

# **Sustainability Assessment in Concrete Industry Using Stochastic Data Envelopment Analysis**

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## **Abstract**

This research aims to develop a stochastic data envelopment analysis (SDEA) model to assess the sustainability of active companies in the concrete industry in Guilan province based on sustainability indicators. In the first step, economic, social, and environmental indicators for evaluating the companies were identified through the literature review. In the next step, these indicators were evaluated using the fuzzy Delphi method, and more important indicators were identified. Finally, a new stochastic DEA model was developed for the sustainability assessment of concrete companies in Guilan province in both linear and nonlinear equations. In the proposed models, errors are incorporated into the model via a stochastic component specified by considering the constraints probabilistically. Based on the results of implementing the presented model, at an alpha level of 0.1, the companies Darvishan and Zahmatkesh, at an alpha level of 0.3, the companies Darvishan, Takht-e-Jamshid, and Zahmatkesh, and finally at an alpha level of 0.5, only the company Darvishan are sustainable. So, the only sustainable, efficient company is Darvishan, which should be considered a benchmark for other units for achieving sustainability efficiency.

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**Keywords:** Stochastic DEA, Undesirable Outputs, Uncontrollable Inputs

## **1-Introduction**

The growing concerns about the environment, led to a concentration on unsustainable patterns of behaviors in operation and production sectors (Geyi et al., 2020). Nowadays, companies not only use standard financial indicators to track their effectiveness but also environmental and social indicators are emerged as a new trend in corporate reporting to the stakeholders (Chen et al., 2015). In light of the above, sustainability is commonly defined as using resources to meet the needs of the present without compromising the ability of future generations to meet their own needs (Ahi and Searcy, 2015). Sustainability is a complex and multidimensional issue, which merges efficiency and inter- and intra-generational equity on an environmental, economic, and social basis. Given the need for tackling issues such as climate change, material scarcity, and energy crisis, sustainability became a critical concept for governments. Accordingly, sustainability has also become widely-recognized as a critical issue for business survival in an increasingly competitive world (Vinodh and Girubha, 2012).

In recent decades, industrial development has given way to sustainable development, particularly in developed countries, and companies are seeking methods to enhance their performance while supporting the environment. Thus, integrating environmental, economic, and social performance to achieve sustainability is considered a main challenge for businesses. According to the World Commission on Environment and Development, "sustainability is the use of resources to meet current needs in a manner that does not jeopardize the ability of future generations to meet their needs." Within this broad definition lie concepts such as the impact of economic activities on the environment, ensuring food security, meeting essential human needs, and protecting non-renewable resources (Ahmadi et al., 2017).

There are various methods to assess the sustainability of a company, among which DEA has led to significant performance improvements in numerous cases as a theoretical framework. While standard DEA focuses on a simple process where inputs are consumed to produce outputs, network DEA considers a sequence of processes, each consuming its own set of inputs to produce its own set of outputs (Homayounfar et al., 2014). To measure the efficiency of such interdependent systems, the network DEA model was proposed (Amirteimouri and Soufi, 2019). In most standard network DEA models, inputs and outputs measures have been considered only under conditions of certainty. However, in real-world environments, uncertainty often manifests as a stochastic environment. Therefore, researchers have proposed stochastic models in DEA to address this variability in data. By using probabilistic constraints, it allowed some DMUs to be beyond the efficient frontier. For these DMUs, the input and output constraints in the DEA envelopment model would be violated. In other words, for  $\alpha$  percent of DMUs, constraints would be violated (Amirteimouri et al., 2022). The drawback of the Olesen and Petersen (2000) model was that it ignored the relationship between DMUs. This issue arises because a convex combination of two DMUs can have less variance than the DMUs themselves. A simple solution for the OP model is to use stochastic vectors instead of linear coefficients for each linear combination, an idea implemented by Olesen and Peterson (2002). Considering the stochastic factor, Huang and Li (2001) calculated the deterministic linear equation with stochastic programming problems through linear programming.

Since, industrial activities increasingly impacting environmental and social dimensions, there is a pressing need for methodologies that can comprehensively evaluate and enhance the sustainability of industrial operations. This research addresses this need by developing a stochastic DEA model that incorporates economic, social, and environmental indicators. Introducing stochastic elements into the DEA model, this research provides a more realistic and robust framework for assessing the efficiency and sustainability of companies. This approach allows for better management and strategic decision-making in the face of uncertainty, ensuring that resources are used effectively without compromising the needs of future generations. Moreover, this research contributes to the theoretical advancement of DEA methodologies by integrating probabilistic constraints and addressing the limitations of existing models. In the proposed approach, errors are incorporated into the model via a stochastic component, which is specified by considering the constraints probabilistically (Bozorgi et al., 2023 and Nozari et al., 2021).

The findings of this study have practical implications for industry managers and policymakers, offering a systematic and quantitative tool for sustainability assessment. This can lead to improved environmental practices, enhanced economic performance, and greater social responsibility within the concrete industry.

The remainder of this paper is structured as follows: Section 2 reviewed the recent literature around sustainability assessment. Section 3 provides an overview of proposed stochastic DEA models for Sustainability measurement. Section 4, illustrates the model's applicability based on the extracted data from the concrete industry in Guilan province, Iran. Section 5 develops conclusion

## **2- Research Background**

Sustainability refers to a company's efforts to achieve economic, social, and environmental objectives simultaneously, ensuring long-term business success and societal well-being (Engida et al., 2018). Given the growing emphasis on sustainable development, sustainability has attracted significant attention from both academic and business, as organizations strive to balance economic growth with social responsibility and environmental stewardship. Recent literature shows a variety of methods to evaluate sustainability, each with distinct advantages and limitations. Among the most prominent are multi-criteria decision-making (MCDM) approaches, data envelopment analysis (DEA), and integrated frameworks combining qualitative and quantitative techniques.

MCDM techniques are widely used to handle the complexity and multi-dimensional nature of sustainability assessments. For instance, Hussain et al. (2023) proposed an entropy weight-TOPSIS approach to analyze the progression of Green Energy Sustainable Investment Index (GESII) for forty-seven countries affiliated with the Belt and Road Initiative (BRI) based on 22 indicators categorized into four dimensions: social, economic, environmental, and institutional. Piya et al. (2022) analyzed the affecting drivers on the resilience level of the oil and gas industry under the COVID-19 pandemic. They identified 15 drivers of supply chain resilience and analyzed them using the integrated fuzzy ISM and DEMATEL methods. Sarker et al. (2021) proposed a sustainability performance measurement model integrating the Balanced Scorecard (BSC) perspective and the Fuzzy multiple-criteria decision-making (FMCDM) approach. Qorri et al. (2022) developed a combined method, consist of content analysis, fuzzy Shannon's Entropy, and fuzzy TOPSIS to evaluates three aspects of

sustainability across the entire supply chain. Ahmadi et al. (2017) prioritized social sustainability criteria of manufacturing companies' supply chains in, using the best worst method (BWM) and proposed a framework for investigating their social sustainability. Nikolaou et al. (2019) proposed a framework to measure corporate sustainability performance by designing a composite sustainability index, namely the triple-bottom-line (TBL) and the principles of strong sustainability. Ahi and Searcy (2015) utilized a triple bottom line (TBL) approach integrating economic, social, and environmental criteria to assess sustainability in supply chains. The use of fuzzy logic in MCDM, as demonstrated by Chen et al. (2015) applying fuzzy Delphi and TODIM, provides a nuanced analysis of sustainable development in the construction materials industry in China. DEA is another prevalent method for assessing corporate sustainability. It is particularly effective in evaluating the relative efficiency of decision-making units. Engida et al. (2018) proposed an integrated method of principal component analysis (PCA) and DEA to measure sustainability of the European food and beverages companies. Haghghi et al. (2016) proposed a novel hybrid BSC-network DEA framework to rank different multi echelon supply chains from sustainability viewpoint to find the efficient and benchmarked units at each echelon. Khodakarami et al. (2015) applied two-stage DEA models to evaluate the sustainability of supply chain management. Izadikhah and Farzipoor Saen (2016) used a two-stage directional measurement approach to assess supply chain sustainability. These studies highlight DEA's utility in identifying best practices and areas for improvement. Finally, integrated frameworks combine various methodologies to provide a comprehensive assessment of sustainability. Table 2 summarizes an overview of various quantitative models employed for selecting sustainability criteria.

**Table 1. Recent studies on sustainability assessment**

Authors	Title	Method (s)
Hussain et al. (2023)	Proposing a sustainable investment index for measuring economic performance and sustainability: A step toward clean and affordable energy	TOPSIS
Carissimi et al. (2023)	Crossing the chasm: investigating the relationship between sustainability and resilience in supply chain management	Thematic Analysis
Sujan et al. (2022)	Analysis of supply chain resilience drivers in oil and gas industries during the COVID-19 pandemic using an integrated approach	Metaheuristic algorithms
Piya et al. (2022)	Analysis of supply chain resilience drivers in oil and gas industries during the COVID-19 pandemic using an integrated approach	Fuzzy ISM, DEMATEL
Qorri et al. (2022)	A practical method to measure sustainability performance of supply chains with incomplete information	Shannon Entropy, TOPSIS
Sarkar et al. (2021)	Measuring sustainability performance using an integrated model	FAHP, SAW, TOPSIS, VIKOR
Geyi et al. (2020)	Agile capabilities as necessary conditions for maximising sustainable supply chain performance: An empirical investigation	SEM
Bousoo et al. (2020)	The role of green supply chain management practices on environmental performance: A case of Indonesian small and medium enterprises	SEM
Piya et al. (2019)	An approach for analysing supply chain complexity drivers through interpretive structural modelling	SEM
Nikolaou et al. (2019)	A framework to measure corporate sustainability performance: A strong sustainability-based view of firm	SEM
Engida et al. (2018)	Measuring corporate sustainability performance– the case of European food and beverage companies	DEA
Ahmadi et al. (2017)	Assessing the social sustainability of supply chains using Best Worst Method	Best-Worst Method
Izadikhah and Farzipoor Saen (2016)	Evaluating sustainability of supply chains by two-stage range directional measure in the presence of negative data	DEA

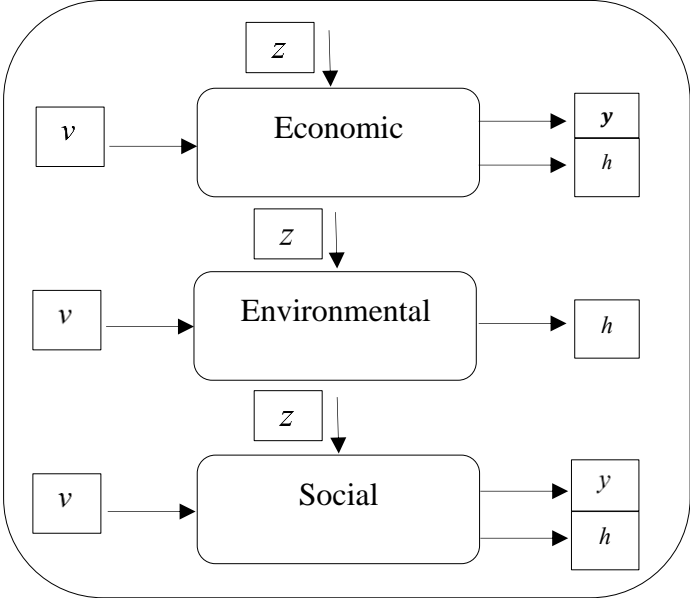
Haghighi et al. (2016)	An integrated approach for performance evaluation in sustainable supply chain networks (with a case study)	DEA
Khodakarami et al. (2015)	Developing distinctive two-stage data envelopment analysis models: An application in evaluating the sustainability of supply chain management	DEA
Ahi and Searcy (2015)	Assessing sustainability in the supply chain: A triple bottom line approach	Probability Theory
Chen et al. (2015)	Multicriteria analysis of sustainable development indicators in the construction minerals industry in China	Fuzzy TODIM
Feil et al. (2015)	Selection and identification of the indicators for quickly measuring sustainability in micro and small furniture industries	Weighted Average

A number of theoretical and practical approaches have been developed for performance measurement, however, it is widely recognized that further work is necessary. This research proposed a DEA based model which can handle uncertainty, ensuring that resources are used effectively without compromising the needs of future generations. Moreover, this research contributes to the theoretical literature by integrating probabilistic constraints and addressing the limitations of existing models.

**3-Stochastic DEA Model for Sustainability Analysis**

Model-based quantitative research is a type of study where models build based on mathematical relationships among models components. This method has been widely used in the sustainability assessment literature. In this research, a stochastic DEA model is used as analytical tool for sustainability assessment in concrete industry.

The research conceptual model for the concrete industry is depicted in Figure 1. Economic, social, and environmental assessment indicators are collected from literature review. Then, the identified indicators were screened according to the opinions of academic experts and industry professionals.



**Figure 1. Sustainability aspects in DMUs**

Based on the network model structure, the model variables and the structure of the stochastic efficiency assessment model for the companies are defined as follows:

$k$	Number of companies	(1)
$n$	Counter for inputs in each of the economic, environmental, and social sectors	(2)
$N^{Economic}$	Set of indices for inputs in the economic sector	(3)
$N^{Environmental}$	Set of indices for inputs in the environmental sector	(4)
$N^{Social}$	Set of indices for inputs in the social sector	(5)
$s$	Counter for desirable outputs in each of the economic, environmental, and social sectors	(6)
$S^{Economic}$	Set of indices for desirable outputs in the economic sector	(7)
$S^{Environmental}$	Set of indices for desirable outputs in the environmental sector	(8)
$S^{Social}$	Set of indices for desirable outputs in the social sector	(9)
$m$	Counter for undesirable outputs in each of the economic, environmental, and social sectors	(10)
$M^{Economic}$	Set of indices for undesirable outputs in the economic sector	(11)
$M^{Environmental}$	Set of indices for undesirable outputs in the environmental sector	(12)
$M^{Social}$	Set of indices for undesirable outputs in the social sector	(13)
$f=1$	Denotes the economic sector	(14)
$f=2$	Denotes the environmental sector	(15)
$f=3$	Denotes the social sector	(16)
$\beta_f$	A predetermined value by the manager that reflects the importance of each of the economic, environmental, and social sectors	(17)
$\varphi_o$	Sustainability of the under evaluation company	(18)
$Z_{nk}$	n-th independent input of the k-th company	(19)
$V_{rk}$	r-th common input of the k-th company	(20)
$Y_{sk}$	s-th desirable output of the k-th company	(21)
$H_{mk}$	m-th undesirable output of the k-th company	(22)
$\theta_o^1$	Stochastic efficiency of the economic sector	(23)
$\theta_o^2$	Stochastic efficiency of the environmental sector	(24)
$\theta_o^3$	Stochastic efficiency of the social sector	(25)
$\lambda_j$	Variable related to the combined virtual unit of the k-th company in the economic sector	(26)
$\gamma_j$	Variable related to the combined virtual unit of the k-th company in the environmental sector	(27)
$\zeta_j$	Variable related to the combined virtual unit of the k-th company in the social sector	(28)

In this research,  $\beta_f$  is considered equal for economic, environmental, and social sectors. According to the above parameters, variables and indices, the stochastic model for sustainability assessment of under evaluation unit illustrated as follows:

<i>Objective Function</i>	$\text{Min } \varphi_o = \frac{\sum_{f=1}^3 \beta_f \theta_o^f}{\sum_{f=1}^3 \beta_f}$	(29)
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<p><i>Economic Constraints</i></p>	$P \left\{ \sum_{k=1}^K \lambda_k \tilde{z}_{nk} \leq \theta_o^1 \tilde{z}_{no} \right\} \geq 1 - \alpha, n \in N^{Economic},$ $P \left\{ \sum_{k=1}^K \lambda_k \tilde{v}_{rk} \geq \tilde{v}_{ro} \right\} \geq 1 - \alpha, r \in R^{Economic},$ $P \left\{ \sum_{k=1}^K \lambda_k \tilde{y}_{sk} \geq \tilde{y}_{so} \right\} \geq 1 - \alpha, s \in S^{Economic},$ $P \left\{ \sum_{j=1}^k \lambda_k \tilde{h}_{mk} \leq \tilde{h}_{mo} \right\} \geq 1 - \alpha, m \in M^{Economic},$ $\sum_{k=1}^K \lambda_k = 1,$	<p>(30)</p>
<p><i>Environmental Constraints</i></p>	$P \left\{ \sum_{k=1}^K \gamma_k \tilde{z}_{nk} \leq \theta_o^2 \tilde{z}_{no} \right\} \geq 1 - \alpha, n \in N^{Environment},$ $P \left\{ \sum_{k=1}^K \gamma_k \tilde{v}_{rk} \geq \tilde{v}_{ro} \right\} \geq 1 - \alpha, r \in R^{Environment},$ $P \left\{ \sum_{j=1}^k \gamma_k \tilde{h}_{mk} \leq \tilde{h}_{mo} \right\} \geq 1 - \alpha, m \in M^{Environment},$ $\sum_{k=1}^K \gamma_k = 1,$	<p>(31)</p>
<p><i>Social Constraints</i></p>	$P \left\{ \sum_{k=1}^K \zeta_k \tilde{z}_{nk} \leq \theta_o^3 \tilde{z}_{no} \right\} \geq 1 - \alpha, n \in N^{Social},$ $P \left\{ \sum_{k=1}^K \zeta_k \tilde{v}_{rk} \geq \tilde{v}_{ro} \right\} \geq 1 - \alpha, r \in R^{Social},$ $P \left\{ \sum_{k=1}^K \zeta_k \tilde{y}_{sk} \geq \tilde{y}_{so} \right\} \geq 1 - \alpha, s \in S^{Social},$ $P \left\{ \sum_{j=1}^k \zeta_k \tilde{h}_{mk} \leq \tilde{h}_{mo} \right\} \geq 1 - \alpha, m \in M^{Social},$ $\sum_{k=1}^K \zeta_k = 1,$	<p>(32)</p>
<p><i>Decision Variables</i></p>	$\lambda_j, \gamma_j, \zeta_j \geq 0$	<p>(33)</p>

The deterministic DEA model for sustainability assessment formed as follows:

Objective Function	$\text{Min } \varphi_o = \frac{\sum_{f=1}^3 \beta_f \theta_o^f}{\sum_{f=1}^3 \beta_f}$	(34)
Economic Constraints	$\sum_{k=1}^K \lambda_k z_{nj} - \phi^{-1}(\alpha) \sigma_n(\lambda_k, \theta_o^1) \leq \theta_o^1 z_{no}, n \in N^{\text{Economic}},$ $\sum_{k=1}^K \lambda_k v_{rk} + \phi^{-1}(\alpha) \sigma_r(\lambda_k) \geq v_{ro}, r \in R^{\text{Economic}},$ $\sum_{k=1}^K \lambda_k y_{sj} - \phi^{-1}(\alpha) \sigma_s(\lambda_k) \geq y_{so}, s \in S^{\text{Economic}},$ $\sum_{k=1}^K \lambda_k h_{mj} - \phi^{-1}(\alpha) \sigma_m(\lambda_k) \leq h_{mo}, m \in M^{\text{Economic}},$ $\sum_{k=1}^K \lambda_k = 1,$ $(\sigma_n(\lambda_k, \theta_o^1))^2 = \sum_k \sum_l \lambda_k \lambda_l \text{cov}(\tilde{z}_{nj}, \tilde{z}_{nl}) + (\theta_o^1)^2 \text{var}(\tilde{z}_{no}) - 2\theta_o^1 \sum_k \lambda_k \text{cov}(\tilde{z}_{nk}, \tilde{z}_{no}), n \in N^{\text{Economic}},$ $(\sigma_r(\lambda_k))^2 = \sum_k \sum_l \lambda_k \lambda_l \text{cov}(\tilde{v}_{rk}, \tilde{v}_{rl}) + \text{var}(\tilde{v}_{ro}) - 2\sum_k \lambda_k \text{cov}(\tilde{v}_{rk}, \tilde{v}_{ro}), r \in R^{\text{Economic}},$ $(\sigma_s(\lambda_k))^2 = \sum_k \sum_l \lambda_k \lambda_l \text{cov}(\tilde{y}_{sk}, \tilde{y}_{sl}) + \text{var}(\tilde{y}_{so}) - 2\sum_k \lambda_k \text{cov}(\tilde{y}_{sk}, \tilde{y}_{so}), s \in S^{\text{Economic}},$ $(\sigma_m(\lambda_k))^2 = \sum_k \sum_l \lambda_k \lambda_l \text{cov}(\tilde{h}_{mk}, \tilde{h}_{ml}) + \text{var}(\tilde{h}_{mo}) - 2\sum_k \lambda_k \text{cov}(\tilde{h}_{mk}, \tilde{h}_{mo}), s \in S^{\text{Economic}},$	(35)
Environmental Constraints	$\sum_{k=1}^K \gamma_k z_{nj} - \phi^{-1}(\alpha) \sigma_n(\lambda_k, \theta_o^2) \leq \theta_o^2 z_{no}, n \in N^{\text{Environment}},$ $\sum_{k=1}^K \gamma_k v_{rk} + \phi^{-1}(\alpha) \sigma_r(\lambda_k) \geq v_{ro}, r \in R^{\text{Environment}},$ $\sum_{k=1}^K \gamma_k h_{mj} - \phi^{-1}(\alpha) \sigma_m(\lambda_k) \leq h_{mo}, m \in M^{\text{Environment}},$ $\sum_{k=1}^K \gamma_k = 1,$ $(\sigma_n(\gamma_k, \theta_o^1))^2 = \sum_k \sum_l \gamma_k \gamma_l \text{cov}(\tilde{z}_{nj}, \tilde{z}_{nl}) + (\theta_o^2)^2 \text{var}(\tilde{z}_{no}) - 2\theta_o^2 \sum_k \lambda_k \text{cov}(\tilde{z}_{nk}, \tilde{z}_{no}), n \in N^{\text{Environment}},$ $(\sigma_r(\gamma_k))^2 = \sum_k \sum_l \gamma_k \gamma_l \text{cov}(\tilde{v}_{rk}, \tilde{v}_{rl}) + \text{var}(\tilde{v}_{ro}) - 2\sum_k \gamma_k \text{cov}(\tilde{v}_{rk}, \tilde{v}_{ro}), r \in R^{\text{Environment}},$ $(\sigma_m(\lambda_k))^2 = \sum_k \sum_l \gamma_k \gamma_l \text{cov}(\tilde{h}_{mk}, \tilde{h}_{ml}) + \text{var}(\tilde{h}_{mo}) - 2\sum_k \gamma_k \text{cov}(\tilde{h}_{mk}, \tilde{h}_{mo}), s \in S^{\text{Environment}},$	(36)

<p><i>Social Constraints</i></p>	$\sum_{k=1}^K \zeta_k z_{nj} - \phi^{-1}(\alpha) \sigma_n(\zeta_k, \theta_o^3) \leq \theta_o^3 z_{no}, n \in N^{Social},$ $\sum_{k=1}^K \zeta_k v_{rk} + \phi^{-1}(\alpha) \sigma_r(\zeta_k) \geq v_{ro}, r \in R^{Social},$ $\sum_{k=1}^K \zeta_k y_{sj} - \phi^{-1}(\alpha) \sigma_s(\zeta_k) \geq y_{so}, s \in S^{Social},$ $\sum_{k=1}^K \zeta_k h_{mj} - \phi^{-1}(\alpha) \sigma_m(\zeta_k) \leq h_{mo}, m \in M^{Social},$ $\sum_{k=1}^K \zeta_k = 1,$ $(\sigma_n(\zeta_k, \theta_o^3))^2 = \sum_k \sum_l \zeta_k \zeta_l \text{cov}(\tilde{z}_{nj}, \tilde{z}_{nl}) + (\theta_o^3)^2 \text{var}(\tilde{z}_{no}) - 2\theta_o^3 \sum_k \zeta_k \text{cov}(\tilde{z}_{nk}, \tilde{z}_{no}), n \in N^{Social},$ $(\sigma_r(\zeta_k))^2 = \sum_k \sum_l \zeta_k \zeta_l \text{cov}(\tilde{v}_{rk}, \tilde{v}_{rl}) + \text{var}(\tilde{v}_{ro}) - 2\sum_k \zeta_k \text{cov}(\tilde{v}_{rk}, \tilde{v}_{ro}), r \in R^{Social},$ $(\sigma_s(\zeta_k))^2 = \sum_k \sum_l \zeta_k \zeta_l \text{cov}(\tilde{y}_{sk}, \tilde{y}_{sl}) + \text{var}(\tilde{y}_{so}) - 2\sum_k \zeta_k \text{cov}(\tilde{y}_{sk}, \tilde{y}_{so}), s \in S^{Social},$ $(\sigma_m(\zeta_k))^2 = \sum_k \sum_l \zeta_k \zeta_l \text{cov}(\tilde{h}_{mk}, \tilde{h}_{ml}) + \text{var}(\tilde{h}_{mo}) - 2\sum_k \zeta_k \text{cov}(\tilde{h}_{mk}, \tilde{h}_{mo}), s \in S^{Social},$	<p>(37)</p>
<p><i>Decision Variables</i></p>	$\lambda_j, \gamma_j, \zeta_j \geq 0$	<p>(38)</p>

Considering the single-factor assumption of random variables in economics and finance, which was utilized by Sharpe and Kahane, the deterministic model transforms into the following linear form:

<p><i>Objective Function</i></p>	$\text{Min } \varphi_o = \frac{\sum_{f=1}^3 \beta_f \theta_o^f}{\sum_{f=1}^3 \beta_f}$	<p>(39)</p>
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<p><i>Economic Constraints</i></p>	$\sum_{k=1}^K \lambda_k z_{nk} - \phi^{-1}(\alpha)(q_n^+ + q_n^-) \leq \theta_o^1 z_{no}, n \in N^{Economic},$ $\sum_{k=1}^K \lambda_k \sigma(z_{nk}) - \theta_o^1 \sigma(z_{no}) = q_n^+ - q_n^-, n \in N^{Economic},$ $\sum_{k=1}^K \lambda_k v_{rk} + \phi^{-1}(\alpha)(q_r^+ + q_r^-) \geq v_{ro}, r \in R^{Economic},$ $\sum_{k=1}^K \lambda_k \sigma(v_{rk}) - \sigma(v_{ro}) = q_r^+ - q_r^-, r \in R^{Economic},$ $\sum_{k=1}^K \lambda_k y_{sk} + \phi^{-1}(\alpha)(q_s^+ + q_s^-) \geq y_{so}, s \in S^{Economic},$ $\sum_{k=1}^K \lambda_k \sigma(y_{sk}) - \sigma(y_{so}) = q_s^+ - q_s^-, s \in S^{Economic},$ $\sum_{k=1}^K \lambda_k h_{mk} - \phi^{-1}(\alpha)(q_m^+ + q_m^-) \leq h_{mo}, m \in M^{Economic},$ $\sum_{k=1}^K \lambda_k \sigma(h_{mk}) - \sigma(h_{mo}) = q_m^+ - q_m^-, m \in M^{Economic},$ $\sum_{k=1}^K \lambda_k = 1,$	<p>(40)</p>
<p><i>Environmental Constraints</i></p>	$\sum_{k=1}^K \gamma_k z_{nk} - \phi^{-1}(\alpha)(q_n^+ + q_n^-) \leq \theta_o^2 z_{no}, n \in N^{Environment},$ $\sum_{k=1}^K \gamma_k \sigma(z_{nk}) - \theta_o^2 \sigma(z_{no}) = q_n^+ - q_n^-, n \in N^{Environment},$ $\sum_{k=1}^K \gamma_k v_{rk} + \phi^{-1}(\alpha)(q_r^+ + q_r^-) \geq v_{ro}, r \in R^{Environment},$ $\sum_{k=1}^K \gamma_k \sigma(v_{rk}) - \sigma(v_{ro}) = q_r^+ - q_r^-, r \in R^{Environment},$ $\sum_{k=1}^K \gamma_k h_{mk} - \phi^{-1}(\alpha)(q_m^+ + q_m^-) \leq h_{mo}, m \in M^{Environment},$ $\sum_{k=1}^K \gamma_k \sigma(h_{mk}) - \sigma(h_{mo}) = q_m^+ - q_m^-, m \in M^{Environment},$ $\sum_{k=1}^K \gamma_k = 1,$	<p>(41)</p>

<i>Social Constraints</i>	$\sum_{k=1}^K \zeta_k z_{nk} - \phi^{-1}(\alpha)(q_n^+ + q_n^-) \leq \theta_o^1 z_{no}, n \in N^{Social} \quad (42)$ $\sum_{k=1}^K \zeta_k \sigma(z_{nk}) - \theta_o^1 \sigma(z_{no}) = q_n^+ - q_n^-, n \in N^{Social},$ $\sum_{k=1}^K \zeta_k v_{rk} + \phi^{-1}(\alpha)(q_r^+ + q_r^-) \geq v_{ro}, r \in R^{Social},$ $\sum_{k=1}^K \zeta_k \sigma(v_{rk}) - \sigma(v_{ro}) = q_r^+ - q_r^-, r \in R^{Social},$ $\sum_{k=1}^K \zeta_k y_{sj} + \phi^{-1}(\alpha)(q_s^+ + q_s^-) \geq y_{so}, s \in S^{Social},$ $\sum_{k=1}^K \zeta_k \sigma(y_{sk}) - \sigma(y_{so}) = q_s^+ - q_s^-, s \in S^{Social},$ $\sum_{k=1}^K \zeta_k h_{mk} - \phi^{-1}(\alpha)(q_m^+ + q_m^-) \leq h_{mo}, m \in M^{Social},$ $\sum_{k=1}^K \zeta_k \sigma(h_{mk}) - \sigma(h_{mo}) = q_m^+ - q_m^-, m \in M^{Social},$ $\sum_{k=1}^K \zeta_k = 1,$	
<i>Decision Variables</i>	$\lambda_j, \gamma_j, \zeta_j, q_n^+, q_n^-, q_r^+, q_r^-, q_s^+, q_s^-, q_m^+, q_m^- \geq 0, \forall j, n, r, s, m. \quad (43)$	

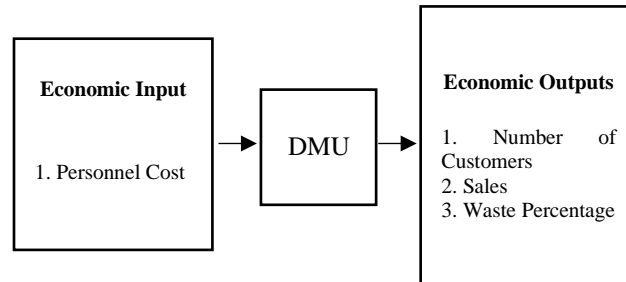
**Definition 1.** A company is considered stochastically economic efficient if and only if  $\theta_o^1=1$ .

**Definition 2.** A company is considered stochastically environmental efficient if and only if  $\theta_o^2=1$ .

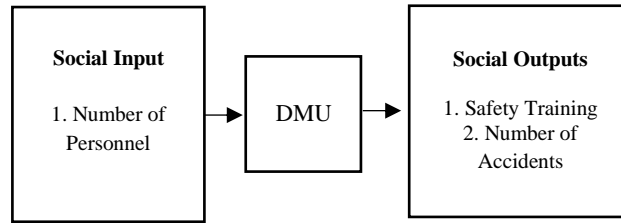
**Definition 3.** A company is considered stochastically social efficient if and only if  $\theta_o^3=1$ .

**Definition 4.** A company is considered stochastically sustainable if the objective function of the linearized model equals one ( $\varphi_o=1$ ).

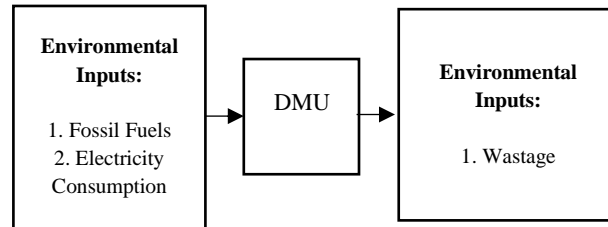
**Definition 5.** A company is considered stochastically sustainable if and only if in all economic, environmental, and social aspects be stochastically efficient ( $\theta_o^1 = \theta_o^2 = \theta_o^3 = 1$ ).



**Figure 2. Economic inputs and outputs of the concrete production companies**



**Figure 3. Social inputs and outputs of the concrete production companies**



**Figure 4. Environmental inputs and outputs of the concrete production companies**

#### 4-Empirical Example

In this research, various inputs and outputs including the financial and inventory data of 15 concrete companies in Guilan province have been extracted for implementing the proposed models, which summarized in Table 2 and Table 3. The feasibility of the inputs and outputs values is examined before model implementation. It should be noted that GAMS 28.2.0 software is used for data analysis.

**Table 2: Average Inputs and Outputs for Sustainability Measures**

Company	Environmental Measures			Economic Measures			Economic Measures			
	Waste	Electricity Consumption	Fossil Fuels	Number of Accidents	Safety Training	Number of Personnel	Waste Percentage	Number of Customers	Personnel Cost	Sale
Darvishan	1.20	5954.77	18605.67	1.21	39.35	23.69	30.68	810.74	492128.85	1040328.70
Kaveh Beton	1.13	5721.56	17452.22	1.45	40.68	44.20	28.75	1182.73	837984.58	1405636.82
Kaspian	1.24	6935.26	19765.31	1.39	38.42	56.61	27.05	1071.74	550398.88	1374678.94
Almas-e Guilan	1.06	6879.05	18132.59	1.58	34.50	56.17	26.91	618.57	766712.29	1229272.13
Shoa Beton Sharq	1.24	6005.02	19217.58	1.41	43.43	62.80	29.32	1777.68	850429.57	870955.86
Takht-e Jamshid	1.12	5171.18	16807.85	1.60	39.14	45.64	27.64	615.40	638725.27	1815428.22
Hital	1.13	6300.00	19424.36	1.54	32.04	15.40	26.47	612.25	365366.56	1269675.54
Khazar Beton	1.21	6032.56	18312.17	1.59	39.11	14.60	28.58	1789.53	331695.55	700760.04
Arya Beton	1.25	6174.71	18012.19	1.47	37.79	30.81	28.12	1123.74	463177.43	699391.95
Rafieyan	1.26	5410.98	16884.88	1.76	32.50	27.70	27.54	1288.09	450845.34	2948815.29
Saramad Beton	1.07	6040.93	16105.66	1.39	33.97	12.20	28.86	1266.55	244484.89	2931492.88
Peyband	1.10	5274.40	15813.76	1.38	47.54	16.79	30.06	780.04	391354.11	2742462.09
Amir Beton	1.01	5049.07	15977.05	1.61	31.40	24.84	27.33	1225.14	353821.26	1521665.34
Vishka Beton	1.10	6598.50	19091.29	1.61	33.32	10.60	32.04	624.63	247478.93	6030466.27
Zahmatkesh	1.18	6766.87	18184.36	1.78	46.30	20.95	27.80	726.48	410872.61	7358294.55

**Table 3. Standard Deviation of Inputs and Outputs for Sustainability Measures**

Company	Environmental Measures			Economic Measures			Economic Measures			
	Waste	Electricity Consumption	Fossil Fuels	Number of Accidents	Safety Training	Number of Personnel	Waste Percentage	Number of Customers	Personnel Cost	Sale
Darvishan	0.10	6276.21	2794.49	0.44	13.97	1.42	4.41	528.93	340485.18	184358.46
Kaveh Beton	0.15	6049.73	4297.83	0.51	11.67	9.09	5.41	272.84	620327.03	126362.05
Kaspian	0.09	7553.72	2484.04	0.30	12.83	9.77	5.62	241.50	355103.59	258252.51
Almas-e Guilan	0.08	7646.26	2717.25	0.40	11.57	6.61	3.65	272.58	524315.99	219890.37
Shoa Beton Sharq	0.12	6459.05	3945.16	0.38	12.83	4.09	4.98	52.54	593197.46	250276.36
Takht-e Jamshid	0.16	5171.39	3048.62	0.53	14.36	6.90	4.26	296.53	435552.48	367116.47
Hital	0.13	6929.89	1548.25	0.59	9.43	1.14	3.20	134.45	210046.50	796148.80
Khazar Beton	0.08	6734.58	3798.61	0.60	10.81	1.52	5.42	104.04	222519.33	139871.93
Arya Beton	0.05	6569.03	3381.36	0.33	5.54	7.85	5.51	450.49	307486.54	130769.33
Rafieyan	0.07	5419.57	3846.63	0.49	13.71	7.55	3.45	299.57	288524.29	609372.16
Saramad Beton	0.12	6719.18	3074.18	0.41	6.90	2.39	1.11	223.45	95467.03	799389.12
Peyband	0.14	5346.05	3664.29	0.49	10.30	3.79	3.64	184.91	264338.11	330865.32
Amir Beton	0.19	5282.75	4609.77	0.41	11.18	0.69	5.71	424.51	235922.18	51230.49
Vishka Beton	0.17	7238.02	3279.72	0.42	8.95	0.89	2.25	305.22	128763.42	1122053.69
Zahmatkesh	0.11	7357.01	2422.43	0.44	10.26	2.24	4.60	347.48	258591.62	1049432.08

Based on the values in Tables (2) and (3), the sustainability of each mentioned company was evaluated at the alpha levels of 0.1, 0.3, and 0.5 using the linearized model. The results are presented in Tables (4) and (5).

**Table 4. Sustainability Assessment Results**

Company	$\alpha=0.1$				$\alpha=0.3$				$\alpha=0.5$			
	Economic Efficiency	Social Efficiency	Environ. Efficiency	Sustain. Efficiency	Economic Efficiency	Social Efficiency	Environ. Efficiency	Sustain. Efficiency	Economic Efficiency	Social Efficiency	Environ. Efficiency	Sustain. Efficiency
Darvishan	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Kaveh Beton	0.9299	0.6825	0.7010	0.7711	0.7146	0.5499	0.6147	0.6264	0.6340	0.9280	0.6345	0.7322
Kaspian	0.7271	0.8842	0.5629	0.7247	0.4504	0.9052	0.5451	0.6336	0.8736	1.0000	0.9245	0.9327
Almas-e Guilan	0.6132	1.0000	1.0000	0.8711	0.5665	1.0000	1.0000	0.8555	0.6171	0.5166	1.0000	0.7112
Shoa Beton Sharq	1.0000	0.7162	1.0000	0.9054	1.0000	0.9735	1.0000	0.9912	1.0000	0.4463	1.0000	0.8154
Takht-e Jamshid	1.0000	0.5691	1.0000	0.8564	1.0000	1.0000	1.0000	1.0000	1.0000	0.5398	1.0000	0.8466
Hital	0.6642	0.8369	0.4858	0.6623	0.4257	0.8972	0.4285	0.5838	0.4214	0.6193	0.8827	0.6411
Khazar Beton	0.8070	0.5437	1.0000	0.7836	0.5311	0.5114	1.0000	0.6808	0.7111	0.5065	1.0000	0.7392
Arya Beton	0.7397	0.5343	1.0000	0.7580	0.4278	0.5139	1.0000	0.6472	0.6265	0.9520	1.0000	0.8595
Rafieyan	0.8952	0.6174	0.5199	0.6775	0.7552	0.5638	0.5276	0.6155	0.3426	0.5850	0.9430	0.6235
Saramad Beton	0.7448	0.6055	0.6590	0.6698	0.4932	0.5782	0.4369	0.5028	0.5285	0.7568	0.7904	0.6919
Peyband	0.7590	0.6645	0.4042	0.6092	0.7703	0.6033	0.4362	0.6033	0.8461	0.5664	0.9668	0.7931
Amir Beton	0.9614	0.7299	1.0000	0.8971	0.8542	0.6166	1.0000	0.8236	0.8712	0.7092	1.0000	0.8601
Vishka Beton	0.9294	1.0000	1.0000	0.9765	0.5361	0.9709	1.0000	0.8357	0.6510	0.4536	1.0000	0.7015
Zahmatkesh	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8918	0.7991	1.0000	0.8970

Figure (5) illustrates an overview of the sustainability and unsustainability of companies.

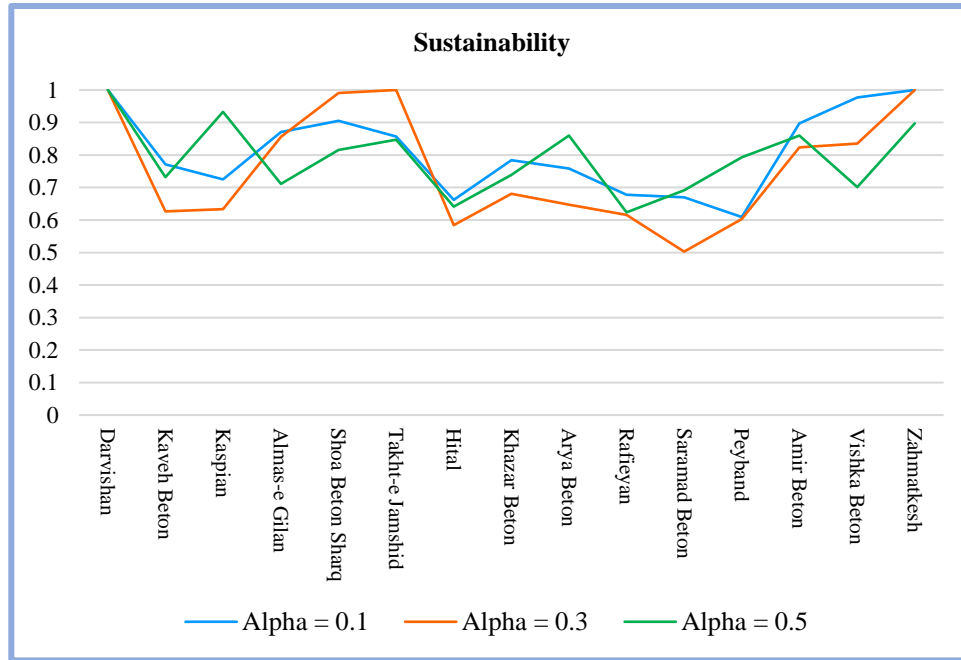


Figure 5. Comparison of Company Sustainability at Different Alpha Levels

Table 4 provides a comprehensive overview of the efficiency and sustainability of each company in the concrete industry across three alpha levels. The findings of this study show that at the 0.1 alpha level, the companies Darvishan, Shoa Beton Shargh, Takht-e Jamshid, and Zahmatkesh are economically efficiency. Meanwhile, Darvishan, Almas Guilan, Vishka Beton, and Zahmatkesh are identified as socially efficient, and Darvishan, Almas Guilan, Shoa Beton Shargh, Takht-e Jamshid, Beton Khazar, Arya Beton, Amir Beton, Vishka Beton, and Zahmatkesh are considered environmentally efficient. Hence, two companies that are sustainably efficient at the 0.1 alpha level are Darvishan and Zahmatkesh.

At the 0.3 alpha level, Darvishan, Shoa Beton Shargh, Takht-e Jamshid, and Zahmatkesh are economically efficient. Social efficiency is observed in Darvishan, Almas Guilan, Takht-e Jamshid, and Zahmatkesh, while environmental efficiency is seen in Darvishan, Almas Guilan, Shoa Beton Shargh, Takht-e Jamshid, Beton Khazar, Arya Beton, Amir Beton, Vishka Beton, and Zahmatkesh. Therefore, since Darvishan, Takht-e Jamshid, and Zahmatkesh are stochastically efficient in all three dimensions, they are also considered sustainable.

At the 0.5 alpha level, the economic efficiency is achieved by Darvishan, Shoa Beton Shargh, and Takht-e Jamshid. Social efficiency encompasses Darvishan, Almas Guilan, Shoa Beton Shargh, Takht-e Jamshid, Beton Khazar, Arya Beton, Amir Beton, Vishka Beton, and Zahmatkesh, whereas environmental efficiency is limited to Darvishan and Caspian. Unlike the findings at the 0.1 and 0.3 alpha levels, at the 0.5 alpha level, only Darvishan is considered sustainable.

## **5- Conclusion**

Based on the results, Darvishan company consistently demonstrates perfect efficiency and sustainability across all alpha levels, indicating robust performance in economic, social, and environmental dimensions. Vishka Beton and Zahmatkesh also achieve perfect efficiency and sustainability at most alpha levels, highlighting their strong and balanced operational practices. Amir Beton shows high sustainability and efficiency, particularly at the 0.3 alpha level, where it scores very close to perfect in all categories. Kaveh Beton and Caspian display notable variations across different alpha levels, indicating areas where they can improve to achieve more consistent performance. Shoa Beton Sharq and Almas-e Guilan show perfect efficiency in certain categories but have possibility to improve in other areas, particularly at the 0.1 alpha level. Based on the results, Takht-e Jamshid and Hital show fluctuations in their efficiency scores.

It's recommended to companies to develop comprehensive programs targeting all economic, social, and environmental efficiencies, simultaneously. This holistic approach ensures balanced growth and sustainability across all operational dimensions. They can also identify and benchmark best practices from companies like Darvishan and Zahmatkesh, which have consistently demonstrated high sustainability efficiency across multiple alpha levels. Disseminating these practices can help other companies enhance their performance. Investment in research and development of new technologies that can improve efficiency in construction and manufacturing processes also advised. Innovations in materials, energy use, and waste management can significantly enhance a company's overall efficiency. Finally, they can conduct regular assessments to monitor and evaluate the efficiency levels of companies. This help companies to identify required improvement areas and maintaining a trajectory towards sustainability.

As a benchmark, Darvishan emerges as a consistently high performer across all three alpha levels in economic, social, and environmental dimensions. This indicates robust sustainability practices that managers should continue to support and enhance. Zahmatkesh also performs well across multiple dimensions at lower alpha levels, highlighting its potential for comprehensive sustainability. Takht-e Jamshid demonstrates sustainable efficiency at the 0.3 alpha level but not at 0.5. Managers should investigate specific areas where the company's performance declines as the criteria become less stringent. Almas Guilan, Shoa Beton Shargh, and Vishka Beton show strengths in certain areas but fail to achieve overall sustainability. Targeted efforts in their weaker dimensions can help these companies improve their holistic sustainability performance. Beton Khazar, Arya Beton, Amir Beton, and Caspian show significant contributions to environmental efficiency. Leveraging their environmental strengths can provide a competitive edge and serve as benchmarks for other companies.

Varying efficiency outcomes across different alpha levels suggest the need for flexible sustainability strategies that adapt to changing criteria and stakeholder expectations.

Companies excelling in different dimensions should consider collaborative initiatives to share best practices and collectively improve sustainability across the industry. This could involve joint ventures, industry consortia, or knowledge-sharing platforms.

As the managerial implications, companies should conduct detailed cost analyses to identify potential savings without sacrificing quality, and diversify product lines and explore new markets to increase revenue streams and enhance their economic efficiency. Companies should implement comprehensive employee engagement programs to enhance satisfaction and productivity, and increase corporate social responsibility activities to strengthen community relations in order to improve their social efficiencies. Additionally, companies should invest in eco-friendly technologies and sustainable practices to reduce environmental impact, and get environmental certifications and comply with international standards to enhance market position, to boost their environmental efficiency.

For the future researches, researchers can conduct longitudinal studies to examine the long-term impact of efficiency improvements on sustainability. Understanding the temporal dynamics will provide deeper insights into sustainable practices. They can also investigate how external factors such as economic downturns, regulatory changes, and technological disruptions affect the efficiency and sustainability of companies. This will help in developing resilient business models.

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