteristics, it is characterized by complex supply chain networks delivering unique end products over short time scales (Russell et al. 2018). Also, the structure of the construction supply chain is long and intertwined. Thus, it is difficult to evaluate the effects of different procedures, components and materials (Bon and Hutchinson, 2000).

CSCM is inspired by manufacturing supply chain management, where the emphasis is on modeling quantity of production, while differs considerably from it (O'Brien et al. 2008). The first difference is the type of production process. In particular, in conventional manufacturing, the most common type of production process is mass production. On the other hand, the construction sector works based on the projects. In the construction industry, workers, contractors, products and even customer types might change one project to another. Therefore, production in the construction industry is specific to a single product (Şerbetçioğlu 2007). Also, a product in the manufacturing industry is produced at a permanent place (such that a factory), but in the construction industry, the construction site and product changes with respect to time and the projects. The other difference in the construction industry is that many firms, known as contractors, may need to work together unlike conventional manufacturing. Most of the time, the final product is manufactured by a single firm (Segerstedt and Olofsson 2010). The length of the time to finish a project is another distinctive aspect of the construction industry. Particularly, the production of any commercial goods takes much less time than any construction project. Therefore, resource planning

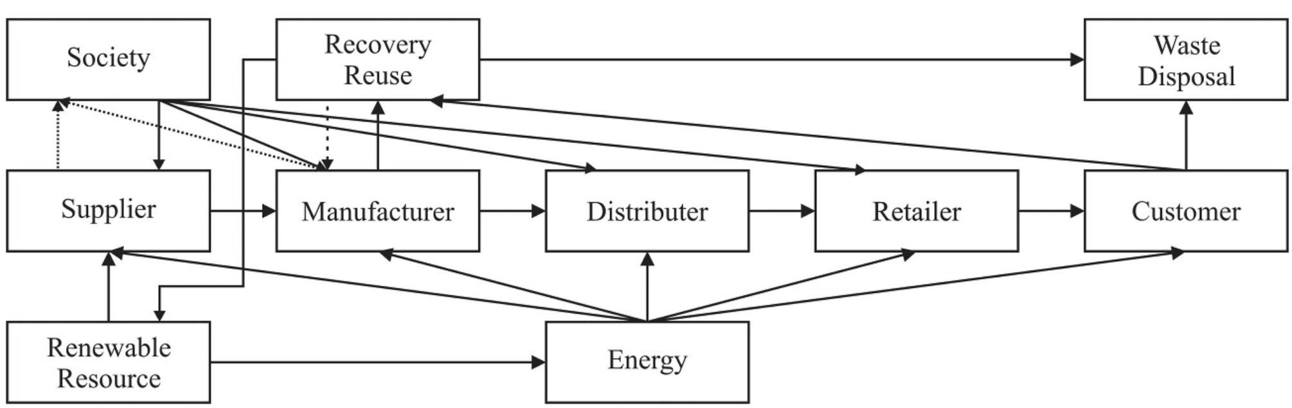


Fig. 1 Sustainable supply chain model

(e.g., money, labor) of construction projects requires special attention to plan long-term necessities (Segerstedt and Olofsson, 2010). The supply of raw material routine in the construction industry is also different than conventional manufacturing. In conventional manufacturing, most of the raw materials and intermediate products can be procured and stored in advance. However, in the construction industry, raw materials and intermediate products are procured as needed. The last difference between the construction and production industries is the lifetime of products. Products of the construction industry may have much longer lifetime than conventional manufacturing.

CSCM is studied in the literature with different perspectives. Vrijhoef and Koskela (2000) present a study that identifies the four roles of the supply chain in the construction industry. These roles are focusing on the interface between the supply chain and the construction site, the supply chain, transferring activities from the construction site to the supply chain, and finally the integrated supply chain management and the construction site. Li et al. (2010) propose a simulation model for the CSCM, based on the multi-agent method under the analysis of the special characters in CSCM. Shi et al. (2016) study a mobile Internet-based CSCM with a thematic and descriptive analysis of publications in this area. They develop an integrated framework containing five aspects of CSCM: material flow and supply management, real-time information sharing and communication, coordination and integration in CSC, technology support for M-Internet and associated safety issues.

We discussed the construction and production industry's differences to point out that the construction industry requires a special form of the supply chain. As we discussed above, the conventional supply chain is not suitable for the construction industry. Therefore, as a special form of the supply chain, a construction supply chain is introduced. A construction supply chain consists of phases of raw material extraction, construction area selection, construction material supply to the construction area, construction, operation and maintenance, and finally, destruction and cleaning of debris at the end of the building's lifetime. The construction phase consists of stages of designing the building, selecting the contractors and constructing. A circular version of the construction supply chain should include all stages of the construction process from the extraction of raw materials to the very end operations such as destruction and debris cleaning (Şerbetçioğlu 2007). Figure 2 depicts the construction supply chain process.

Sustainable supply chain in the construction industry involves utilizing best practices, clean and resource-efficient techniques for construction from the extraction of the raw materials to the demolition and disposal of all parts (Savage and Lye 2011). In order to realize sustainable construction, the industry should adopt and implement practices such as green purchasing, government policies to promote sustainability, cleaner production, which green the supply chain (Ofori, 1999). Sustainable supply chain in construction should take into account local and global goals (Presley and Meade 2010).

Ofori (2000) states that the SSCM is not well known in the construction industry based on a study for the Singapore construction industry. Chun et al. (2015) present a work of green supply chain management in the Korean construction industry. They classify the SSCM activities in four factors, i.e., green purchase, green production, green logistics and reuse based on the results of factor analysis. Dadhich et al. (2015) use a hybrid life cycle assessment method to analyze the supply chain of plasterboard which is one of the most commonly used products in the UK construction industry. Their study shows how emission hotspots across the product life cycle can be analyzed and identified using different intervention options in the supply chain to decrease greenhouse gas emissions.

Kim et al. (2016) examine the shared understanding of suppliers' environmental management capabilities between the contractor and suppliers in Korea through a case study investigating a supply chain comprising a major construction company and 106 suppliers. Their study points out that the suppliers' self-evaluation scores of environmental capabilities are higher than the contractor. Balasubramanian (2020) study supply chain stakeholders' responsibilities in delivering sustainable supply chain in the construction industry. Alwan et al. (2017) present a case study in the UK construction industry on housing construction with zero carbon and zero waste. They present a bottom-up strategy as a way of

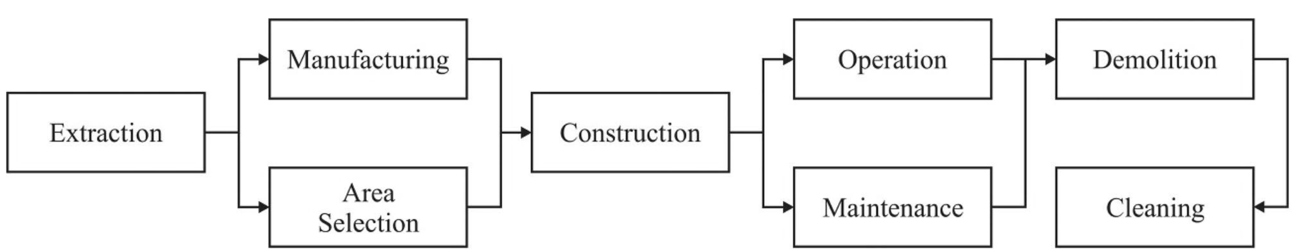


Fig. 2 Construction supply chain model

coordinating the stakeholders within the industry. Balasubramanian and Shukla (2017) present a multi-dimensional green supply chain management (GSCM) framework and validate by data collected through a structured questionnaire. Their findings show that the implementation of green practices positively impacts the environmental, economic and organizational performance for all stakeholders. Zeng et al. (2018) study a model to reveal the relationship between construction supply chain (CSM) integration and sustainable use of construction materials with an empirical investigation by partial least squares-based structural equation modeling (PLS-SEM). They find that CSM integration positively correlates with the sustainable use of construction materials and emphasized that it is worth investing in construction supply chain integration for sustainability.

The literature review above reveals that sustainability has come into prominence, yet it is considered difficult to implement in the construction industry. A well-structured, unifying framework for sustainability in the construction industry has been missing (Alwan et al. 2017). Therefore, new practices and approaches are needed (Russell et al. 2018). Moreover, building design and material choices must be evaluated according to their long-term economic, social and environmental impacts (Hassan, 2006). Supply chain management considerations are mostly about economics. However, environmental and social considerations also need to be considered in supply chain management. Thus, to perform a sustainable supply chain for the construction industry, we combine the construction supply chain with the principles of three dimensions of sustainability. In order to take care of environmental and social aspects, here, we change one of the supply chain elements from cleaning to recycling. This transformation dramatically influences the diminishing negative effects of the construction industry on the environment and society (US EPA, 2016). We utilize the life cycle assessments of construction to form the construction supply chain, including extraction, manufacturing, area selection, construction, operation, maintenance, demolition and cleaning.

Research methodology

In this study, an ANP model is developed to explore the importance of sustainable supply chain elements in the construction industry. We exploit qualitative and quantitative techniques to structure an ANP model since both can be beneficial in different characteristics of a decision situation. In particular, while quantitative techniques are used to present interrelationships among criteria, utilizing qualitative techniques are more convenient to capture intangible characteristics of a decision problem.

ANP is a well-known decision-making tool developed by (Saaty, 1999) that provides a structure that simultaneously takes into account both the relationships of feedback and dependence. Indeed, ANP is the general form of the analytic hierarchy process (AHP). The main difference between them is that AHP uses hierarchies, while ANP uses networks to make decisions. By using networks, ANP shows the relationship and dependencies between criteria and alternatives, while AHP does not take into account the relationships between criteria. Precisely, ANP allows developing more generalized decision-making models with interdependency (dependency between network elements) and outer dependency (dependency between clusters of elements). Interdependencies among different levels of criteria are graphically presented with two-way arcs. Due to its nonlinear structure resulting network, ANP can be used in situations where cycles occurred. ANP does not emphasize elements; it focuses on a cluster of elements (Saaty, 1999).

We discuss the generic steps for AHP and ANP (some of them specific to ANP). The first step of ANP models is similar to the AHP models, yet there are some differences. Instead of hierarchy, in ANP, the problem is modeled as a network that can represent relationships and dependencies. As in AHP, the elements among the same cluster and other clusters and the clusters are compared each other by using pairwise comparisons with respect to their relations using a scale of absolute numbers ranging from 1 and 9 where 1 shows the equal importance between two criteria and the importance level increasing as the rank increases. The scale of these absolute numbers is given Table 1.

When *activity i* is compared to *activity j*, the importance value will be one of the numbers from Table 1. To find the importance value of the *activity j* compared to *activity i*, the reciprocal of the importance value is taken. For example, if the importance value between is *activity i* compared to *activity j* is 5, then the importance value of the *activity j* compared to *activity i* is its reciprocal, 1/5 (Saaty 2008). Then the matrices are formed the same as AHP and normalized to find the weights. Finally, the consistency of the matrices is checked.

The difference between AHP and ANP method reveals in the second step. A supermatrix consisting of all the clusters with their elements is formed. Inside this supermatrix, the weights of the elements are written with respect to the corresponding elements. This matrix is called the unweighted supermatrix (Saaty and Vargas, 2006). In the third step, the unweighted supermatrix and weighted supermatrix are obtained. The fourth step of the ANP is the calculation of the limit matrix. By taking the $k + 1$ power of the weighted supermatrix, the limit matrix is calculated where k is an arbitrary number which makes the weighted matrix stable. The ranking of the alternatives is derived from the limit matrix, (Saaty and Vargas, 2006). There are many articles about

Table 1 Fundamental scale of absolute numbers (Saaty, 2008)

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another: its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

ANP application in the literature such as (Tavana et al. 2017; Leksono et al. 2019). We depict the steps of the research methodology implemented in this study in Fig. 3.

Application of the ANP model

The proposed ANP model explores the importance of sustainable supply chain elements in the construction industry. In this study, using the sustainability dimensions as a reference, decision criteria clusters are defined under three categories: economic, environmental and social. The possible elements under each cluster are determined from the existing literature. After that, by consulting with experts from the Turkish construction industry, the elements under each cluster are selected. To make the model more robust and lean, some elements are combined and some are eliminated. In order to determine the inner and interdependence relationship among those critical elements, we conduct in-depth interviews and focus group sessions.

We first present elements of SSCM and discuss SSCM clusters in detail, and later, we present inner and interdependence relationships.

Development of the ANP model

We present the development process of the ANP model as having eight steps as follows:

Step1 Figure 4 shows the sustainable supply chain management model for construction, which includes extraction, manufacturing, transportation, area selection, construction, operation, maintenance, demolition and recycling. The main dimensions of the SSCM factors were determined by reviewing the literature review and confirmed with experts from the construction industry. Each element in the model is briefly defined below.

Construction sustainable supply chain management elements:

- ***Extraction*** This element represents the extraction of raw materials and delivering the resources to the manufacturers.
- ***Manufacturing*** This element represents the manufacturing of construction materials. Manufacturing consists of two stages: product design and production.
- ***Transportation*** This element represents the transportation of construction materials to the construction site.
- ***Area selection*** This element resents the selection criteria of the construction site.
- ***Construction*** This element represents all operations performed during the construction stage.
- ***Marketing*** This element focuses on selling the products.
- ***Operation*** This element includes all activities necessary for an operational building.
- ***Maintenance*** This element represents the maintenance activities to keep the building functional in its life cycle.
- ***Demolition*** This element deals with the demolition of the buildings at the end of their life cycles.
- ***Recycling*** This element deals with the recycling of the debris after the demolition

Table 2 presents essential activities for each sustainable supply chain management element to achieve a successful sustainable construction supply chain system. We also express the connection between those activities and the dimensions of sustainability.

Main clusters of the ANP models

Economic cluster

We define four criteria of the economic cluster, which are related to mainly economic factors. These are: total cost of

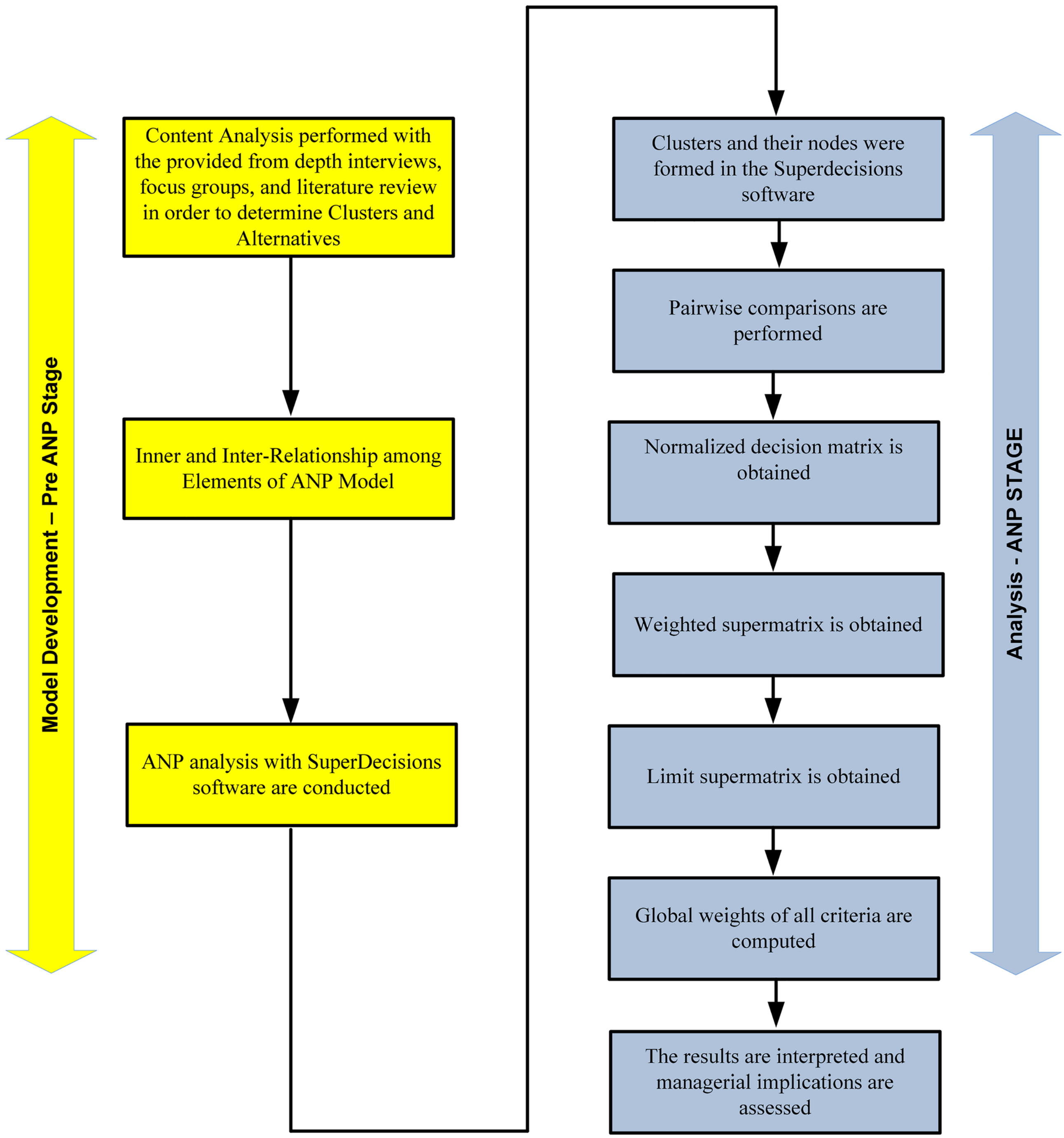


Fig. 3 Research methodology

ownership, investment rate, quality and efficiency. Although those four elements are standard economic performance indicators, they must follow some rules that are formed to achieve economic sustainability (Elliott, 2005). We consider the following rules in defining economic criteria:

The first rule suggests that economic structures must be planned and formed for long terms so that the present generation and also the future generations can benefit from them. This rule is related to the first element, "Total Cost of Ownership."

The second rule is the total capital of a company should always be at the same levels. This rule suggests that the investments' returns should not reduce the total capital, at least keep at the same level. So, in the future, the company

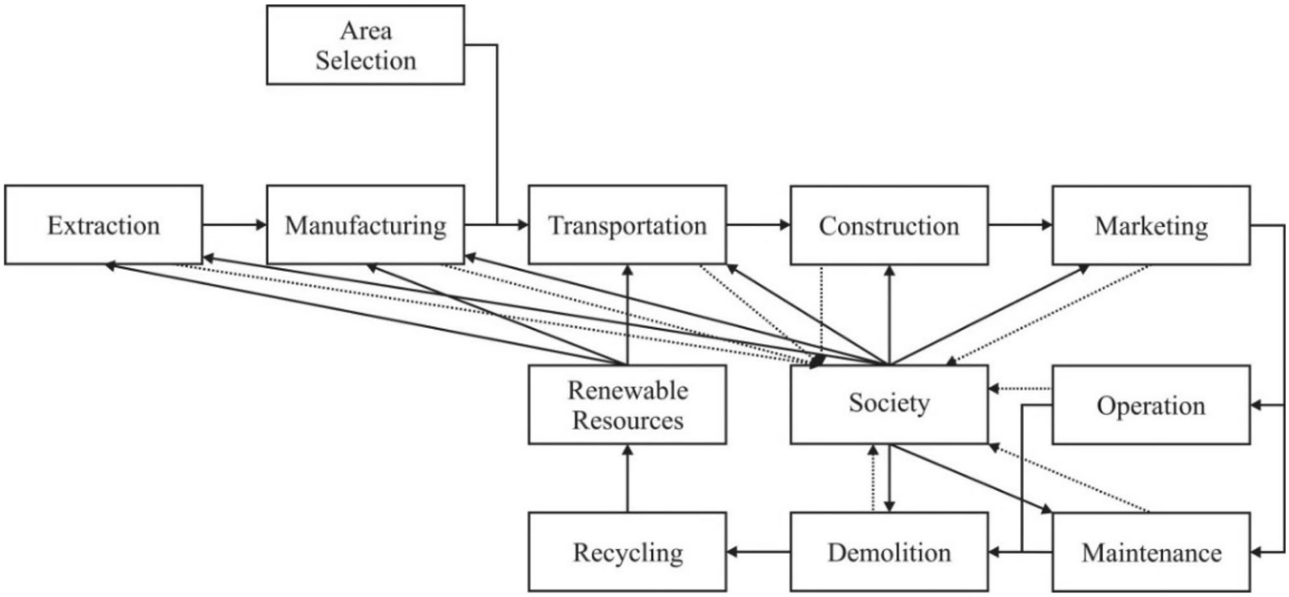


Fig. 4 Sustainable supply chain model for construction

can seize new opportunities. This rule is related to the first element, "Total Cost of Ownership" and the second element, "Investment Rate."

The next rule indicates that the price of materials and services or loans must be paid by the generation that uses them and must not leave to the future generations. This rule aims to avoid being a burden to future generations. In other words, each generation must be self-sufficient. This rule is also related to the first element, "Total Cost of Ownership," and the second element, "Investment Rate."

Another important rule for Economic sustainability is to ensure that the current resources at hand must be used most efficiently, so that the wastage, while using the resources, can be minimized without a decrease in quality. This rule is related to the third rule, "Quality" and the fourth rule, "Efficiency."

The other rule states that the government should keep the monetary value stable so that a more stable economic environment can be formed. The last rule states that the government should designate reasonable tax levels such that taxpayers' operations or productivity cannot be affected. These last two rules affect all the elements in the Economic cluster.

Environmental cluster

In general, the elements of the environmental cluster can be categorized into two subjects as the usage of green technologies and protecting nature (Mahler, 2007). In this subsection, we define five criteria of the environmental cluster which are related to environmental factors. These are: usage of green techs, effects on the environment, usage of natural resources, energy usage and waste management.

The usage of green technologies is designed to protect the environment, making it more viable and sustainable. The main green technologies are recycling technologies, sewer and wastewater treatment systems, waste management systems, renewable energy and energy preservation systems. The main goal of green technologies is to use technological advancement so that the resources can be renewed and pollution can be controlled.

The second element deals with the construction industry's "effects on the environment." Once a resource enters the supply chain, at some point it will leave the supply chain in the form of products and by-products. The environmental effects of those resources and their by-products are a responsibility on the companies' shoulder that uses them. These responsibilities are generally satisfied with the usage of green technologies, and the main goal is to limit the harmful effects of products and by-products on nature. The main technologies used in the supply chain include recycling, solid waste management, energy conservation, water and air purification, electrical vehicles, renewable energy and resources, and solar and wind power (Oren, 2010).

The third and fourth elements ("usage of natural resources" and "energy usage") should be considered together since both of them are interconnected to each other since the energy needs of constructions are provided by consuming natural resources. In particular, environmental sustainability aims to reduce and limit the usage of non-renewable resources (e.g., coal, oil, gas, etc.) and find alternative renewable resources (Linton et al. 2007).

Table 2 Elements of sustainable supply chain model for construction

	Economic	Environmental	Social
Extraction	Low cost method with high yield	Not harmful to environment Extraction rate lower than the renewability rate	After extraction, extraction site must be reformed
Manufacturing	Sufficient production rate to satisfy the market demand	Raw materials must be non-hazardous, renewable and recyclable materials Longer product life cycle to minimize the waste	Improved working conditions Noise and odor
	Minimum raw material usage without compromising the quality	Energy usage Reduce the waste of both time and materials for production process Waste management	
Transportation	Transportation of construction materials to the construction site with lowest cost	Alternative mode of transportation which has less effects on environment	Noise and odor of transportation vehicles
Area selection	For high demand, should be close to population centers	Should not be close to farms and water reservoirs Light pollution and urban heat islands	Closeness to various transportation utilities Complaint management
	Being closer to the population centers increases the costs In order to increase the demand for far places, extra cost occurs	Closeness of the dump sites of the diggings and the wastes	Obeying the regulation of the selected area
Construction	Cheaper construction materials and labor without lowering the quality	Keeping the effects of construction on environment under control Construction should be designed with respect to green buildings standards Type of construction materials should be recyclable and non-hazardous materials Water and other natural resources usage Renewable energy usage Green technologies usage and innovations In landscaping, indigenous plants of that area should be used Excavated soil should be stored so that it can be used again in the landscaping Plants should be selected from durable plants which use less water	Worker safety The social security and worker's rights Constructions effects on nearby population centers Complaint management
	Level of quality must be determined with respect to customer type and should be achieved with the minimum cost	Management of the construction waste	
Marketing	Using sustainability as a competitive tool Green buildings certificates	–	–
Operation	No positive output; there is a continuous consumption of resources, even little savings have big impact	Self-sufficient green techs Energy and resource saving technologies Waste management	Apartment life's effects on the neighbor relations Neighborhood concept Complaint management laws and regulation for operation of the building Social events
Maintenance	Can be a costly so should be done in most efficient way	An opportunity to implement new or lacking green techs to the building nature-friendly, renewable and recyclable materials should be used Waste management	Should be arranged in a manner which should not disturb the society

Table 2 (continued)

	Economic	Environmental	Social
Demolition	Cost of demolition	Effects of the demolition	Demolition effects on society
		Cleaning the debris	
		Restoring the surrounding area's environment	Can be very disturbing for society
Recycling	A very effective way to make saving	Reduces the usage of natural resources	

However, the usage of renewable resources must not exceed their renewability rate. For example, if the cutting rate of trees exceeds the growth rate, in the near future most parts of the forests might be gone (Linton et al. 2007).

The last element of the environmental cluster deals with "waste management." The most important factors for this element are the type of waste, quantity and its effect on the environment. The construction industry worldwide is a prominent consumer of many types of raw materials. Also, it produces a large amount of waste, both during construction and the demolition of buildings. These wastes need to be classified as recyclable and non-recyclable. Recyclable parts can be used again after the proper process, but non-recyclable parts may create some problems (Linton et al. 2007).

Social cluster

Social cluster mainly focuses on two subjects: living conditions of society and the working environment (Mahler, 2007). However, each subject has effects on the supply chain both during and after construction. In this subsection, we define five criteria for the social cluster. These are: effects on society, safer working conditions, grievance management, compliance to laws and regulations, and social activities.

As indicated above, social cluster handle issues for both people in the society and also workers. The second element, "safer working condition" and the fourth element, "compliance to laws and regulations" are mainly interested in improving working conditions (Seuring and Müller, 2008). The first element, "Effects on Society," third element "Complaint Management," fourth element "Compliance to Laws and Regulations" and the fifth element, "Social Activities" mainly deal with people's living conditions.

The supply chain of the construction industry has both positive and negative effects on society. The positive effects are basically social events, projects, fundraisers and awareness-raising that the companies in supply chain performs. For the adverse effects on society, companies' disturbance (e.g., noise, odor, dust and waste) must be investigated (Seuring and Müller, 2008).

Alternative cluster

As discussed in the literature review, the main elements of sustainable supply chain management in the construction industry are extraction, manufacturing, transportation, land selection, construction, marketing, operation, maintenance, demolition and recycling.

Step 2: inner and interrelationship among elements of ANP model

The ANP model consists of clusters of elements connected by their dependence on each other. We define a whole set of network clusters and their nodes in which CSCM can be measured using the ANP method. We then connect all the nodes in each cluster with respect to their outer and inner dependencies that are determined by the analysis of conducted in-depth interviews and focus group session results. The connections indicate the impact between the nodes where arrows between clusters show impacts or influences. The loops above the cluster denote inner dependency among the nodes in the same cluster (Saaty 2005). We present interdependencies among nodes and clusters in Table 3.

Step 3: ANP-based proposed CSCM model

In this step, we construct an ANP-based CSCM model based on literature review and expert opinion. The constructed model is depicted in Fig. 5. This model has three main clusters and one alternative cluster with their elements.

Step 4: Pairwise comparison of clusters

In this step, a pairwise comparisons matrix is formed to show the relative importance of dimensions in achieving the SSCM in the construction industry. Experts are asked to respond to the relative weighting of each dimension. The fundamental comparison scale values (1–9) are used to show relative importance where a score of 1 represents equal importance between two nodes (dimensions), and a score of 9 denotes the extreme importance of one node to another node. This comparison matrix demonstrates the relative importance status of node i on the node j. The

Table 3 Dependency matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
A_1: Extraction											×		×			×		×			×	×	×	
A_2: Manufacturing											×		×	×		×	×	×		×	×		×	×
A_3: Transportation											×	×				×		×		×	×			
A_4: Land selection											×	×			×			×			×	×		
A_5: Construction											×	×	×	×	×	×	×	×	×	×	×	×	×	×
A_6: Marketing													×		×					×			×	
A_7: Operation														×	×		×		×	×	×	×	×	×
A_8: Maintenance											×		×			×	×	×		×	×	×	×	×
A_9 – Demolition											×				×	×	×	×			×			×
A_{10}: Recycling											×	×		×	×			×		×				×
Ec_1: Total cost of ownership	×	×	×	×	×	×	×	×	×	×		×	×	×										
Ec_2: Investment rate		×	×	×	×	×																		
Ec_3: Quality	×	×			×	×		×																
Ec_4: Efficiency		×			×			×																
S_1: Effects on society				×	×	×	×	×		×						×	×	×	×					
S_2: Safer working conditions	×	×			×			×	×															
S_3: Complaint management		×	×		×		×		×															
S_4: Compliance to laws and regulations	×	×		×	×		×	×	×															
S_5: Social activities							×																	
En_1: Usage of green tech		×	×		×	×	×	×																
En_2: Effects on environment	×	×	×	×	×		×		×											×		×	×	×
En_3: Usage of natural resources	×		×		×		×																	
En_4: Energy usage	×	×	×		×		×		×	×														
En_5: Waste management		×			×		×			×														

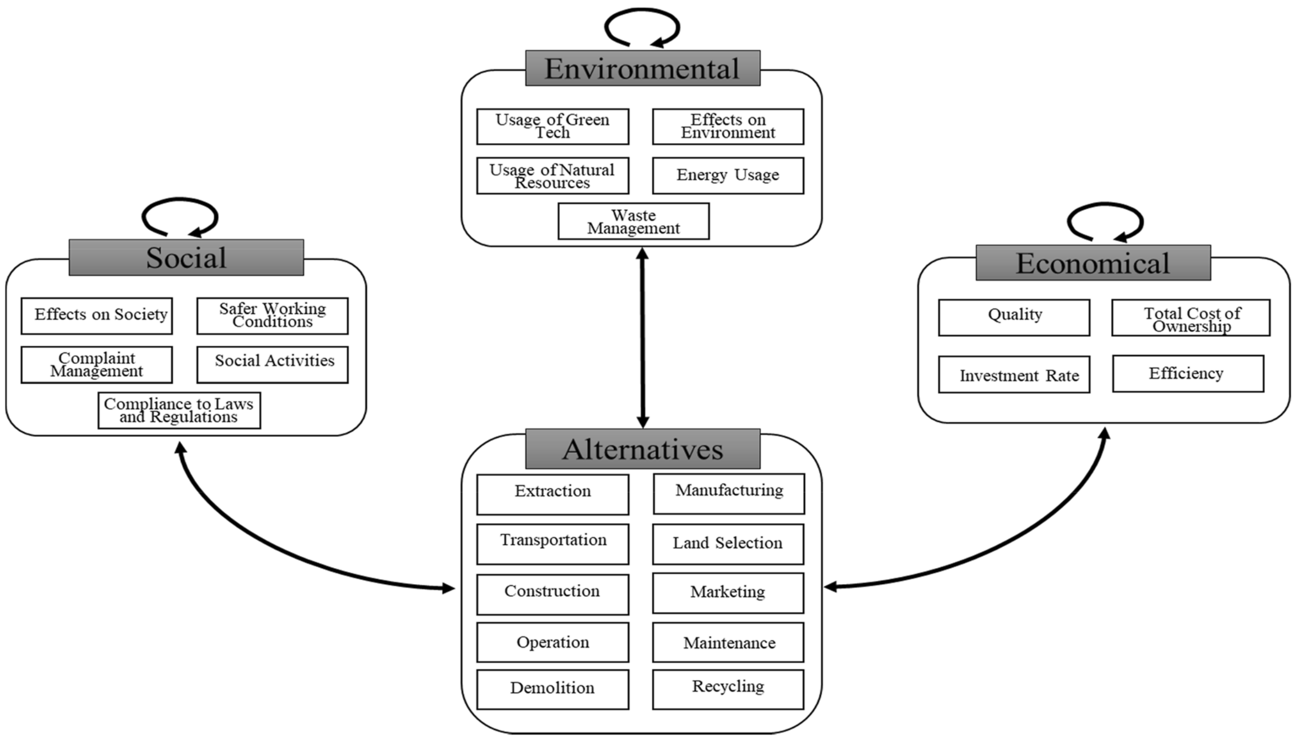


Fig. 5 Network model

Table 4 Pairwise comparison of dimensions

DMU	Economic	Social	Environment	Weight
Economic	1	1	1	0.3333
Social	1	1	1	0.3333
Environment	1	1	1	0.3333
Inconsistency ratio: 0				

relative importance value a_{ij} is calculated by $a_{ij} = \frac{w_i}{w_j}$ where w_i is the weight of node i (Saaty 1999).

Once the comparison matrices are developed, local priority vectors (*aka* eigenvectors) is computed using the Super Decision software. The priority values are simply obtained by solving Eq. (1).

$$Aw = \lambda_{max} w \tag{1}$$

where w is the corresponding eigenvector and λ_{max} is the largest eigenvalue of the comparison matrix. The pairwise comparison of nodes (dimensions) and corresponding eigenvalues are presented in Table 4. Our analysis based on expert opinions shows that three dimensions of sustainability have equal importance. This is consistent with sustainability literature.

Step 5: Pairwise comparisons between dimensions/element

In this step, experts are asked to respond to the relative weighs of each element (for each dimension). Each expert provides comparison values by comparing two elements at a time. The relative importance of each element for a dimension is calculated through a pairwise comparison matrix. In this study, we have three such matrices, one for each dimension. The pairwise comparisons matrix for the environmental dimension is given in Table 5. Similarly, the same procedure is applied for all the remaining elements of all clusters.

Step 6: Evaluation of alternatives

The final set of pairwise comparisons is conducted for the relative impact of each alternatives on the elements in influencing the dimensions. The number of such pairwise comparison matrices depends on the number of elements in each dimension. In this study, we have a total of 14 elements belongs to 3 dimensions. Thus, in this step, 14 such pairwise comparison matrices were constructed. Table 6 shows one example of such a matrix. Table 6 presents the impacts of alternatives that are calculated based on the element' Usage of Green Tech' in the environmental dimension.

Table 5 Pairwise comparison for social dimension

DMU	S_1	S_2	S_3	S_4	S_5	Weight
S_1	1	1	1	1	1	0.1920
S_2	1	1	0.5	0.25	0.25	0.1098
S_3	1	2	1	0.5	1	0.1796
S_4	1	4	2	1	3	0.3499
S_5	1	2	1	0.333	1	0.1688
Inconsistency ratio: 0.007						

Table 6 Pairwise comparison of alternatives based on 'Usage of Green Tech' element

DMU	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Weight
A_1	1	0.33	1	0.5	0.2	4	0.25	1	5	5	0.0689
A_2	3	1	4	0.5	1	5	3	4	5	6	0.1834
A_3	1	0.25	1	0.33	0.2	4	0.33	1	4	5	0.0634
A_4	2	2	3	1	2	5	3	4	6	6	0.2145
A_5	5	1	5	0.5	1	7	1	2	6	7	0.1674
A_6	0.25	0.2	0.25	0.2	0.14	1	0.14	0.14	0.25	0.25	0.0177
A_7	4	0.33	3	0.33	1	7	1	4	6	7	0.1508
A_8	1	0.25	1	0.25	0.5	7	0.25	1	7	8	0.0833
A_9	0.2	0.2	0.25	0.17	0.17	4	0.17	0.14	1	0.5	0.0244
A_{10}	0.2	0.17	0.2	0.17	0.14	4	0.14	0.13	2	1	0.0261
Inconsistency ratio: 0.09											

Step 7: Supermatrix formation

A supermatrix is a data structure that contains priorities from the comparison groups. It provides the relative importance of all components. The unweighted supermatrix contains all pairwise comparison results where a weighted supermatrix rated by the importance of clusters is important for network models. The limit supermatrix is the final version of the supermatrix, obtained by raising the weighted supermatrix to its odd powers as in Eq. 2.

$$W = \lim_{k \to \infty} (A)^{2k+1} \tag{2}$$

where A is weighted supermatrix.

At this step, weighted, unweighted and limit supermatrices are constructed (see Table 7, 8, 9). Priority vectors are derived in the supermatrix, a "0" appearing in the matrix means that the element in its row has no effect on the element in its column. The unweighted supermatrix includes the local priorities resulting from the pairwise comparisons of the model (see Table 7). The supermatrix is required to be stochastic to derive reasonable limiting priorities. A matrix is a stochastic matrix when all of its columns add up to one. The weighted supermatrix is obtained using the cluster matrix (formed after the cluster comparisons) to normalize the supermatrix.

Step 8: Selection of the best alternative (ranking of the alternatives)

The rank of each alternative is determined based on the value of the normalized values. The desirability indices, Di for alternative i are defined as Idealized values are found by dividing the biggest normalized value by all normalized values. Ideal, normal and raw values for "Alternatives" are given in Table 10. The importance of the "Alternatives" ranking given in Fig. 6 based on ideal values.

Results and discussion

In this study, the construction industry elements are ranked in a sustainability perspective based on ANP methodology. Table 11 shows the ranking of the 14 criteria based on the values of limiting priorities. At the cluster level, the economic cluster has the highest level of importance (0.365) followed by environmental (0.324) and social (0.311) clusters.

Table 7 Unweighted supermatrix

Unweighted supermatrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
A_1: Extraction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.000	0.040	0.000	0.000	0.180	0.000	0.088	0.000	0.000	0.111	0.461	0.079	0.000
A_2: Manufacturing	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.183	0.297	0.246	0.405	0.000	0.199	0.071	0.085	0.000	0.261	0.141	0.000	0.179	0.202
A_3: Transportation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.063	0.053	0.000	0.000	0.000	0.000	0.042	0.000	0.000	0.139	0.087	0.141	0.110	0.000
A_4: Land selection	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.214	0.373	0.000	0.000	0.209	0.000	0.000	0.252	0.000	0.000	0.109	0.000	0.000	0.000
A_5: Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.204	0.388	0.481	0.119	0.480	0.374	0.241	0.000	0.301	0.145	0.134	0.182	0.120
A_6: Marketing	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.074	0.071	0.000	0.032	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000
A_7: Operation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.151	0.000	0.000	0.000	0.321	0.000	0.309	0.252	1.000	0.120	0.379	0.264	0.349	0.597
A_8: Maintenance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.255	0.114	0.258	0.039	0.000	0.045	0.000	0.145	0.000	0.000	0.036	0.000
A_9: Demolition	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.000	0.000	0.000	0.000	0.102	0.205	0.036	0.000	0.000	0.028	0.000	0.022	0.000
A_{10}: Recycling	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.081
Ec_1: Total cost of ownership	0.800	0.444	0.750	0.500	0.493	0.000	0.000	0.500	1.000	0.455	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_2: Investment rate	0.000	0.000	0.250	0.500	0.282	0.000	0.000	0.000	0.000	0.455	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_3: Quality	0.200	0.111	0.000	0.000	0.075	1.000	0.000	0.500	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_4: Efficiency	0.000	0.444	0.000	0.000	0.150	0.000	1.000	0.000	0.000	0.091	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_1: Effects on society	0.000	0.000	0.000	0.200	0.090	0.167	0.077	0.000	0.110	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_2: Safer working conditions	0.500	0.280	0.200	0.000	0.370	0.000	0.000	0.268	0.259	0.000	0.000	0.000	0.000	0.000	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_3: Complaint management	0.000	0.094	0.000	0.000	0.132	0.000	0.171	0.117	0.095	0.000	0.000	0.000	0.000	0.000	0.216	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_4: Compliance to laws and regulations	0.500	0.627	0.800	0.800	0.345	0.833	0.521	0.614	0.536	0.833	0.000	0.000	0.000	0.000	0.480	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 7 (continued)

Unweighted supermatrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
S_5: Social activities	0.000	0.000	0.000	0.000	0.064	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
En_1: Usage of green tech	0.000	0.478	0.333	0.000	0.293	0.750	0.214	0.435	0.000	0.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000
En_2: Effects on environment	0.126	0.137	0.333	0.500	0.062	0.000	0.105	0.081	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
En_3: Usage of natural resources	0.458	0.000	0.333	0.500	0.122	0.000	0.164	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000
En_4: Energy usage	0.416	0.277	0.000	0.000	0.350	0.250	0.302	0.242	0.000	0.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000
En_5: Waste management	0.000	0.108	0.000	0.000	0.173	0.000	0.216	0.160	0.500	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000

In the Economic cluster, "Total Cost of Ownership" is the most essential criterion followed by "Efficiency" and "Investment Rate." "Quality" has the lowest importance level in the Economic cluster. This result arises because elements involving to cost are main concern in Turkish Construction Industry, which leads to decreased weight of quality in our model.

Within the environmental cluster, the "Usage of Green Technologies" criterion has the highest level of importance, followed by "Energy Usage" and "Usage of Natural Resources." "Waste Management" and "Effects on Environment" have relatively small importance in the environmental cluster.

Finally, within the social cluster, the "Compliance to Laws and Regulations" criterion has the highest level of importance, followed by "Safer Working Conditions" and "Complaint Management." "Social Activities" and "Effects on Society" have the lowest two importance levels in the social cluster. Our results imply that criteria of social cluster involving safety and regulations are main concerns, while the other elements are unnoticed in the SCM process.

Our analysis indicates that the "Compliance to Laws and Regulations" criterion has the highest level in the overall ranking. It is followed by "Total Cost of Ownership" and "Efficiency." On the other hand, "Complaint Management," "Social Activities" and "Effects on Society" have the lowest importance levels, respectively. Remarkably, the most important criterion (Compliance to Laws and Regulations) and three criteria with the lowest importance level belong to Social Cluster. The overall ranking of all criteria is presented in Table 11.

We present the ranking of alternatives in Table 10. Our findings show that "Construction" is the most important element of SSCM in Construction alternatives (stages). The second and third important elements are "Operation" and "Manufacturing," respectively. They followed by "Land selection," "Extraction," "Maintenance," "Transportation," "Demolition," "Marketing" and "Recycling," respectively.

As stated above, "Construction," "Operation" and "Manufacturing" are the most crucial alternatives to the construction industry. This is expected because these alternatives affect all three dimensions of sustainability. Also, since "Construction" and "Manufacturing" are the most resource-consuming alternatives, firms focus on sustainability practices at these alternatives to the cost and resource usage. Similarly, "Operation" alternatives are also very important due to the high energy and natural resources usage. The most significant part of the social dimension is directly related to the "Operation" as well.

In the course of selecting a construction material, its reparability, maintenance cost and difficulty should be considered. Concrete's maintenance might be extremely difficult. In particular, it is hard to repair, heavy, and does not allow us a partial replacement. On the other hand, timber and steel provide easier maintenance and reparability capabilities. Furthermore, timber is light, easy to carry; its application is relatively easier and allows us a partial replacement. However, short useful life might be a negative factor for timber. Also, Timber has a relatively low recyclability rate of nearly 13%. However, timber waste can be used in other industries without losing its value instead of construction (King et al. 2015). Also, its effect on nature is minor, and it is a more environmentally friendly material than concrete.

Steel has a very high recyclability rate of nearly 94%. Steel preserves its high value over time. Steel's effect on the environment is also minimal due to the high recyclability rate. Although heavyweight is a negative factor for steel, maintenance of steel is easier than concrete. Maintenance of steel is possible with repair techniques and processes such as welding (plasma, laser, electron beam) and metal stitching. Therefore, in order to increase the sustainability of recycling alternatives, the usage of steel as the primary construction material is recommended.

"Marketing" has the second-lowest score among alternatives. The sustainability factors are used as a marketing and advertisement tool for some sectors in recent years. Especially for home appliances, it is widely used as a marketing strategy. Many home appliance producers highlight the performance of their products in water and energy efficiency. Indeed, energy efficiency is emphasized in many sectors, from mobile devices to automotive. However, the usage of sustainability in marketing is very new for the construction industry in Turkey. Although it is a new concept, increased environmental consciousness in the population leads construction companies to consider sustainability dimensions in the buildings. The number of buildings that implemented sustainable technologies are increasing. Thus, sustainability factors may have a more important role in the marketing of the Turkish construction industry in the near future.

Conclusion

Sustainability is one of the most crucial topics of today's business and academic world. Nowadays, global warming and environmental pollution have become one of the main problems. In particular, climate change threatens not only humanity but also the environment. Therefore, the ways of being sustainable are widely criticized by academics, writers and politicians. There are many different sustainability perspectives, but one important concept is the *triple bottom line* approach (Seuring and Müller 2008). It implies the "*integration and achievement of an organization's social, environmental and economic goals in the systemic coordination*" (Carter and Rogers 2008). Therefore, sustainability can be satisfied by considering environmental, social and economic performance together (Elkington 1998).

In this study, a sustainable supply chain management model in construction is developed, and the sustainability level of Turkey's construction industry is evaluated via this model. According to the triple bottom line approach, decision criteria clusters are determined under three categories: economic, environmental and social. Our analysis for clusters, show that social cluster has the lowest weight, but contains the highest weight element "Compliance to Laws and Regulations." The rest of the elements in social cluster have relatively lower weights, which implies social aspect of SSCM should be improved. We also observe that in the economical cluster, quality has the lowest importance,

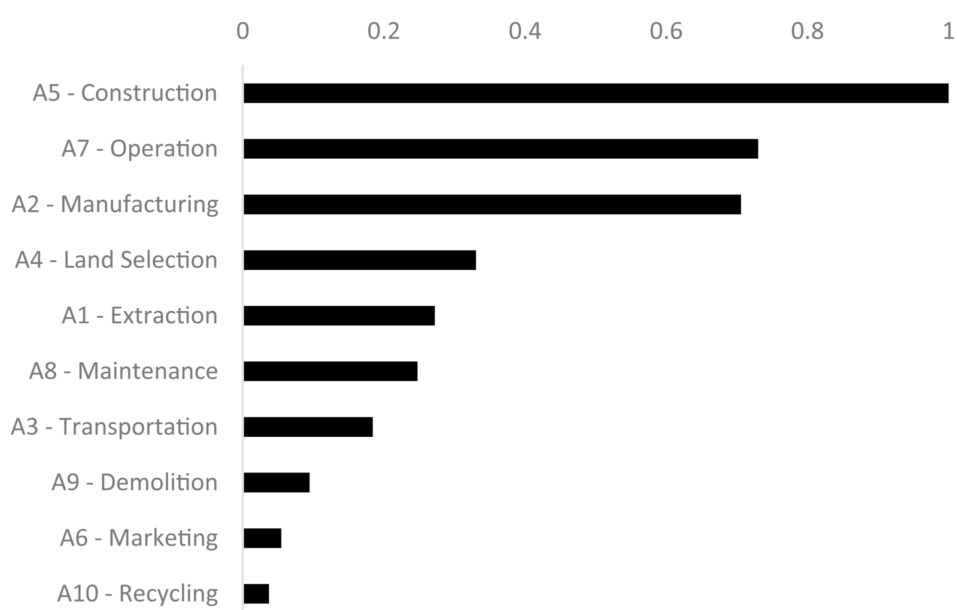


Fig. 6 Ideal ranking of alternatives

Table 8 Weighted supermatrix

Weighted supermatrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
A_1: Extraction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.040	0.000	0.000	0.180	0.000	0.088	0.000	0.000	0.055	0.461	0.079	0.000
A_2: Manufacturing	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.092	0.297	0.246	0.405	0.000	0.199	0.071	0.085	0.000	0.261	0.071	0.000	0.179	0.202
A_3: Transportation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.053	0.000	0.000	0.000	0.000	0.042	0.000	0.000	0.139	0.043	0.141	0.110	0.000
A_4: Land selection	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.373	0.000	0.000	0.105	0.000	0.000	0.252	0.000	0.000	0.055	0.000	0.000	0.000
A_5: Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.084	0.204	0.388	0.481	0.060	0.480	0.374	0.241	0.000	0.301	0.073	0.134	0.182	0.120
A_6: Marketing	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.074	0.071	0.000	0.016	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000
A_7: Operation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.000	0.000	0.000	0.160	0.000	0.309	0.252	1.000	0.120	0.190	0.264	0.349	0.597
A_8: Maintenance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.000	0.255	0.114	0.129	0.039	0.000	0.045	0.000	0.145	0.000	0.000	0.036	0.000
A_9 – Demolition	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.102	0.205	0.036	0.000	0.000	0.014	0.000	0.022	0.000
A_{10}: Recycling	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.081
Ec_1: Total Cost of ownership	0.267	0.148	0.250	0.167	0.164	0.000	0.000	0.167	0.333	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_2: Investment rate	0.000	0.000	0.083	0.167	0.094	0.000	0.000	0.000	0.000	0.152	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_3: Quality	0.067	0.037	0.000	0.000	0.025	0.333	0.000	0.167	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ec_4: Efficiency	0.000	0.148	0.000	0.000	0.050	0.000	0.333	0.000	0.000	0.030	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_1: Effects on society	0.000	0.000	0.000	0.067	0.030	0.056	0.026	0.000	0.037	0.056	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_2: Safer working conditions	0.167	0.093	0.067	0.000	0.123	0.000	0.000	0.089	0.086	0.000	0.000	0.000	0.000	0.000	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_3: Complaint management	0.000	0.031	0.000	0.000	0.044	0.000	0.057	0.039	0.032	0.000	0.000	0.000	0.000	0.000	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_4: Compliance to laws and regulations	0.167	0.209	0.267	0.267	0.115	0.278	0.174	0.205	0.179	0.278	0.000	0.000	0.000	0.000	0.240	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_5: Social activities	0.000	0.000	0.000	0.000	0.021	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 8 (continued)

Weighted supermatrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
En_1: Usage of green tech	0.000	0.159	0.111	0.000	0.098	0.250	0.071	0.145	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000
En_2: Effects on environment	0.042	0.046	0.111	0.167	0.021	0.000	0.035	0.027	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
En_3: Usage of natural resources	0.153	0.000	0.111	0.167	0.041	0.000	0.055	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000
En_4: Energy usage	0.139	0.092	0.000	0.000	0.117	0.083	0.101	0.081	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000
En_5: Waste management	0.000	0.036	0.000	0.000	0.058	0.000	0.072	0.053	0.167	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000

since it is negatively correlated to overall cost. The analysis of the environmental cluster shows the relationship between marketing and environmental elements. The environmental elements are considered as marketing tools for the competition between firms.

Our analysis shows that alternatives with the highest scores are construction, operation and manufacturing, respectively. In addition to this, the lowest scores are recycling and marketing. We discuss the importance of alternatives with the highest score, and also, the reasons for the insufficient sustainability integration and ways to improve for alternatives with low scores are shown.

This study's merit contribution is developing a sustainable construction supply chain model by using the life cycle of buildings as its supply chain elements. Common construction supply chain models generally deal with the planning and construction part of structures, and sustainability integration with just these steps is not enough to fully analyze and satisfy sustainability. Therefore, we use not only planning and construction, but also usage, demolition and recycling steps in the sustainable supply chain management. Otherwise, the effects of sustainability dimensions (Economic, environmental and social) on sustainable supply chain management in construction cannot be fully explained.

This study can be extended in several ways. For example, this model is applied to residential buildings. However, the construction sector is not limited to residential buildings. The sustainability of structures like bridges, roads, education, government, social and sports facilities can be measured. For future study, with minor changes, this model can be applied to other structure types. Also, the SSCM model can be applied to big sized production projects that have similarities to construction supply chain, such as shipbuilding.

Finally, the collected data for analytic network process analysis is of crucial importance. In order to avoid subjective data, interviewed experts can be controlled and verified by other experts, so that the subjectivity of the results can be minimized in this way.

Appendix

See Tables 9, 10 and 11.

Table 9 Limit supermatrix

Limit matrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
A_1: Extraction	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
A_2: Manufacturing	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091
A_3: Transportation	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
A_4: Land selection	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
A_5: Construction	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128
A_6: Marketing	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
A_7: Operation	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
A_8: Maintenance	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
A_9: Demolition	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
A_{10}: Recycling	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Ec_1: Total cost of ownership	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
Ec_2: Investment rate	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
Ec_3: Quality	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Ec_4: Efficiency	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
S_1: Effects on society	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
S_2: Safer Working conditions	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
S_3: Complaint management	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
S_4: Compliance to laws and regulations	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089

Table 9 (continued)

Limit matrix	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	Ec_1	Ec_2	Ec_3	Ec_4	S_1	S_2	S_3	S_4	S_5	En_1	En_2	En_3	En_4	En_5
S_5: Social activities	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
En_1: Usage of green tech	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
En_2: Effects on environment	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
En_3: Usage of natural resources	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
En_4: Energy usage	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
En_5: Waste management	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024

Table 10 Alternative rankings

Alternatives	Limiting	Normalized	Ideals	Ranking
A_1—Extraction	0.036	0.077	0.286	5
A_2—Manufacturing	0.091	0.192	0.712	3
A_3—Transportation	0.022	0.046	0.171	7
A_4—Land selection	0.048	0.102	0.377	4
A_5—Construction	0.128	0.269	1.000	1
A_6—Marketing	0.007	0.015	0.056	9
A_7—Operation	0.094	0.198	0.734	2
A_8—Maintenance	0.030	0.064	0.238	6
A_9—Demolition	0.012	0.026	0.098	8
A_{10}—Recycling	0.005	0.011	0.040	10

Table 11 Normalized clusters and priorities

Cluster	Name	Normalized by cluster	Limiting	Overall ranking	Ranking inside cluster	Total	Normalized cluster
Economical	Ec_1—Total Cost of Ownership	0.353	0.068	2	1	0.192	0.365
	Ec_2—Investment Rate	0.224	0.043	6	3		
	Ec_3—Quality	0.121	0.023	11	4		
	Ec_4—Efficiency	0.302	0.058	3	2		
Social	S_1—Effects on Society	0.065	0.011	14	5	0.163	0.311
	S_2—Safer Working Conditions	0.221	0.036	7	2		
	S_3—Complaint Management	0.101	0.017	12	3		
	S_4—Compliance to Laws and Regulations	0.546	0.089	1	1		
	S_5—Social Activities	0.067	0.011	13	4		
Environmental	En_1—Usage of Green Tech	0.271	0.046	4	1	0.171	0.324
	En_2—Effects on Environment	0.146	0.025	9	4		
	En_3—Usage of Natural Resources	0.178	0.030	8	3		
	En_4—Energy Usage	0.262	0.045	5	2		
	En_5—Waste Management	0.143	0.024	10	5		

Declarations

Conflict of interest The author declared that there is no conflict of interest.

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