Available online at http://sanad.iau.ir/journal/ijim/
Int. J. Industrial Mathematics (ISSN 2008-5621)
Vol. 16, No. 2, 2024 Article ID IJIM-1629, 30 pages
Research Article

Science and Research Branch (IAU)

Sustainability assessment in concrete industry supply chain in stochastic environment

F. Shoaeshargh [1], M. Soufi [1*], A. Amirteimoori [2], M. Fadaei[1]

[1]Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran.
[2] Department of Applied Mathematics, Rasht Branch, Islamic Azad University, Rasht, Iran.

Submission Date: 2023/08/23, Revised Date: 2023/09/25, Date of Acceptance: 2024/08/28

Abstract
This research aims to develop data envelopment analysis (DEA) for predicting the supply chain sustainability of the concrete industry using stochastic variables. In the first phase, the mines and companies that organized the four supply chains of the Guilan concrete industry based on competitive elements were identified. After that, based on economic, social, and environmental indexes, the sustainability of the supply chains was chosen using the Fuzzy Delphi model and input and output of mines and concrete companies, which include controllable, desirable, and undesirable inputs and outputs. Finally, data envelopment analysis was used to measure the supply chain sustainability of the concrete industry employing crisp data and a linear model. The errors were entered into the model with a stochastic element based on the probability of the errors. In other words, according to stochastic data envelopment analysis, all input and output data were considered randomly. The output data shows that none of the four supply chains of the Guilan concrete industry is sustainable.

Keywords: Data Envelopment Analysis; Concrete Industry; Sustainability; Supply chain; Undesirable Outputs.

* Corresponding author: Email: msoufi45@gmail.com

1. Introduction

Many leading companies today regard the sustainability of their supply chains as a vital strategy for enhancing their competitive advantage [1]. Sustainable supply chain management serves as a unifying element that integrates economic, social, and environmental considerations across all stages of the supply chain, including product design, raw material selection and procurement, production, distribution, customer service, recycling management, and resource reuse. The aim is to optimize energy and resource utilization and improve the overall efficiency of the supply chain.

However, the prioritization of sustainable development elements varies across countries depending on their societal, cultural, and historical context. Given the global nature of sustainable development, practical solutions should be tailored to local or national levels to account for such differences. Effective sustainable supply chain management should therefore consider the unique social, cultural, and economic characteristics of each region to address local challenges while advancing sustainable development goals. Sustainable development frameworks embody diverse social, economic, environmental, and management challenges faced by different nations, and consequently, the definitions and interpretations of sustainable development often reflect their values and interests [2].

Sustainability entails meeting human needs while preserving environmental resources, and companies strive to produce goods without causing harm to society or the environment. Sustainable supply chain management is the foundation of sustainability in the supply chain. Essentially, sustainable supply chain management involves orienting the supply chain towards social, economic, and environmental considerations to minimize harm within the chain. Additionally, effective management can mitigate problems typically associated with traditional supply chains. The prevailing definition of sustainable supply chain management is the management of the supply chain that incorporates environmental, social, and economic concerns to achieve long-term economic goals at all levels of the supply chain [3].

Within the literature review of supply chain measurement, extensive research has been carried out across various industries to evaluate their sustainability performance. However, despite the significant adverse impacts associated with sand mining, which is a critical raw material in the concrete industry, there is a conspicuous lack of recognition of sustainability in the supply chain of the concrete industry at both the sand mining and concrete company levels. The production of concrete is a resource-intensive process that involves the extraction of sand from rivers and beaches, causing environmental damage and social disruptions in the local communities.

Although sustainability measurements have been conducted separately for sand mines and concrete companies, the lack of scholarly research focused on the sustainability of the entire supply chain, including the linkages between sand mining and concrete companies, has become a critical knowledge gap. Without a holistic understanding of the supply chain, it is difficult to identify the root causes of sustainability problems and implement effective solutions. The need for more comprehensive studies that take into account the entire supply chain and the interconnectivity between different companies has become increasingly pressing in the context of the growing demands for sustainability in the business world. By enhancing the sustainability performance of the supply chain, companies can not only improve their reputations but also gain a competitive advantage in the market.

Stochastic data envelopment analysis (SDEA) is a technique based on random programming that can evaluate the efficiency of a set of decision-making units. By predicting the efficiency and productivity of these decision-making units in the future, managers can identify and rectify any weaknesses to enhance performance and adopt alternative solutions. Therefore, the primary aim of this research is to develop a model that measures stability in sand mines and concrete production companies in Iran under a stochastic environment. This model will help these companies to identify inefficiencies in their supply chains and develop strategies to improve their sustainability and competitiveness.

Therefore, the main goal of this research is to provide a model for measuring the stability of sand mines and concrete production companies in Iran within a stochastic environment. This model will enable managers to assess the sustainability performance of their decision-making units and identify areas for improvement. The research will focus on analyzing the efficiency and productivity of sand mines and concrete production companies in Iran, as well as the factors that influence their performance. The results of this study will contribute to the understanding of the sustainability of the supply chain in the concrete industry and provide insights into how companies can improve their sustainability performance and enhance their competitiveness.

The rest of this paper is organized as follows: Section 2 briefly reviews the literature on sustainability. Section 3 discusses the proposed model to evaluate the sustainability in a stochastic environment. In Section 4, the proposed approach is applied to assessing sustainability of the supply chain of the Guilan concrete industry. Ultimately, Section 5 presents the conclusions.

2. Literature review

The design of DEA to assess sustainable supply chain function involves planning to minimize costs, social and environmental harm, and maximize social benefits and economic profits. The objective is to transform inputs into outputs using the most efficient and cost-effective solution during a specified time period. The primary aim is to achieve predetermined goals with the lowest possible cost or highest profit margin. The duration of such projects can range from short-term to mid-term and can be operational or tactical in nature [4]. Given the significance of a sustainable supply chain and its impact on the return on capital for supply and production companies, as well as its social and environmental effects, it is essential to understand this concept. To this end, it is important to explore studies pertaining to other industries to gain a better understanding of sustainable supply chain and their relevance.

Safari et al. [5] stated that “the importance of strategy related to supply chain and level of supply chain sustainability for increasing competitive power, performance and productivity improvement during the operation are one of the major challenges of companies.” Consequently, analyzing the supply chain sustainability of concrete companies within the competitive LARG supply chain in Bushehr resulted in ranking related strategies, with environmental issues identified as the most significant aspect of supply chain sustainability in Bushehr's concrete companies. Dervish Motavalli et al. [6] put that “regarding sustainable environment indexes are very significant and special heed is paid to it. Environmental pollutions of some industries and its impact on supply chain will affect the sustainability.” The research findings indicate that supply chain sustainability indices in the concrete industry play a significant role in preventing environmental pollution.

Mahmoudi and et al. [7] believe that “in designing a model for sustainable supply chain management performance of state hospitals using grounded theory approach is one of the most important decisions can be made in health supply chain management which leaves a considerable impact on capital return and its overall performance if supply chain management performance will be analyzed.” They proposed that their model could serve as a tool for predicting and policymaking in analyzing the sustainable supply chain management performance of state hospitals. Planning and policymaking for health improvement and environmental management systems can foster collaboration among various departments, reduce incorrect diagnoses and prescriptions, meet the specific needs of each patient, implement educational and care programs, and minimize pollutants.

Mohaghar and Abbasi [8] proposed a sustainable supply chain model for the banking industry. Through data analysis and expert confirmation, they identified six main dimensions (superior condition, mediator, background, strategies, sustainable policy-making, processes and outcomes) and recognized the main indicators of sustainability in the supply chain of the banking industry. In another study, Allahyari et al. [9] examined the sustainability of the supply chain in the pharmaceutical industry. Given the complexity of the healthcare industry and the role of the pharmaceutical sector in it, they added a governance dimension to the economic, social, and environmental aspects of supply chain sustainability.

Safaie and Gholamreza Tabar [10] tried to find a framework for food supply chain sustainability. Through a review of relevant literature and collaboration with various organizations including university scholars, Kalleh Meat Products of Amol, Zarbal Co. and Filleh Poultry Packaging Co., they proposed a sustainability framework based on Food and Agriculture Organization United Nations (FAO) guidelines. The study found that the physical and mental health of personnel and greenhouse gas emissions were the most critical factors in food supply chain sustainability. In addition, among the sub-criteria of the governance and economic dimensions, certified products and food security were found to be the most significant.

Seyed Houseini and Dervish Motavalli [11] investigated the potential of the concrete industry in Iran to become a hub in Asia, using data envelopment analysis to assess its supply chain performance. Sustainability is an emerging field in supply chain research that lacks established frameworks, models, and theories. There are two primary challenges to implementing sustainability in supply chains. First, sustainability depends on various factors that can either facilitate or hinder its success, significantly impacting the supply chain's sustainability performance. Second, sustainability requires a triad approach, addressing environmental, economic, and social performance simultaneously. These challenges make implementing sustainability in the supply chain a complex process involving many interactions. To address these challenges, this article proposes a mathematical model for analyzing supply chain sustainability. The model assumes that there is a probable sustainability display that can explain these challenges effectively. The proposed model's ease of use, simplicity, and ability to provide rapid feedback on supply chain sustainability during a specified period make it a valuable tool [12].

A literature review indicates that measuring supply chain sustainability has been a contentious topic in academia within and outside Iran, with various approaches employed across different industries. Table 1 summarizes the research findings from the last decade.

Table 1. Review of Related Literature about Sustainable Supply Chain in Different Industries on National and International Levels.

Method	Industry	Title	Author
Meta Synthesis and GTMA	Petro-chemical	Recognizing and Prioritizing Empowerment of Supply Chain Sustainability Management in Petro-chemical Industry Using Mixed Approached of "Meta-synthesis, GTMA	Sangbar and et al.[13]
Fuzzy DEMATEL& SME	Car-manufacturing	Surveying Challenges of Block chain Technology in Sustainable Supply Chain in Car Industry using Mixed Approach of Fuzzy DEMATEL& Fuzzy SME	Pilehvari and et al.[14]
Fuzzy Network DEA & DEMATEL	Shipbuilding	Recognizing and Ranking Obstacles of Sustainable Supply Chain Management Using Mixed Approach of Fuzzy ANP-DEMATEL in Bushehr Shipbuilding Company	Davoudi and Sazgari[15]
Factor Analysis	Construction	A Framework for Analysis of Sustainable Supply Chain Performance	Olfat and Moqimi [16]
Electron microscope	Sand	Recognizing Geological Indexes of Sand Sectoriculates in West of Tehran	Menhaj Bana et al [17]
Fuzzy DEA & DEMATEL	Car-manufacturing	Applying Mixed Approach for Improvement of Sustainable Supply Chain Management in Manufacturing Companies of Iran	Dehghan et al. [18]
Grounded Theory	State Hospital	Designing Analysis Model of Sustainable Supply Chain Performance in State Hospitals Using Grounded Theory Approach	Mahmoudi and et al. [19]
Multi Objective PSO	Glass	Mathematical Modeling of Sustainable Supply Chain Network in Indeterminate Situation Using Metaheuristic Algorithms	Fathi and et al. [20]
Data Envelopment Analysis (DEA)	Energy	Data Envelopment Analysis Method for Measuring Sustainable Supply Chain of Renewable Energy	Gorji and Javadian [21]
Time-spatial comparison method	Sand	Surveying Outcomes of Sand Extraction on River Morphology (A Case Study: River-Kerman)	Mohammad et al. [22]
ANOVA	Sand	Surveying Effects of Sand Water Waste on Environmental Indexes of Tirum River (Mazandran Province)	Bagheri et al. [23]
Kruskal-Wallis	Sand	Surveying Environmental Effects of Sand Extraction of Tonkabon River	Roshan Tabari et al. [24]
Two-layer vector drawing	Sand	Measurement of Morphological Changes in Kashkan River Due to Sand Extraction	Shayan et al. [25]
DEMATEL	Pharmaceutical	Suggesting An Integrated Measuring Model of Sustainable Performance in Supply Chain	Yuvisal [26]
Multi-dimensional Indexes	Sports-clothes	A Framework for Development and Sustainability Analysis with Multi-dimensional Indexes	Varsehie et al. [27]
Review	-	Analysis of Used Criteria for Measuring Performance in GSSC	Ahi and Sersi [28]
Mathematical	-	Sustainability Analysis of Supply Chain: Triad Linear Approach	Ahi and Sersi [29]

Review	-	Analysis of Performance Indexes of Social Responsibility	Sersi et al. [30]
DEA	Resin	Using Data Envelopment Analysis dear (DEA-R)	Khodakarami et al. [31]
DEA	Medical	Analysis of Supply Chain Sustainability Using	Izadkhah and Saen [32]
Best-Worst	Recycle	Social Sustainability Analysis of Supply Chain Using the Best & Worst Methods	Ahmadi and et al [33]
Data Mining	Minerals	Environmental Crisis of Raw Material, A New Method for Potential Global Dangers of Materials	Menhart et al [34]
Data Mining	Minerals	Mine Efficiency and the Fourth Industrial Revolution	Homphris et al [35]
Grounded Theory	Sand	The Impact of Extractions on River Systems in Europe Focusing on Today River	Maab et al. [36]
DEA	Sand	A Way for Environmental Quality Preservation Using Sustainable Sand Extraction and Using Produced Sand as an Alternative for Natural Sand	Boupati et al.[37]
DEA	Transport	Sustainability assessment of supply chains by a novel robust two-stage network DEA model: a case study in the transport industry	Fathi et al. [38]
DEA	Healthcare	Forecasting sustainability of healthcare supply chains using deep learning and network data envelopment analysis.	Azadi et al. [40]
DEA	Supplier	Assessing sustainability of suppliers: A novel stochastic-fuzzy DEA model.	Tavassoli et al. [41]
DEA	Gas	Sustainability assessment and most productive scale size: A stochastic DEA approach with dual frontiers.	Jahani et al. [42]

The literature review indicates a lack of research on the concrete and sand industries and their two-level supply chain. The excessive use of sand mines has a detrimental effect on rivers and their ecosystems. The demand for sand has increased in recent years due to improvements in living standards. Concrete is a crucial component in the construction of various structures, such as roads and industries like mosaic-making and glass-making. The negative impact of river extraction has reached its peak in some Iranian cities, resulting in a ban on such activities. Extracting sand from riverbeds alters the river's geometry and causes river diversion, sediment deposition, and deep holes. River extraction involves digging trenches and holes in the riverbed or superficially extracting sand piles. As a result, the river's previous morphology changes, leading to temporary sediment shortage and damage to the upper side of the waterway. Sand supply mainly comes from alluviums, but due to environmental issues and the lack of appropriate materials from rivers, more attention is paid to aggregates. Sand extraction from riverbeds can benefit producers, but it can also have negative effects on the environment's natural balance and the ecosystem of aquatic animals, particularly if not monitored. Hoever, following standard processes for sand extraction minimizes its drawbacks and increases the river's sustainability, making it a reliable source for construction materials. Table 2 outlines the findings of the supply chain literature review based on Table 1.

Table 2. Economic, Environmental and Social Criteria.

Environmental Criteria	**Economic Criteria**	**Social Criteria**
Green House Emission	Committed to Cost Reduction	Social-human Resources Management Skill
Co Emission	Committed to Delay Reduction	Training & Development of Staff
Chemical Waste Control	Competitive Price	Staff Satisfaction
Availability of Green Technology	Usable and Refundable Costs	Human Investment
Environmental Certificate	Sharing Cost	Social-human Resources Management Skill
Environmental Policies	Transaction Costs	Employed Staff Per Non-Renewable Resources
Environmental-friendly Materials usage	Full Education Cost	Work, Life, Family Balance
Waste Recycle	Average Capital	Mutual Relationship
Changeable Return	Social Responsivity Investment	Easy Communication
Landfill	Financial Status	Governmental Connections
Using Renewable Materials	Inventory Turnover	Regular Communication
Using Non-renewable Materials	Delivery Capacity	Serious and Dangerous Events
Using Limited Material	On-time Delivery	Health Programs
Water Usage	Service Reliability	Safety Standards
Energy Usage	Probability	Safety Programs
Inflammable Energy Usage	Unique Merits	Safety Teaching
Efficient Energy Use	Turnover Reduction Programs	Social Project Coordination
Re-usage Proportion	Tools and Methods of Measurement	Business Morale
Solid Waste	Sale	Educational Institutes
Recycle	Market Share	Working Condition
Toxic Material Production	Capital Return	Supporting Projects of Associations
	Assets Return	Local Association Penetrations
	The Difference Between Value and Quantity	Job Opportunity for Local Associations
	Value in Danger	Level of service

3. Stochastic Data Envelopment Analysis Model in Concrete Industry Supply Chain of Guilan Industry

This section introduces a model for assessing the sustainability of the supply chain of sand and concrete mining companies under a stochastic environment. In this regard, we consider the two-level supply chain structure of the concrete industry in the economic, social, and environmental sectors, as illustrated in Figure 1.

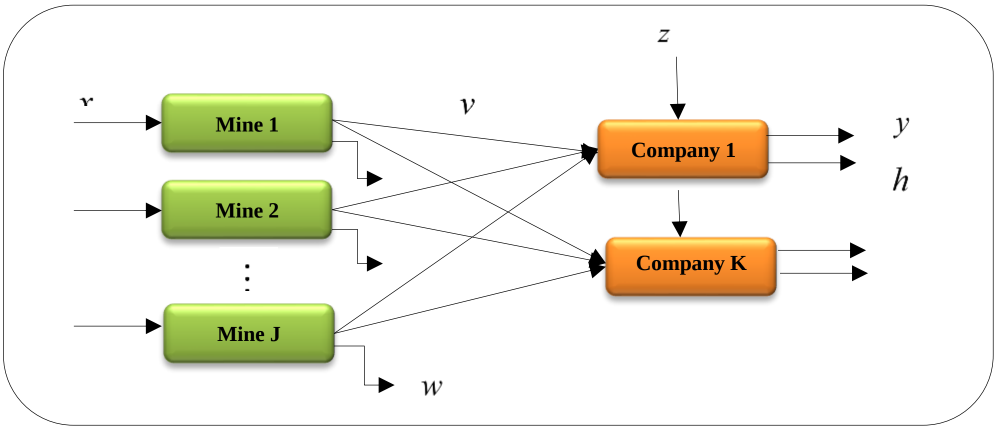

Figure 1. Overall Structure of Two-level Supply Chain of Concrete Industry

In order to develop a sustainability assessment model using stochastic data envelopment analysis, all indicators are summarized as follows:

J : No. of the first phase component (mine),

K : No. of the second phase component (company),

P : Periods,

δ_o^p : Performance of Supply chain analysed during p period,

f : Dimensions [economic, environmental, social]

As an illustration, the economic sector is denoted by $f=1$, the environmental sector by $f=2$, and the social sector by $f=3$.

β_f^p : are user-defined values which reflect the importance of each dimension of sustainability.

In this study, all three dimensions are equally weighted, each assigned a value of $\frac{1}{3}$.

θ_o^{1p} : Stochastic efficiency of economic sector in period p,

θ_o^{2p} : Stochastic efficiency of environmental sector in period p,

θ_o^{3p} : Stochastic efficiency of social sector in period p,

x_{ij}^p : i th input of the j th mine in period p,

w_{tj}^p : t th undesirable output of the j th mine in period p,

v_{rjk}^{p} : r th desirable output of the j th mine to the k th company in period p (Intermediate measure),

z_{nk}^{p} : n the input of the k th company in period p ,

y_{sk}^{p} : s th desirable output of the k th company in period p ,

h_{mk}^{p} : m th undesirable output of the k th company in period p ,

λ_{j}^{p} : Weight variables of the j th mine for the economic sector in period p ,

γ_{j}^{p} : Weight variables of the j th mine for the environmental sector in period p ,

ζ_{j}^{p} : Weight variables of the j th mine for the social sector in period p ,

$\lambda_{k}^{'p}$: Weight variables of the k th company for the economic sector in period p ,

$\gamma_{k}^{'p}$: Weight variables of the k th company for the environmental sector in period p ,

$\zeta_{k}^{'p}$: Weight variables of the k th company for the social sector in period p ,

3.1. Stochastic DEA Model of Sustainable Supply Chain in Guilan Concrete Industry

Drawing on the aforementioned indicators, we present a stochastic planning model based on the data envelopment analysis approach, which serves to evaluate the sustainability of the supply chain of the concrete industry. The model is presented as follows:

$$Max \frac{\sum_{p=1}^{P} \delta_{o}^{p}}{P} \tag{1}$$

$s.t.$

- The first phase constraints:

$Economic\ sector:$

$$P\left\{\sum_{j=1}^{J} \lambda_{j}^{p} \tilde{x}_{ij}^{p} \le \theta_{o}^{1p} \tilde{x}_{io}^{p}\right\} \ge 1-\alpha,\ i \in I^{Economic}, p=1,\dots,P,$$

$$P\left\{\sum_{j=1}^{J} \lambda_{j}^{p} \tilde{v}_{rj}^{p} \ge \tilde{v}_{rok}^{p}\right\} \ge 1-\alpha,\ r \in R^{Economic}, p=1,\dots,P,\ k=1,\dots,K$$

$$P\left\{\sum_{j=1}^{J} \lambda_{j}^{p} \tilde{w}_{tj}^{p} \le \tilde{w}_{to}^{p}\right\} \ge 1-\alpha,\ t \in T^{Economic}, p=1,\dots,P,$$

$$\sum_{j=1}^{J} \lambda_{j}^{p} = 1,\ p=1,\dots,P,$$

$$Environmental\ sector:$$

$$P\left\{\sum_{j=1}^{J}\gamma_j^p\,\tilde{x}_{ij}^p \le \theta_o^{2p}\tilde{x}_{io}^p\right\} \ge 1-\alpha,\ i\in I^{Environment},\ p=1,\dots,P,$$

$$P\left\{\sum_{j=1}^{J}\gamma_j^p\tilde{v}_{rj}^p \ge \tilde{v}_{rok}^p\right\} \ge 1-\alpha, r\in R^{Environment},\ p=1,\dots,P,\ k=1,\dots,K$$

$$P\left\{\sum_{j=1}^{J}\gamma_j^p\tilde{w}_{tj}^p \le \tilde{w}_{to}^p\right\} \ge 1-\alpha, t\in T^{Environment},\ p=1,\dots,P,$$

$$\sum_{j=1}^{n}\gamma_j^p = 1,\ p=1,\dots,P,$$

$$Social\ sectore:$$

$$P\left\{\sum_{j=1}^{J}\zeta_j^p\,\tilde{x}_{ij}^p \le \theta_o^{3p}\tilde{x}_{io}^p\right\} \ge 1-\alpha, i\in I^{Social},\ p=1,\dots,P,$$

$$P\left\{\sum_{j=1}^{J}\zeta_j^p\tilde{v}_{rjk}^p \ge \tilde{v}_{rok}^p\right\} \ge 1-\alpha, r\in R^{Social},\ p=1,\dots,P,\ k=1,\dots,K$$

$$P\left\{\sum_{j=1}^{J}\zeta_j^p\tilde{w}_{tj}^p \le \tilde{w}_{to}^p\right\} \ge 1-\alpha, t\in T^{Social},\ p=1,\dots,P,$$

$$\sum_{j=1}^{J}\zeta_j^p = 1,\ p=1,\dots,P,$$

- The second phase constraints:

$$Economic\ sector:$$

$$P\left\{\sum_{k=1}^{K}\lambda_k^{'p}\,\tilde{z}_{nk}^p \le \tilde{z}_{no}^p\right\} \ge 1-\alpha,\ n\in N^{Economic},\ p=1,\dots,P,$$

$$P\left\{\sum_{k=1}^{K}\lambda_k^{'p}\tilde{v}_{rjk}^p \le \tilde{v}_{rjo}^p\right\} \ge 1-\alpha, r\in R^{Economic},\ p=1,\dots,P,\ j=1,\dots,J$$

$$P\left\{\sum_{k=1}^{K}\lambda_k^{'p}\tilde{y}_{sk}^p \ge \tilde{y}_{so}^p\right\} \ge 1-\alpha, s\in S^{Economic},\ p=1,\dots,P,$$

$$P\left\{\sum_{j=1}^{k}\lambda_k^{'p}\tilde{h}_{mk}^p \le \tilde{h}_{mo}^p\right\} \ge 1-\alpha, m\in M^{Economic},\ p=1,\dots,P,$$

$$\sum_{k=1}^{K}\lambda_k^{'p} = 1,\ p=1,\dots,P,$$

$$Environmental\ sector:$$

$$P\left\{\sum_{k=1}^{K}\gamma_k^{'p}\,\tilde{z}_{nk}^{p} \le \tilde{z}_{no}^{p}\right\} \ge 1-\alpha, n \in N^{Environment}, p=1,...,P,$$

$$P\left\{\sum_{k=1}^{K}\gamma_k^{'p}\tilde{v}_{rjk}^{p} \le \tilde{v}_{rjo}^{p}\right\} \ge 1-\alpha, r \in R^{Environment}, p=1,...,P,\ j=1,...,J$$

$$P\left\{\sum_{k=1}^{K}\gamma_k^{'p}\,\tilde{y}_{sk}^{p} \ge \tilde{y}_{so}^{p}\right\} \ge 1-\alpha, s \in S^{Environment}, p=1,...,P,$$

$$P\left\{\sum_{k=1}^{K}\gamma_k^{'p}\tilde{h}_{mk}^{p} \le \tilde{h}_{mo}^{p}\right\} \ge 1-\alpha, m \in M^{Environmenr}, p=1,...,P,$$

$$\sum_{k=1}^{K}\gamma_k^{'p} = 1, p=1,...,P,$$

$$Social\ sector:$$

$$P\left\{\sum_{k=1}^{K}\zeta_k^{'p}\,\tilde{z}_{nk}^{p} \le \tilde{z}_{no}^{p}\right\} \ge 1-\alpha, n \in N^{Social}, p=1,...,P,$$

$$P\left\{\sum_{k=1}^{K}\zeta_k^{'p}\tilde{v}_{rjk}^{p} \le \tilde{v}_{rjo}^{p}\right\} \ge 1-\alpha, r \in R^{Social}, p=1,...,P, j=1,...,J,$$

$$P\left\{\sum_{k=1}^{K}\zeta_k^{'p}\,\tilde{y}_{sk}^{p} \ge \tilde{y}_{so}^{p}\right\} \ge 1-\alpha,\ s \in S^{Social}, p=1,...,P,$$

$$P\left\{\sum_{k=1}^{K}\zeta_k^{'p}\tilde{h}_{mk}^{p} \le \tilde{h}_{mo}^{p}\right\} \ge 1-\alpha, m \in M^{Social}, p=1,...,P,$$

$$\sum_{k=1}^{K}\zeta_k^{'p} = 1, p=1,...,P,$$

$$General\ constraints:$$

$$\delta_o^p = \frac{\sum_{f=1}^{3}\beta_f^p\theta_o^{fp}}{\sum_{f=1}^{3}\beta_f^p},$$

$$\lambda_j^p,\ \lambda_k^{'p}, \gamma_j^p, \gamma_k^{'p},\ \zeta_j^p,\ \zeta_k^{'p} \ge 0, \forall j,k,p.$$

There are two phases in Model (1), namely phase 1 and phase 2. In phase 1, the constraints pertaining to mines are presented, with a clear separation of their economic, environmental, and social sectors. On the other hand, phase 2 showcases the constraints related to concrete companies, also separated into their respective economic, environmental, and social sectors.

3.2. Crisp Model of Sustainable Supply Chain of Guilan Concrete Industry

Consider a unit under evaluation, where x_{ij}^{p}, v_{rjk}^{p}, w_{tj}^{p}, z_{nk}^{p}, y_{sk}^{p} and h_{mk}^{p} for i,r,n,s,m,j,k represent the average values of inputs and outputs. Let us also assume the inverse of the standard normal cumulative distribution function, represented by ϕ^{-1}. Based on the central limit theorem, the stochastic model can be converted to a deterministic form, which is expressed as follows:

$$Max \frac{\sum_{p=1}^{P} \delta_o^p}{P} \qquad (2)$$

$$s.t.$$

- The first phase constraints:

$$Economic\ sector:$$

$$\sum_{j=1}^{J} \lambda_j^p x_{ij}^p - \phi^{-1P}(\alpha)\sigma_i(\lambda_j^p, \theta_o^{1p}) \le \theta_o^{1p} x_{io}^p, i \in I^{Economic}, p = 1,\dots,P,$$

$$\sum_{j=1}^{J} \lambda_j^p v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\lambda_j^p) \ge v_{rok}^p, r \in R^{Economic}, p = 1,\dots,P, k = 1,\dots,K,$$

$$\sum_{j=1}^{J} \lambda_j^p w_{tj}^p - \phi^{-1P}(\alpha)\sigma_t(\lambda_j^p) \le w_{to}^p, t \in T^{Economic}, p = 1,\dots,P,$$

$$\sum_{j=1}^{J} \lambda_j^p = 1, p = 1,\dots,P,$$

$$\left(\sigma_i(\lambda_j^p, \theta_o^{1p})\right)^2 = \sum_j \sum_l \lambda_j^p \lambda_l^p \operatorname{cov}(\tilde{x}_{ij}^p, \tilde{x}_{il}^p)$$

$$+(\theta_o^{1p})^2 \operatorname{var}(\tilde{x}_{io}^p) - 2\theta_o^{1p} \sum_j \lambda_j^p \operatorname{cov}(\tilde{x}_{ij}^p, \tilde{x}_{io}^p), i \in I^{Economic}, p = 1,\dots,P,$$

$$\left(\sigma_r(\lambda_j^p)\right)^2 = \sum_j \sum_l \lambda_j^p \lambda_l^p \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rlk}^p) + \operatorname{var}(\tilde{v}_{rok}^p)$$

$$-2\sum_j \lambda_j^p \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rok}^p),\ r \in R^{Economic}, p = 1,\dots,P, k = 1,\dots,K,$$

$$\left(\sigma_t(\lambda_j^p)\right)^2 = \sum_j \sum_l \lambda_j^p \lambda_l^p \operatorname{cov}(\tilde{w}_{tj}^p, \tilde{w}_{tl}^p) + \operatorname{var}(\tilde{w}_{to}^p)$$

$$-2\sum_j \lambda_j^p \operatorname{cov}(\tilde{w}_{tj}^p, \tilde{w}_{to}^p),\ t \in T^{Economic}, p = 1,\dots,P,$$

$$Environmental\ sector:$$

$$\sum_{j=1}^{J}\gamma_j^p x_{ij}^p - \phi^{-1P}(\alpha)\sigma_i(\gamma_j^p,\theta_o^{2p}) \le \theta_o^{2p} x_{io}^p, i \in I^{Environment}, p=1,\dots,P,$$

$$\sum_{j=1}^{J}\gamma_j^p v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\gamma_j^p) \ge v_{rok}^p,\ r \in R^{Environment}, p=1,\dots,P, k=1,\dots,K,$$

$$\sum_{j=1}^{J}\gamma_j^p w_{tj}^p - \phi^{-1P}(\alpha)\sigma_t(\gamma_j^p) \le w_{to}^p, t \in T^{Environment}, p=1,\dots,P,$$

$$\sum_{j=1}^{J}\gamma_j^p = 1, p=1,\dots,P,$$

$$\left(\sigma_i(\gamma_j^p,\theta_o^{2p})\right)^2 = \sum_j\sum_l \gamma_j^p\gamma_l^p \operatorname{cov}(\tilde{x}_{ij}^p,\tilde{x}_{il}^p)$$

$$+(\theta_o^{2p})^2 \operatorname{var}(\tilde{x}_{io}^p) - 2\theta_o^{2p}\sum_j \gamma_j^p \operatorname{cov}(\tilde{x}_{ij}^p,\tilde{x}_{io}^p), i \in I^{Environment}, p=1,\dots,P,$$

$$\left(\sigma_r(\gamma_j^p)\right)^2 = \sum_j\sum_l \gamma_j^p\gamma_l^p \operatorname{cov}(\tilde{v}_{rjk}^p,\tilde{v}_{rlk}^p) + \operatorname{var}(\tilde{v}_{ro}^p)$$

$$-2\sum_j \gamma_j^p \operatorname{cov}(\tilde{v}_{rjk}^p,\tilde{v}_{rok}^p), r \in R^{Environment}, p=1,\dots,P, k=1,\dots,K,$$

$$\left(\sigma_t(\gamma_j^p)\right)^2 = \sum_j\sum_l \gamma_j^p\gamma_l^p \operatorname{cov}(\tilde{w}_{tjk}^p,\tilde{w}_{tlk}^p) + \operatorname{var}(\tilde{w}_{to}^p)$$

$$-2\sum_j \gamma_j^p \operatorname{cov}(\tilde{w}_{tjk}^p,\tilde{w}_{tok}^p), t \in T^{Environment}, p=1,\dots,P, k=1,\dots,K,$$

$$Social\ sector:$$

$$\sum_{j=1}^{J}\xi_j^p x_{ij}^p - \phi^{-1P}(\alpha)\sigma_i(\xi_j^p,\theta_o^{3p}) \le \theta_o^{3p} x_{io}^p, i \in I^{Social}, p=1,\dots,P,$$

$$\sum_{j=1}^{J}\xi_j^p v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\xi_j^p) \ge v_{rok}^p, r \in R^{Social}, p=1,\dots,P, k=1,\dots,K,$$

$$\sum_{j=1}^{J}\xi_j^p w_{tj}^p - \phi^{-1P}(\alpha)\sigma_t(\xi_j^p) \le w_{to}^p, t \in T^{Social}, p=1,\dots,P,$$

$$\sum_{j=1}^{J}\xi_j^p = 1, p=1,\dots,P,$$

$$\left(\sigma_i(\xi_j^p,\theta_o^{3p})\right)^2 = \sum_j\sum_l \xi_j^p\xi_l^p \operatorname{cov}(\tilde{x}_{ij}^p,\tilde{x}_{il}^p)$$

$$+(\theta_o^{3p})^2 \operatorname{var}(\tilde{x}_{io}^p) - 2\theta_o^{3p}\sum_j \xi_j^p \operatorname{cov}(\tilde{x}_{ij}^p,\tilde{x}_{io}^p), i \in I^{Social}, p=1,\dots,P,$$

$$\left(\sigma_r(\xi_j^p)\right)^2 = \sum_j \sum_l \xi_j^p \xi_l^p \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rlk}^p) + \operatorname{var}(\tilde{v}_{rok}^p)$$
$$-2\sum_j \xi_j^p \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rok}^p), r \in R^{Social}, p = 1,...,P, k = 1,...,K,$$
$$\left(\sigma_t(\xi_j^p)\right)^2 = \sum_j \sum_l \xi_j^p \xi_l^p \operatorname{cov}(\tilde{w}_{tj}^p, \tilde{w}_{tl}^p) + \operatorname{var}(\tilde{w}_{to}^p)$$
$$-2\sum_j \xi_j^p \operatorname{cov}(\tilde{w}_{tj}^p, \tilde{w}_{to}^p), t \in T^{Social}, p = 1,...,P,$$

- ❖ The second phase constraints:

Economic sector :

$$\sum_{k=1}^{K} \lambda_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)\sigma_n(\lambda_k^{'p}) \le z_{no}^p, \ \ n \in N^{Economic}, p = 1,...,P,$$
$$\sum_{k=1}^{K} \lambda_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\lambda_k^{'p}) \ge v_{rjo}^p, r \in R^{Economic}, p = 1,...,P, j = 1,...,J,$$
$$\sum_{k=1}^{K} \lambda_k^{'p} y_{sk}^p + \phi^{-1P}(\alpha)\sigma_s(\lambda_k^{'p}) \ge y_{so}^p, s \in S^{Economic}, p = 1,...,P,$$
$$\sum_{k=1}^{K} \lambda_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)\sigma_m(\lambda_k^{'p}) \le h_{mo}^p, m \in M^{Economic}, p = 1,...,P,$$
$$\sum_{k=1}^{K} \lambda_k^{'p} = 1, p = 1,...,P,$$
$$\left(\sigma_n(\lambda_k^{'p})\right)^2 = \sum_k \sum_l \lambda_k^{'p} \lambda_l^{'p} \operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{nl}^p)$$
$$+\operatorname{var}(\tilde{z}_{no}^p) - 2\sum_k \lambda_k^{'p} \operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{no}^p), n \in N^{Economic}, p = 1,...,P,$$
$$\left(\sigma_r(\lambda_k^{'p})\right)^2 = \sum_k \sum_l \lambda_k^{'p} \lambda_l^{'p} \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjl}^p) + \operatorname{var}(\tilde{v}_{rjo}^p)$$
$$-2\sum_k \lambda_k^{'p} \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjo}^p), r \in R^{Economic}, p = 1,...,P, j = 1,...,J,$$
$$\left(\sigma_s(\lambda_k^{'p})\right)^2 = \sum_k \sum_l \lambda_k^{'p} \lambda_l^{'p} \operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{sl}^p) + \operatorname{var}(\tilde{y}_{so}^p)$$
$$-2\sum_k \lambda_k^{'p} \operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{so}^p), s \in S^{Economic}, p = 1,...,P,$$
$$\left(\sigma_m(\lambda_k^{'p})\right)^2 = \sum_k \sum_l \lambda_k^{'p} \lambda_l^{'p} \operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{ml}^p) + \operatorname{var}(\tilde{h}_{mo}^p)$$
$$-2\sum_k \lambda_k^{'p} \operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{mo}^p), m \in M^{Economic}, p = 1,...,P,$$

$$Environmental\ sector:$$

$$\sum_{k=1}^{K}\gamma_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)\sigma_n(\gamma_k^{'p}) \le z_{no}^p, n \in N^{Environment}, p=1,...,P,$$

$$\sum_{k=1}^{K}\gamma_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\gamma_k^{'p}) \ge v_{rjo}^p,\ r \in R^{Environment}, p=1,...,P, j=1,...,J,$$

$$\sum_{k=1}^{K}\gamma_k^{'p} y_{sk}^p + \phi^{-1P}(\alpha)\sigma_s(\gamma_k^{'p}) \ge y_{so}^p, s \in S^{Environment}, p=1,...,P,$$

$$\sum_{k=1}^{K}\gamma_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)\sigma_m(\gamma_k^{'p}) \le h_{mo}^p, m \in M^{Environment}, p=1,...,P,$$

$$\sum_{k=1}^{K}\gamma_k^{'p} = 1, p=1,...,P,$$

$$\left(\sigma_n(\gamma_k^{'p})\right)^2 = \sum_k\sum_l \gamma_k^{'p}\gamma_l^{'p}\operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{nl}^p)$$

$$+\operatorname{var}(\tilde{z}_{no}^p) - 2\sum_k \gamma_k^{'p}\operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{no}^p), n \in N^{Environment}, p=1,...,P,$$

$$\left(\sigma_r(\gamma_k^{'p})\right)^2 = \sum_k\sum_l \gamma_k^{'p}\gamma_l^{'p}\operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjl}^p) + \operatorname{var}(\tilde{v}_{rjo}^p)$$

$$-2\sum_k \gamma_l^{'p}\operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjo}^p), r \in R^{Environment}, p=1,...,P, j=1,...,J,$$

$$\left(\sigma_s(\gamma_k^{'p})\right)^2 = \sum_k\sum_l \gamma_k^{'p}\gamma_l^{'p}\operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{sl}^p) + \operatorname{var}(\tilde{y}_{so}^p)$$

$$-2\sum_k \gamma_l^{'p}\operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{so}^p), s \in S^{Environment}, p=1,...,P,$$

$$\left(\sigma_m(\gamma_k^{'p})\right)^2 = \sum_k\sum_l \gamma_k^{'p}\gamma_l^{'p}\operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{ml}^p) + \operatorname{var}(\tilde{h}_{mo}^p)$$

$$-2\sum_k \gamma_l^{'p}\operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{mo}^p), m \in M^{Environment}, p=1,...,P,$$

$$Social\ sector:$$

$$\sum_{k=1}^{K}\zeta_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)\sigma_n(\zeta_k^{'p}) \le z_{no}^p, n \in N^{Social}, p=1,...,P,$$

$$\sum_{k=1}^{K}\zeta_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\zeta_k^{'p}) \ge v_{rjo}^p,\ r \in R^{Social}, p=1,...,P, j=1,...,J,$$

$$\sum_{k=1}^{K}\zeta_k^{'p} y_{sk}^p + \phi^{-1P}(\alpha)\sigma_s(\zeta_k^{'p}) \ge y_{so}^p, s \in S^{Social}, p=1,...,P,$$

$$\sum_{k=1}^{K}\zeta_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)\sigma_m(\zeta_k^{'p}) \le h_{mo}^p, m \in M^{Social}, p=1,...,P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} = 1,\ p = 1,...,P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)\sigma_n(\zeta_k^{'p}) \le z_{no}^p, n \in N^{Social}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)\sigma_r(\zeta_k^{'p}) \ge v_{rjo}^p,\ r \in R^{Social}, p = 1,...,P, j = 1,...,J,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} y_{sk}^p + \phi^{-1P}(\alpha)\sigma_s(\zeta_k^{'p}) \ge y_{so}^p, s \in S^{Social}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)\sigma_m(\zeta_k^{'p}) \le h_{mo}^p, m \in M^{Social}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} = 1,\ p = 1,...,P,$$

$$\left(\sigma_n(\zeta_k^{'p})\right)^2 = \sum_k \sum_l \zeta_k^{'p} \zeta_l^{'p} \operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{nl}^p)$$
$$+ \operatorname{var}(\tilde{z}_{no}^p) - 2\sum_k \zeta_k^{'p} \operatorname{cov}(\tilde{z}_{nk}^p, \tilde{z}_{no}^p), n \in N^{Social}, p = 1,...,P,$$

$$\left(\sigma_r(\zeta_k^{'p})\right)^2 = \sum_k \sum_l \zeta_k^{'p} \zeta_l^{'p} \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjl}^p) + \operatorname{var}(\tilde{v}_{rjo}^p)$$
$$-2\sum_k \zeta_l^{'p} \operatorname{cov}(\tilde{v}_{rjk}^p, \tilde{v}_{rjo}^p), r \in R^{Social}, p = 1,...,P, j = 1,...,J,$$

$$\left(\sigma_s(\zeta_k^{'p})\right)^2 = \sum_k \sum_l \zeta_k^{'p} \zeta_l^{'p} \operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{sl}^p) + \operatorname{var}(\tilde{y}_{so}^p)$$
$$-2\sum_k \zeta_l^{'p} \operatorname{cov}(\tilde{y}_{sk}^p, \tilde{y}_{so}^p), s \in S^{Social}, p = 1,...,P,$$

$$\left(\sigma_m(\zeta_k^{'p})\right)^2 = \sum_k \sum_l \zeta_k^{'p} \zeta_l^{'p} \operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{ml}^p) + \operatorname{var}(\tilde{h}_{mo}^p)$$
$$-2\sum_k \zeta_l^{'p} \operatorname{cov}(\tilde{h}_{mk}^p, \tilde{h}_{mo}^p), m \in M^{Social}, p = 1,...,P,$$

General constraints:

$$\delta_o^p = \frac{\sum_{f=1}^{3} \beta_f^p \theta_o^{fp}}{\sum_{f=1}^{4} \beta_f^p},$$

$$\lambda_j^p, \lambda_k^{'p}, \gamma_j^p,\ \gamma_k^{'p}, \zeta_j^p,\ \zeta_k^{'p} \ge 0, \forall j,k,p.$$

3.3. Linear model of sustainable supply chain of Guilan concrete industry

In the context of economics and finance, the single-factor hypothesis is often used to characterize random variables. This hypothesis has been previously employed by Sharp [42] and Kahane [43]. Applying this hypothesis to the previously defined deterministic model, it can be expressed in the following linear form:

$$Max \frac{\sum_{p=1}^{P} \delta_o^p}{P} \tag{3}$$

$s.t.$

- The first phase constraints:

$Economic\ sector:$

$$\sum_{j=1}^{J} \lambda_j^p x_{ij}^p - \phi^{-1P}(\alpha)(q_i^{+P} + q_i^{-P}) \le \theta_o^{1p} x_{io}^p, i \in I^{Economic}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \lambda_j^p \sigma(x_{ij}^p) - \theta_o^{1p} \sigma(x_{io}^p) = q_i^{+P} - q_i^{-P}, i \in I^{Economic}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \lambda_j^p v_{rjk}^p + \phi^{-1P}(\alpha)(q_r^{+P} + q_r^{-P}) \ge v_{rok}^p, r \in R^{Economic}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \lambda_j^p \sigma(v_{rjk}^p) - \sigma(v_{rok}^p) = q_r^{+P} - q_r^{-P}, r \in R^{Economic}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \lambda_j^p w_{tj}^p - \phi^{-1P}(\alpha)(q_t^{+P} + q_t^{-P}) \le w_{to}^p, t \in T^{Economic}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \lambda_j^p \sigma(w_{tj}^p) - \sigma(w_{to}^p) = q_t^{+P} - q_t^{-P}, t \in T^{Economic}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \lambda_j^p = 1, p = 1,...,P,$$

$Environmental\ sector:$

$$\sum_{j=1}^{J} \gamma_j^p x_{ij}^p - \phi^{-1P}(\alpha)(q_i^{+P} + q_i^{-P}) \le \theta_o^{2p} x_{io}^p, i \in I^{Environment}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \lambda_j^p \sigma(x_{ij}^p) - \theta_o^{2p} \sigma(x_{io}^p) = q_i^{+P} - q_i^{-P}, i \in I^{Environment}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \gamma_j^p v_{rjk}^p + \phi^{-1P}(\alpha)(q_r^{+P} + q_r^{-P}) \ge v_{rok}^p, r \in R^{Environment}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \gamma_j^p \sigma(v_{rjk}^p) - \sigma(v_{rok}^p) = q_r^{+P} - q_r^{-P}, r \in R^{Environment}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \gamma_j^p w_{tj}^p - \phi^{-1P}(\alpha)(q_t^{+P} + q_t^{-P}) \le w_{to}^p, t \in T^{Environment}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \gamma_j^p \sigma(w_{tj}^p) - \sigma(w_{to}^p) = q_t^{+P} - q_t^{-P}, t \in T^{Environment}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \gamma_j^p = 1, p = 1,...,P,$$

Social sector:

$$\sum_{j=1}^{J} \xi_j^p x_{ij}^p - \phi^{-1P}(\alpha)(q_i^{+P} + q_i^{-P}) \le \theta_o^{3p} x_{io}^p, i \in I^{Social}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \xi_j^p \sigma(x_{ij}^p) - \theta_o^{3p} \sigma(x_{io}^p) = q_i^{+P} - q_i^{-P}, i \in I^{Social}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \xi_j^p v_{rjk}^p + \phi^{-1P}(\alpha)(q_r^{+P} + q_r^{-P}) \ge v_{rok}^p, r \in R^{Social}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \xi_j^p \sigma(v_{rjk}^p) - \sigma(v_{rok}^p) = q_r^{+P} - q_r^{-P}, r \in R^{Social}, p = 1,...,P, k = 1,...,K,$$

$$\sum_{j=1}^{J} \xi_j^p \sigma(w_{tj}^p) - \phi^{-1P}(\alpha)(q_t^{+P} + q_t^{-P}) \le w_{to}^p, t \in T^{Social}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \xi_j^p \sigma(w_{tj}^p) - \sigma(w_{to}^p) = q_t^{+P} + q_t^{-P}, t \in T^{Social}, p = 1,...,P,$$

$$\sum_{j=1}^{J} \xi_j^p = 1, p = 1,...,P,$$

- ❖ The second phase constraints:

Economic sector:

$$\sum_{k=1}^{K} \lambda_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)(q_n^{+P} + q_n^{-P}) \le z_{no}^p, n \in N^{Economic}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} \sigma(z_{nk}^p) - \sigma(z_{no}^p) = q_n^{+P} - q_n^{-P}, n \in N^{Economic}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)(q_n^{+P} + q_n^{-P}) \ge v_{rjo}^p, r \in R^{Economic}, p = 1,...,P, j = 1,...,J,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} \sigma(v_{rjk}^p) - \sigma(v_{rjo}^p) = q_r^{+P} - q_r^{-P}, r \in R^{Economic}, p = 1,...,P, j = 1,...,J,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} y_{sk}^p + \phi^{-1P}(\alpha)(q_s^{+P} + q_s^{-P}) \ge y_{so}^p, s \in S^{Economic}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} \sigma(y_{sk}^p) - \sigma(y_{so}^p) = q_s^{+P} - q_s^{-P}, s \in S^{Economic}, p = 1,...,P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)(q_m^{+P} + q_m^{-P}) \leq h_{mo}^p, m \in M^{Economic}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} \sigma(h_{mk}^p) - \sigma(h_{mo}^p) = q_m^{+P} - q_m^{-P}, m \in M^{Economic}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \lambda_k^{'p} = 1, p = 1,..., P,$$

Environmental sector :

$$\sum_{k=1}^{K} \gamma_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)(q_n^{+P} + q_n^{-P}) \leq z_{no}^p, n \in N^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} \sigma(z_{nk}^p) - \sigma(z_{no}^p) = q_n^{+P} - q_n^{-P}, n \in N^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)(q_r^{+P} + q_r^{-P}) \geq v_{rjo}^p, \ r \in R^{Environment}, p = 1,..., P, \ j = 1,..., J,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} \sigma(v_{rjk}^p) - \sigma(v_{rjo}^p) = q_r^{+P} + q_r^{-P}, \ r \in R^{Environment}, p = 1,..., P, \ j = 1,..., J,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} y_{sj}^p + \phi^{-1P}(\alpha)(q_s^{+P} + q_s^{-P}) \geq y_{so}^p, \ \ s \in S^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} \sigma(y_{sk}^p) - \sigma(y_{so}^p) = q_s^{+P} - q_s^{-P}, \ s \in S^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} h_{mk}^p - \phi^{-1P}(\alpha)(q_m^{+P} + q_m^{-P}) \leq h_{mo}^p, \ m \in M^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} \sigma(h_{mk}^p) - \sigma(h_{mo}^p) = q_m^{+P} - q_m^{-P}, m \in M^{Environment}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \gamma_k^{'p} = 1, p = 1,..., P,$$

Social sector :

$$\sum_{k=1}^{K} \zeta_k^{'p} z_{nk}^p - \phi^{-1P}(\alpha)(q_n^{+P} + q_n^{-P}) \leq z_{no}^p, \ n \in N^{Social}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} \sigma(z_{nk}^p) - \sigma(z_{no}^p) = q_n^{+P} - q_n^{-P}, \ n \in N^{Social}, p = 1,..., P,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} v_{rjk}^p + \phi^{-1P}(\alpha)(q_r^{+P} + q_r^{-P}) \geq v_{rjo}^p, \ r \in R^{Social}, p = 1,..., P, \ j = 1,..., J,$$

$$\sum_{k=1}^{K} \zeta_k^{'p} \sigma(v_{rjk}^p) - \sigma(v_{rjo}^p) = q_r^{+P} + q_r^{-P}, \ r \in R^{Social}, p = 1,..., P, \ j = 1,..., J,$$

$$\sum_{k=1}^{K}\zeta_k^{'p} y_{sj}^{p} + \phi^{-1P}(\alpha)(q_s^{+P} + q_s^{-P}) \geq y_{so}^{p}, s \in S^{Social}, p = 1,...,P,$$
$$\sum_{k=1}^{K}\zeta_k^{'p} \sigma(y_{sk}^{p}) - \sigma(y_{so}^{p}) = q_s^{+P} - q_s^{-P}, s \in S^{Social}, p = 1,...,P,$$
$$\sum_{k=1}^{K}\zeta_k^{'p} h_{mk}^{p} - \phi^{-1P}(\alpha)(q_m^{+P} + q_m^{-P}) \leq h_{mo}^{p}, m \in M^{Social}, p = 1,...,P,$$
$$\sum_{k=1}^{K}\zeta_k^{'p} \sigma(h_{mk}^{p}) - \sigma(h_{mo}^{p}) = q_m^{+P} - q_m^{-P}, m \in M^{Social}, p = 1,...,P,$$
$$\sum_{k=1}^{K}\zeta_k^{'p} = 1, p = 1,...,P,$$

General constraints:

$$\delta_o^p = \frac{\sum_{f=1}^{3}\beta_f^p \theta_o^{fp}}{\sum_{f=1}^{4}\beta_f^p},$$
$$\lambda_j^p, \lambda_k^{'p}, \gamma_j^p, \gamma_k^{'p}, \zeta_j^p, \zeta_k^{'p} \geq 0, \forall j,k,p,$$
$$q_i^{+P}, q_i^{-P}, q_r^{+P}, q_r^{-P}, q_t^{+P}, q_t^{-P}, q_n^{+P}, q_n^{-P}, q_s^{+P}, q_s^{-P}, q_m^{+P}, q_m^{-P} \geq 0, \forall i,r,t,n,s,m,p.$$

The above model is feasible under all error levels of α.

Theorem 1. For any predetermined level of $\alpha \leq 0.5$, the stochastic efficiency score calculated from Model (3) ranges between 0 and 1.

Based on the value of the objective function of Model (3), the following definitions can be derived:

Definition 1. The supply chain under analysis is called stochastically stable if and only if the objective value of Model 3 is equal to one.

Definition 2. The supply chain under analysis is called stochastically stable if and only if it is stochastically efficient in all three economic, environmental and social randomly sectors in all periods (i.e. $\theta_o^{1p} = \theta_o^{2p} = \theta_o^{3p} = 1$: $p = 1,...,P$).

Definition 3. The supply chain of each of the economic, environmental and social sectors in the period of p is stochastically called efficient if and only if we have, respectively: $\theta_o^{1p} = 1$, $\theta_o^{2p} = 1$ and $\theta_o^{3p} = 1$.

In other words, the supply chain in question is referred to as economic stochastic efficient, environmental stochastic efficient, and social stochastic efficient in each period if $\theta_o^{1p} = 1$, $\theta_o^{2p} = 1$, and $\theta_o^{3p} = 1$ for $p = 1,...,P$, respectively. Moreover, if the supply chain is efficient in all periods, it is called economically, environmentally, and socially efficient.

4. Analysis of data of Guilan concrete industry supply chain

The concrete industry of Guilan was found to comprise of four distinct supply chains, each characterized by a unique structure as illustrated in Figure 1. It should be noted that the number of mines and companies involved in each supply chain varies. Specifically, the first supply chain consists of six mines and three companies, whereas the second supply chain comprises of six mines and six companies. The third supply chain is composed of five mines and three companies, and the fourth supply chain involves three mines and two companies.

As previously mentioned, the structure of each of the four identified supply chains in the concrete industry of Guilan includes three sectors: economic, environmental, and social. Each of these sectors comprises two components, namely, mine and company. Accordingly, the input and output variables for each of the sections in all four supply chains are outlined as follows:

❖ **Economic Sector:**

- **Mine:**

Inputs: personnel cost, number of employees,

Desired Output: sales amount,

Undesired Output: wastage,

- **Company:**

Input: personnel cost,

Desired Output: number of customers, amount of sales,

Undesirable Output: waste percentage,

❖ **Environmental Section:**

- **Mine:**

Inputs: Water consumption, Gasoline fuel, Electricity consumption,

Desired Output: Withdrawal from the river,

Undesirable Output: waste,

- **Company:**

Input: Fossil fuel, Electricity consumption,

Undesirable Output: Waste,

❖ **Social Section:**

- **Mine:**

Input: Number of employees,

Desired Output: On-time delivery,

- **Company:**

Input: Number of personnel,

Desired Output: Safety training,

Undesirable Output: Number of incidents.

It should be noted that for each period, data were collected over 12 months for each index, and the average and standard deviation were subsequently determined.

According to the data taken from the financial documents of the aforementioned four supply chain companies, the model output using GAMS software is shown in Table 3.

As we know, when the tolerance level is considered between 0 and 0.5, the efficiency value is also determined between zero and one [44]. Therefore, in this study, three tolerance levels of 0.1, 0.3 and 0.5 were considered.

4.1. Economic Efficiency

In the first supply chain, units 3, 4, 5, and 6 exhibited stochastic efficiency in specific periods, while the other units were inefficient. However, since no unit demonstrated stochastic efficiency across all periods, none of them can be considered generally stochastically efficient at the $\alpha = 0.1$ level from an economic perspective. In the second and third supply chains, none of the units demonstrated stochastic efficiency in any period. Thus, at the $\alpha = 0.1$ level, these supply chains are generally not considered stochastically efficient from an economic point of view. In the fourth supply chain, only unit 3 in the third period exhibited stochastic efficiency, while the other units were randomly inefficient. However, like the previous supply chains, the fourth supply chain is not considered stochastically efficient from an economic point of view. These findings hold true at varying error levels ($\alpha = 0.3$ and $\alpha = 0.5$), indicating that none of the supply chains are overall stochastically efficient from an economic perspective.

4.2. Environmental Efficiency

At an alpha error level of 0.1, it was found that in the first supply chain, units 4, 1, and 6 exhibited stochastic efficiency in one and two periods, respectively, from an environmental standpoint. On the other hand, units 5 and 7 were inefficient in all periods, while unit 3 demonstrated stochastic efficiency throughout the entire chain. As such, unit 3 is the only unit that demonstrated complete stochastic efficiency from an environmental perspective. In the second supply chain, units 1, 2, 4, and 6 exhibited stochastic efficiency in only one period, and units 3 and 6 were efficient in two periods. However, as no unit was efficient throughout all periods, there was no unit in this supply chain that demonstrated overall stochastic efficiency from an environmental perspective. In the third supply chain, units 1 and 2 were inefficient in all periods, while units 3, 4, and 5 demonstrated stochastic efficiency in two and one periods, respectively. Thus, there was no unit in this supply chain that demonstrated overall stochastic efficiency from an environmental perspective. In the fourth supply chain, only unit 1 exhibited stochastic efficiency in the fifth period, and unit 2 was efficient in the fourth and fifth periods, while the third unit demonstrated no stochastic efficiency in any period. Consequently, in this chain, there was no unit that demonstrated overall stochastic efficiency from an environmental perspective.

Furthermore, calculations were conducted at the alpha error level of 0.3 and 0.5, which indicated that none of the supply chains demonstrated stochastic efficiency from an environmental perspective.

4.3. Social Efficiency

The results of the analysis indicate that, in the first supply chain, only units 1, 4, and 7 were stochastically efficient in a single period, while the remaining units were deemed inefficient. Furthermore, no unit demonstrated stochastic efficiency across all periods, indicating a lack of stochastic efficiency from a social viewpoint. Similarly, in the second supply chain, only unit 2 demonstrated social stochastic efficiency in period 3, while the other units were found to be inefficient. Likewise, in the third supply chain, only unit 3 exhibited stochastic efficiency in one period, while the other units were deemed inefficient. The fourth supply chain also showed a similar pattern, as only unit 2 demonstrated stochastic efficiency in the second period from a social viewpoint, with the remaining units being inefficient. To validate the robustness of the findings, the analysis was performed at error levels of 0.5 and 0.3. The results showed that none of the supply chains demonstrated stochastic efficiency at any level from a social viewpoint.

Table 3. Economic, Social and Environmental Performance of Supply Chain $(\alpha = 0.1)$

Supply Chain	Unit	Economic Performance					Environmental Performance					Social Performance				
		Period 1	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**
1	1	0.8021	0.8574	0.8298	0.8259	0.8201	1.0000	1.0000	0.9852	0.9897	0.9975	1.0000	0.8083	0.8087	0.8760	0.9480
	2	0.8332	0.8761	0.8518	0.8281	0.8182	0.9548	0.9616	0.9675	1.0000	0.9884	0.8125	0.9094	0.8513	0.9066	0.8813
	3	0.9842	1.0000	0.8970	0.9604	0.9368	1.0000	1.0000	1.0000	1.0000	1.0000	0.8840	0.8763	0.8856	0.8989	0.9566
	4	1.0000	0.9111	1.0000	0.8946	0.8596	0.9596	0.9812	1.0000	0.9552	0.9539	0.8189	0.8229	0.9414	0.8599	1.0000
	5	0.8957	0.8294	0.9051	0.9464	1.0000	0.9834	0.9607	0.9591	0.9640	0.9802	0.9551	0.9382	0.8310	0.8730	0.9148
	6	0.8897	0.9319	1.000	0.9691	0.8870	0.9695	0.9701	1.0000	1.0000	0.9577	1.0000	0.9576	0.9061	0.9029	0.9329
	7	0.7932	0.9288	0.8826	0.8762	0.9935	0.9898	0.9895	0.9745	0.9740	0.9772	0.9661	0.9867	0.9450	0.9282	0.9800
2	1	0.7039	0.8149	0.8340	0.8431	0.7993	0.9753	0.9849	1.0000	0.9916	0.9775	0.9095	0.8787	0.9889	0.8283	0.8420
	2	0.9407	0.9643	0.9053	0.8925	0.9143	0.9607	1.0000	0.9858	0.9582	0.9532	0.8754	0.8507	1.0000	0.8192	0.8558
	3	0.9497	0.9521	0.9454	0.9786	0.9651	1.0000	1.0000	0.9610	0.9566	1.0000	0.8864	0.8669	0.9290	0.9105	0.8971
	4	0.8786	0.9493	0.9230	0.9064	0.9173	0.9693	0.9768	1.0000	0.9892	0.9729	0.8515	0.9418	0.9019	0.8760	0.8077
	5	0.8807	0.8471	0.9635	0.8837	0.8560	0.9605	0.9676	0.9544	1.0000	1.0000	0.9076	0.9505	0.9402	0.8583	0.9257
	6	0.8731	0.8654	0.8967	0.8763	0.9331	1.0000	0.9500	0.9830	0.9652	0.9603	0.9184	0.9149	0.9438	0.8764	0.8782
3	1	0.8869	0.9932	0.9325	0.9088	0.9320	0.9768	0.9502	0.9568	0.9520	0.9701	0.8484	0.8274	0.9600	0.9341	0.8242
	2	0.8206	0.8243	0.8350	0.8182	0.7815	0.9631	0.9717	0.9692	0.9527	0.9604	0.9326	0.9029	0.9707	0.8653	0.9153
	3	0.9079	0.9783	0.8552	0.8625	0.7977	1.0000	1.0000	0.9868	0.9611	0.9741	1.0000	0.9613	0.9767	0.8716	0.8982
	4	0.8804	0.8978	0.8261	0.9118	0.8454	0.9846	0.9696	1.0000	0.9770	1.0000	0.8416	0.9203	0.8821	0.9095	0.8497
	5	0.8323	0.9794	0.8919	0.9420	0.7018	0.9646	0.9606	0.9563	0.9868	1.0000	0.9601	0.9310	0.8252	0.8811	0.9408
4	1	0.9066	0.9108	0.9177	0.9861	0.9619	0.9842	0.9700	0.9616	0.9516	1.0000	0.9214	0.9628	0.8961	0.9333	0.9414
	2	0.7917	0.8549	0.9232	0.9584	0.8916	0.9542	0.9819	0.9794	1.0000	1.0000	0.8508	1.0000	0.8783	0.9381	0.8455
	3	0.8845	0.9525	1.0000	0.8903	0.7037	0.9530	0.9521	0.9504	0.9974	0.9693	0.8347	0.8672	0.8385	0.9808	0.9882

4.4. Efficiency of Sustainable Supply Chain

Table 4. Sustainability of Supply Chain $(\alpha = 0.1)$.

Supply Chain	Unit	Efficiency					
		Period 1	Period 2	Period 3	Period 4	Period 5	Overall Efficiency
1	1	0.9340	0.8886	0.8745	0.8972	0.9219	0.9032
	2	0.8668	0.9157	0.8902	0.9116	0.8960	0.8961
	3	0.9561	0.9588	0.9275	0.9531	0.9645	0.9520
	4	0.9262	0.9050	0.9805	0.9032	0.9378	0.9305
	5	0.9447	0.9094	0.8984	0.9278	0.9650	0.9291
	6	0.9531	0.9532	0.9687	0.9574	0.9259	0.9516
	7	0.9164	0.9683	0.9340	0.9261	0.9836	0.9457
2	1	0.8629	0.8928	0.9409	0.8877	0.8729	0.8915
	2	0.9256	0.9383	0.9637	0.8900	0.9078	0.9251
	3	0.9454	0.9397	0.9451	0.9486	0.9541	0.9466
	4	0.8998	0.9560	0.9416	0.9239	0.8993	0.9241
	5	0.9163	0.9217	0.9527	0.9140	0.9272	0.9264
	6	0.9305	0.9101	0.9412	0.9059	0.9239	0.9223
3	1	0.9040	0.9236	0.9497	0.9316	0.9087	0.9235
	2	0.9054	0.8996	0.9250	0.8788	0.8857	0.8989
	3	0.9693	0.9799	0.9396	0.8984	0.8900	0.9354
	4	0.9022	0.9292	0.9027	0.9328	0.8984	0.9131
	5	0.9190	0.9570	0.8912	0.9366	0.8809	0.9169
4	1	0.9374	0.9479	0.9251	0.9570	0.9678	0.9470
	2	0.8656	0.9456	0.9270	0.9655	0.9124	0.9232
	3	0.8907	0.9239	0.9296	0.9562	0.8871	0.9175

To achieve overall sustainability, it is essential to maintain sustainability consistently across all periods. The relationship between sustainability and consistency is crucial, as demonstrated by the values presented in Table 4. A supply chain can only be considered completely sustainable if it demonstrates sustainability consistently across all periods. Conversely, if sustainability is not maintained during even a single period, the supply chain cannot be deemed overall sustainable.

Table 4 exhibits the stochastic efficiency of the supply chain in the economic, social, and environmental sectors, with an error level of 0.1. The first five columns of the table show the stochastic efficiency of the supply chain in these sectors for each period. The final column represents the sustainability of the supply chain. However, upon analyzing the data, it becomes apparent that none of the units across all periods has achieved stochastic efficiency in all three aspects. This indicates that the supply chain is not sustainable. Therefore, to achieve sustainability in the supply chain, it is necessary to focus on consistency in all periods across all three sectors. This requires a holistic approach that takes into account economic, social, and environmental factors and prioritizes sustainability throughout the supply chain. Only by doing so can we ensure the long-term viability of the supply chain and achieve overall sustainability.

5. Conclusion

There is a paucity of academic research that delves into the intricacies of the concrete industry's supply chain, specifically with respect to the utilization of concrete, sand, and the associated two-level supply chain. However, what is known is that the excessive usage of sand mines has led to detrimental impacts on rivers and their surrounding ecosystems. These negative consequences include, but are not limited to, erosion, siltation, and the destruction of aquatic habitats. Upon analyzing the data presented in this study, it becomes clear that none of the units involved in the first supply chain have been able to achieve stochastic efficiency across all three crucial areas: economic, environmental, and social. As such, it can be inferred that the supply chain of the Guilan concrete industry is not sustainable in its current state. For the industry to achieve sustainability, an overhaul of both mines and companies is necessary. Specifically, reducing inputs in mines and increasing outputs in concrete companies would need to occur to create a more sustainable and efficient supply chain. Additionally, calculations were conducted at both 0.3 and 0.5 error levels, revealing that none of the supply chains examined can be considered sustainable at either level. These findings underscore the urgency of implementing measures that promote sustainability within the concrete industry's supply chain. Such measures could include the utilization of more sustainable alternatives to sand in concrete production, the implementation of stricter regulations on sand mining practices, and the adoption of more environmentally-friendly manufacturing processes in concrete companies.

References

[1] Ghasemi, A. R., Rait Pisheh, M.A. (2018). “Presenting a Model for Assessing of Supply Chain Sustainability with Meta Synthesis Approach.” Journal of executive management, Vol. 14 No. 7, pp. 91-112.

[2] Toude Bahambari, R., & Soufi, M. (2019). “Investigating the Moderating Role of Competitive Strategies on the Impact of Supply Chain Integration on the Financial and Operational Performance (Case Study: The car manufacturing industry in IRAN.” Iranian Journal of Optimization, Vol. 11 No. 2, pp. 137-147.

[3] Al-Odeh, m., & Smallwood, J. (2018). "Sustainable Supply Chain Management: Literature Review, Trends and Framework." International Journal of Computational Engineering & Management(IJCEM), Vol. 15, No. 1, pp 230-239.

[4] Amirteimoori A, Soofi M. "Provide a New Targeting Model in a Centralized Decision Making Environment with a Multi-Component Network Structure." jor 2019; Vol. 16, Nov. 1, pp 93-115.

[5] Safari, M. Jamali, G. Bavarsad, B. (2021). “Analyzing Dimensions of Supply Chain Sustainability in Cement Companies Based on LARG Supply Chain Competitive Strategies.” Research in industrial management, Vol. 16, Nov. 56, pp. 102-122.

[6] Darvish Motevalli, M. H., Hosseinzadeh Lotfi, F., Shoja, Naghi, & Abri, A. G. (2020). "Preventing of Environmental Pollution in the Sustainable Supply Chain of the Cement Industry: A Factor Analysis and Fuzzy Decision Making.” Journal of Environmental Science And Technology, Vol. 22, No. 7(98), pp 229-247.

[7] Mahmoudi V., Feizpour M. A., Amoozad Mahdiraji H., Dehmoubed sharifabadi B. (2019), “Designing a Model for Assessing the Sustainable Supply Chain Performance of Governmental Hospitals using Grounded Theory Approach.” jha, Vol. 22, No. 1, pp. 103-118

[8] Mohghar, A., Abbasi, H. (2018). Designing and Explaining the Sustainability Model for Banking Supply Chain (A Case Study of Mellat Bank. Management researches in Iran, Vol. 3, No. 23, pp. 55-74.

[9] Alahyari, M., Pilevari, N., & Radfar, R. (2019). "Providing a Model for Assessing Pharmaceutical Industries Supply Chain Sustainability Using Adaptive Neuro- Fuzzy Inference System (ANFIS)." Journal of healthcare management, Vol. 10, No. 3, pp. 77-88.

[10] Safai Qadiklai, AH., Gholamrezatbar, Z. (2016). “Explaining a framework for assessing the sustainability of the food supply chain using the fuzzy NAP (case study: selected companies producing meat products in Mazandaran province).” Industrial Management (Tehran University), Vol. 6, No. 14, pp 535-554.

[11] Seyed Hosseini, S.M., Darvish Mutauli, M. H. (2015). “Evaluation of cement industry supply chain performance using DEA.” Quantitative Studies in Management, Vol. 25, pp. 41-64.

[12] Ahi, P., Searcy, C., (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. J. Clean. Prod. Vol. 52, pp. 329-341.

[13] Sangbor, M. A., Safi, M. R., & Rabieh, M. (2022). "Analyzing and Prioritizing of Sustainable Supply Chain Management Enablers by Combined Approach of Meta-Synthesis Method and GTMA in Petrochemical Industry." Industrial Management Studies, Vol. 20, No. 64, pp 1-34.

[14] Pilehvari Salmasi, N., Kasraei, A.H., Jeihuni, M. (2021). "Examining the challenges of accepting blockchain technology in the sustainable supply chain in the automotive industry using the combined method of fuzzy DEMATEL and SEM." Quantitative Studies in Management, Vol. 44, No. 20, pp. 139-158.

[15] Davoodi, S. M. R., & Sazegari, S. (2021). "Identifying and Ranking the Barriers to Sustainable Supply Chain Management, Using a Hybrid Fuzzy ANP-DEMATEL Approach: A Case of shipyard in Bushehr." Iranian Journal of Trade Studies, Vol. 25, No. 100, pp. 105-130.

[16] Olfat, L., Moghimi Shahri, B. (2021). Providing a framework for performance evaluation in sustainable supply chain management (case study of construction materials manufacturing industries in Khorasan). Quantitative Studies in Management Vol. 44, No. 28, pp.159-186.

[17] Menhaje Bena, R., Koohi, M.K., Modabberi, S., Ghazi Khansari, M., & Bakand, S. (2021). "Investigation of Geological and Environmental Factors of Airborne Suspended Particles from Sand and Gravel Quarries in The West of Tehran, Iran." Journal of Health And Safety At Work, Vol. 11, No. 1, pp. 117-135.

[18] Dehghan Shabani, N. (2018). "Application of mixed approach to improve sustainable supply chain management in manufacturing industries of Iran, automotive industry (case study: Kerman Motor. Third International Science and Engineering Congress.

[19] Mahmoudi V, Feizpour M A, Amoozad Mahdiraji H, dehmoubed sharifabadi B. "(2019). Designing a Model for Assessing the Sustainable Supply Chain Performance of Governmental Hospitals using Grounded Theory Approach." Jha, Vol. 22, No. 1, pp 103-118

[20] Fathi, M. R., Nasrollahi, M., & Zamanian, A. (2020). "Mathematical Modeling of Sustainable Supply Chain Networks under Uncertainty and Solving It Using Metaheuristic Algorithms." Industrial Management Journal, Vol. 11, No. 4, pp. 621-652.

[21] Georji, N., Javadian, N. (2016). "Data envelopment analysis method for measuring supply chain sustainability. Studies of industrial engineering and production management," Vol. 3, No. 3, pp. 1-9.

[22] Mohammad Khan, S., Narmashiri, F., Yazdan Panah, A. (2018). "Geomorphic effect of instream gravel mining Case study (Dehbala River â Kerman)." Quantitative Geomorphological Research, Vol. 5, No. 1, pp. 14-26.

[23] Bagheri Tavani, M., Norozi, M., & Faridi, S. (2015). "Investigating sand and gravel factory hogwash on biological, environmental and ecological indices in Tirom River (Mazandaran Province). Journal of Animal Research", Iranian Journal of Biology, Vol. 28, No. 1, pp. 9-20.

[24] Rowshantabari, M., Kiabi, B., Solimanroudi, A., Vahedi, F., Makhlogh, A., & Rahmati, R. (2014). "Environment Risk Assessment of Sand and Silt Exploitation from Tonekabon river." Journal of Environmental Science and Technology, Vol. 16, No. 1, pp. 167-176.

[25] Shayan S., Sharifi Kia M., Dehestani D. (2014). "Extraction and measurement of morphological changes of the Kashkan river due to the extraction of sand resources." Geographical space, Vol. 13, No. 43, pp. 191-207.

[26] Uysal, F. (2012). "An integrated model for sustainable performance measurement in supply chain." Procedia - Social and Behavioral Sciences, Vol. 62, pp. 689-694.

[27] Varsei, M., Soosay, C., Fahimnia, B., Sarkis, J. (2014). Framing sustainability performance of supply chains with multidimensional indicators. Supply Chain Manag. Int. J. 19(3), 242-257.

[28] Ahi, P. Searcy, C. (2015a). "An analysis of metrics used to measure performance in green and sustainable supply chains." J. Clean. Prod. Vol. 86, pp. 360-373.

[29] Ahi, P., Searcy, C.(2015b). "Assessing sustainability in the supply chain: a triple bottom line approach." Applied Mathematical Modelling. pp. 2882-2896.

[30] Searcy, C., Dixon, S.M., Neumann, W.P. (2016). "The use of work environment performance indicators in corporate social responsibility reporting." J. Clean. Prod. Vol. 112, No. 4, pp. 2907e292.

[31] Khodakarami, M., Shabani, A., Saen, R. F., Azadi, M. (2015). "Developing distinctive two-stage data envelopment analysis models: An application in evaluating the sustainability of supply chain management." Measurement: Interdisciplinary Research and Perspectives, Vol. 70, pp. 62-74.

[32] Izadikhah, M., Saen, R.F., (2016). "Evaluating sustainability of supply chains by twostage range directional measure in the presence of negative data." Transp. Res. Vol. 49, pp. 110e126.

[33] Ahmadi, H.B., Kusi-Sarpong, S., Rezaei, J., (2017). "Assessing the social sustainability of supply chains using BestWorst Method. Resour. Conservat." Recycl. 126, 99e106.

[34] Manhart, A., Vogt, R., Priester, M. (2019). "Correction to: The environmental criticality of primary raw materials—a new methodology to assess global environmental hazard potentials of minerals and metals from mining." Miner Econ Vol. 32, pp.109.

[35] Humphreys, D. "Mining productivity and the fourth industrial revolution." Miner Econ Vol. 33, pp.115–125.

[36] Maab, AL., Schüttrumpf, H. & Lehmkuhl, F. (2021). "Human impact on fluvial systems in Europe with special regard to today's river restorations." Environ Sci Eur Vol. 33, pp. 119.

[37] Bhoopathy, V., Subramanian, S.S. (2022). "The way forward to sustain environmental quality through sustainable sand mining and the use of manufactured sand as an alternative to natural sand." Environ Sci Pollut Res, Vol. 29, pp. 30793–30801.

[38] Fathi, A., Karimi, B., & Saen, R. F. (2022). "Sustainability assessment of supply chains by a novel robust two-stage network DEA model: a case study in the transport industry." Soft Computing, Vol. 26, No. 13, pp.6101-6118.

[39] Azadi, M., Yousefi, S., Saen, R. F., Shabanpour, H., & Jabeen, F. (2023). "Forecasting sustainability of healthcare supply chains using deep learning and network data envelopment analysis." Journal of Business Research, Vol. 154, pp.113357.

[40] Tavassoli, M., Saen, R. F., & Zanjirani, D. M. (2020). "Assessing sustainability of suppliers: A novel stochastic-fuzzy DEA model. Sustainable production and consumption," Vol. 21, pp. 78-91.

[41] Jahani Sayyad Noveiri, M., Kordrostami, S., & Amirteimoori, A. (2021). "Sustainability assessment and most productive scale size: A stochastic DEA approach with dual frontiers." Environmental Modeling & Assessment, Vol. 26, No. 5, pp.723-735.

[42] Sharpe, W. F. (1963). "A simplified model for portfolio analysis." Management Science, Vol. 9, No. 2, pp. 277-293.

[43] Kahane, Y. (1977). "Determination of the product mix and the business policy of an insurance company—a portfolio approach." Management Science, Vol. 23, No. 10, pp. 1060-1069.

[44] Cooper, W. W., Deng, H., Huang, Z., & Li, S. X. (2002). "Chance constrained programming approaches to technical efficiencies and inefficiencies in stochastic data envelopment analysis." Journal of the Operational Research Society, Vol. 53, No. 12, pp. 1347-1356.