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Analyzing the Criteria of Efficient Carbon Capture and Separation Technologies for Sustainable Clean Energy Usage

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Abstract: This study focuses on carbon capture and distribution technology, which is a new approach to the solution of this problem. In order to use this technology more effectively, six significant criteria are defined by considering the essentials of the international Loss Control Institute and the supported literature. Moreover, the analytic network process (ANP) is applied for measuring the relative importance of each factor. The findings demonstrate that organizational factor has the greatest importance, whereas market factor is the weakest element. In addition, the education of the personnel is the most important criterion for low-cost industrial carbon dioxide capture and separation technologies. In this context, it is seen that companies need competent personnel in order to reduce the costs of these products. There are two types of strategies that companies can develop to achieve this goal. Firstly, it would be appropriate for companies to provide their staff with the necessary training on carbon capture and storage technologies. The second most important strategy is for the new personnel to be employed in the company. When choosing new employees, it is necessary to measure whether they have sufficient knowledge about this technology. These strategies will contribute to lower costs when developing products for carbon capture and storage technology.

Keywords: carbon emission; carbon capture and storage; sustainability; green energy; ANP

1. Introduction

One of the methods used to reduce the emission of carbon dioxide in the industry is capturing it before it enters the atmosphere [1]. When a fossil fuel burns, carbon combines with oxygen to form carbon dioxide gas [2]. In this process, it is possible to capture and store the carbon dioxide gas that is released. Thus, the problem of the emission of carbon dioxide gas can be minimized [3,4]. What is important here is that this process is costly. A significant technological investment is required for the separation of said gas. This situation increases the cost of generating energy. Therefore, companies may be reluctant to implement this technology [5,6].

It is vital that these technologies be implemented at a low cost. In this context, all the issues that create cost in this process should be examined in detail. For example, the development of the technological infrastructure of the company is important to decrease cost. In addition, the competence of the personnel who will use this technology should be ensured. Within this framework, competent personnel may be employed, or existing personnel may be provided with the necessary training [7].

In this study, we will examine how to reduce costs in the process of carbon dioxide capture and storage technology. For this purpose, first of all, the criteria necessary to reduce these costs will be determined. In this process, cost reduction methods specified by the International Loss Control

Institute will be considered. On the other hand, the ANP method can be very helpful to define which criteria are more important. In this way, it will be possible to implement this technology, which is necessary to reduce the emission of carbon dioxide at a lower cost.

The most important difference in this study from the others is that the significance of a set of criteria is analyzed. The fact that this method has been used very little in the aforementioned subject increases the authenticity of the study. On the other hand, by using the ANP method, interdependency between the criteria can be taken into consideration. Another important contribution of this study is that it presents different alternatives to implement carbon capture and separation technologies more effectively. Moreover, more significant items are also identified. These results pave the way for companies to adopt this technology. Hence, this situation provides a positive contribution to the problem of the decrease in carbon emissions.

2. Literature Review

One of the most important issues in the literature regarding cost management is the technological competence of the company. Diefenbach et al. [8] stated that effective cost management has a significant effect on the performance of the organization. They argued that the most necessary issue in this process was to invest in the technology of the company. Ruiz-Rosa et al. [9] and Wouters et al. [10] addressed this issue for different sectors and stated that technologically sufficient companies could perform more efficient cost management. Sun [11] and Mo [12] also emphasize the importance of technological infrastructure in low cost management.

Another important issue in cost management is environmental factors. Henri et al. [13] and Papagiannis et al. [14] stated that it is not possible for a company to perform effective cost management when the environmental costs are high. Durán et al. [15] conducted a similar study within the framework of fuzzy logic. As a result, they argued that companies could not manage their costs very successfully in the event of uncertainty in the market. Ashraf and Uddin [16] examined underdeveloped countries in their studies and concluded that the taxes imposed by the state are the most effective issue in the cost management of companies.

Moreover, benchmarking is also accepted as an important factor in effective cost management. Xue et al. [17] conducted a study on effective cost management in the construction sector. In this process, it is stated that a company should compare its values with its competitors. Smith [18] also found that, as a result of a comparison with competitors, it is possible for a company to see possible errors in the cost management process. Botín and Vergara [19] emphasized that companies should compare themselves with the sector average. Schindler et al. [20] and Smith [21] made a study on different sectors such as construction and health and expressed the importance of the same issue.

Risk management is another important issue to reduce costs. Pheng [22] and Amir et al. [23] stated how the cost management of large projects can be performed. In these studies, where different sectors were analyzed, they stated that companies should bear more costs if they do not manage their risks effectively. Miguel et al. [24] emphasized that the most important element of effective cost management is the accurate definition of the risks of companies. On the other hand, Zhu et al. [25] performed a similar analysis using the Monte Carlo simulation technique. They found that companies can manage their costs more successfully when risks can be accurately identified and managed.

In the process of effective cost management, the quality of staff is another highlight. Zhou et al. [26] conducted a review on cost management in small- and medium-sized enterprises. It is stated that companies with competent personnel are more successful in cost management. Liu et al. [27] emphasized similar issues in their review. Similarly, Liu and Wen [28] also focused on effective cost management. In this study, it is stated that the most important element of effective cost management is the competence of the personnel. Therefore, it was concluded that the necessary training should be given to the personnel for this framework.

The International Loss Control Institute (ILCI) also focused on ways to minimize the costs. They considered many different factors at the same time and generated many different standards regarding cost minimization. In this context, first of all, one of the most important cost items is stated as human cost. In other words, if the personnel working in a company do not have the necessary competence, this will create a high amount of cost to the company in the long term. This is because these people work inefficiently, adversely affecting the performance of the company. Therefore, it has been determined by this institution, as a standard, to have effective personnel to reduce costs. In this context, the company offers two different opportunities. The company either provides good training to its existing employees or makes sure that the new personnel have these qualifications.

Another standard created by the ILCI to reduce costs is a company's technological infrastructure. This standard is described under the name of technical feasibility and is of vital importance for the company. Especially in recent years, technology is advancing rapidly. This situation affects the productivity of companies in particular. It is stated that companies that can adapt to this developing technology can be more successful in reducing their costs. The need for market recognition is another issue emphasized by the ILCI for this purpose. The agency stated that the damage to the brand of a company is one of the biggest risks for a company. In this context, it is underlined that companies need to know their markets well in order to reduce their costs. In this context, it will be appropriate to determine the current situation of the company by making comparisons with important competitors in the market. In this case, the early detection of potential problems will help in taking timely action. In addition, it is possible to avoid unnecessary costs in the products produced by effectively determining customer expectations. The cost reduction criteria resulting from the analysis of similar studies in the literature are in line with the standards established by the ILCI [29,30].

Carbon capture technologies were also discussed in the literature by many different researchers. The main purpose of these technologies is to capture, store and maintain the released carbon dioxide [31]. Thus, it is possible to greatly reduce greenhouse gas emission and to slow down climate changes. A significant portion of the studies focused on the effects of these technologies on reducing carbon emissions [32,33]. In these studies, it has been mentioned that environmental pollution will be significantly reduced thanks to carbon capture and storage technologies. Another point emphasized in these studies is that this situation will have an impact on the social and economic development of a country [34]. In an environment without air pollution, people will be less sick. In this way, labor force participation in the country will be higher. This will contribute to the development of industry. On the other hand, it may also be possible to reduce healthcare costs in a country where disease rates are falling [35].

Some of the researchers who consider carbon capture technologies have focused on the costs of this technology. Thanks to this technology, the resulting carbon gas will be captured without being released into the atmosphere by an application. This captured carbon gas is then stored appropriately [36]. Oil and gas wells, coal deposits and oceans are alternatives that can be used for storage [37]. As can be seen, the implementation of this technology is very costly. Therefore, it is obvious that companies will not want to use this application unless the costs of carbon capture technology are reduced [38]. In such research, it has been argued that, in general, it should be focused on cost-cutting applications in carbon capture technology. In this context, it has been argued that low-cost applications should be learned quickly by following current technologies [39,40].

The results of the literature review indicate that cost management is handled from many different perspectives. These studies have often sought to determine which issues are important to minimize the costs. In these studies, case studies were generally considered as the methodology. In some studies, econometric methods such as regression and Monte Carlo analysis were preferred. A new study in which cost management will be addressed in a different way would be very useful. In our study, cost management in carbon dioxide capture technologies is discussed. For this purpose, the ANP method was used. Therefore, the aim of the study is to satisfy this need.

3. Methodology of the Analytic Network Process

The method of the analytic network process (ANP) is a widely known pairwise comparison technique among the multi-criteria decision-making models [41]. This technique has several advantages by using the comparisons of factors and sub-factors with the possible interdependencies. The method could be summarized in the following steps as in [42].

The first step of the ANP is to determine the linguistic scales and values for the pair-wise comparison [43]. There are several linguistic scales for defining the weights, entitled "equally", "moderately", "essentially", "very strongly" and "extremely important" as the numbers of importance from 1 to 9, respectively.

The second step is to define the comparison matrix. Pair-wise comparisons among the factors are illustrated with the scales and constructed in Equation (1).

$$A = \begin{bmatrix} a_{11} & a_{21} & a_{13} & & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

$$a_{ij} = \frac{1}{a_{ji}},\ a_{ii} = 1,\ a_{ij} > 0 \quad (2)$$

In this equation, a_{ij} is the pair-wise comparison evaluation among the related factors and $i, j = 1, 2, \ldots n$. Additionally, n represents the number of criteria.

The third step is to calculate the eigenvector of each comparison. The value is provided by Equation (3).

$$Aw = \lambda_{max} w \quad (3)$$

where w is the priority vector and λ_{max} is the major eigenvalue of matrix A.

The fourth step is to compute the consistency index (CI). The index is obtained with Equation (4).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

The fifth step is to test the consistency. The consistency ratio (CR) is used with Equation (5) [44].

$$CR = \frac{CI}{RI} \quad (5)$$

The sixth step is to select the value of the random index (RI) [45]. The values are defined according to the number of criteria. In this study, the values of 0.58 and 1.24 are defined for the pair-wise comparison matrices with three and six criteria, respectively. If the consistency ratio is less than 0.1, it is assumed that the evaluations of the pair-wise comparison matrix are appropriate. In other cases, the evaluations are revised until the consistency ratio is limited in the value of 0.1. The seventh step is to construct the supermatrix. Unweighted values are converted to the weighted and limit matrix properly by Equation (6) [46]. Limiting powers are applied to the super matrix until the weights of the criteria are stable [47,48].

$$
W = \begin{array}{c c} & \begin{array}{ccccccc} C_1 & \cdots & C_k & & \cdots & C_n & \\ & e_{11} & e_{12} & \cdots e_{1m1} & \cdots & e_{n1} \quad e_{n2} & \cdots e_{nmn} \end{array} \\ \begin{array}{cc} C_1 & e_{11} \\ & e_{12} \\ \vdots & \vdots \\ C_k & e_{1m1} \\ & \vdots \\ \vdots & e_{n1} \\ & e_{n2} \\ C_n & \vdots \\ & e_{nmn} \end{array} & \begin{bmatrix} w_{11} & w_{21} & w_{13} & & \cdots & w_{1n} \\ w_{21} & w_{22} & w_{23} & & \cdots & w_{2n} \\ w_{31} & w_{32} & w_{33} & & \cdots & w_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ w_{n1} & w_{n2} & w_{n3} & & \cdots & w_{nn} \end{bmatrix} \end{array} \quad (6)
$$

4. Results

This analysis includes the factors that affect the cost of carbon capture technologies. Factors and sub-factors are generated by the essentials of the International Loss Control Institute and the supported literature. The method of the analytic network process is applied for measuring the relative importance of each factor and sub-factors under the assumption of the interdependencies among them. The factors and sub-factors are given in Table 1.

Table 1. Factors of sustainable low-cost industrial CO_2 capture and separation technologies.

Factors	Sub-Factors	Supported Literature
Organizational (factor 1)	Training (sub-factor 1) Personnel efficiency (sub-factor 2)	Zhou et al. [26]; Liu et al. [27] Liu and Wen [28]; Zhou et al. [26]
Technical (factor 2)	Engineering improvements (sub-factor 3) Technological infrastructure (sub-factor 4)	Diefenbach et al. [8]; Ruiz-Rosa et al. [9] Wouters et al. [10]; Sun [11]; Mo [12]
Market (factor 3)	Benchmarking (sub-factor 5) Socio-demographic competencies (sub-factor 6)	Xue et al. [17]; Smith [18]; Botín and Vergara [19] Henri et al. [13]; Papagiannis et al. [14]; Durán et al. [15]

As can be seen from Table 1, three different factors and six different sub-factors related to cost reduction were determined in carbon capture technologies. These issues contribute to the reduction of costs. Carbon emission is a very significant problem which affects countries negatively in both social and economic manners. Hence, this problem should be eliminated. Carbon capture technology is a way to avoid this problem, but some factors should be taken into consideration to have effective carbon capture technology. Education is one of the most important criteria in this process [26]. Carbon capture technologies are very complex and require specific information. Therefore, it will be possible to reduce the costs during the implementation of this technology through the training of personnel [27]. In other words, with the help of necessary education, it can be much easier to implement this technology. On the other hand, ensuring the effectiveness of the personnel in the working environment will help to reduce costs in this process [28]. The main reason for this is that the costs are minimized in an environment where personnel work effectively. Thus, companies should give priority to improving the qualifications of the personnel. In this regard, necessary education should be defined and they should be provided for the personnel.

Technological factors also help to reduce costs in the implementation of carbon capture technologies. Technological advances enable a product to be produced more easily. This is more important for carbon capture technologies [8]. Because of this situation, companies should make necessary investments to improve their engineering knowledge. Otherwise, it will be very difficult to be successful in the implementation of carbon capture technologies. As mentioned earlier, the implementation of these technologies is quite complex and difficult. A strong technological infrastructure of a company plays an important role in this process, which requires significant engineering skills [11]. In this context, companies with a strong technological infrastructure are expected to realize the process of applying carbon capture technologies at a lower cost.

In addition to the aforementioned issues, market conditions are another factor that stands out in this process. If a company wants to reduce its cost, it must first know its market very well. The prerequisite for getting to know the market closely is to follow the competitors [18]. In this context, it is important for companies to compare themselves with their most important competitors. In this way, companies will be able to see where they are compared to their competitors. This will contribute to the early detection of a possible problem. This is especially important for complex technologies such as carbon capture [19]. When companies compare themselves periodically with their competitors, they will also be able to master the technological developments in the market. On the other side, socio-demographic competencies are also very important in this regard. The main reason for this is that the public's environmental awareness has an effect on this technology. Companies may have to take measures to reduce carbon emissions if the public is sensitive to the environment in a particular country. Carbon capture and storage technology will also play a very important role in meeting the expectations of people who are sensitive to the environment. In the following process, the pair-wise comparison matrices are constructed. In this framework, the evaluations of three decision makers are taken into account. These people have more than 15 years of experience in this area. Table 2 represents the results for the pair-wise comparison of factors with respect to sub-factors.

In this table, PCV represents pair-wise comparison values. Additionally, normalized values are given as NV. On the other side, the results for the pair-wise comparison of sub-factors with respect to each factor are demonstrated in the Appendix A (Tables A1–A3). At the final step, the limit matrix is generated, as seen in Table 3.

The final results show that the organizational factor (factor 1) has the highest importance, with 40.5%, while the market factor (factor 3) is the weakest element with 26.2%. However, training (sub-factor 1), personnel efficiency (sub-factor 2), engineering improvements (sub-factor 3), technological infrastructure (sub-factor 4), benchmarking (sub-factor 5) and socio-demographic competencies (sub-factor 6) are listed consecutively, and it is seen that the sub-factor of training is the most important factor, relatively, and the socio-demographic sub-factor has the last seat according to the weighting results.

These results indicate that education has the most importance (0.326). Similarly, personnel competence is another important factor in effective cost management (0.232). Based on these issues, it was concluded that the criteria of organizational factors (factor 1) are the most important. While the criteria regarding the technological dimension (factor 2) are in the middle rankings, the criteria for the market (factor 3) have the lowest importance weight.

When the analysis results are taken into consideration, the quality of the personnel should be given priority in order to reduce costs in carbon dioxide capture technologies. In this context, since the carbon dioxide capture process involves complex steps, it would be appropriate to provide extensive training to existing personnel. In this way, the risk of personnel error can be minimized. Another application to achieve this goal is to employ personnel who know this technology. In this way, it will be possible to reduce training costs. In summary, it is important either to increase the level of training of existing personnel or to employ experienced personnel. Otherwise, the costs required for companies will be increased.

Table 2. The results for the pair-wise comparison of factors with respect to sub-factors.

	Factors	PCV			NV			E.V	CI	CR
		F1	F2	F3	F1	F2	F3			
For Sub-factor 1	Organizational (factor 1)	1.00	3.00	3.00	0.60	0.67	0.50	0.589	0.027	0.046
	Technical (factor 2)	0.33	1.00	2.00	0.20	0.22	0.33	0.252		
	Market (factor 3)	0.33	0.50	1.00	0.20	0.11	0.17	0.159		
For Sub-factor 2	Organizational (factor 1)	1.00	2.00	5.00	0.59	0.60	0.56	0.581	0.002	0.003
	Technical (factor 2)	0.50	1.00	3.00	0.29	0.30	0.33	0.309		
	Market (factor 3)	0.20	0.33	1.00	0.12	0.10	0.11	0.110		
For Sub-factor 3	Organizational (factor 1)	1.00	0.33	0.14	0.09	0.08	0.10	0.088	0.004	0.006
	Technical (factor 2)	3.00	1.00	0.33	0.27	0.23	0.23	0.243		
	Market (factor 3)	7.00	3.00	1.00	0.64	0.69	0.68	0.669		
For Sub-factor 4	Organizational (factor 1)	1.00	0.14	0.33	0.09	0.11	0.05	0.083	0.033	0.057
	Technical (factor 2)	7.00	1.00	5.00	0.64	0.74	0.79	0.724		
	Market (factor 3)	3.00	0.20	1.00	0.27	0.15	0.16	0.193		
For Sub-factor 5	Organizational (factor 1)	1.00	5.00	3.00	0.65	0.56	0.69	0.633	0.019	0.033
	Technical (factor 2)	0.20	1.00	0.33	0.13	0.11	0.08	0.106		
	Market (factor 3)	0.33	3.00	1.00	0.22	0.33	0.23	0.260		
For Sub-factor 6	Organizational (factor 1)	1.00	0.20	0.33	0.11	0.13	0.08	0.106	0.019	0.033
	Technical (factor 2)	5.00	1.00	3.00	0.56	0.65	0.69	0.633		
	Market (factor 3)	3.00	0.33	1.00	0.33	0.22	0.23	0.260		

Table 3. Limit matrix.

	Sub-Factor 1	Sub-Factor 2	Sub-Factor 3	Sub-Factor 4	Sub-Factor 5	Sub-Factor 6	Factor 1	Factor 2	Factor 3
Sub-factor 1	0.000	0.000	0.000	0.000	0.000	0.000	0.326	0.326	0.326
Sub-factor 2	0.000	0.000	0.000	0.000	0.000	0.000	0.232	0.232	0.232
Sub-factor 3	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190
Sub-factor 4	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.114	0.114
Sub-factor 5	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.070	0.070
Sub-factor 6	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.068	0.068
Factor 1	0.405	0.405	0.405	0.405	0.405	0.405	0.000	0.000	0.000
Factor 2	0.333	0.333	0.333	0.333	0.333	0.333	0.000	0.000	0.000
Factor 3	0.262	0.262	0.262	0.262	0.262	0.262	0.000	0.000	0.000

This result is parallel to many studies in the literature. For example, Zhou et al. [26] sought answers to the question of how to reduce costs in small- and medium-sized enterprises. In this context, they considered many different criteria. As a result, they stated that the training to be provided to the personnel will contribute to the reduction of costs in the long term. Moreover, Liu et al. [27] also focused on cost management by conducting a survey analysis with many different companies. According to the results of the analysis, it was determined that cost management can be more effective if the training given to the personnel are correct and in place. This situation was also discussed in some studies related to carbon capture technologies, such as [31,32].

5. Conclusions

In this study, it was investigated how effective cost management will be in carbon dioxide capture technologies. First, six different criteria were identified that could affect these costs. In this process, the relevant criteria were selected considering the factors determined by the International Loss Control Institute. An analysis was performed using the ANP method in order to determine which of these criteria had more importance. According to the results of the analysis, organizational factors are the most important. However, technical factors are second. On the other hand, market factors were found to be least important.

On the other side, with respect to the criteria, it is concluded that training is the most significant factor that affects the effectiveness of the carbon capture technologies. Similarly, it is also identified that personnel efficiency also plays an important role within this framework. In addition to this situation, it is also determined that engineering improvements and technological infrastructure are also essential for this condition. Nevertheless, it is also seen that benchmarking and socio-demographic competencies have lower weights in comparison with the others.

The most important contribution of this study from the others is that the significance of the set of criteria is analyzed. Another important contribution of this study is related to the methodology. In this context, by using the ANP method, the interdependency between the criteria can be taken into consideration. On the other side, there are also some criticisms for the ANP methodology. The main reason is that the inner dependency between the variables are defined subjectively. This situation increases the uncertainty in the analysis. Another important contribution of this study is that it presents different alternatives to implement carbon capture and separation technologies more effectively. Furthermore, more significant items are also identified as a result of the analysis. These results may lead companies to adopt this technology more easily. Owing to this issue, it can be said that this situation has a positive contribution to the problem of the decrease of carbon emissions.

The main limitation of this study is that it focuses only on carbon dioxide retention technologies for reducing carbon dioxide emissions. In future studies, different methods can be analyzed according to their importance in order to reduce the mentioned problem. For example, new technological improvements to reduce the cost of carbon capture and separation technologies can be evaluated. On the other hand, the methodologies used, especially in recent years, can be used in new studies. In this way, it will be possible to avoid the problem of carbon dioxide emissions, which has negative effects on both the economy and environment. On the other side, in this study, the weights of the dimensions and criteria are only calculated. The exact effect can be calculated with regression analysis. In future studies, this analysis can be performed.

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Appendix A

Table A1. The results for the pair-wise comparison of sub-factors with respect to factor 1.

Sub-Factors	Pairwise Comparison Values						Normalized Values						E.V	CI	CR
	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6			
Training (sub-factor1)	1.00	3.00	2.00	3.00	3.00	3.00	0.35	0.54	0.32	0.29	0.17	0.30	0.329	0.075	0.060
Personnel efficiency (sub-factor 2)	0.33	1.00	2.00	3.00	5.00	2.00	0.12	0.18	0.32	0.29	0.28	0.20	0.232		
Engineering improvements (sub-factor 3)	0.50	0.50	1.00	2.00	5.00	2.00	0.18	0.09	0.16	0.19	0.28	0.20	0.183		
Technological infrastructure (sub-factor 4)	0.33	0.33	0.50	1.00	3.00	1.00	0.12	0.06	0.08	0.10	0.17	0.10	0.104		
Benchmarking (sub-factor 5)	0.33	0.20	0.20	0.33	1.00	1.00	0.12	0.04	0.03	0.03	0.06	0.10	0.062		
Socio-demographic competencies (sub-factor 6)	0.33	0.50	0.50	1.00	1.00	1.00	0.12	0.09	0.08	0.10	0.06	0.10	0.090		

Table A2. The results for the pair-wise comparison of sub-factors with respect to factor 2.

Sub-Factors	Pairwise Comparison Values						Normalized Values						E.V	CI	CR
	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6			
Training (sub-factor 1)	1.00	3.00	3.00	5.00	7.00	9.00	0.47	0.58	0.40	0.30	0.38	0.32	0.409	0.113	0.091
Personnel efficiency (sub-factor 2)	0.33	1.00	3.00	3.00	3.00	7.00	0.16	0.19	0.40	0.18	0.16	0.25	0.224		
Engineering improvements (sub-factor 3)	0.33	0.33	1.00	7.00	5.00	5.00	0.16	0.06	0.13	0.42	0.27	0.18	0.204		
Technological infrastructure (sub-factor 4)	0.20	0.33	0.14	1.00	2.00	3.00	0.09	0.06	0.02	0.06	0.11	0.11	0.076		
Benchmarking (sub-factor 5)	0.14	0.33	0.20	0.50	1.00	3.00	0.07	0.06	0.03	0.03	0.05	0.11	0.058		
Socio-demographic competencies (sub-factor 6)	0.11	0.14	0.20	0.33	0.33	1.00	0.05	0.03	0.03	0.02	0.02	0.04	0.030		

Table A3. The results for the pair-wise comparison of sub-factors with respect to factor 3.

Sub-Factors	Pairwise Comparison Values						Normalized Values						E.V	CI	CR
	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6	S.F1	S.F2	S.F3	S.F4	S.F5	S.F6			
Training (sub-factor 1)	1.00	2.00	1.00	1.00	2.00	2.00	0.22	0.40	0.19	0.15	0.18	0.17	0.217	0.080	0.065
Personnel efficiency (sub-factor 2)	0.50	1.00	1.00	3.00	3.00	3.00	0.11	0.20	0.19	0.44	0.27	0.25	0.243		
Engineering improvements (sub-factor 3)	1.00	1.00	1.00	1.00	1.00	3.00	0.22	0.20	0.19	0.15	0.09	0.25	0.183		
Technological infrastructure (sub-factor 4)	1.00	0.33	1.00	1.00	3.00	2.00	0.22	0.07	0.19	0.15	0.27	0.17	0.177		
Benchmarking (sub-factor 5)	0.50	0.33	1.00	0.33	1.00	1.00	0.11	0.07	0.19	0.05	0.09	0.08	0.098		
Socio-demographic competencies (sub-factor 6)	0.50	0.33	0.33	0.50	1.00	1.00	0.11	0.07	0.06	0.07	0.09	0.08	0.081		

References

1. Chi, Y.; Yang, P.; Ren, S.; Ma, N.; Yang, J.; Xu, Y. Effects of fertilizer types and water quality on carbon dioxide emissions from soil in wheat-maize rotations. *Sci. Total Environ.* **2020**, *698*, 134010. [CrossRef]
2. Yüksel, S.; Ubay, G.G. Identifying the influencing factors of renewable energy consumption in Turkey with MARS methodology. *Ekonomi İşletme ve Maliye Araştırmaları Dergisi* **2020**, *2*, 1–14.
3. Wen, W.; Wang, Q. Re-examining the realization of provincial carbon dioxide emission intensity reduction targets in China from a consumption-based accounting. *J. Clean. Prod.* **2020**, *244*, 118488. [CrossRef]
4. Benjamin, N.I.; Lin, B. Quantile analysis of carbon emissions in China metallurgy industry. *J. Clean. Prod.* **2020**, *243*, 118534. [CrossRef]
5. Liu, L.; Jin, S.; Ko, K.; Kim, H.; Ahn, I.S.; Lee, C.H. Alkyl-functionalization of (3-Aminopropyl) triethoxysilane-grafted zeolite beta for carbon dioxide capture in temperature swing adsorption. *Chem. Eng. J.* **2020**, *382*, 122834. [CrossRef]
6. Erans, M.; Nabavi, S.A.; Manović, V. Carbonation of lime-based materials under ambient conditions for direct air capture. *J. Clean. Prod.* **2020**, *242*, 118330. [CrossRef]
7. Llamas, B.; Ortega, M.F.; García, M.J.; Mora, P. Carbon Storage and Utilization as a Local Response to Use Fossil Fuels in a Sustainable Manner. In *Sustaining Resources for Tomorrow*; Springer: Cham, Switzerland, 2020; pp. 275–290.
8. Diefenbach, U.; Wald, A.; Gleich, R. Between cost and benefit: Investigating effects of cost management control systems on cost efficiency and organisational performance. *J. Manag. Control* **2018**, *29*, 63–89. [CrossRef]
9. Ruiz-Rosa, I.; García-Rodríguez, F.J.; Mendoza-Jiménez, J. Development and application of a cost management model for wastewater treatment and reuse processes. *J. Clean. Prod.* **2016**, *113*, 299–310. [CrossRef]
10. Wouters, M.; Morales, S.; Grollmuss, S.; Scheer, M. Methods for cost management during product development: A review and comparison of different literatures. In *Advances in Management Accounting*; Emerald Group Publishing Limited: London, UK, 2016; pp. 139–274.
11. Sun, H. Permeation of Computer Technology in Enterprise Management. In Proceedings of the 2016 International Conference on Economics, Social Science, Arts, Education and Management Engineering, Changsha, China, 30–31 July 2016.
12. Mo, L. The Application Analysis of BIM Technology in Whole-Process of Engineering Cost Management. In Proceedings of the 2018 International Conference on Engineering Simulation and Intelligent Control (ESAIC), Changsha, China, 10–11 August 2018; IEEE: Piscataway, NJ, USA, 2018; pp. 404–406.
13. Henri, J.F.; Boiral, O.; Roy, M.J. Strategic cost management and performance: The case of environmental costs. *Br. Account. Rev.* **2016**, *48*, 269–282. [CrossRef]
14. Papagiannis, F.; Gazzola, P.; Burak, O.; Pokutsa, I. Overhauls in water supply systems in Ukraine: A hydro-economic model of socially responsible planning and cost management. *J. Clean. Prod.* **2018**, *183*, 358–369. [CrossRef]
15. Durán, O.; Afonso, P.S.; Durán, P.A. Spare Parts Cost Management for Long-Term Economic Sustainability: Using Fuzzy Activity Based LCC. *Sustainability* **2019**, *11*, 1835. [CrossRef]
16. Ashraf, J.; Uddin, S. New public management, cost savings and regressive effects: A case from a less developed country. *Crit. Perspect. Account.* **2016**, *41*, 18–33. [CrossRef]
17. Xue, H.; Zhang, S.; Su, Y.; Wu, Z.; Yang, R.J. Effect of stakeholder collaborative management on off-site construction cost performance. *J. Clean. Prod.* **2018**, *184*, 490–502. [CrossRef]
18. Smith, P. Global professional standards for project cost management. *Procedia Soc. Behav. Sci.* **2016**, *226*, 124–131. [CrossRef]
19. Botín, J.A.; Vergara, M.A. A cost management model for economic sustainability and continuos improvement of mining operations. *Resour. Policy* **2015**, *46*, 212–218. [CrossRef]
20. Schindler, M.; Danis, M.; Goold, S.D.; Hurst, S.A. Solidarity and cost management: Swiss citizens' reasons for priorities regarding health insurance coverage. *Health Expect.* **2018**, *21*, 858–869. [CrossRef]
21. Smith, P. Project cost management with 5D BIM. *Procedia Soc. Behav. Sci.* **2016**, *226*, 193–200. [CrossRef]
22. Pheng, L.S. Project cost management. In *Project Management for the Built Environment*; Springer: Singapore, 2018; pp. 97–112.
23. Amir, A.; Auzair, S.M.; Amiruddin, R. Cost management, entrepreneurship and competitiveness of strategic priorities for small and medium enterprises. *Procedia Soc. Behav. Sci.* **2016**, *219*, 84–90. [CrossRef]

24. Miguel, A.; Madria, W.; Polancos, R. Project Management Model: Integrating Earned Schedule, Quality, and Risk in Earned Value Management. In Proceedings of the 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA), Tokyo, Japan, 12–15 April 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 622–628.
25. Zhu, W.; He, Y.; Ren, H.; Wang, X.; Tian, H. The MonTe Carlo Method Application in Cost Risk Management of Pre-Transmission Line Project Based on Markov Chain. In Proceedings of the 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2), Beijing, China, 20–22 October 2018; IEEE: Piscataway, NJ, USA, 2018; pp. 1–6.
26. Zhou, F.; Zhao, X.; Zhao, B. Promotion of Management Accounting to Cost Management and Management Decision in Small and Medium-sized Enterprises. In Proceedings of the 2018 International Conference on Management, Economics, Education and Social Sciences (MEESS 2018), Shanghai, China, 11–12 August 2018.
27. Liu, X.; Liu, X.; Reid, C.D. Stakeholder orientations and cost management. *Contemp. Account. Res.* **2019**, *36*, 486–512. [CrossRef]
28. Liu, S.; Wen, R. Elementary Analysis of Strategic Management Accounting. In Proceedings of the 2017 7th International Conference on Education, Management, Computer and Society (EMCS 2017), Shenyang, China, 17–19 March 2017.
29. Katsakiori, P.; Sakellaropoulos, G.; Manatakis, E. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. *Saf. Sci.* **2009**, *47*, 1007–1015. [CrossRef]
30. Rachmawati, I.A.; Ardyanto, Y.D.; Soewandi, T. An analysis of the factor affecting substandard practice of personal protective equipment (PPE) usage in cement industry maintenance workers. *Int. J. Public Health Clin. Sci.* **2018**, *5*, 149–155.
31. Wongchitphimon, S.; Lee, S.S.; Chuah, C.Y.; Wang, R.; Bae, T.H. Composite Materials for Carbon Capture. *Mater. Carbon Capture* **2020**, 237–266. [CrossRef]
32. Bolton, S.; Kasturi, A.; Palko, S.; Lai, C.; Love, L.; Parks, J.; Xin, S.; Tsouris, C. 3D printed structures for optimized carbon capture technology in packed bed columns. *Sep. Sci. Technol.* **2019**, *54*, 2047–2058. [CrossRef]
33. Mukherjee, S.; Kumar, A.; Zaworotko, M.J. Metal-organic framework based carbon capture and purification technologies for clean environment. In *Metal-Organic Frameworks (MOFs) for Environmental Applications*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 5–61.
34. Fennell, P.S. Comparative Energy Analysis of Renewable Electricity and Carbon Capture and Storage. *Joule* **2019**, *3*, 1406–1408. [CrossRef]
35. Roelofse, C.; Alves, T.M.; Gafeira, J.; Kamal'deen, O.O. An integrated geological and GIS-based method to assess caprock risk in mature basins proposed for carbon capture and storage. *Int. J. Greenh. Gas Control* **2019**, *80*, 103–122. [CrossRef]
36. Liang, W.; Bhatt, P.M.; Shkurenko, A.; Adil, K.; Mouchaham, G.; Aggarwal, H.; Mallick, A.; Jamal, A.; Belmabkhout, Y.; Eddaoudi, M. A tailor-made interpenetrated MOF with exceptional carbon-capture performance from flue gas. *Chem* **2019**, *5*, 950–963. [CrossRef]
37. Severo, I.A.; Deprá, M.C.; Zepka, L.Q.; Jacob-Lopes, E. Carbon dioxide capture and use by microalgae in photobioreactors. In *Bioenergy with Carbon Capture and Storage*; Academic Press: Cambridge, MA, USA, 2019; pp. 151–171.
38. Wen, C.; Karvounis, N.; Walther, J.H.; Yan, Y.; Feng, Y.; Yang, Y. An efficient approach to separate CO_2 using supersonic flows for carbon capture and storage. *Appl. Energy* **2019**, *238*, 311–319. [CrossRef]
39. Baena-Moreno, F.M.; Rodríguez-Galán, M.; Vega, F.; Alonso-Fariñas, B.; Vilches Arenas, L.F.; Navarrete, B. Carbon capture and utilization technologies: A literature review and recent advances. *Energy Sources Part A Recovery Util. Environ. Eff.* **2019**, *41*, 1403–1433. [CrossRef]
40. Mandova, H.; Patrizio, P.; Leduc, S.; Kjärstad, J.; Wang, C.; Wetterlund, E.; Kraxner, F.; Gale, W. Achieving carbon-neutral iron and steelmaking in Europe through the deployment of bioenergy with carbon capture and storage. *J. Clean. Prod.* **2019**, *218*, 118–129. [CrossRef]
41. Yüksel, İ.; Dagdeviren, M. Using the analytic network process (ANP) in a SWOT analysis—A case study for a textile firm. *Inf. Sci.* **2007**, *177*, 3364–3382. [CrossRef]
42. Saaty, T.L.; Vargas, L.F. *Prediction, Projection and Forecasting*; Kluwer Academic: Boston, MA, USA, 1991.
43. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
44. Ayağ, Z.; Yücekaya, A. A fuzzy ANP-based GRA approach to evaluate ERP packages. *Int. J. Enterp. Inf. Syst.* **2019**, *15*, 45–68. [CrossRef]

45. Alilou, H.; Rahmati, O.; Singh, V.P.; Choubin, B.; Pradhan, B.; Keesstra, S.; Ghiasi, S.S.; Sadeghi, S.H. Evaluation of watershed health using Fuzzy-ANP approach considering geo-environmental and topo-hydrological criteria. *J. Environ. Manag.* **2019**, *232*, 22–36. [CrossRef] [PubMed]
46. Kılıç, H.; Kabak, Ö. Analysis of Relation between Human Development and Competitiveness Using Fuzzy ANP and DEA. In *International Conference on Intelligent and Fuzzy Systems*; Springer: Cham, Switzerland, 2019; pp. 859–866.
47. Mahdiyar, A.; Tabatabaee, S.; Durdyev, S.; Ismail, S.; Abdullah, A.; Rani, W.N.M.W.M. A prototype decision support system for green roof type selection: A cybernetic fuzzy ANP method. *Sustain. Cities Soc.* **2019**, *48*, 101532. [CrossRef]
48. Bathaei, A.; Mardani, A.; Baležentis, T.; Awang, S.R.; Streimikiene, D.; Fei, G.C.; Zakuan, N. Application of Fuzzy Analytical Network Process (ANP) and VIKOR for the Assessment of Green Agility Critical Success Factors in Dairy Companies. *Symmetry* **2019**, *11*, 250. [CrossRef]