Risk Factors in a Sustainable Supply Chain: An Empirical Study of the Egyptian Petrochemical Sector

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Abstract
Sustainability and risk management are considered as priorities of modern supply chains. Firms are increasingly focusing on developing sustainable supply chains; however, the risks attached to this are still under-investigated. The petrochemical industry is one of the most important strategic industries in Egypt which has adopted integrated strategies to achieve sustainable development. This paper is attempting to identify and evaluate the risk factors related to a sustainable supply chain in the petrochemical industry in Egypt The risk factors related to sustainability dimensions (environmental, social and economic) are first identified through the literature and then the industry experts participated in evaluating and ranking the risk factors using AHP approach. The results of this paper are expected to help managers to understand sustainability-related risks and enable them to better manage their operations and eventually achieve sustainability.

Keywords
Risk management, Sustainability, Petrochemical industry, Egypt.

1. Introduction
Sustainable supply chain management (SSCM) is defined as the explicit integration of environmental and social goals into economic development (Seuring and Müller 2008). SSCM is becoming a strategic requirement for companies in different industries (Song et al. 2017). The petrochemical industry is one of the most strategic industries in Egypt as many other complementary industries are dependent on it. The structure of the petrochemical industry is cross-linked and can be visualized as a network of chemical processes connecting basic feedstock chemicals to the desired final products (Al-Sharrah et al. 2010). Due to the nature of the products in addition to the ambiguities that are affecting the business environment, the petrochemical sector can be facing difficulties in adopting sustainability practices. SSCM can result in long-term strategic advantages for companies, therefore the management and elimination of risks to supply chain sustainability is becoming a priority (Valinejad and Rahmani 2018). Several studies were conducted to identify the sustainability enablers and indicators in the petrochemical sector in Egypt (Al-Sharrah et al. 2010;

Mostafa and Negm 2018; Soliman and El-Kady 2020). This study identifies and ranks the risks related to SSCM and that can obstruct the implementation of its practices.

2. Literature Review

2.1 Sustainability in supply chain management

Nowadays, sustainability has been recognized as a main topic. Sustainability is crucial in managing various industries' supply chains. It is comprised of three main dimensions: economic, environmental, and social (Miemczyk and Luzzini 2019). Sustainability in manufacturing companies is to meet customers' expectations taking into consideration cost effectiveness, environmental improvement and better working conditions for labours (Pimsakul et al. 2021). Sustainable practices ought to impact the firms' performances and increase their efficiency, profits and leads to financial and operational improvements (Govindan et al. 2020).

Mota et al. (2015) observed that governments are calling firms to go for sustainability, however, the integration of the three dimensions is still lacking. Moreover, implementing technologies should assist in managing risks and the problems faced by the companies to be able to achieve sustainability in the supply chain (Bag et al. 2018).

To that point, sustainability is considered as a critical area for research including its main dimensions in addition to innovation to increase firms' efficiency and business value lasting (Silva et al. 2019). Despite that, limited studies have been conducted in the area of supply chain sustainability and most of the studies available focus only on one or two dimensions in certain sectors (Giannakis and Papadopoulos 2016).

2.2 Risk management

Risk management is defined as "coordinated activities to direct and control an organization with regard to risk", it includes decision-making on avoiding, reducing, retaining or transferring risk and uncertainty as well as on increasing uncertainty (Grote 2015).

Risk management is the process of identifying, assessing and controlling threats to an organization's capital and earnings. These risks stem from a variety of sources including financial uncertainties, legal liabilities, technology issues, strategic management errors, accidents and natural disasters (Olsson 2007). It aims at developing systems to identify and analyze potential hazards to prevent accidents, injuries, and other adverse occurrences, and by attempting to handle events and incidents which do occur in such a manner that their effect and cost are minimized (Motaleb 2021). Typical risk management encompasses four steps: risk identification, risk analysis, implementation of risk management actions and risk monitoring (Hallikas et al. 2004).

Risk identification is one of the first steps in risk management (Yim et al. 2015), it is defined as the process to identify risk types and factors (Ho et al. 2015). It helps to develop a common understanding of the future uncertainties surrounding the supply chain, thus recognizing the potential risks in order to manage these scenarios effectively (Tuncel and Alpan 2010). The output of this step is an efficient risk register produced by different departments in an organization (Kırılmaz and Erol 2017). Risk analysis is the second step of the risk management process. It aims to measure the value of the identified risk which is the product of the probability of risk occurrence and the impact of the risk (Kırılmaz and Erol 2017). The third step is risk management actions which include different mitigation strategies for dealing with the identified and analyzed risks. The choice of a risk mitigation strategy also varies based on the category of risk and the organization's financial plan (Yang et al. 2017). The following are the basic types of risk mitigation strategies: avoid, transfer, accept, share, contingency, enhance and exploit (Motaleb 2021). The fourth step is risk monitoring, the purpose of this step is to monitor the occurrence of the risk and determine whether changes are needed in the risk treatment strategy (Trkman and McCormack 2009).

2.3 Sustainability risk factors:

Giannakis and Papadopoulos (2016) differentiated between typical risks and sustainability risks. Typical supply chain risks are caused by supply risks, procurement-related risks, logistics and transportation risks, supply chain relational risks, demand risks and infrastructure and system risks. However, sustainable supply chain risk focuses on risks related to the sustainability dimensions which can negatively affect the social image, profitability, competitiveness, and supply chain sustainability in the long run (Valinejad and Rahmani 2018).

The risk guiding principle to environmental dimension is to satisfy the requirements towards the quality of a shared eco system. The social dimension refers to the delivery of responsibilities towards employees, customers, business partners, governments and societies (Porter and Kramer 2006; Pullman et al. 2009). The economic dimension incorporates monetary risks brought about by the financial environment, deceitful behaviour of corporations and individuals, and an endeavour for sustained economic growth (Jeucken 2004).

The elimination of risks and threats to supply chain sustainability is vital as it leads to effective allocation of resources across the supply chain and better realization of sustainability (Valinejad and Rahmani 2018). Table 1 presents a list of thirty-eight SSCM risk factors that were identified by the literature, factors are grouped into three main dimensions, environmental risk factors, social risk factors and economic risk factors.

Table 1. SSCM risk factors

Sustainability dimension	**Risk factor**	**Reference**
Environmental risk factors	Energy consumption	Giannakis and Papadopoulos (2016), Christopher and Gaudenzi (2018),Nieuwenhuis et al. (2021)
	Environmental accidents	Giannakis and Papadopoulos (2016)
	Greenhouse gases emission	Giannakis and Papadopoulos (2016), Christopher and Gaudenzi (2018), Keyghobadi et al. (2020)
	Non-compliance with sustainability laws	Giannakis and Papadopoulos (2016), Alam Tabriz et al. (2017)
	Pollution	Giannakis and Papadopoulos (2016), Alam Tabriz (2017) Christopher and Gaudenzi (2018), Mukhtar et al. (2019), Qingquan et al. (2020)
	Product waste	Giannakis and Papadopoulos (2016)
	Unnecessary packaging	Giannakis and Papadopoulos (2016), Christopher and Gaudenzi (2018)
	Natural disasters	Torabi et al. (2016), Song et al. (2017), Christopher and Gaudenzi (2018)
	Heat waves, droughts	Keyghobadi et al. (2019)
	Inefficient use of resources	Alam Tabriz (2017)
	Hazardous wastes generation	Dües et al. (2013), Zhang et al. (2022)
	Explosions, fire, chemical accidents	Christopher and Gaudenzi (2018), Keyghobadi et al. (2019)
Social risk factors	Violation of human rights	Giannakis and Papadopoulos (2016)
	Unhealthy work environment	Halldórsson et al. (2009), Giannakis and Papadopoulos (2016)
	Unfair wages	Giannakis and Papadopoulos (2016)
	Demographic challenges	Giannakis and Papadopoulos (2016)
	Social instability	Giannakis and Papadopoulos (2016), Alam Tabriz et al. (2017)
	Failure to fulfil the social commitment	Maloni and Brown (2006), Song et al. (2017)
	Violation of business ethics	Song et al. (2017)
	Dangerous working conditions	Halldorsson et al. (2009), Song et al. (2017)
	Inadequate personal protective equipment (PPE)	Tafere et al. (2020), Moktadir et al. (2021)
	Unfriendly relations between management and workers	Torabi et al. (2016), Moktadir et al. (2021)
	Lack of work culture	Torabi et al. (2016), Song et al. (2017)
	Lack of healthy partnership among supply chain partners	Moktadir et al. (2021)

Table 1.(continued) SSCM risk factors

Sustainability dimension	Risk factor	Reference
Economic risk factors	Antitrust claims	Giannakis and Papadopoulos (2016)
	Bribery allegations	Giannakis and Papadopoulos (2016)
	False claims	Giannakis and Papadopoulos (2016)
	Tax avoidance	Giannakis and Papadopoulos (2016)
	Boycotts	Giannakis and Papadopoulos (2016)
	Energy price volatility	Keyghobadi et al. (2019)
	Financial crisis	Giannakis and Papadopoulos (2016)
	Inflation of exchange rate	Song et al. (2017)
	Price and cost volatility	Song et al. (2017), Moktadir et al. (2021)
	Market share reduction	Song et al. (2017)
	Reputation loss	Sodhi et al. (2012), Song et al. (2017)
	High cost of hazardous wastes disposal	Dües et al. (2013), Moktadir et al. (2021)
	High cost of maintenance	Torabi et al. (2016), Moktadir et al. (2021)
	Fiscal changes	Song et al. (2017), Moktadir et al. (2021)

3. Methods

This paper aims to identify and rank the risk factors that obstruct the operations of a sustainable supply chain in the Egyptian petrochemical sector. Figure 1 shows the approaches used to fulfill the research aim.

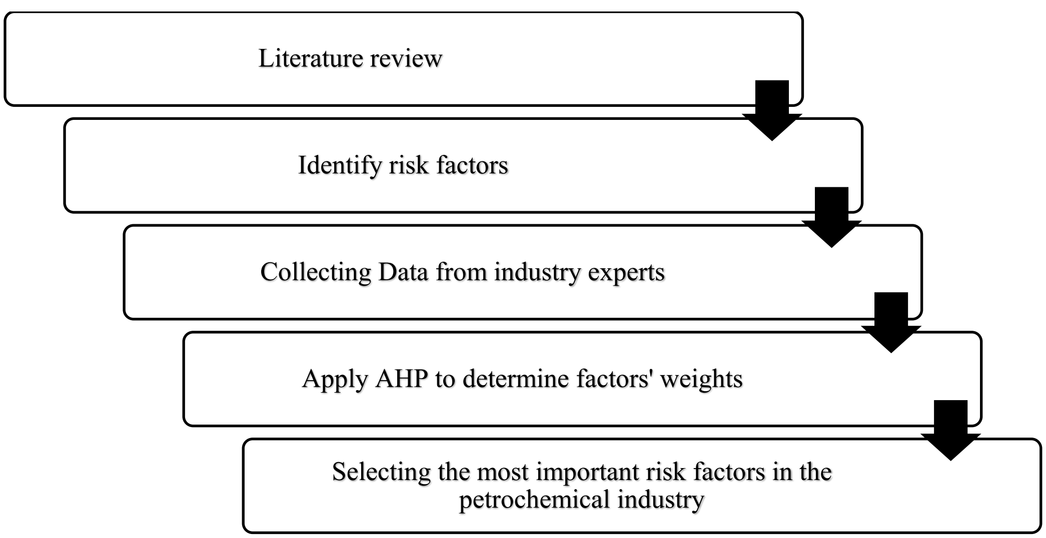

Figure 1. The research approaches

Thirty-eight risk factors were identified by the literature, classified into three groups, the first group is risks affecting economic sustainability (14 factors), the second group is risks affecting social sustainability (12 factors) and the third is risks affecting environmental sustainability (12 factors). A survey was sent to experts in order to determine the risks relevant to the petrochemical sector, the most significant risks were determined by using the Content Validity Ratio method (CVR) (Vazifehdan and Darestani 2019). The CVR method represents as proportional level of experts' agreement in rating an item as essential (Hadzaman et al. 2018). Experts were asked to respond to each of the criteria and sub-criteria in the questionnaire as "necessary", "useful but not necessary" and "not necessary". Responses were calculated as follows:

$$\mathrm{CVR} = (\mathrm{Ne} - \mathrm{N}/2)/(\mathrm{N}/2) \qquad \text{Equation (1)}$$

Where Ne denotes the number of experts who responded to the "necessary" option and N denotes the total number of experts.

Next, an AHP analysis was conducted in order to determine the most important risk factors in the petrochemical industry. AHP was developed in the '70s by Thomas L. Saaty as a technique for decision-making. The AHP is one of the principal techniques of multi criteria decision making (MCDM) (Alshehri et al. 2022). It starts with decomposing a problem into a hierarchy of criteria to be easily analyzed and then conducting pairwise comparisons between criteria (Vargas 2010). The AHP procedure starts first by representing the problem in a hierarchal manner .The second step is the pairwise comparison which is done based on a nine-point scale as shown in table 2. Industry experts were invited to participate in assessing the importance of sustainability risk factors through responding to an AHP survey. Six experts participated in the survey representing the Egyptian petrochemical sector, there is a general consensus on the AHP method does not require a large sample size (Goral 2020) and according to Schmidt et al. (2015), sample sizes differing between four and nine have been used.

Table 2. Saaty's scale of relative importance

Level of importance	Value definition
1	Both factors have equal importance
3	1st factor is more important than 2nd factor
5	1st factor is far more important than to 2nd factor
7	1st factor is highly significant compared to 2nd factor
9	1st factor is very highly significant compared to 2nd factor
2,4,6,8	The intermediate value of degrees in the choice between two factors

Source: Darko et al. (2019)

The third step is organizing the pairwise comparison in a square matrix (i, j) that represents the different criteria reached in the first step. If the criterion on row i is more important than the criterion on column j, the element value is greater than one. The element value is 1 in case the criteria are equally important, and less than 1 if the criterion in column j is more important than the criterion in the row i (Bhushan and Rai 2004).

The fourth step is the calculation of the individual weights of the criteria using the value of the main eigenvalue of the comparison matrix and the corresponding normalized eigenvector. In step five, the consistency ratio (CR) is calculated by first calculating the consistency index (CI) using equation (1), and then the Consistency Ratio (CR) should be calculated through the use of Equation (2). The Random Index (RI) values shown in Table 3 are used for the calculation of the consistency ratio.

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{Equation (2)}$$

$$CR = \frac{Consistency\ Index\ (CI)}{Random\ Index\ (RI)} \qquad \text{Equation (3)}$$

Table 3. Random index values

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Source: Saaty (1994)

If the consistency ratio calculated for the comparison matrices is less than or equal to 0,1; the eigenvector "w" can be used as the weighted vector after the normalization. Otherwise, the comparison matrix needs to be revised (Deng et al. 2014; Uludag and Yazar 2019).

4. Results and Discussion

In this research, CVR was calculated for each risk factor, according to Lawshe (1975) and the total number of participants, the min CVR value was 0.99 for this research. The accepted risk factors were included in the AHP survey distributed to experts in order to determine the importance of each factor. The final hierarchy of the problem reached based on the CVR values is illustrated in figure 2.

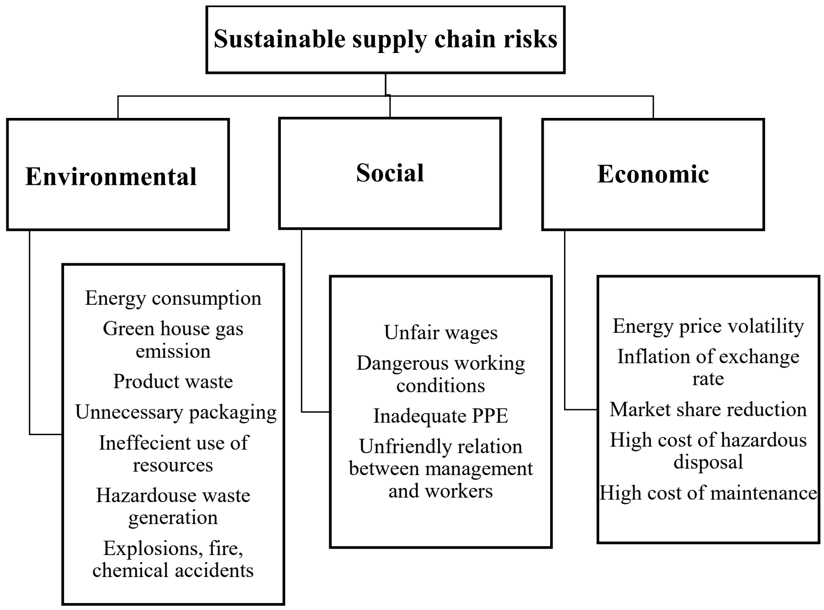

Figure 2. AHP hierarchy

A sample of the data entry sheet illustrating the inputs of ranking from each individual is shown in figure 3.

Criteria	ER1	ER2	ER3	ER4	ER5	ER6	ER7
ER1	1	0.2	0.5	2	0.33	0.2	0.14
ER2	5	1	0.25	9	1	1	0.5
ER3	2	4	1	4	0.5	0.33	0.25
ER4	0.5	0.11	0.25	1	0.16	0.11	0.11
ER5	3	1	2	6	1	0.5	0.5
ER6	5	1	3	9	2	1	0.5
ER7	7	2	4	9	2	2	1

CI	0.11703
RI	1.32
CR	0.088659

Criteria	SR1	SR2	SR3	SR4
SR1	1	0.125	0.125	4
SR2	8	1	1	8
SR3	8	1	1	9
SR4	0.25	0.125	0.11	1

CI	0.080494
RI	0.9
CR	0.089437

Criteria	ECR1	ECR2	ECR3	ECR4	ECR5
ECR1	1	1	1	0.33	0.25
ECR2	1	1	1	0.33	0.25
ECR3	1	1	1	0.33	0.33
ECR4	3	3	3	1	4
ECR5	4	4	3	0.25	1

CI	0.079928
RI	1.12
CR	0.071364

Figure 3. Data analysis sample

In order to obtain the group ranking, individual rankings were aggregated by using the aggregated individual priorities (AIP) method which uses the geometric mean of the individual rankings.

The final outcome of the AHP listed from the highest to lowest weight under each category is illustrated in Table 4. Based on the weights, the most dominant risk factors were explosions, fires and chemical accidents (environmental factors), inadequate PPE (social factors) and the high cost of hazardous disposal (economic factors).

Table 4. Local weights of sustainability risk factors and sub factors

Sustainability risk factors	Sub factors	Local weights	Rank
Environmental	Explosions, fire, chemical accidents	0.35	1
	Hazardous waste generation	0.28	2
	Greenhouse gas emission	0.15	3
	Inefficient use of resources	0.07	4
	Energy consumption	0.057	5
	Product waste	0.05	6
	unnecessary packaging	0.03	7
Social	Inadequate PPE	0.45	1
	Dangerous working condition	0.42	2
	Unfair wages	0.077	3
	Unfriendly relations between management and workers	0.04	4
Economic	High cost of hazardous disposal	0.26	1
	Inflation of exchange rate	0.21	2
	high cost of maintenance	0.19	3
	Market share reduction	0.17	4
	Energy price volatility	0.14	5

Based on the weights, the most dominant risk factors were explosions, fires and chemical accidents under the environmental factors category. Explosions, fires and chemical accidents can be managed through effective emergency response which can lead to the reduction of life and property losses, prevention is a critical element which can be achieved through safety management of equipment and safety training for employees (Zhu et al. 2020).

The inadequate PPE ranked first under the social factors category. Several factors can discourage workers from using PPE such as ill-fitting, ineffective vision, overconfidence, increased workload and lack of availability (Zahiri Harsini et al. 2020). The firm needs to have high-quality PPE that meets recognized standards (Rose and Rae 2019).

The high cost of hazardous disposal recorded the highest weight under the economic factors category. The petrochemical industry generates a wide range of solid waste and sludge that could be classified as hazardous waste due to the presence of highly toxic organic compounds and heavy metals (MIGA 2004); wastes are generated through the production process, maintenance, packaging process and wastewater treatment. Jafarinejad (2017) introduced several waste management alternatives including prevention, waste minimization, recycling, treatment, and disposal (Ghazizade 2021). Abduli et al. (2006) indicated that waste minimization or source reduction can lead to reduced waste treatment costs and reduced capital and reduced off-site treatment and disposal costs. Ittiprasert and Chavalparit (2020) stated that the reuse or recycling of hazardous wastes can reduce the cost associated with waste disposal.

5. Conclusion

This paper introduced a weighting method for sustainability risk factors in the Egyptian petrochemical sector using AHP. This sector has been chosen as it is considered as one of the critical and strategic sectors in different countries, however, there are still different risk factors standing against achieving sustainability in this sector. A group of six experts were asked to determine a list of relevant sustainability risk factors relevant to the industry and then respond to a pairwise comparison survey in order to assign weights to the identified factors. Sustainability risk factors were divided into three categories (environmental, social and economic), and those categories were divided into sub-categories. The results generated can help decision makers to prioritize sustainability risk factors and be able to proactively manage these risks and allow firms to avoid any negative effects on their social image, profitability, competitiveness, and supply chain sustainability.

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