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Are we ready for climate risk? Assessing the bottom-up climate maturity

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ABSTRACT

Nationally Determined Contribution in UN members focuses on the readiness for national mitigation and adaptation. There still remains a need for firm climate data relevant to measuring the climate situation. Many studies have concluded that the successful path of climate risk adaptation and mitigation should work together between top-down (national) climate policy and bottom-up (firm) climate policy. To address this concern, this study empirically assessed climate maturity, measured by the firm's ability to mitigate and adapt to physical and transition risks. Furthermore, the authors analysed the influential factors enhancing climate maturity using the Task Force on Climate-related Financial Disclosures framework with multiple discriminant analysis (MDA). This research gathered empirical data from listed companies in Thailand and conducted in-depth interviews using two case studies. Our quantitative model using clustering displayed the low maturity of the Thai firms relating to climate risk, except for the energy sector. Large companies perform better in terms of climate risk. After analysing stepwise MDA, two significant factors were found to enhance climate mitigation and adaptation: climate strategy and climate metrics. Finally, a climate policy to increase climate maturity will be proposed.

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Climate change risk; climate mitigation; climate adaptation; firm climate risk maturity; sustainability

Introduction

Climate change has become a global issue. Furthermore, adaptation and mitigation of climate-related risks remain significant challenges. After the birth of the rachet mechanism-Paris Agreement—the successful peer pressure top-down approach several nations have announced the path of carbon neutrality and zero carbon (Rogelj et al., 2016, 2018). The United Nations Climate Change Conference (UNFCC) in COP27 reviewed that all UN members agreed on the institutional arrangements, committed to limiting global temperature increase to well below 2 °C, and set up funding for loss and damage (United Nations Development Programme, 2022). As mentioned, UNFCCC enhances the structure of top-down approaches, while the effective management of climate-related risk also requires a bottom-up cooperative.

There is evidence of the positive impact of bottom-up mechanisms on climate risk management. According to Hori et al. (2022: 834) and Kuramochi et al. (2020), the role of non-state actors and firms was significantly correlated with successful climate-related goals. Therefore, it is necessary to determine an incentivised mechanism for adapting and mitigating climate-related risks from the business sector.

Climate risk exposure differs across countries and continents. The most significant impact due to climate disasters from 2000–2019 accounted for in Puerto Rico (David Eckstein & Schäfer, 2021). Thailand's climate risk situation also seems critical (Amnuaylojaroen et al., 2022; Marks, 2011). According to the Climate Risk Index (CRI) score conducted by David Eckstein and Schäfer (2021), Thailand is now the ninth country to be confronted with climate risk measured by fatalities, losses in the millions, loss per unit GDP, and the number of climate disaster events. Therefore, our first research question was, 'are we ready for this catastrophic risk?'

There are several non-profit organizations trying to measure the climate readiness, yet it covers only in national level. To illustrate, the Climate Action Tracker (CAT) (Climate Action Tracker, 2021), an independent scientific analysis produced by two research organisations tracking climate action since 2009, rates countries from target governments and their actions to limit greenhouse gas (GHG) emissions. It categorises a country's readiness level as sufficient, almost sufficient, insufficient, highly insufficient, and critically insufficient. Each maturity level explains the details of the policies and actions, domestic targets, fair share targets,

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and climate finance. At this top-down level, Thailand's overall rating was insufficient. However, we cannot conclude that the weakness of our top-down approach is rooted in the low maturity of the company or the bottom-up view as CAT excludes the readiness of firms' information. Moreover, most of climate data contain only national level. We then need to perceive climate data as well as the readiness in firm level.

To this concern, it still remains a need of bottom-up (firm level) climate readiness data. The studying of climate risk disclosure at firm level is not new. Several types of research displayed motivational factors in managing climate-related risks at firm level (Gustafsson et al., 2022; Hori et al., 2022). Well-known climate risk disclosure framework by the Task Force on Climate Financial Disclosures (TCFD) could be found in the work of (Siew, 2020, 2022) who studied the climate risk disclosure in Malaysia listed companies. However, our team tried to add-up two research points of view from the previous studies. The first objective in this study related to empirically cluster maturity level of firms' adaptation and mitigation of climate-related risks disclosure using the Task Force on Climate Financial Disclosures (TCFD) four recommendations. We not only studied about the alignment between climate disclosure with TCFD, but this study also clustered firm climate maturity with three level: high, medium, low. Apart from that, in order to depart what the previous studies do, this study proposed the second objective relating to the analysis successful factors on effective adaptation and mitigation using multiple discriminant analysis.

As we not only relied on quantitative modelling, but we also validated the quantitative result with case-studies. We selected qualitative case studies from refrigerants and air conditioning manufacturers because the energy sector is a major contributor to climate change (Knutti et al., 2013). Given mixed-method research, policy recommendations will be proposed for policy-makers, company leadership, and households.

The consensus of scientific climate studies has shown a rapid rate of climate change. The temperature increased by ~ 1.1 ^{o}C, the rise of the sea level, and the declining ice glaciers (Knutti et al., 2013) are abnormal. This study aims to contribute to an improved understanding of the current state of climate change. Although industries are starting to cope with climate change accordingly, instruments to measure whether they are doing so accurately are unavailable. Thus, the research outcome suggests determinant factors as a bottom-up reference for firms.

Besides practical contributions, climate change research often cites and presents scientific information on econometric models and social science. However, even though climate knowledge is derived from science, human beings remain the main factors to climate risk. Social science research, therefore, supports the soft-side mechanism in climate studies, which focuses on people's attitudes, motives, and institutional factors. Ultimately, our research team also understands the negative side from people perspective using survey data that depends on bias. Future studying that gathers reliable secondary data would welcome.

Theoretical construction

Thailand climate risk current situations

Climate-related risks exhibit both micro- and macro-level impacts. In the former, climate change exposes individual businesses and households; nonetheless, the aggregate impact of climate change affects capital depreciation, labour productivity, and financial stability. For example, the 2011 Thai flood was a consequence of climate change that negatively affected the global semiconductor (Haraguchi & Lall, 2015). This is an example of operational risk, yet it ends up with the macro effect.

The Asian Development Bank's (ADB) published country climate risk profile indicated the physical risks due to the increased temperature across Thailand since the mid-20th century (Asian Development Bank, 2021: 2). The most physical risk from several sources converges to flood, closely followed by drought and cyclone impacts. Such physical climate risks generate both economic and human impacts. ADB projects that the number of people affected by an extreme river flood could expand by over a million by 2035–2044 (Asian Development Bank, 2021: 2) but the consequences will depend on the policy response.

In addition to physical risks, transition risks in Thailand are a concern. Transition risks account for adjusting the business model to low (Carney, 2017). Transition risks are exposed from the rapid change of policy, the substitution of prior products and services with lower emissions choices, and a shift in customer preference. Physical risk relies on extreme climate events driven by anthropological activities, while transition risk is a function of a country's low emission targets.

Thailand summited its initial Nationally Determined Contribution (NDC) in 2016 and the second updated NDC in 2022. We commit to reducing greenhouse gas emissions by 30% compared with business-as-usual (BAU) levels by 2030. Furthermore, Thailand has proposed vigorous achievement of carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. Thus, the transition risk will not be severe if Thailand's business sectors start to have a low-carbon business model.

Not only does Thailand face high physical risk exposure, but it also faces a severe transition impact. Bank of Thailand hinted that market mechanisms in the Thai economy do not significantly reflect climate-related opportunities and risks; consequently, price and cost schemes do not incentivise several sectors. For example, transit in the low-emission industry implies a high setup cost, yet the future benefit is challenging. Further, the policy agenda across different sectors should be synchronised because climate risk is interconnected among different sectors.

However, there are some positive signs from the Thai regulators. For example, the Securities and Exchange Commission (SEC) and The Stock Exchange of Thailand (SET) enacted a policy to disclose the GHG scope of Thai-listed companies to gather climate data. Such data can serve as early indicators of transition risk.

Climate change risk management framework

The Scopus database shows 47,344 documents for searching the 'climate change risk' keyword. However, from 1987–2023, Scopus documents about climate change risk accounted for 10,629 limited to the social science field. According to Figure 1, the study of climate change risk has been renowned since the launch of the Paris Agreement in 2015.

Publications on climate risk have shown an upward trend, with most of them originating from developed countries. Implementing a climate risk framework in the context of developing and undeveloped countries, both at the country and firm levels, is a starting point.

Nevertheless, the awakening of climate risk differs across the sectors. For example, the energy sector, which majorly contributes to the emissions, expressively embeds climate risk in its corporate strategy. Moreover, in 2017, the Financial Stability Board launched the framework called 'Task Force on Climate-related Financial Disclosures' (Carney, 2017) that provides a climate risk framework for firms to enhance climate-related financial disclosures through their existing reporting processes. Since then, financial institutions have started to implement a climate risk framework, but they are now widely spread across sectors (Task Force on Climate-Related Financial Disclosures TCFD, 2022). The TCFD proposed four core elements of climate-related financial disclosure: governance, strategy, risk management, and metrics (Carney, 2017) While TFCD represents the best practice framework, several research papers have empirically studied the effectiveness of its elements (Braasch & Velte, 2023; Demaria & Rigot, 2021). More importantly, Nisanci (2021) implicated the alignment of TCFD with other standard corporate report carbon disclosure projects, the Climate Disclosure Standards Board, the GRI, the International Integrated Reporting Council, and the work of the Sustainability Accounting Standards Board.

Overall, the TCFD is still new for Thai firms. Only large and well-known firms in Thailand are now implementing it: Kasikorn Bank, Siam Commercial Bank PCL, and PTT PCL. Therefore, here, we were interested in the introduction of this framework and a foundation climate risk-implementing framework.

Policy response

Different nations have their way of handling climate situations. However, how the company or NSA rectifies this lack of information remains to be understood. There are three solutions: climate adaptation, climate mitigation, and geoengineering.

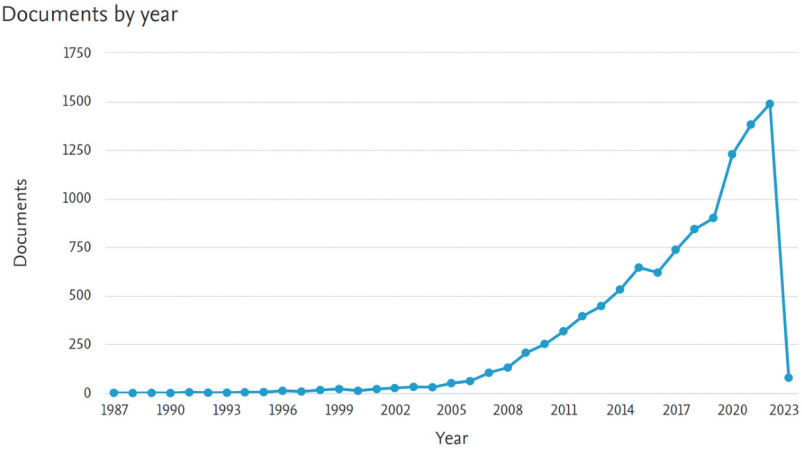

Figure 1. The upward trend of Climate Change Risk Research in scopus.

Climate adaptation strategy refers to the response to climate disasters. As an illustration, if a climate disaster leads to a flood, an adaptive response to this accounts for building of seawalls, or the company will relocate to a new location. Thailand launched the National Adaptation Plan (NAP) in six priority sectors: water resources management, agriculture and food security, tourism, public health, natural resources management, and human settlements and security. At the firm level, an adaptive system in a climate scenario incorporates a business continuity management system (BCMS). BCMS is 'a holistic process that identifies potential threats and the impact to business operations that those threats, if realised, might cause (Baba et al., 2014; Torabi et al., 2014). However, information disclosing BCMS readiness at the firm level remains unavailable. We do not have any secondary data for BCMS; thus, primary data will be included in the survey.

However, adaptive strategies for addressing climate change still need to be improved. Firms that create adaptive models without government involvement will be ineffective because of the large scale of resources and the difficulty of decision-making. Moreover, maladaptation-decreasing climate vulnerability in one place may increase harm in another. To this end, climate risk mitigation by reducing GHG emissions fosters companies to sustain long-term low-carbon business models.

The mitigation strategy involves adopting energy efficiency and renewable technologies such as wind, solar, hydropower, etc. Firms that operate renewable energy businesses are included in this research. According to International Energy Agency (2018) solar and wind are powerful renewable energy sources in Thailand. Notably, the updated NDC indicates that Thailand needs support in terms of consolidated data and research on local areas related to mitigation strategies (Limmeechokchai & Dul, 2023)

Conceptual model

This study integrated a quantitative method to hypothesise the conceptual model shown below and followed up with a qualitative case study:

Methodology

The above-mentioned conceptual model was hypothesised using mixed methodology. This project followed qualitative extensions with a case study of core quantitative research projects. This study's analysis unit accounts for the organisational level of around 700 Thai-listed companies across eight industries.

Descriptive and inferential statistics were used. Simple descriptive likes frequency analyses to study organisational phenomena have been reported. To answer the first research question, the maturity of climate risk adaptation and mitigation uses cluster analysis. Cluster analysis involves sorting *'groups, individuals, or objects into clusters'* (Ho, 2006). This study embedded clusters based on the Z score. Cross-tabulation (crosstab) indicates the relationship among maturity level, firm size, and sectors.

After crosstab analysis, inferential statistics began with an analysis of variance (ANOVA), which was used to identify significant differences among the independent variables. Ultimately, the statistically significant relationships between the independent variables (climate governance, climate strategy, climate risk management, and climate metrics) and dependent variables (climate risk adaptation and mitigation) were fixed by multiple discriminant analysis (MDA). MDA is an extension of discriminant analysis and builds a predictive model for a group membership when the dependent variables are known *a priori* and a category-nonmetric (Härdle & Simar, 2007; Ho, 2006). After conducting maturity with clustering, climate maturity was assessed using the four mentioned predictors. If Y_i=MDA :i = 1−ClusteringN the predictive model in this study is γ_i= the discriminant coefficient or weight for that variable. MDA function accounts for $Y_i = a + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 + \varepsilon_i$ where X_i= predictive variable i, a= intercept. As mentioned in the equation, it assumed the linearity among the variable. Moreover, before determinants were fixed, data assumption was tested the normality and multicollinearity.

In addition to quantitative analysis, the conceptual model was verified using case study qualitative research. Finally, the researchers selected air conditioners that contributed to the major GHG emissions to conduct policy recommendations at the end.

Empirical result

Due to the lack of secondary data on climate risk in Thai business sectors, gathering data from primary sources was adopted to address this research question. The quantitative results of both the descriptive and inferential statistics were explored.

Organizational context

Starting with approximately 215 questionnaires obtained from the respondents, only 200 were used in the analysis (~15 questionnaires were eliminated due to incompletion). Approximately half the 200

Table 1. The descriptive statistics of organizational context

Sector	Frequency	Percent
Service	34	17
Industrial	30	15.0
Financial Institution	21	10.5
Real Estate	20	10.0
Agro & Food	19	9.5
Resources & Energy	16	8.0
Consumer Product	15	7.5
Technology & Innovation	6	3.0
Others	39	19.5
Total	200	100.0
Size given staff #	**Frequency**	**Percent**
0–500	105	52.5
501–1,000	33	16.5
1,001–1,500	13	6.5
1,501–2,000	10	5
>2,000	39	19.5
Total	200	100.0
Respondent Positions	**Frequency**	**Percent**
Manager	98	49
Staff Level	96	48
Management & Board	6	3
Total	200	100.0

respondents were managers; therefore, they have enough seniority to handle the information in the questionnaire.

We set the business sector types in the questionnaire using the formal sector code from the SEC. Most respondents selected 'others' as they do not precisely know what formal sectors they do in. Most respondents were from the service sector, accounting for 17%, closely followed by the industry (30/200). However, the sample gathered from equally distributed firms is indicated in Table 1. The firm size was divided by the number of staff members. Approximately half of the respondents worked in small companies and were closely followed by large companies (staff of more than 2000).

Table 2. ANOVA of 3 cluster to show the significant climate adaptation and mitigation across maturity level

Zscore	F statistics	Significant
Zscore (Adaptation)	349.1	0.0
Zscore (Mitigation)	743.75	0.0

Table 3. The result of overall maturity level from clustering

Maturity Level	Definition	Number of Firm
High	Both adaptation and mitigation of Climate risk are well implemented.	33
Medium	Firms have just started to realize is climate risk.	53
Low	Firms have not started yet to realize in climate risk	114
Total		200

Analysis of maturity climate risk management

Climate risk management is measured by the ability of firms to adapt and mitigate climate physical and transition risks. Cluster analysis was conducted using the K-means method with Zscore. According to Table 2, the clustering maturity level with climate adaptation and mitigation was significant. Thus, the clustering of climate maturity under the K-Means is appropriate.

Under K-means, there are three clusters. In approximately 114 out of 200 firms (57%), climate risk management maturity is low (not yet realising climate risks), while in only approximately 17% (33/200), both climate risk adaptation and mitigation are well implemented. That is, business sectors in Thai industries still need to implement a climate risk framework in their circumstances (Table 3).

Determinants analysis with multiple discriminants analysis (MDA)

MDA applies to normality and fewer multicollinearity effects of the data. In addition, this study assumed linearity between the dependent and independent variables. Figure 2 shows the extent of the linearity across the three clusters (Table 5).

The VIF value was relatively high but within the acceptable range (VIF <10). Notably, the empirical data displayed symmetry such that the skewness and kurtosis values in Table 6 and 7 are in the range of −2 to 2 (Ho, 2006). Upon violation of data assumption, a simpler ANOVA among variables using three factors —business sectors, company size, and respondent positions—is fixed. The results indicate that the determinants and maturity of climate risk are significantly distinctive across business sectors and company size.

Table 4. Maturity Level Across Company Size

	Company Size (Staff Number)					
Maturity Level	0–500	501–1,000	1,001–1,500	1,501–2,000	>2,000	Total
High	11	4	2	2	14	33
Medium	18	6	6	7	16	53
Low	76	23	5	1	9	114
Total	105	33	13	10	39	

Table 5. Maturity level across sectors

Sectors	High Maturity	Medium Maturity	Low Maturity
Agro & Food	3	10	6
Consumer Product	2	6	7
Industry	6	10	14
Financial Institution	2	3	16
Real Estate	2	5	13
Service	1	7	26
Resources & Energy	11	3	2
Technology & Innovation	1	3	2
Others*	5	6	28
Total	33	53	114

As shown in Table 4, a large company has higher climate maturity than does a small company. Conversely, most of the small-sized companies (76/105), where the number of staff is less than 500, perceive a low climate maturity. In addition, the energy sector, which directly relates to most GHG emissions, has the highest maturity. Conversely, nearly all the service sectors are low in maturity.

Table 6. Testing normality and multicollinearity

Variables	VIF	Skewness and Kurtosis
Climate Governance	4.4	(0.62, −0.87)
Climate Strategy	7.2	(0.61,-0.73)
Climate Risk Management	8.1	(0.73, −0.65)
Climate Metric	4.8	(0.81, −0.69)
Maturity of Climate Risk	Not Test for Dependent Variable	(0.63,-1.4)

Table 7. ANOVA of determinants and maturity of climate risk

Variables	Sectors (Sig)	Company Size (Sig)
Climate Governance	0.001	0.026
Climate Strategy	0.001	0.043
Climate Risk Management	0.005	0.005
Climate Metric	0.000	0.002
Maturity of Climate Risk	0.000	0.000

Thus, the business sector and size are important regarding climate governance, climate strategy, climate risk management, climate metrics, and climate risk maturity.

81.0 % of original grouped cases correctly classified

As the non-metric dependent variable was classified into three levels (low, medium, and high), there were two discriminant functions in the model. In Table 8, the first MDA function is selected because the p-value of Wilks' Lambda is perceived as less than 0.05 and has a higher canonical correlation. The predictive power of four determinants accounted for 70% (0.839^2). For the model of fit, 81% of the grouped cases were correctly classified (Table 10) using three maturity predictive models, as the following:

Table 8. Overall model fit

MDA Function	Wilks' Lambda (Sig)	Canonical Correlation
1	0.000	0.839
2	0.561	0.102

Low Maturity of Climate Risk: $Y_1 = -15.189 + 0.453X_1 + 1.545X_2 + 0.450X_3 + 2.416X_4$

Medium Maturity of Climate Risk : $Y_2 = -29.218 + 0.597X_1 + 2.055X_2 + 1.002X_3 + 3.324X_4$

High Maturity of Climate Risk: $Y_3 = -6.281 + 0.423X_1 + 1.346X_2 + 0.074X_3 + 1.134X_4$

The proposed conceptual model in Figure 3 was answered by the discriminant analysis. All independent variables were statistically significant (Table 9 and 11). However, the power of the explanation under the standardised canonical discriminant function coefficients varied, displaying higher predictive power from climate metrics and climate strategy.

Using the Mahalanobis distance, the researcher refined the model with a stepwise MDA. The variables included in the model were the climate metrics and climate strategy. In conclusion, climate metrics and strategies significantly enhance climate risk maturity in Thai-listed companies.

This research validated the quantitative result with case studies of two companies: XYZ, which manufactures refrigerants, and ABC, which manufactures air conditioning. Data for these case studies were gathered through in-depth interviews with senior executives and a review of industry trends. Our research team prepared semi-structure questions from the TCFD guidelines as the following.

(I) The readiness of the organization relating to climate risk committee
(II) The supportive role of leader in the aspects of climate risk
(III) Corporate strategy relating to the inclusion of climate risk roadmap
(IV) The integration between enterprise risk and climate risk
(V) Climate risk metric

The data were evaluated to assess the implications of climate strategy and climate metrics on companies' adaptation and mitigation strategies, including their plans to decrease greenhouse gas emissions, respond to the effects of climate change, and limit exposure to climate risks.

XYZ company

The manufacturing of refrigerants significantly impacts the environment, particularly in terms of climate change. Hydrofluorocarbons (HFCs), which are common refrigerants, are potent greenhouse

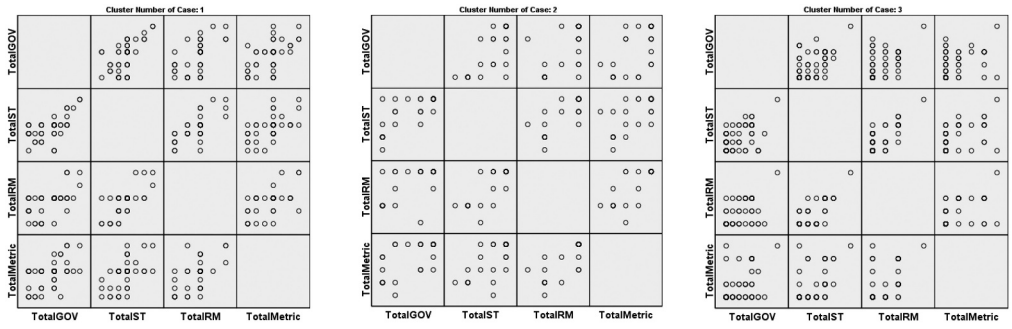

Figure 2. Linearity testing.

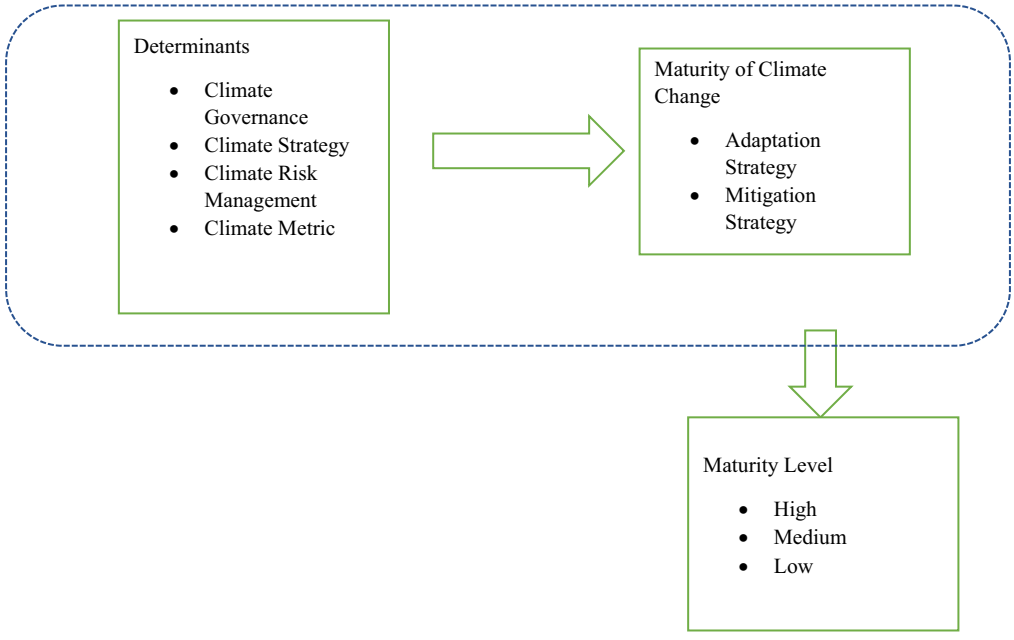

Figure 3. Proposed conceptual framework.

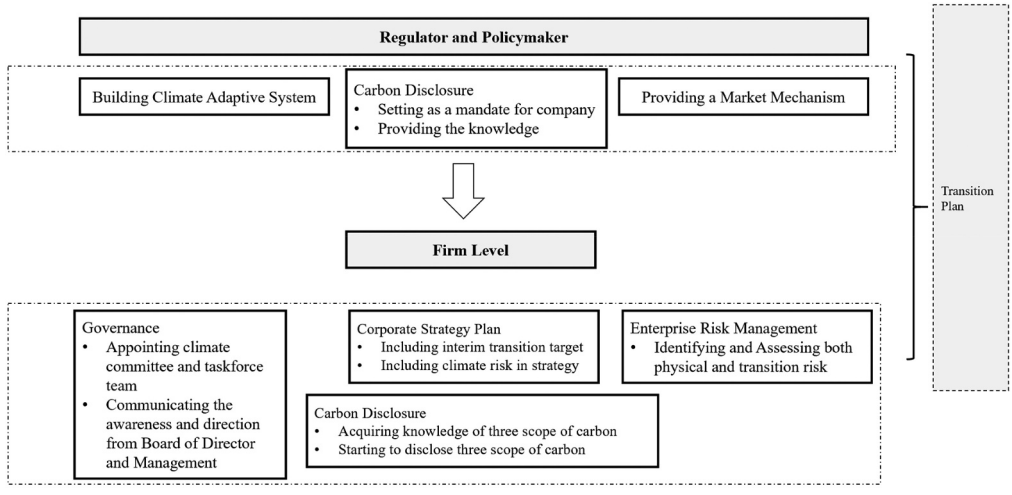

Figure 4. Proposed policy recommendation Model.

Table 9. Determinants size effect

Factor	Tests of Equality of Group Means (Sig)	Standardized Canonical Discriminant Function Coefficients
Climate Governance	0.000	0.070
Climate Strategy	0.000	0.205
Climate Risk Management	0.000	0.191
Climate Metric	0.000	0.663

Table 10. Classification results

		Predicted Group Members			
	Maturity	Low	Medium	High	Total
Case	Low	35	5	13	53
	Medium	9	24	0	33
	High	10	1	103	114
Percent	Low	66.0	9.4	24.5	100
	Medium	27.3	72.7	0	100
	High	8.8	0.9	90.3	100

Table 11. Refined model with MDA Stepwise

Variable in the Analysis	Variable not in the Analysis
Climate Metric	Climate Governance
Climate Strategy	Climate Risk Management

Case Studies.

gases contributing to global warming. Other greenhouse gases and air pollutants may be released while synthesising these refrigerants, which consume significant energy. As a large contributor to global greenhouse gas (GHG) emissions, the refrigerant industry is under increased pressure to address climate change problems. TCFD offers a framework for reporting climate-related risks and opportunities to assist businesses in managing these difficulties. In this study, we concentrated on XYZ Refrigerant Company to examine how the TCFD guidelines were implemented.

Through an in-depth interview with the company's executive, we determined that the company was aware of climate change and the efforts to decrease these effects; however, the governance structure needed to be clarified. The company has developed a thorough climate strategy to reduce greenhouse gas (GHG) emissions and enhance energy efficiency. Moreover, the company has implemented programs to promote sustainability throughout its operations and supply chain and established goals to reduce its carbon footprint. Climate metrics have measured GHG emissions and energy use and set goals to reduce its carbon footprint. Understanding the three scopes of carbon is also an organizational challenge. Ultimately, the company implemented a sustainability management system to monitor its progress and identify improvement areas.

This case study emphasises the importance of climate strategy and climate metrics for refrigerant firms implementing TCFD. These tools can inform and guide a company's adaptation and mitigation initiatives, resulting in greater alignment with the Paris Agreement. As a result, its adoption is increasingly vital to a company's long-term sustainability strategy.

ABC company

Climate change presents various problems for the air-conditioning industry, including reducing greenhouse gas emissions, enhancing energy efficiency, and limiting vulnerability to climate risks. ABC has committed to lowering greenhouse gas emissions, providing complete climate-related information consistent with the Paris Agreement, and exhibiting industry leadership.

This case study highlights the significance of climate strategy and climate metrics in TCFD implementation for air conditioning companies. These tools can assist in educating and directing a company's adaptation and mitigation initiatives, increasing alignment with the Paris Agreement, and enhancing stakeholder and investor decision-making. In addition, the company has developed a climate change policy and governance framework to address climate risks and opportunities; however, conveying communication to all staff can be challenging. The company created a comprehensive climate strategy that involves lowering GHG emissions, improving energy efficiency, and investing in renewable energy. The business has also established goals for reducing its carbon footprint and has implemented initiatives to encourage sustainability throughout its supply chain and operations that confirm the establishment of climate matrices. The corporation measures its GHG emissions and energy usage using climate metrics and has set goals to lower its carbon footprint.

Finally, the company demonstrates its commitment to tackling the issues posed by climate change by including climate indicators and initiatives in its operations and management processes. The company's activities are consistent with TCFD principles and contribute to enhanced transparency and comparability in climate-related disclosures. In addition, a company's experience can be a model for other businesses interested in incorporating climate metrics and strategies into their operations and management processes.

Conclusions and policy recommendations

This research bridges the gap between the readiness of top-down and bottom-up strategies to deal with climate risk using Thailand as an empirical study. Several reliable sources grade the critical level in Thailand's top-down climate policy readiness. However, we also find that Thailand's business sectors are not ready to mitigate and adapt to climate change risks.

The research results gathered climate information on 200 firms relating to their physical and transition risks, determinants under the TCFD framework, climate risk adaptation, and climate risk mitigation. We can conclude that the business sector and size both matter. That is, the resources and energy sector, composed of the energy utility and mining firms, perceive the highest climate risk adaptation and mitigation maturity. In contrast, the service sector has the lowest maturity. The energy sector, which posits as the most significant emission contributor early, has started implementing climate risk strategies. Moreover, top-down policy in the Thai context also supports the energy sector, confirming the importance of institutional arrangements (Hori et al., 2022). The results show that large firms perform significantly better in climate risk management.

We constructed predictive variables using the TCFD framework, the most well-known global climate disclosure method. Based on the TCFD status report (TCFD, 2022), the average number of recommended disclosures per company by fiscal year has increased over the past 5 years, with an annual growth rate of 32 %. According to the MDA, all TCFD recommendations (climate governance, climate strategy, climate risk management, and climate metrics) are significantly associated with climate risk maturity. However, the relationships between these predictive variables and climate risk maturity differ. The climate matric is the most influential factor in inclined climate risk maturity in Thai-listed companies. After modelling the MDA stepwise, the model had only two predictive variables: climate strategy and climate matrix.

Theoretically, all TCFD recommendations should, to some extent, incline toward climate risk maturity, but our empirical study displayed only two variables: climate strategy and climate matrix. This result implies that firms still need to implement a TCFD framework. Hence, these are new recommendations for climate risk disclosure.

In particular, the authors validated quantitative research with two company case studies: XYZ, which manufactures refrigerants, and ABC, which manufactures air conditioning. These two companies exhibited two reconciliation findings. First, they started to implement climate risk based on sustainability policies. Moreover, they adopted their policy and conducted a strategic roadmap and GHG reduction target. Second, their regulators forced them to disclose their carbon footprint. Therefore, both the quantitative results and the two case studies converge.

The findings clearly showed the low maturity of climate risk in Thai industries, despite some positive signs of awareness. Therefore, the ultimate goal in this paper is to propose a climate policy to enhance the adaptation and mitigation of climate change risks from these below two points of view.

Recommendations for relating stakeholders

For policymaker and regulator

Firms' direction without national policy support is ineffective, especially for the adaptive response. For example, firms building seawalls covering the entire community require consensus and resources from the government. Thus, first of all, government and policy maker should support nation in building the resistant climate adaptive system. Moreover, climate metrics are significantly associated with climate maturity due to the explicit policy of Thailand regulators in reporting carbon footprints. But the result displayed the significant difference of the ability to report climate matrices across business sectors and size. Currently, the regulator in Thailand is not enacting carbon disclosure in a mandate. In order to achieve carbon net-zero, they should equally cover knowledge and provide the support system relating three scope of carbon disclosure across industry. Furthermore, not matter what sector and size are, reporting carbon should set as a mandate.

Even our scope of work did not include the market mechanism variable, the data from two companies in case-study indicated that the market mechanism does not provide adequate incentives

throughout all sectors. Then, regulator and policy-maker should put market mechanism priority.

For leader and manager in firm level

At the firm level, the effectiveness of climate action should start with the precise role of climate governance. Incidentally, research has found a low correlation between climate maturity and climate governance, even though it is a mandate. Carney (2017)indicated that to implement climate governance, firms should establish a clear role in the board's oversight and management of climate-related risks and opportunities. However, the empirical results and the case study show the association between climate strategy and maturity, which is more effective if the board of directors and management convey information about climate risk to all levels of staff. Ultimately, C-suit should embed climate risk into corporate strategy if they need the effective of climate risk management.

Additionally, based on an empirical study, most of the listed companies have already implemented the enterprise risk management (ERM) program. However, a low correlation between climate risk management and maturity was observed in this study. This implies that the listed companies must still include climate risk in their risk management programs. As mentioned, there are two types of climate risks: physical and transition. Therefore, firms should not isolate such climate risks in the ERM program. Currently, financial institutions are affected by physical and transition risks, translating to traditional risk categories: operational, credit, liquidity, underwriting, and market risks toward micro- and macroeconomics (Campiglio et al., 2018; Lawrence et al., 2020). Thus, firms should not mitigate climate risk separately in an ERM program.

Recommendations for transition plan

Decarbonization and transition pathway are the hot-spots topic relating to climate risk (Bataille, 2020; Vatalis et al., 2022). This research also insisted that national transition plan would not be achieved if we lack of the reporting of climate matric or carbon disclosure process in firm level. Based on our research outcomes, we suggested that firm should embed transition plan in corporate strategy. Apart from reporting three scope of carbon, setting a sound transition plan should clear interim target in order to determine the reliable carbon neutrality in firm level (Task Force on Climate-related Financial Disclosures, 2021).

From the above two points of recommendation, we propose the model moving forward relating to enhance climate risk adaptation and mitigation as below (Figure 4).

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Public interest statement

Thailand is proposing plan to become carbon neutral and the net-zero emission target by 2050 and 2065 respectively. This goal will be realistic if firms are ready to cope with the climate risk. This study then empirical assessed the readiness of Thailand listed companies relating to climate adaptation and mitigation. The result showed that most of the companies aware of climate crisis but they are not ready yet to achieve carbon neutral and net-zero target. The ability to cope with climate crisis depends on size, sector. Our work suggested that company should start from understanding how to report the three scope of carbon accurately.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request.

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