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Developing a Model for Assessing Environmental Insurance Premiums Related to Maritime Loss and Pollution from the Oil and Gas Industries

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ABSTRACT

Background: The issue of environmental insurance has been raised since the early 1990s and has undergone extensive changes until today. The purpose of this research is to design a model for determining environmental insurance premiums related to maritime losses and pollution resulting from the oil and gas industry.
Methods: This study is applied and employs survey methodologies as well as expert panels. In order to analyze the data, SPSS 22 and Expert Choice 11 software were used while hierarchical analysis was used to prioritize the components of the model. The final model was designed based on the Environmental Failure Mode and Effects Analysis method (EFMEA), and its goodness of fit was determined through conformity factor analysis.
Results: The research identified six categories of activities and four major types of accidents associated with the oil and gas industry. Moreover, five environmental aspects were determined. Fire and explosions in facilities, pipelines, and tanks (0.886), Pipeline breakage or corrosion (0.714), Maritime accidents and vessel collisions (0.656), and Operational disruptions in facilities (0.631) were prioritized respectively. The calculated Root Mean Square Error of Approximation (RMSEA) index was 0.068, indicating that the proposed model demonstrates an adequate fit.
Conclusion: Environmental pollution risks could be covered by commercial insurance by relying on international law within domestic, regional, or global insurance policies in compliance with the principles governing such policies.

1. Introduction

Environmental management and the conservation of natural areas require employing various sciences and techniques, including environmental law (Cochran et al., 2016). Environmental law and natural resources have been affected by advancements in science and technology, highlighting the need for a foundational understanding of environmental issues (Mirkamali & Hajivand, 2017). Pollution is potentially a huge danger and may cause irreversible loss to human health and the environment over time (Hankin, 2003). Two main goals are pursued in legal documents: first, preventing pollution; and second, facilitating the investigation into loss and claims for compensation by affected parties. To this end, international conventions have established compulsory civil liability insurance mechanisms, which aim to cover most oil-related losses occurring within the territorial seas and exclusive economic zones of member states, though some losses remain uncompensated. Currently, the issues of environmental loss and compensation represent significant topics in the realm of international law and the insurance system, both at national and international levels (Zhang et al., 2016). As countries become aware of and sensitive to environmental concerns, the prevention of such incidents is likely to improve. Countries are utilizing diverse tools such

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as regional or international treaties, negotiations, and dispute resolution mechanisms, to transform Lex Ferenda into Lex Lata (Lynch et al., 2015). The environmental damage caused by pollution is often so extensive that restoration to its original state is frequently unattainable. Consequently, compensation for damages, as stipulated by international treaties, falls under the purview of governments, and in some cases, the responsibility of polluting units. Timely compensation is vital for environmental restoration; therefore, the existence of an authority or institution that provides economic actors and businesses with compensation for damages caused by their activities is essential. This assurance not only fosters confidence but also encourages economic and social activities. In terms of international environmental law, there is no international institution that can cover and pay all pollution-related costs. Instead, insurance associations can adopt the liability for damages and losses caused by polluting facilities. This research tries to propose a comprehensive plan for compensating environmental damages caused by pollution, including the structural and legal rules involved. The primary objective is to introduce an environmental insurance premium model based on the risk assessment model. Pollutants are usually the result of human activities and are permanent companions of advanced human societies that use modern technology (Dabiri et al., 2016). Marine pollution refers to the direct or indirect introduction of substances or energy into the marine environment by human actions leading to harmful impacts such as human health deterioration, hindering marine activities such as fishing, and water quality reduction in terms of consumption and amenities (Azizi et al., 2022; Fataei, 2020). Therefore, the primary focus is on humans and the harmful effects of waste materials rather than natural inputs to marine ecosystems. With the advancement of human knowledge, it can be said that levels of pollution once considered harmless may have detrimental environmental consequences. Environmental law emphasizes the prevention of pollution and the protection of ecosystems, advocating for the adoption of common global standards to regulate certain actions or prohibit certain activities (Heydarzadeh & Mozafarizadeh, 2014). However, the establishment of such standards alone is insufficient. It is imperative to implement mechanisms for enforcement and compensation in cases of violations of environmental law, thereby ensuring accountability for those who transgress these legal frameworks. Environmental insurance, also known as pollution insurance or pollution coverage, protects losses or damages resulting from unexpected releases of pollutants that are typically excluded from general liability and property insurance policies. The coverage offered by environmental insurance generally addresses claims for bodily injury, property damage, cleanup costs, and business interruption (Wu et al., 2022). The environmental insurance industry is undergoing a significant transformation, having matured over more than 25 years of development. As of 2021, the industry has reached an annual premium of approximately $2 billion and has experienced double-digit growth, surpassing the growth rate of the broader property and casualty insurance market (Elmagrhi et al., 2019). Regarding accountability for environmental pollution, extensive research has been conducted (Hosseini Dinani et al., 2023; Safaee et al., 2024). Li et al. (2019) examined the legal frameworks of European countries concerning marine pollution and stated that the laws of the European Union and several member states-including Germany, Sweden, France, Finland, Norway, and Switzerland-consider civil liability for pollution as an absolute liability. Despite these studies, little research has been conducted in terms of compulsory liability insurance. The Civil Liability Convention established a limited liability system for ship owners and mandated liability insurance. In addition, the Convention created a complementary compensation system managed by an intergovernmental organization, which compensates pollution victims who are unable to recover their full damages from insurance companies or ship owners in the respective members′ states (Boyle & Brinie, 2005). Research by Yan Feng et al. (2022) identified two main patterns of pollution insurance practices globally and within China: voluntary insurance and mandatory insurance. In order to evaluate the efficiency of pollution insurance practices, they conducted comparative studies between voluntary insurance in Chongqing and compulsory insurance in Jiangsu province. Based on the data analysis, they differed in terms of local policies, the level of government intervention, and the attitude of stakeholders. Also, the results showed that in contemporary China, the mandatory promotion of pollution insurance helps local governments build a relatively mature pollution insurance system and reduce environmental risks (Hajivand et al., 2018). According to the research background and theoretical foundations, it can be inferred that the most important method of compensation for damage to the environment is the payment of financial compensation. Achieving this goal necessitates a series of regional treaties at the global level. Insurance policies are fundamentally grounded in principles that form the basis of contractual agreements. While fixed and uniform principles are not universally defined, certain concepts may be recognized as insurance principles in some contexts but not in others. Nevertheless, the existence and validity of insurance contracts remain undisputed, and the principles of insurance are broadly accepted as foundational (Javadinejad et al., 2014; DOE, 2020). It can be concluded that in the 2020s, environmental insurance claims are on the rise, with social inflation and an unprecedented frequency and severity of pollution lawsuits (Anisimov et al., 2023). The primary objective of this research is to identify an executive model for determining environmental insurance premiums, particularly in relation to oil and gas pollution. This focus aims to bridge the gap in understanding how environmental insurance can be effectively operationalized within this critical sector.

2. Materials and Methods

This applied research was conducted in 2023. The general approach of this research is based on the Environmental

Failure Mode and Effects Analysis (EFMEA) model. EFMEA is a systematic process aimed at reviewing various components, assemblies, and subsystems to identify potential failure modes in a system, along with their causes and effects. This model qualitatively and quantitatively examines all activities, incidents, and their consequences to pinpoint project failure points and centers of environmental risk. This model is a method for environmental risk assessment (AIAG, 2019; Sekhavati & Jalilzadeh, 2022). The statistical population for this study comprised subject matter experts in international law, environmental law, environmental management, and insurance management. For this purpose, the Delphi panel method was used. According to scientific sources, a minimum of five participants is considered acceptable for forming a Delphi panel (Rahmani et al., 2020; Aaleagha et al., 2023). In this research, a total of 18 experts were selected through purposeful sampling. The characteristics of the panel members are summarized in Table 1.

Table 1. Characteristics of panel members

Gender		Degree	Work history		
Woman	Man	Ph.D.	10-20	21-30	More than 31
3	15	18	5	8	5

The panel members have at least 10 years of related work experience and have related articles or books. A total of 26 individuals were identified in this field, of which 18 were selected based on availability. In the Delphi process, Kendall′s coefficient of concordance was used to reach consensus. This coefficient is represented by the symbol w and is a value between 0 and 1. A Kendall coefficient of zero indicates a lack of complete agreement, a value of one means complete agreement. The characteristics of Kendall's coefficient have provided one of the most important applications of this test in management. In this research, the calculated coefficient was 0.86. To form the pairwise comparison matrix, elements are compared in pairs such that when element i is compared with element j, the decision-maker states that the relative importance of i over j using one of the defined states (Saaty, 2000; Bertolini et al., 2006): The responses obtained from the previous step are incorporated into matrix A. Each element of matrix A is represented as $a_{ij} = \frac{w_i}{w_j}$, where a_{ij} indicates the weight of factor i relative to factor j. The outline of matrix A is shown below.

$$A = (a_{ij}) = \begin{bmatrix} 1 & {}^{w_1}/_{w_2} & \cdots & {}^{w_1}/_{w_n} \\ {}^{w_2}/_{w_1} & 1 & \cdots & {}^{w_2}/_{w_n} \\ \vdots & \vdots & \vdots & \vdots \\ {}^{w_n}/_{w_1} & {}^{w_n}/_{w_2} & \cdots & 1 \end{bmatrix} \quad (1)$$

This matrix is checked separately for the main criteria as well as the main sub-criteria. Matrix A has positive elements and is reversible, such that $a_{ij} = \frac{1}{a_{ji}}$ ، $(i, j = 1, 2, \dots, n)$. Moreover, the matrix $a_{ii} = 1 \quad (i, i = 1, 2, \dots, n)$. If the judgments of the decision-makers are thoroughly consistent and stable, then it follows that $a_{ij} = a_{ik} \times a_{kj} \quad (i, j, k = 1, 2, \dots, n)$. In cases where complete stability is not present in the comparison matrix, the Analytical Hierarchy Process (AHP) method uses the eigenvector technique to calculate the weights (w_i) and to resolve inconsistencies. Therefore, to calculate the W vector, λ_{max}, the maximum eigenvector of matrix A is used.

$$A_w = \lambda_{max} \times W \quad (2)$$

The eigenvector method can be interpreted as a simple averaging process such that the final vector W is obtained by averaging all possible ways of comparing the indices with each other. In this method, to calculate the weight of each criterion, first, the sum of the elements of each row is calculated to obtain a column vector, and then this column vector is normalized. The normalized column vector is the weight vector. This method provides an appropriate measure of the degree of inconsistency of a matrix as $\lambda_{max} - n$, which in general is $\lambda_{max} - n$, and egality occurs only if the comparison matrix A is completely stable. Additionally, the consistency index, after normalization, is expressed as follows

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

The software employed in this research compares the CI with a random index (RI) and shows the consistency ratio (CR) as follows:

$$CR = \frac{CI}{RI} \quad (4)$$

CR = Consistency Ratio CI = Consistency Index RI = Random Consistency Index

If CR ≤ 0.1, the consistency of the matrix is accepted. Conversely, if this ratio is greater than 0.1, the decision-maker should be asked to revise their comparative judgments to enhance consistency (Saaty, 2000). In order to analyze the data, SPSS 22 and Expert Choice 11 software were utilized. To review and analyze the research data, the Kolmogorov-Smirnov test was employed, and hierarchical analysis was used for prioritizing the model elements. Following these, the goodness of fit of the developed model was verified using the confirmatory factor analysis. The indices of goodness of fit examined in this research include the normed chi-square (χ^2/df), which is a general index that accounts for free parameters in the calculation of fit indices. The normed chi-square is calculated by dividing the chi-square statistic by the degrees of freedom of the model. Moreover, the RMSEA is also used in confirmatory factor analyses and structural equation models. A value of RMSEA less than 0.08 indicates a very good model fit, while values ranging from 0.08 to 0.10 are considered acceptable; values greater than 0.10 indicate a poor fit. To calculate the fit index, the sample size, chi-square value, and degrees of freedom are needed. The RMSEA index is calculated using the following equation:

$$RMSEA=\frac{\sqrt{(x2-df}}{\sqrt{[df-(n-1)]}} \quad (5)$$

3. Results and Discussion

In the first step of the research, the components of the research were identified through in-depth study. For this purpose, several sources were used, which are shown in Table 2.

Table 2. Methods and resources used in the in-depth study process

Scientific source	Number	Persian	English
Academic articles	34	◆	◆
Specialized books	5		◆
Reference sites	7	◆	◆
Applications	4		◆
Reports	12	◆	◆
Rules	17	◆	◆

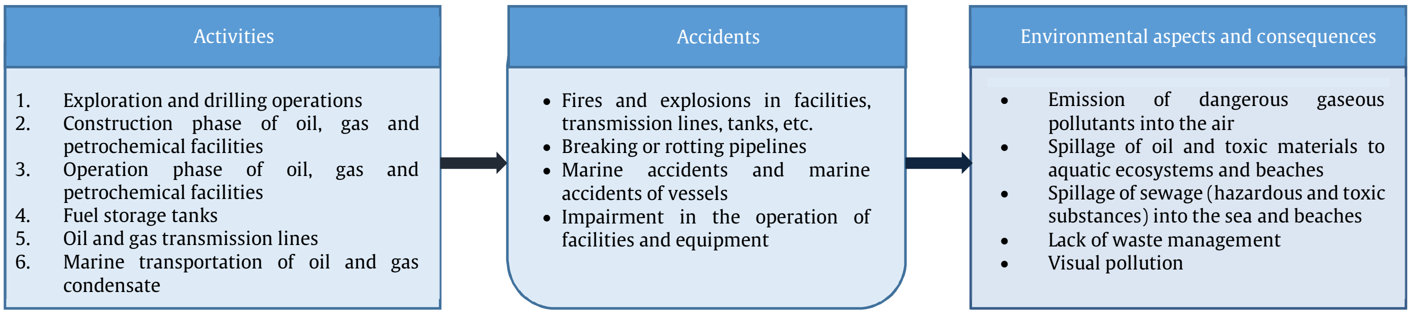

Figure 1. The relationship between activities, accidents, and environmental aspects and consequences caused by marine oil and gas activities

Based on the literature review and the research theories, six categories of activities were identified within the oil and gas industry: 1- Exploration and drilling operations. 2- Construction phase of oil, gas, and petrochemical facilities. 3- Operation phase of oil, gas, and petrochemical facilities. 4- Fuel storage tanks. 5- Oil and gas pipelines. 6- Maritime transport of oil and gas condensates. In this context, the identified incidents corresponding to the aforementioned activities are as follows: 1- Fire and explosion in facilities, pipelines, tanks, etc. 2- Pipeline breakage or corrosion. 3- Maritime accidents and vessel collisions. 4- Operational disruptions in facilities. Finally, the environmental aspects and consequences of the aforementioned incidents are as follows: 1- Emission of dangerous gaseous pollutants into the air. 2- Spillage of oil and toxic materials into aquatic ecosystems and coastlines. 3- Spillage of sewage (hazardous and toxic substances) into the sea and coastlines. 4- Lack of waste management. 5- Visual pollution (Figure 1). The proposed model for environmental insurance of industrial activities (oil and gas) is illustrated below (Figure 2).

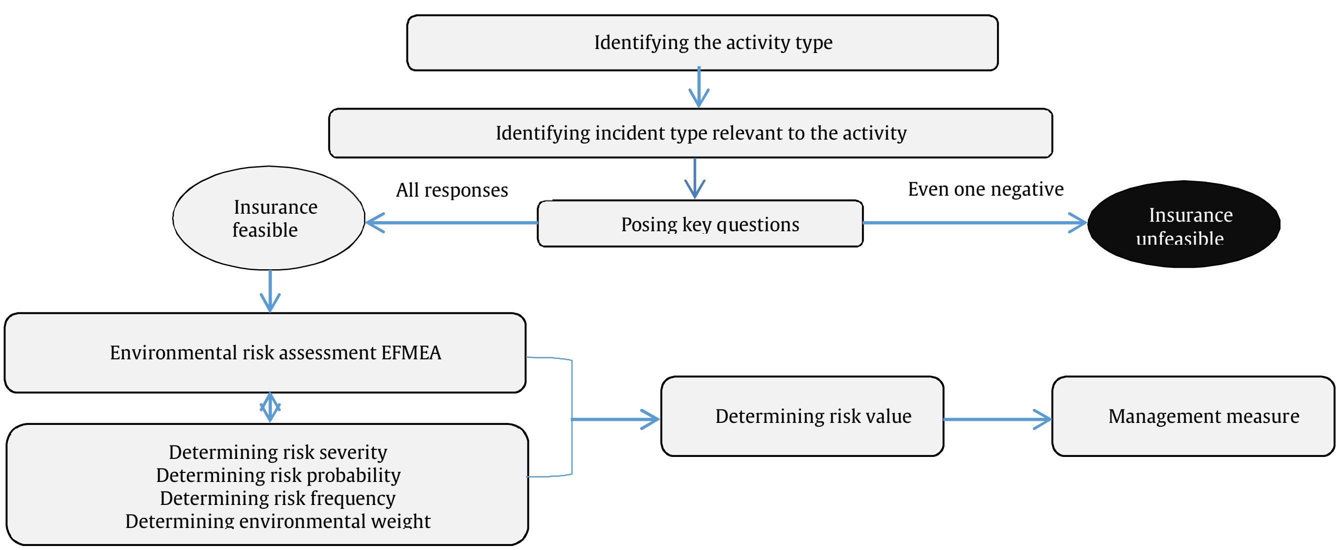

Figure 2. The proposed model for environmental insurance of oil and gas activities

An important point is the potential to incorporate further relevant activities and events. Additionally, examining the insurability of the project in question holds significance. The following should be taken into account: 1- Is the damage to the environment accidental and unintentional? 2- Is the environmental damage inherently measurable? 3- Is the environmental damage associated with catastrophic risks? 4- Is the environmental risk divided into numerous similar broad cases? 5- Is the chance of damage to the environment low? If any of the responses to the above questions are negative, the project in question is considered insurable. Following the collection of data and information, the research findings were analyzed. The Kolmogorov-Smirnov test was used to check the normality of the distribution of variable scores; all variables in the questionnaire had a normal distribution (Table 3).

Table 3. Results of t-test

Accident	Average	Mean	Mean Standard deviation	t-test	sig.
Fires and explosions in facilities, transmission lines, tanks, etc.	3	3.92	0.96	15.85	0.001
Breaking or rotting pipelines	3	4.12	0.83	13.14	0.001
Marine accidents and marine accidents of vessels	3	3.77	0.76	14.57	0.001
Impairment in the operation of facilities and equipment	3	3.26	0.77	14.88	0.001

In order to weigh the incidents identified in the current research, a matrix questionnaire was designed using the AHP method. The designed questionnaire was given to the participants in the research, which was formulated in the pairwise comparison (Table 4).

Table 4. Pairwise-comparison of the maritime oil and gas incidents leading to environmental damage

	Fires and explosions in facilities, transmission lines, tanks, etc.	Breaking or rotting pipelines	Marine accidents and marine accidents of vessels	Impairment in the operation of facilities and equipment
Fires and explosions in facilities, transmission lines, tanks, etc.	1	7	3	5
Breaking or rotting pipelines	1/7	1	1/4	1/2
Marine accidents and marine accidents of vessels	1/3	4	1	2
Impairment in the operation of facilities and equipment	1/5	2	2	1

Table 4 shows the importance of each criterion compared to other criteria. Expert Choice 11 software was used to weigh the criteria and determine the importance of each indicated per Figure 3 and 4.

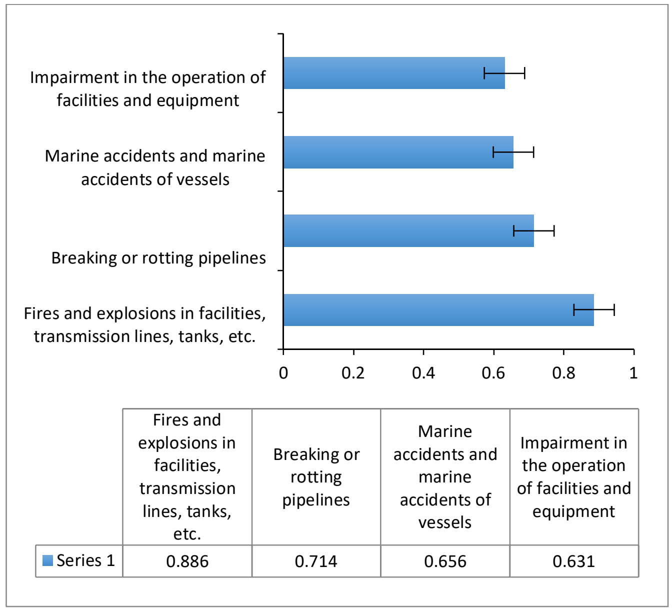

Figure 3. Weight of each maritime oil and gas incident leading to environmental damage from the expert panel's perspective

The results indicated that fire and explosions in facilities, pipelines, and tanks (0.886), Pipeline breakage or corrosion (0.714), Maritime accidents and vessel collisions (0.656), and Operational disruptions in facilities (0.631) were prioritized respectively.

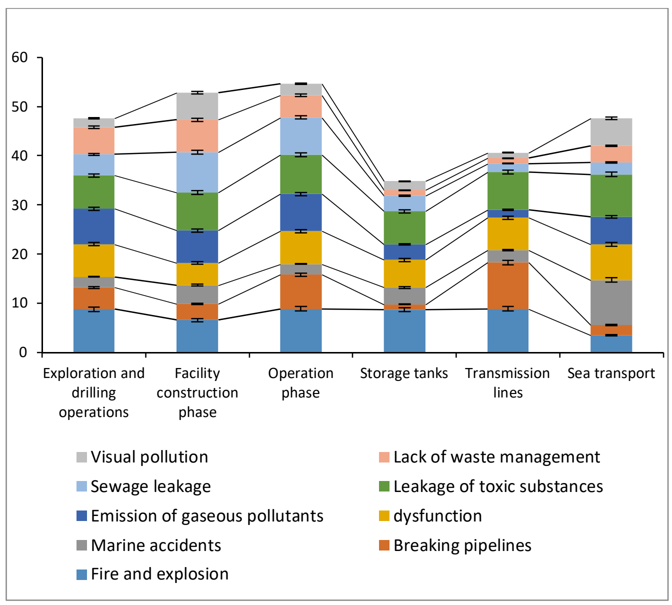

Figure 4. Distribution diagram of the relationship between the oil and gas activities and environmental incidents and aspects

According to the results of Bartlett's test, the value of the KMO index is equal to 0.652; therefore, the number of samples is sufficient for the analysis and structural equation model. In addition, the significance level of Bartlett's test is less than 5% and the assumption of a known correlation matrix is rejected (Table 5).

Table 5. Fit indices to confirm the components of the model

Index	Absolute fit indices		Comparative fit indices			parsimonious fit indices	
	RMR	GFI	TLI	CFI	IFI	RMSEA	CMIN/DF
Standard value	Less than 0.08	More than 0.09	More than 0.09	More than 0.09	More than 0.09	Less than 0.08	1 to 5
Results	0.085	0.955	0.961	0.943	0.917	0.068	4.111

Table 5 shows that the model's goodness of fit is satisfactory, as the calculated values for all indices fall within the acceptable range; thus, the model is deemed valid. Marine pollution is potentially a major threat and can cause irreversible damage to humans and the environment in the long term (Henking, 2002). One of the major sources of this pollution spillage from ships occurs due to oil fuel spillage, the discharge, and release of ballast water, or as a result of collisions with seamounts, ship collisions, or fire and explosion of their cargos. For instance, the horrific collision of the oil tanker Amoco Cadiz in Spain resulted in the spillage of over 230,000 tons of crude oil into the sea within a few hours, contaminating one hundred kilometers of the country's coastline (Haris, 2003; Garcia et al., 2023). The main question pertains to the accountability for compensating damages caused by such a marine incident, and the mechanisms available for environmental protection and damage compensation. To address this issue, the International Maritime Organization (IMO) has supplemented customary international rules by enacting the Civil Liability Convention for Oil Pollution Damage in 1969, which was later amended by the protocols of 1976 and 1992. Furthermore, the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties was established in the same year. Following these initiatives, the International Oil Pollution Compensation Fund Convention and the Bunker Convention (2001) were drafted and adopted in 1971 (Boyle & Brinie, 2005). In environmental insurance, the premium must be calculated based on the risk level of the unit to be covered. Therefore, the following factors will influence the determination of the premium for a unit: 1- The probability of pollution occurrence. 2- The degree of safety measures in place against pollution. 3- The intrinsic value of the ecosystem at risk of pollution. Today, most human societies increasingly recognize the issue of pollution and its harmful effects, which has also gained attention in the insurance industry. Although the impact of pollution damage relates to many insurance sectors, it is specifically classified under "public liability insurance". The concept of liability about pollution is somewhat different; thus, it is essential to consider the following points: 1- The nature of pollution risks. 2- The methods by which insurers cover such risks. 3- Existing methods and potential future developments. Although pollution transcends national borders, there is a lack of an international legal framework governing pollution liability; thus, only national laws apply in this context. From an insurance perspective, risks are categorized into two types: 1- Insurable risks. 2- Uninsurable risks that. A risk is considered uninsurable if it is not economically insurable. Therefore, the criteria for an insurable risk are as follows: 1- Accidental and Unintentional Damage: The damage must generally be accidental and unintentional. If the damage is not accidental, it lacks uncertainty; in such cases, insurance serves no purpose, as it is intended to reduce the risk. Intentional damage does not allow for risk reduction. 2- Measurable and Predictable Damage: The damage must be inherently measurable and predictable. 3- Non-Catastrophic Hazards: The damage should not be due to catastrophic hazards. In other words, it should not be a disaster, meaning the damage should not be extremely high. For example, nuclear energy explosions are difficult to insure because the potential damages are unpredictable. 4- Distribution of Risk: The risk must be distributed among a sufficient number of similar cases. 5- Low Probability and Acceptable Costs: The probability of damage should be low, and the associated costs must be reasonably acceptable. If the probability of damage is higher than 40 percent, the cost of the insurance policy will exceed the amount the insurer would be obligated to pay under the policy.

4. Conclusion

The results of the present study indicated that, in order to determine the insurance premium for marine environmental damages caused by the oil and gas industry, it is essential to first identify the types of related activities and potential incidents. Then, the environmental aspects and consequences resulting from these activities should be determined. Using an appropriate management model will facilitate the evaluation of whether the activity in question can be insured. If insurable, the environmental risks of these activities should be evaluated based on the EFMEA model. The effective parameters in this process include risk severity, risk probability, risk frequency (each based on a 10-point value spectrum), and weight of the environmental aspect (5-point value spectrum). These assessments will lead to the determination of a risk number, which categorizes risks into three classifications: 1- Certain Risks: These should be eliminated or reduced. 2- Permissible Risks: These exist without requiring any control. 3- Controllable Risks: These require active management and control. The risks and dangers caused by environmental pollution are considered as emerging risks. Naturally, insurers seek to cover emerging risks that they can compensate for the findings suggest that the risks of environmental pollution can be covered by commercial insurance by relying on international laws, structured as domestic, regional, or global insurance contracts in compliance with the principles governing insurance contracts. Accidental, unintentional, and unexpected risks of environmental pollution are covered in the form of mandatory (as seen in China) or optional insurance. The insurer accepts the risk after checking and predicting the probability of a risk and checking and estimating the extent of possible damage, taking into account the ratio of his financial resources. Emphasizing and paying attention to international environmental laws can open the way for environmental insurance activities in the country. Insurers must identify the types of activities, accidents, and their associated impacts through comprehensive studies to effectively assess the feasibility of insuring the desired activity. The model proposed in this research aims to reduce decision-making errors. Among the limitations of this research are the non-cooperation of some experts as well as the lack of access to specific confidential documents and reports. For future research, it is recommended to conduct similar studies addressing other aspects of pollution, such as air, soil, and noise pollution.

Authors' Contributions

Nahid Seyrafian: Conceptualization; Investigation; Funding acquisition; Visualization; Writing. Mansour Pournouri: Methodology; Project administration; Supervision; Validation. Hamidreza Ghaffarzadeh: Formal analysis; Resources. Reza Simbar: Software.

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Conflicts of Interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Ethical considerations

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Using artificial intelligence

Artificial intelligence was not used in the preparation of this article.

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