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Original Article

Carbon neutrality implementation in Thailand: The use of analytic hierarchy process

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Abstract

Countries worldwide push towards carbon neutrality, urging public, private, and industrial sectors to reduce carbon and greenhouse gas (GHG) emissions. This study uses the analytic hierarchy process (AHP) to assess factors influencing carbon neutrality (CN) implementation in Thailand. Three major industry groups, including property and construction, industrial, and service groups, were considered for the interviews for data collection. Five key factors and 13 sub-factors form a hierarchical model with three CN solutions. The analysis results underscore the importance of the policy factor, emphasizing its alignment with government directives. Cost, specifically material cost, is crucial in CN implementation. Readiness in technology and market dynamics is also a concern, and government support is necessary to sustain the implementation plans. A case study was performed with a steel production company, and the results suggested that solar cells could be a solution to achieve CN in the long term. The study results provide a systematic method for selecting suitable CN implementation in the company. Extending the industry groups is recommended in future studies to yield better results.

Keywords: analytic hierarchy process, carbon neutrality, case study, Thailand

1. Introduction

The issues of global warming and natural disasters have prompted many countries, including Thailand, to focus on promoting CN. It promotes the sustainable development of the economy and social environment. The European Union has set a goal of achieving climate neutrality by 2050 (Carbon Brief, 2023). The USA initiates various laws to promote the reduction of GHG emissions and encourage consumers to use clean energy through tax policies. In Asia, many countries pay attention to green strategies. For example, China set up an emissions quota trading market in 2021 to support the reduction of GHG emissions in the industrial sector. Singapore and Japan use clean energy, reduce GHG emissions from the transportation sector, and plan to enter CN in 2050 (Xiaobei, Fan, & Jun, 2022). In Thailand, the National Energy Plan was established in 2022 as a roadmap to being a carbon-neutral country by 2050 (UN, 2022). Addressing critical factors in the industrial sector is crucial to achieving this goal. The Zero Industry Waste to Landfill and the Green Industry Mark for Green Processes policies are among the initiatives implemented to reduce waste generation (Thailand Carbon Neutral Network [TCNN], 2022).

The Thai government attempts to reduce reliance on fossil fuels and revise GHG targets to match global trends. The use of renewable energy in the country is slightly higher than the world average by 12% through using carbon sink, carbon capture, carbon storage, and carbon credits (Lee, 2022; TCNN, 2022). Nevertheless, CN implementation in the country is still limited due to several causes, e.g., limited skills and technologies and high investment cost. To successfully conduct CN implementation, it is necessary to understand key factors influencing the implementation decisions. As various methods may be implemented, it is also crucial to systematically select suitable methods for the companies. For example, Ghasemi, Azari, and Zahed (2024) stated that lack of regulations to address CN can hinder the ability to address national and regional environmental challenges effectively.

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Moreover, a lack of technology, incentives, carbon market, and uncontrolled risks are barriers to the successful CN implementation. Various renewable energy methods, such as solar cells, wind energy, and biomass, may be adopted to achieve CN (Pietzcker, Stetter, Manger, & Luderer, 2014). International Energy Agency [IEA] (2013) stated that carbon capture and storage (CCS) systems are a solution to overcome climate change. About 19% of CO_2 emissions should be captured to prevent global temperature rising more than 2°C by 2050.

This study utilizes the AHP to systematically examine key factors affecting CN and select suitable methods for implementation. It identifies key factors influencing CN implementation decisions, assigns the importance weights of those factors, and guides suitable strategies for companies. It is utilized in several CN-related studies in many countries like Korea, Indonesia, and China (Sukmasari & Nugroho, 2024; You & Yi, 2022). The study results are expected to provide insights into implementing CN and assist the government, related authorities, and industries in planning for long-term sustainable decisions.

2. Materials and Methods

2.1. Key factors influencing carbon neutrality implementation

It is crucial to understand key factors influencing CN implementation so that effective plans can be established. In this study, the Science Direct database is used to extract key factors affecting the carbon-neutral transition path in Thailand in the past 10 years. Keywords, including CN, factor, implementation, method, and Thailand, are input into the database search. The frequency statistics are used to rank the top keywords to be discussed and brainstormed to extract five key factors related to CN implementation, i.e., policy, readiness, cost, source of energy, and risk, with a total of 13 sub-factors and three implementation methods (i.e., solar cells, wind turbine, and CCS). For example, You and Yi (2022) mentioned that technology, management, innovation, and digitalization are crucial for CN transition. Sukmasari and Nugroho (2024) concluded the environment (e.g., types and sources of energy), economic (e.g., investment and operation costs), and social as key aspects for carbon mitigation. The hierarchical model of CN implementation is developed; Figure 1.

2.2 AHP

The AHP is a pairwise matrix process that determines the weights of different parameters. It structures the problem as a hierarchy and classifies factors and sub-factors based on comparative analysis (Chinda & Ammarapala, 2016). The weights of factors are calculated using a pairwise comparison matrix with a scale of 1-9, see Table 1. The analysis comprises several steps: 1) define the decision problem, 2) list factors and sub-factors relating to the decision problem, 3) develop the decision hierarchy, where the first level represents goal, the second level displays main factors, the third level lists sub-factors, and the last level shows choices, 4) collect data from the experts, 5) construct the matrix to employ pairwise comparison using the scale 1-9, 6) calculate weights of factors and sub-factors, 7) measure the consistency in the pairwise comparison using the random index (RI) values, where 0 and 1 are used for matrices 2×2 and 5×5, and 8) prioritize factors and sub-factors based on the analysis results (Ammarapala *et al*., 2018).

Table 1. Scoring system for the AHP (Chinda & Ammarapala, 2016)

Score	Definition
1	Equal importance between the two factors
3	Moderate importance of one factor over another
5	Strong importance of one factor over another
7	Very strong importance of one factor over another
9	Extreme importance of one factor over another
2, 4, 6, 8	Intermediate values

2.3 Data collection

Data collected from the in-depth interviews are analyzed to examine the significance of each factor and sub-factor from the perspectives of the experts. According to SET (2022), the Thai industries are categorized into eight groups; Table 2. This study selected experts from the three groups property and construction, industry, and service, as these

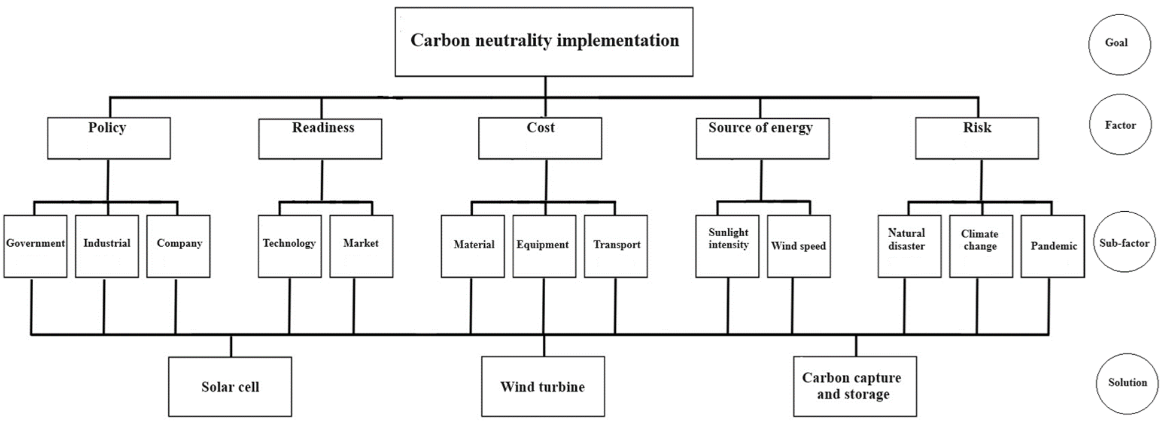


Figure 1. Hierarchical model of CN implementation

Table 2. Industry groups in Thailand (SET, 2022)

Industry	Sector
Argo and food industry	Agribusiness, food, and beverage
Consumer product	Fashion, home and office products, personal products, and pharmaceuticals
Financial	Banking, finance, and insurance
Industrial	Automotive, machinery, paper and printing materials, petrochemicals, packaging, steel, and metal
Property and construction	Construction materials and property development
Resource	Energy, utilities, and mining
Service	Commerce, healthcare services, media, tourism, transportation, and logistic
Technology	Electronic component and IT

industries have experienced CN implementation. For example, Siam Cement Public Company Limited [SCG] (2023), a large-sized construction company, implements a comprehensive environmental strategy that includes reducing GHG emissions, increasing energy efficiency, and utilizing alternative fuels. GC (2024) commits to reducing GHG emissions and improving energy efficiency by investing in renewable energy projects, CCS technologies, and energy-efficient processes. Bangkok Airways (2021) is working towards CN by enhancing fuel efficiency, reducing waste, investing in carbon offset programs, and emphasizing sustainable tourism.

Prior to collecting data for the analysis, a pilot test was performed with three experts in the three selected groups to clarify and ensure the interpretation of the pairwise statements. These experts are executives and managers involved in CN implementation, such as installing solar cells and designing green buildings. They also provide insights into the current CN-related regulations and practical considerations for CN goals.

The final interview questions are used to collect data from seven experts. Melon, Beltran, and Cruz (2008) stated that 5-7 experts are considered reliable to provide data for in-depth interviews. They are executives and managers in property and construction, industrial, and service groups; Table 3. They are asked to compare each pair of factors and sub-factors related to CN implementation using scores 1-9; Figure 2. Each interviewee's importance weights of factors and sub-factors are calculated and verified using the RI values (Table 1). If the calculated RI values are not in the acceptable range, the expert is asked to reconsider the scores of factors and sub-factors before the importance weights are finalized.

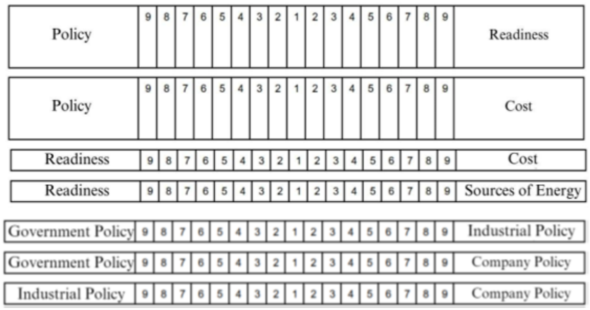


Figure 2. Example of pairwise score form

The weights of factors and sub-factors from seven interviewees are normalized using the geometric mean to achieve the final hierarchical model of factors influencing CN implementation in the Thai industries.

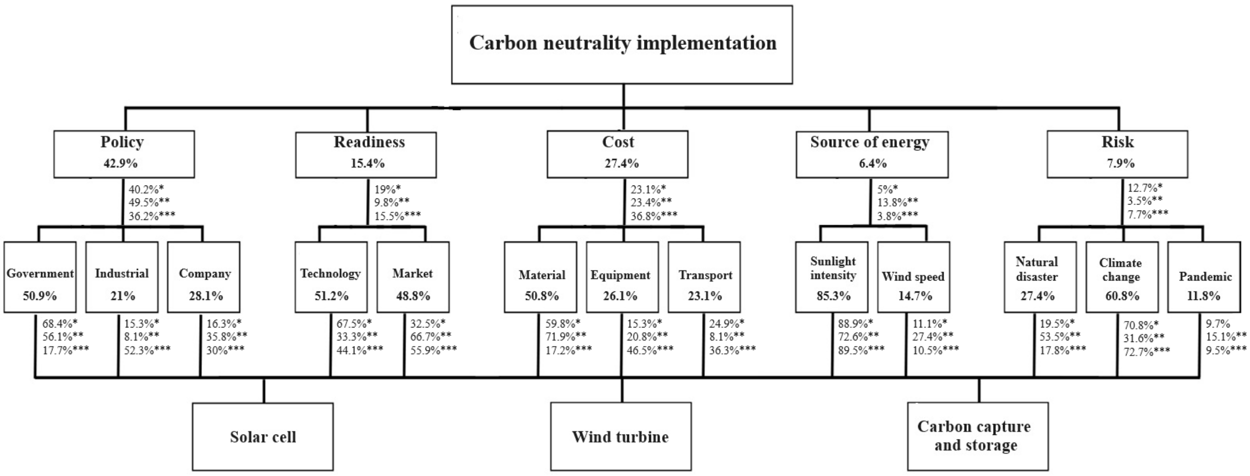
3. Results

3.1 AHP results

The data collected from seven experts are analyzed using the AHP approach. The calculated importance weights of each expert are checked with RI values, and they fall in acceptable ranges. All the weights are averaged to achieve the final hierarchical model, Figure 3. The results reveal that "policy" is the most crucial factor when planning to implement CN, with an importance weight of 42.92%. Specifically, the "government policy" sub-factor plays a significant role in achieving CN with a weight of 50.9%. This may be because Thailand aims to achieve CN by 2050 and net zero before 2065 (UN, 2022). These goals require emission reductions from 25% to 40%, leading to the development of cost-effective technologies and accessible financial support for investments in clean businesses (Office of Natural Resources and Environmental Policy and Planning [ONEP], 2022). To stay in line with government directives, companies must disaggregate government policies into practical strategies and industrial policies. This results in lower importance weights of the "company" and "industrial" policies (i.e., 28.1% and 21%) compared with the "government" policy. For example, Thai Oil (2015), a leading petrochemical company in Thailand, aligns with government policies by setting its targets so as to achieve CN by 2050 and net zero by 2060. The company's policies may also follow international standards, such as ISO 14067, to minimize carbon footprints (Duangsong & Theerathammakorn, 2024).

Table 3. Experts involved in the AHP analysis

Sector	No	Company size	Position	Experience (years)	Specialization
Property and construction	1	Large	Executive	30	Construction engineering and logistics
	2	Large	Manager	12	Engineer advisor and data management
	3	Large	Manager	21	Manufacturing excellence and lean system
Industrial	1	Large	Manager	25	Steel production and technical knowledge engineering
	2	Large	Executive	28	Natural gas and petrochemical
Service	1	Large	Manager	18	Sustainability management and policy
	2	Large	Manager	9	Human resources and sustainability



Note: * represents percentages in the property and construction group.
** represents percentages in the industrial group.
*** represents percentages in the service group.

Figure 3. A final hierarchical model of CN implementation.

"Cost" is the second most important factor, with an importance weight of 27.4%. For example, when undertaking commercial-scale solar roofing projects, it is imperative to consider the materials, equipment, and transportation costs (Pietzcker *et al*., 2014). Materials for solar installations, such as solar panels, solar mounting, wiring, and connectors, make up a significant portion of the project cost. The choice of materials affects the upfront capital expenditure and long-term efficiency (Tongwei, 2024). This results in the "material" sub-factor getting the highest weight of the "cost" factor (i.e., 50.8%). Equipment costs relate to the devices and tools required to install and operate the renewable system. Equipment, such as inverters and monitoring systems, may need replacement or upgrades during the lifetime of the solar installation, which can affect long-term operational costs (Tongwei, 2024).

The results also show that readiness in technology and market is another key to achieving CN (with an importance weight of 15.4%). Hashim, Samsuri, and Idris (2021) stated that having technology without organizational readiness can lead to failure in technology adoption. Lack of system knowledge, strategic management, and technical expertise can hinder the successful implementation of new technologies. Sutabutr (2024) mentioned that research in new technology and innovation, such as digital technology and direct air capture, are crucial to achieving CN in Thailand.

The "risk" and "source of energy" factors are found to be the least important when considering the implementation of CN. The interviewees mentioned that risk is uncontrollable and hard to manage. Thailand is in a topography where sunlight and wind support using renewable energy, i.e., solar cells and wind turbines (Yoomak, Patcharoen, & Ngaopitakkul, 2019).

3.2 Results of the property and construction group

Data from the three companies in the property and construction group (Table 3) are used to calculate the importance weights of factors and sub-factors reflecting this group's perspectives. The results in Figure 3 confirm the importance of the "policy" factor in achieving CN. The industry supports using certified carbon footprint products following the Thai standards (Thailand Greenhouse Gas Management Organization [TGO], 2023). SCG (2023) claimed that 10 of their products are certified with the carbon footprint of the product label and 29 with the carbon footprint reduction label. The CPAC low-carbon concrete is made from processes that involve less GHG emission, reducing carbon by 3.9 kg CO_{2eq}/m^3 compared with the type 1 Portland cement (SCG, 2023).

This group also considers the "cost" factor, specifically materials and transportation costs, crucial in implementing the CN programs. The experts highlight this prioritization as a result of the massive investment in solar farms using the smart grid system, which results in the high demand for solar cells and special transportation.

Most companies within this group already have adequate technological capabilities aligned with government policy, such as elevating construction processes through pre-fabrication technology that significantly reduces waste through offsite processes. Furthermore, companies establish dedicated departments to manage risks and energy sources (SCG, 2023).

3.3 Results of the industrial group

Data from the two companies in the industrial group are used to calculate the importance weights of this group's perspectives. The most critical factor in this industry group is "policy" (with an importance weight of 49.5%), particularly the government policy, Figure 3. According to ONEP (2022), the National Industrial Development Master Plan 2012-2031 was established to achieve sustainable production, focusing on social and environmental considerations. This aligns with the European Union's implementation of the carbon border adjustment mechanism through tax barriers. This mechanism classifies steel as one of the four product groups, and companies that fail to comply may face trade barriers to market entry (Presidential Climate Commission, 2023).

Like the property and construction group, the "material cost" is a significant focus in CN implementation in this group. Many companies invest in green processes and use low-pollution technologies, specifically solar rooftops. Consequently, the "sunlight intensity" is critical for effective solar rooftop systems (Yoomak *et al*., 2019).

3.4 Results of the service group

The AHP results of the two companies in the service group reveal that the "cost" and "policy" are critical factors, Figure 3. In contrast to the property and construction and industrial groups, this group primarily concerns the "equipment" and "transportation" costs in CN implementation. This may be because a significant portion of carbon emissions comes from the energy used in buildings and equipment, such as heating and ventilating systems, lighting, and office appliances. Companies can significantly reduce their carbon footprint by investing in energy-efficient equipment and improving building infrastructure (Apinunwattanakul, 2023). Initial investment in green logistics technologies may be required; however, it will provide long-term cost savings and economic benefits for logistics companies (Khoa & Nhung, 2020).

The service group also focuses on the "readiness," specifically the "market" readiness. The interviewees mention that the Thai carbon market is still insecure, as the carbon prices could fluctuate significantly due to uncertainties in regulations and standards. This is consistent with Kasikorn Research Center (2022) in that the trading volume of carbon credits in Thailand is still low, accounting for 0.1% of total GHG emissions in 2021.

3.5 Case study

In this study, a large-sized steel company located in Rayong province, Thailand, is used as a case study for CN method selection using the AHP results. It is a global enterprise with over 25 years of experience. It has various plans to achieve CN, such as solar cells, wind turbines, and CCS. As part of the company's ongoing commitment to sustainability, it is developing CCS technology and collaborating with organizations to advance this technology. In addition, it has successfully implemented solar cells and is involved with wind turbines to reduce carbon footprint further. However, the company commented that most of Thailand's topography is unsuitable for wind turbines as the wind speed level is low compared to neighboring countries like Vietnam.

The division manager, sales manager, and account manager brainstormed and provided the scores of sub-factors based on each CN method (e.g., solar cell, wind turbine, and CCS) using scores 1-5. The calculation steps are as follows.

- The scores for factors and sub-factors are given. For the solar cell method, for instance, if the company perceives that the "government" policy fully supports solar cell installation and operations, a score of 5 is given. This 5-point score is multiplied by the importance weight of this sub-factor (i.e., 0.509) to achieve the weighted score of the "government" policy of 2.546 in this case study, see Table 4. The scores of the "industrial" and "company" policies are also given and weighted to achieve the weighted scores of the "industrial" and "company" policies for the solar cell method (i.e., 1.05 and 0.843, see Table 4).
- The weighted scores of the three sub-factors under the "policy" factor (i.e., "government," "industrial," and "company" policies) are summed and multiplied by the importance weight of the "policy" factor (i.e., 0.429) to achieve the total weighted score of the "policy" factor of the solar cell method (i.e., 1.905, Table 4).
- The scores of the sub-factors under the "readiness," "cost," "source of energy," and "risk" factors are also given, weighted, and summed to achieve the final scores of all key factors based on the solar cell method.

Table 4. Results of CN method selection using the AHP results

Factor	Factor weight	Sub-factor weight	Score			Weighted score			Total Weighted score		
			Solar cell	Wind turbine	Carbon capture and storage	Solar cell	Wind turbine	Carbon capture and storage	Solar cell	Wind turbine	Carbon capture and storage
Policy	0.429	0.509	5	3	2	2.546	1.527	1.018	1.905	1.047	0.768
		0.210	5	3	1	1.050	0.630	0.210			
		0.281	3	1	2	0.843	0.281	0.562			
Readiness	0.1540	0.512	5	1	3	2.560	0.512	1.536	0.770	0.379	0.462
		0.488	5	4	3	2.440	1.952	1.464			
Cost	0.2740	0.508	5	3	1	2.540	1.524	0.508	1.370	0.695	0.337
		0.261	5	3	1	1.305	0.783	0.261			
		0.231	5	1	2	1.155	0.231	0.462			
Source of energy	0.0640	0.853	3	1	1	2.559	0.853	0.853	0.173	0.073	0.064
		0.147	1	2	1	0.147	0.294	0.147			
Risk	0.0790	0.274	1	1	1	0.274	0.274	0.274	0.308	0.290	0.271
		0.608	5	5	5	3.040	3.040	3.040			
		0.118	5	3	1	0.590	0.354	0.118			
								Final weighted score	4.527	2.485	1.903
								Normalized score	0.508	0.279	0.213

- The total weighted scores of five key factors are summed up to achieve the solar cell method's final weighted score, 4.527.
- The process is repeated with the wind turbine and CCS methods.
- The final weighted scores of the three CN methods (i.e., solar cell, wind turbine, and CCS) are normalized to achieve the normalized scores, and the method with the highest score is considered the most suitable solution for the implementation.

Table 4 indicates that the solar cell method is the most suitable solution for this case study as it receives the highest score among the three methods (i.e., the normalized score of 0.508). This is consistent with the company's current practices of using solar cells as an alternative solution for implementing CN.

4. Conclusions

Implementing CN is necessary to mitigate climate change and global warming. This study utilizes the AHP method to identify and assign weights to five key factors influencing CN implementation in Thailand. The interviews are performed to collect data from seven experts in three industry groups. The results reveal the importance of government-supporting policies to achieve CN in the long term. The government should set clear policy directions by, for example, implementing GHG benchmarking and supporting the use of renewable energy. Cost is also a concern in CN implementation. The government should support materials and equipment used in renewable energy applications. For example, tax incentives and import duty exemption may be initiated to promote the investment of solar panels and material prices. Readiness in advanced technologies and the carbon trading market are also crucial and require support from the government and industries. With limited access to new and advanced CN technologies, collaborations between the government and private sectors are required to reach innovation processes and targets set by regional and global markets (BOI, 2022). To achieve sustainability, R&D is required to develop the technological advances of solar cells, wind turbines, and other equipment installations. The engagement of local communities in lowering carbon emissions is also crucial to building a sustained CN culture.

In the property and construction group, government policies are required to support the material and transportation costs. The use of new technologies, such as digitalization, can advance logistics and optimize cargo transportation (Khoa & Nhung, 2020). For the industrial group, government support such as tax incentives, market access for environmentally friendly products, and the use of renewable energy are required to achieve CN. In contrast, the service group focuses more on the industrial over the government policies to achieve CN. The Thai business sector has gathered with the Thailand Climate Change Network to negotiate a carbon trading agreement and create the carbon credit market (ONEP, 2022). Improving Thailand's carbon credits is essential to expand the demand to foreign markets.

A case study is performed with a large steel company (in the industrial group). The results recommend solar cells as the best implementation solution due to the proper investment cost, suitable topography of the location, and the company's knowledge and readiness of this solution.

The government and industries can use the study's importance weights to plan for CN implementation. Industries may adjust their weights to suit their work practices. Data collection to cover more industry groups is recommended to achieve accurate results.

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