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Exploring the Factors Associated with Climate-Related Issues in a Special Economic Development Zone: Application of a DPSIR Framework

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ABSTRACT

The rapid global increase in Special Economic Zones (SEZs) raises concerns regarding potential impacts on the environment, especially water use intensity, an increased risk of natural disasters, and an elevated greenhouse gas (GHG) emissions. However, studies examining these impacts are limited. Therefore, the aim of this paper is to examine the influence of SEZ development factors on flooding, water scarcity, and GHG emissions using Tak SEZ in Thailand as a case study. A Driver-Pressure-State-Impact-Response (DPSIR) framework, together with structural equation modeling (SEM) through the partial least squares (PLS) approach, has been used to examine the interrelationships between these factors. The results revealed that economic, industrial, and urban development are key drivers associated with flooding, water scarcity, and GHG emissions in the zone. The increased population density, water consumption, waste generation, and vehicular traffic are all significantly put pressure on climate change impacts. The integration of DPSIR framework together with PLS-SEM technique to explore the relationship among multiple sustainability indicators contributes to the existing sustainability assessment methodology. Future research can utilize the presented indicators to identify potential factors for the evaluation of other types of development zones that have a variety of socio-economic activities.

1. INTRODUCTION

Special Economic Zones (SEZs) are one of the political tools used to drive national economies. The main characteristics of SEZs include a specified boundary, management by an individual administrative organization, beneficial provisions for investors, and a separated customs area [1]. The general objectives of establishing SEZs are to 1) attract foreign direct investment, 2) serve as 'pressure valves' to alleviate large scale unemployment, 3) act as experimental laboratories for the application of new policies and approaches, and 4) support a wider economic reform strategy [2].

The establishment of SEZs has emerged rapidly over the past two decades [3], and this swift increase can have significant impacts on the livelihoods of local communities and the natural environment. While rapid urbanization promises to deliver economic benefits, it is also likely to exacerbate existing vulnerabilities and environmental pressures. Environmental and resource constraints pose challenges for many SEZs [4], and sustainability issues resulting from socio-economic activities in SEZ development are made more complex because of the impacts of climate change. Climate-related hazards can affect the large and local scale economies, as well as household income, health, and general well-being. For example, due to the great floods that occurred in Thailand in 2011, the national GDP in quarter 4 of that year decreased from 2.6 to 1.0 percent, and almost half of all businesses experienced severe to very severe impacts [5]. Such climatic events can therefore influence the future of economic areas, such as SEZs.

The sustainability of the SEZ implies more than an aggregation of the key developmental issues. Importantly, it refers to their interlinkages and the dynamics within a system [6]. Understanding the interactions between urbanization, regionalization, and climate change is necessary for the development of policies related to SEZs, which often have incomplete environmental impact assessments, no urban planning, and little consideration of climate risks.

The potential negative sustainability impacts of SEZs can be minimized by prior sustainability assessments (SAs). However, existing assessments tend to concentrate on only a single aspect of sustainability, such as the availability of natural resources, economic profitability, or environmental impacts [7]. Many studies have singularly focused on groundwater resource exploitation, industrial SO_2 emissions, or national and regional CO_2 [8-10]. Specific methods have been adopted to examine their determinants. For example, the LMDI model is widely used to identify influential factors of CO_2 emissions within the limited scope of the factors (e.g. GDP per capita, population, energy consumption intensity, etc.) which is not comprehensive enough [11-13]. Exploring influential factors of water resources and flooding issues is usually undertaken using qualitative methods [14, 15], which does not allow measuring the exact level of influence. These methods are not ideal within the context of SEZs, which are at the center of many economic development activities. Driven by the business and private sectors, little consideration has been paid to climate risks. In order to identify and assess the impact of SEZ development policies on the sustainability of the area, the inter-relationships between the various factors behind SEZ development need to be deeply understood. Therefore, ex-ante assessments should be more strategic, comprehensive, and integrative [16], hence, a more holistic trans-disciplinary approach is needed [17].

Therefore, this study aims at filling the methodological gap resulting from fragmented and reductionistic SAs by establishing a connection between socio-economic development and social and environmental impacts in the context of SEZ development. To this end, a Driver-Pressure-State-Impact-Response (DPSIR) framework was adopted to understand the dynamic effects of socio-economic development on the key sustainability issues associated with SEZ development.

The DPSIR approach has been widely used to both qualitatively and quantitatively explore the relationships among factors in complex systems, including social, political and environmental systems [18]. According to Hazarika and Nitivattananon [8], drivers represent the major social and economic developments that affect people's lives and the environment, while pressure is the stress that can result from driving forces. State refers to a status that can be changed by pressure, and impact is the effect from the development that can provide either positive or negative results. Finally, responses involve actions from relevant sectors that are needed to avoid, reduce/mitigate, or enhance either the drivers, pressures, states, or impacts. Figure 1 illustrates the relationships among DPSIR components in the framework.

The DPSIR framework is normally used as a tool during development to achieve sustainability in sectoral development, large-scale area planning, and even specific issues [19]. While DPSIR analyses aim to achieve sustainable development, most studies have applied this framework in a retrospective fashion to evaluate sustainability [20]. Rarely has this approach been used as a prospective SA tool for policy, plan, and program (PPP).

Thus, the objective of this paper is to assess the relationships between socio-economic development, society, natural resources and the environment in the development of SEZs, by applying the DPSIR concept to the Tak SEZ in Thailand as a case study. The main expected outcomes are 1) an improved understanding of the relationship between SEZ development and sustainability issues, and 2) the attainment of detailed information on the socio-economic and environmental impacts in relation to SEZ development, namely in terms of climate-related security risks, water resources and atmospheric emissions. Interrelationships between such influential factors as water and climate-related issues are likely to emerge from SEZ development, thus, highlighting the need for a holistic approach during the strategic development of SEZ policy.

The Tak SEZ, the first border economic zone in Thailand, was first established in 2004 [21] and was formally launched at the end of 2015 [22]. The zone is located in the western part of Thailand and shares a border with Myanmar (Figure 2). Defining the area boundaries for the current study proved somewhat challenging as the Tak SEZ covers parts of three districts in the Tak province, including Mae Ramat, Mae Sot, and Phop Phra. As this study relies on series data from historical time, the study area boundary was based on administrative districts. Significantly, more than 50% of the SEZ total area falls into the Mae Sot administrative jurisdiction (Figure 2) wherein land use in this region is targeted as the center of development activities. Therefore, the data set used in the current study was collected only from the Mae Sot administrative district and serves as a proxy for the whole Tak SEZ.

The Tak SEZ has issues vis-a-vis several climate-related hazards. The area frequently experiences water shortages, especially in the summer season, and droughts can occur. The area also often has floods during the rainy season and ineffective flood prevention measures directly affect community security. A report from the ONEP [23] shows that the Tha Sai Luad sub-district, a location for various industries and warehouses, is located in a low lying area and communities in this region are at a high risk for both flash flooding and drought. The report also emphasizes that the frequency and effects of these disasters tend to increase over time. Thus, this area is vulnerable to climate change.

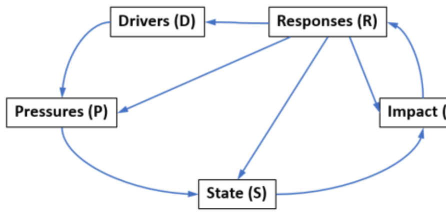

Figure 1. The DPSIR causal framework (Source: Modified from [9])

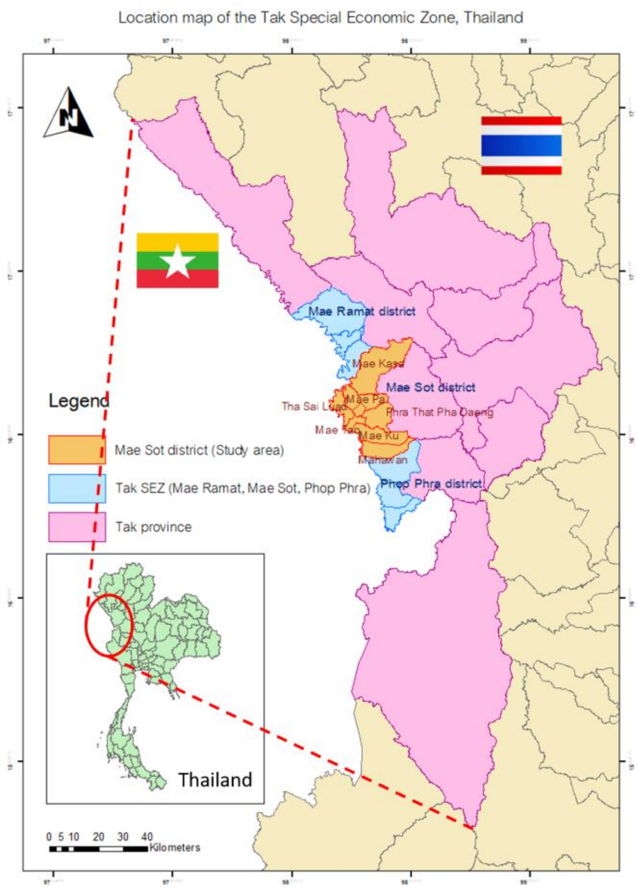

Figure 2. Map of the Tak province (Source: Created by ArcMap 10.7, data from [24])

2. METHODOLOGY

2.1 Conceptual framework

As outlined above, many studies have employed specific models to explore the potential impacts of single specific environmental issues [9, 10, 25]. Here, we have adopted a holistic DPSIR framework to explore the interrelationships between various factors associated with climate-related issues and SEZ development factors. The DPSIR model was established to analyze five factors: 1) driving factors from economic and social development, 2) pressures on local society, natural resources and the environment, 3) the state factors of society, natural resources and the environment, 4) the impacts on society, natural resources and the environment, and 5) responses to improve sustainable development. A flow chart outlining this model is shown in Figure 3.

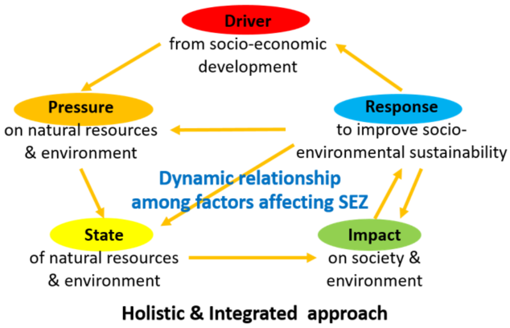

Figure 3. The DPSIR conceptual framework (Source: Modified from [19, 26])

To summarize the model, SEZs can be viewed as systems where there are pressures from the socio-economic drivers of change that may ultimately require a response to promote sustainability (Figure 3). For example, economic, infrastructural, industrial, and urban development are all driving factors that can increase pressure on natural resources and the environment. These pressures, in turn, can result in various impacts on society and the environment. In the case of these changes, both public and private authorities may need to respond to improve socio-environmental sustainability by dealing with the influential driving factors. Of course, in this holistic model, all of these factors may influence each other within the SEZ system.

2.2 Analytical procedure

The DPSIR candidate indicators were developed based on a review of previous DPSIR studies, analyzing water issues and climate-related hazards. The set of candidate indicators were then finalized by experts from several relevant agencies. The main influential factors selected by the panel were subsequently used to construct the DPSIR model to explore the relationships among the indicators in the SEZ system. The specific details of each step are outlined below.

2.2.1 Selection of DPSIR candidate indicators

The observable candidate indicators were obtained using secondary data from a literature review and primary data from stakeholder discussion.

First, the literature review was conducted using social science databases and the candidate indicators were selected from journal articles, project reports, and case studies. The articles using a DPSIR framework to evaluate issues surrounding water resources, water-related hazards, and greenhouse gas (GHG) emissions, were chosen based on their relevancy to the SA and the challenges associated with SEZ development. The similar indicators were grouped together to make it is easier when consulting with the stakeholders.

Then, round table meetings with public/ private agencies and group discussions with local communities were used in order to develop an understanding of the relevant DPSIR factors associated with the Tak SEZ. The interview guide questions used during these meetings were designed to be as comprehensive as possible. Each candidate indicator was analyzed based on probable maximum data availability and applicability to the local setting. A causal effect diagram was used as a supporting tool in building the relationships among DPSIR components. Some of the indicators pre-selected from the literature were needed to be recategorized into five factor categories of the DPSIR model. The common indicators in the same component (D-P-S-I-R) were chosen for expert validation.

2.2.2 Confirmation of DPSIR indicators

DPSIR indicators can vary by location, scale, and other factors [27]. In order to reduce the large number of indicators gathered from literature review and stakeholder consultations, candidate indicators were reviewed by several experts.

Experts in areas relevant to the study were invited to complete a questionnaire, rate the suitability of the candidate indicators as well as the relevancy to the context of SEZ. These individuals had expertise in fields such as hydrology, water resources, disaster prevention and mitigation, air/water pollution, policy and planning, urban environmental management, and socio-economic impact assessments. Most of the experts worked for the central government or academic institutions. Previous studies have revealed that, when an expert judgment is used, the error can be very small; particularly, when the number of specialists is between 13 and 25 [28]. In total, the questionnaires were electronically distributed to 30 experts.

A Likert scale was used by the experts to rate the suitability of each candidate indicator. The scale included five levels: 1) Not suitable, 2) Quite unsuitable, 3) Not sure, 4) Quite suitable, and 5) Most suitable. The indicators on the questionnaire were tested for reliability and internal consistency using Cronbach's alpha.

SPSS software was used to calculate the median from the ratings for each candidate indicator. The formula for the median is shown in Eq. (1).

$$Med = Lo + I\frac{(F_n - F_1)}{(F_1 - F_2)} \qquad (1)$$

where:

N = Number of data points

$F_n = N/2$

$F_1 = F$ next to F_n with a value less than F_n,

$F_2 = F$ next to F_n with value more than F_n,

Lo = Actual lower limit of F_2,

I = Interval of the actual lower limit of level of F_2.

The median values were interpreted as 1) 1.00 - 1.49 = Not suitable, 2) 1.50 - 2.49 = Quite unsuitable, 3) 2.50 - 3.49 = Neutral, 4) 3.50 - 4.49 = Quite suitable, and 5) 4.50 - 5.00 = Most suitable. Only the indicators identified as the most suitable were chosen for further analysis.

2.2.3 Exploration of the main driving factors

The driving factors selected for a DPSIR analysis should have high degree of correlation with the dependent variables to provide the most accurate assessment. Thus, a correlational analysis was performed in order to examine the relationships between the identified independent variables and each dependent variable. The variables with non-significant correlations (p-value > 0.01, which corresponds to a 99% confidence) were excluded from further analysis to prevent multicollinearity [29].

When the correlation coefficient approaches 1.0, the results of the analysis are likely to be more accurate. If we require the correlation coefficient to be between 0.8 - 0.9, a minimum of sample size should be between 8 and 11 observations for each variable to achieve reliable results (for one correlation test with power = 90%, alpha = 0.05) [30]. Due to the Tak SEZ, launched recently in 2015 (less than the required 8 years of observations); the correlations in this study were modeled for 11 years, from 2008 to 2018, the latest year which data is available for. The indicator values were obtained from the relevant government agencies responsible for each indicator. The main source of data was the National Statistical Office (NSO).

2.2.4 Construction of the DPSIR model for the Tak SEZ

After the set of factors was selected, the DPSIR indicators were used to construct a structural equation model (SEM). In case, a variable could be measured directly, or measured through an indicator, and converted to a total or Z-score or Mean or Factor score, Path analysis (PA) or Path modeling (PM) can be applied. On the other hand, if the variable is a concept, like the DPSIR conceptual framework, which cannot be measured directly (known as a latent variable), it must be measured through indicators (e.g., index, dummy, manifest variables) and presented in the form of the SEM to show the measurement model [31].

Due to the limitations of the recorded historical data, a partial least squares (PLS) regression model was used to explore the path relationships between the identified climate-related issues and their influential factors. SmartPLS® software was used to carry out this analysis. The PLS technique can be used with small samples, non-normally distributed data, and formative measures, and focuses on prediction, model complexity, and exploratory research [32]. The impact indicators were defined as dependent variables (Y), while the driver indicators were used as independent variables (X). In order to identify the factors affecting key issues, a general regression model was constructed as shown in Eq. (2).

$$Y_i = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_n X_{n,i} + u_i \qquad (2)$$

where:

β_0, β_1, …, and β_n = Estimated parameters,

$X_{k,i}$ = i^{th} observation of X_k,

u_i = The random error term of observation i.

3. RESULTS

3.1 DPSIR framework to valuate key climate-related issues associated with SEZ development

A total of 167 candidate factors were selected from the literature based on relevancy and probable availability of long-term historical data. The candidate indicators were then grouped and categorized into 76 observable variables under 29 latent variables, according to the DPSIR categories (Figure 4).

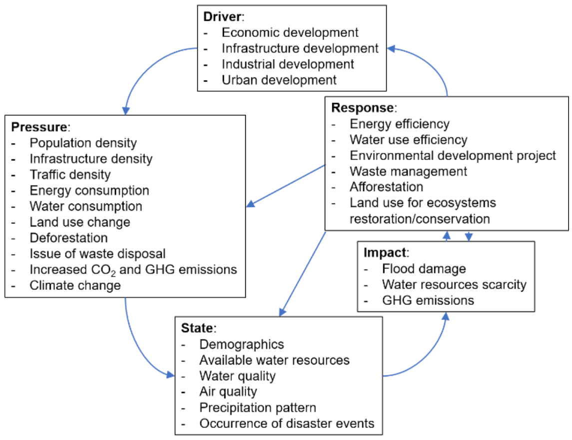

Figure 4. The DPSIR framework used in this study (Source: Literature review and stakeholder group discussions)

Stakeholders mentioned that water shortages were one of their key sustainability concerns. Water demand in the Tak SEZ will likely continue to increase due to the expansion of domestic and industrial water use, while the supply remains uncertain. Changes in water availability are also influenced by climate change. Increasing the use of ground water and water recycling by industry may help to reduce the risk of water scarcity but the impacts of these changes may not be significant.

Natural disasters constitute another security concern for local people as climate change is linked closely to sustainability in the zone. Industry, transport and energy sectors are major emitters of GHGs, including CO_2 and CH_4; emission trends are perpetually increasing. While exact figures on emissions from the industrial sector in the Tak SEZ are not available, based on air pollution monitoring stations in the province, it is clear that pollution from industrial activities and transportation is a persistent problem. As far as impact is concerned, changing rainfall and temperature patterns are resulting in more frequent and intense flooding beside longer and hotter drought periods. Local communities raised the point that the area still lacks a comprehensive disaster preparation and mitigation plan. These observations indicate that communities in the SEZ are highly vulnerable to climate change impacts.

3.2 DPSIR indicator set

As outlined above, the 76 candidate variables were evaluated for their suitability by identified experts. Amongst the thirty questionnaires that were distributed, only 14 completed forms were returned. Analysis of the responses indicated that 53 of the variables were identified as the most suitable indicators (Median values = 4.50-5.00). The selected indicators and their descriptive statistics are shown in the Appendix. However, only 38 of them have sufficient data for further statistical analysis (Table 1).

3.3 Main influential factors associated with the key climate-related issues

The selected indicators were analyzed to identify the main influential factors. First, a correlational analysis was performed to ensure significant correlations between the independent variables and each dependent variable (i.e. impacts). The factors that are significantly associated with floods, water scarcity and GHG emissions are shown in Table 2.

As can be seen from Table 2, most indicators of economic, industrial, and urban development are positively associated with all three climate-related issues.

In particular, the analysis suggests that urban development, as indexed by the urbanization rate, is a key driver for community vulnerability to flooding ($r = 0.835$, $p = 0.001$). Among the pressure and stress indicators, population density ($r = 0.851$, $p = 0.001$), and the percentage of urban population ($r = 0.847$, $p = 0.001$) are also strongly associated with flooding. Clearly, greater urbanization increases the chances of a community confronting natural disasters. Other indicators of economic, industrial, and urban development are also associated with flooding (See Table 2), although to a lesser degree.

Table 1. The DPSIR factors associated with impacts on local society, natural resources and environment, focusing on climate-related issues

Latent variables	References	ID	Observable variables	References
Drivers				
Economic development	[15, 33, 34]	DE1	Average income per capita (baht/person/year)	Stakeholder consultation
		DE3	Border trade value (Mbaht)	Stakeholder consultation
		DE4	Value of investment within SEZ (Mbaht)	[2, 35]
Infrastructure development	Public participation	DI1	Investment in Industry, Infrastructure, Real estate, Public utilities (Bbaht)	[35], [36]
Industrial development	[27, 33]	DN2	Number of factories registered in the area (factory)	Stakeholder consultation
		DN3	Energy used in industrial sector (MW)	[15, 7]
Urban development	[8, 27, 33]	DU2	Urbanization rate (%)	[9, 10]
		DU5	Energy demand from household sector (MW)	[36, 37]
Pressure				
Population density	[9, 10]	PP1	Population density (persons/km^2)	[9, 10]
Traffic density	Public participation	PT1	Traffic Density (vehicle/km)	Stakeholder consultation
		PT2	Volume-to-Capacity Ratio (V/C) (vehicle)	Stakeholder consultation
Energy consumption	[33]	PE1	Total energy consumption (kWh/year)	[10]
		PE2	Energy consumption per capita (kWh/person)	[10]
Water consumption	[33]	PW2	Sectoral water use rate (m^3/day)	[27, 34, 38, 39]
Waste disposal	[33]	PA1	Amount of waste generated from industrial and municipal sectors (ton/day)	[2, 40, 41]
		PA3	Amount of waste accumulated (ton)	Stakeholder consultation
Increased GHG emissions	[15]	PG1	Carbon emission per energy consumption (kgCO_2eq/kWh)	[10]
		PG2	Annual Average Daily Traffic (AADT) (vehicle)	Stakeholder consultation
Climate change	[27, 42, 43]	PC1	Number of days of extreme rainfall (Precipitation > 80 mm) (day/year)	[44]
		PC2	Maximum precipitation (mm)	[42, 44]
		PC3	Total precipitation in rainy season (mm)	[44]
State				
Demographics	[10]	SD1	Total population (people)	[10]
		SD2	Urban population (% of total population)	[10]
Available water resources	[27, 34]	SB1	Water budget (Mm^3)	Stakeholder consultation
Water quality	Public participation	SW1	Water Quality Index (WQI)	Stakeholder consultation
Air quality	Public participation	SA2	Average PM2.5 or PM10 concentration (μg/m^3)	[19]
Precipitation pattern	[15, 34]	SP1	Change in annual rainfall from base year value (%)	[44]
Occurrence of floods	[15, 33, 42]	SO1	Number of flood events (time)	[44]
Impact				
Flood damage	[33, 45]	IF2	Number of households affected by flood (household)	[33]
		IF3	Economic loss (baht)	[33]
		IF5	Vulnerability Index	[44]
Water resource scarcity	[34, 43]	IW2	Level of water stress (%)	[46]
Emission levels	[9]	IG1	Total GHGs emission (kgCO_2eq)	[37, 39, 47]
Response				
Environmental development project	[33, 43]	RS1	Ratio of environmental protection investment as a percentage of total investment (%)	[10]
		RS2	Investment of water project (Mbaht)	[8, 34]
Waste management	Public participation	RM1	Urban solid waste with proper disposal (ton/day)	Stakeholder consultation
		RM2	District recycling rate (%)	[37]
Afforestation	[33, 34]	RA1	Growth rate of forest cover rate (%)	Stakeholder consultation

Source: Literature review and Public participation

Table 2. Influential factors associated with water scarcity, flooding, and GHG emissions

				I		
				Floods	**Water scarcity**	**GHG emissions**
	Factor	**ID**		**IF5**	**IW2**	**IG1**
D	Economic development	DE1	r		.901**	.684*
			Sig.		0.000	0.020
		DE3	r		.890**	.641*
			Sig.		0.000	0.034
		DE4	r	.647*	.975**	.650*
			Sig.	0.031	0.000	0.030
	Industrial development	DN2	r		.890**	.670*
			Sig.		0.000	0.024
		DN3	r	.678*	.974**	.626*
			Sig.	0.022	0.000	0.039
	Urban development	DU2	r	.835**	.871**	
			Sig.	0.001	0.000	
		DU5	r	.662*	.980**	.618*
			Sig.	0.026	0.000	0.043
P	Population density	PP1	r	.851**	.902**	
			Sig.	0.001	0.000	
	Energy consumption	PE1	r		.715*	
			Sig.		0.013	
		PE2	r		.665*	
			Sig.		0.025	
	Water consumption	PW2	r	.742**	.997**	
			Sig.	0.009	0.000	
	Waste disposal	PA1	r	.828**	.926**	
			Sig.	0.002	0.000	
		PA3	r		.669*	.757**
			Sig.		0.024	0.007
	Increased GHG emissions	PG1	r		-.626*	-.605*
			Sig.		0.039	0.048
		PG2	r	.656*	.745**	
			Sig.	0.028	0.009	
S	Demographics	SD1	r	.844**	.896**	
			Sig.	0.001	0.000	
		SD2	r	.847**	.886**	
			Sig.	0.001	0.000	
	Available water resources	SB1	r		-.778**	-.708*
			Sig.		0.005	0.015
	Air quality	SA2	r		.634*	
			Sig.		0.036	
	Occurrence of disaster events	SO1	r	.737*		
			Sig.	0.037		
R	Waste management	RM1	r	-.678*	-.964**	
			Sig.	0.022	0.000	
		RM2	r	-.698*	-.941**	
			Sig.	0.017	0.000	
	Afforestation	RA1	r		-.688*	-.728*
			Sig.		0.019	0.011

Note: r = Correlation Coefficient, ** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

The correlational analysis also shows that indicators of economic, industrial, and urban development are strongly associated with water resource scarcity. Among the economic development indicators, average income per capita ($r = 0.901$, $p = 0.000$), border trade value ($r = 0.890$, $p = 0.000$), and value of investment within the SEZ ($r = 0.975$, $p = 0.000$) positively correlate with the degree of water scarcity. With regard to industrial indicators, the number of factories registered in the area ($r = 0.890$, $p = 0.000$) and the energy used in the industrial sector ($r = 0.974$, $p = 0.000$) are also positively associated with water scarcity. In addition, indicators of urban development, including the urbanization rate ($r = 0.871$, $p = 0.000$) and energy demand from the household sector ($r = 0.980$, $p = 0.000$) are strongly positively correlated with the degree of water scarcity (See Table 2). Thus, the increased water consumption associated with these driving factors likely increases the risk of communities having to confront a drought situation. It should also be noted that the state of water availability has an inverse relationship with the level of water stress ($r = - 0.778$, $p = 0.005$).

With regard to GHG emissions, most indicators of economic, industrial and urban development (with the exception of urbanization rate) significantly associate with the level of emissions in positive manner (See Table 2). In addition, the pressure from the amount of waste accumulated is associated with GHG emissions ($r = 0.757$, $p = 0.007$). Accumulated waste can emit CH_4, one of the key harmful GHGs, which may increase environmental pollution.

3.4 DPSIR and PLS-SEM model evaluation of key climate-related issues that likely result from SEZ development

The external load coefficients between the first- and second-level indices were calculated. With the PLS-SEM method, a negative value and a value less than 0.5 for the loadings of the observable variables indicate non-significant variables. The non-significant variables were excluded from the SEM to prevent multicollinearity [48]. The validity of the PLS-SEM results can be tested through factor loading (basically known as path coefficient: PC), Cronbach's alpha (α_q), and R^2 values [49]. As a rule of thumb, the statistical analysis results are significant when loading ≥ 0.707, or at least 0.500, which indicates that the Average Variance Extracted (AVE_q) is ≥ 0.500. In addition, the Cronbach's alpha, which combines the correlations with equal weights, should be ≥ 0.700. The Composite Reliability (CR or ρ), which combines the loading values with the same weight, should be ≥ 0.600 [31, 50]. Figure 5 illustrates the DPSIR and PLS-SEM model used to evaluate the various indicators of SEZ development that are associated with climate-related issues. The path coefficients for each indicator and DPSIR category are shown.

As can be seen from Figure 5, analysis showed that the pressure indicators have the most influence on climate-related issues (PC = 0.721), while the response indicators have the least influence (PC = 0.050). Analysis also shows that the reliability and validity of the utilized DPSIR model was adequate. Each DPSIR category exhibited a high Cronbach's alpha (with the exception of state), thus, implying a high degree of internal consistency (See Table 3). The CR and AVE_q also pass the criteria of a good statistical significance.

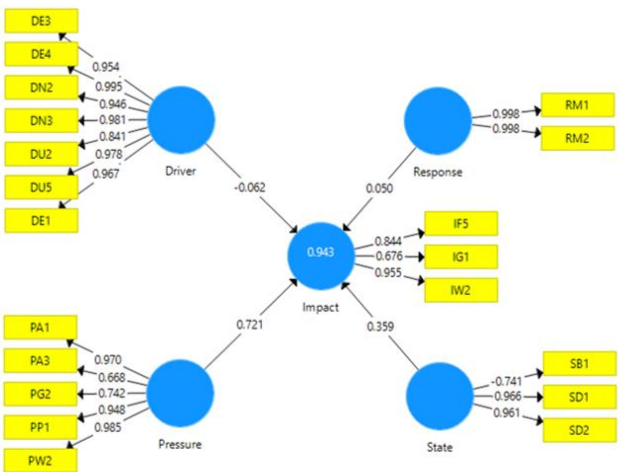

Figure 5. The DPSIR and PLS-SEM model (Source: PLS-SEM analysis, using SmartPLS® 3.0)

Table 3. Reliability of the DPSIR categories

	Cronbach's alpha	rho_A	CR	AVE_q
Driver	0.983	0.984	0.986	0.908
Impact	0.770	0.828	0.870	0.694
Pressure	0.915	0.943	0.940	0.761
Response	0.996	0.996	0.998	0.996
State	-0.074	0.894	0.704	0.802

Source: PLS algorithm, using SmartPLS® 3.0

Moreover, the validity of the separate DPSIR categories was assessed by calculating discriminant validity values, which indicate the degree of differentiation among all the categories. For adequate discriminant validity, the square roots of the average extracted variance of the variables should be above the absolute value of the corresponding correlation coefficients of the variables and over 0.50 [51]. Analysis showed that all of the discriminant validity values were above the absolute value of the corresponding correlation coefficients of the variables and over 0.50, which implies that DPSIR model is valid (Table 4).

Table 4. Discriminant validity of the DPSIR categories

	Driver	Impact	Pressure	Response	State
Driver	0.953				
Impact	0.931	0.833			
Pressure	0.965	0.969	0.873		
Response	-0.945	-0.884	-0.924	0.998	
State	0.957	0.965	0.985	-0.907	0.896

Source: PLS algorithm, using SmartPLS® 3.0

4. DISCUSSION

The SEZ system is complex and comprised of various socio-economic activities. SEZ policy planning tends to focus more on socio-economic development while ignoring potential environmental impacts, especially with regard to climate change. In order to effectively plan for sustainable SEZs, key issues related to climate impacts need to be understood. As the factors associated with SEZ development are interconnected, a holistic approach is needed to assess this complex system. Therefore, this study adopted a DPSIR framework to explore the influential factors associated with climate-related risks.

Overall, the analysis showed that production and human activities in the Tak SEZ place increased pressure on natural resources and the environment, which, in turn, impact community safety and security. When considering each factor separately, the current analysis indicated that economic, industrial, and urban development are all driving factors associated with flooding, water scarcity, and GHG emissions. The SEM analysis also showed that pressure indicators, including increased population density, water consumption, waste disposal, and vehicular traffic are most closely associated with the climate-related issues in the Tak SEZ.

Based on the results of the correlational analysis, it can be concluded that economic development, rapid industrialization, and urbanization are among the significant anthropogenic driving factors associated with climate-related changes in the SEZ. In particular, urbanization is closely associated with an increased risk of flooding. Besides, water scarcity is linked with all three types of development, and GHG emissions are moderately linked with the three categories of development.

Increased water consumption from development within the SEZ places significant stress on water resources within the zone. The intensive use of water resources from various sectors, including industrial plants and households, contribute to pressure on the water supply. These observations are consistent with the DPSIR results of Pandey and Shrestha [27], which indicate that industry, energy demands, and an increased number of households are driver indicators for water quantity issues. In addition, the qualitative DPSIR study by Hazarika and Nitivattananon [8] affirms that population increases and urbanization are key drivers for groundwater resource exploitation and can result in a significant decline in the groundwater level.

Climate change resulting from SEZ development activities may also exacerbate an already precarious water resource situation, and, consequently, may contribute to flooding risks within the zone. Climate change is associated with alterations in rainfall patterns and temperature, which can affect both water availability and increase the risk of natural disasters. For instance, heavy rainfall may lead to severe flooding, while intermittent rain in the summer season can lead to water supply problems. The current results indicate that development in SEZs may increase these risks via climate-related changes due to heightened GHG emissions.

Indeed, economic, industrial, and urban development in the SEZ drive the demand for fuel for increased freight and vehicular traffic, increased power for industrial production processes, and increased electricity demand for household use. These increased demands clearly increase GHG emissions in the Tak SEZ. Additionally, increased waste disposal in the SEZ places stress and pressure on local communities and contributes to the emission of GHGs.

The results outlined above indicate the need for several mitigation strategies to promote the sustainability of the Tak SEZ. In particular, both supply- and demand-side mitigation measures should be implemented to reduce industrial and household water use in the zone. Besides, policies to lower the rate of GHG emissions, including decrease in vehicular traffic and waste disposal, should be developed. Moreover, the adaptive capacity of local communities to deal with flooding needs improvement to reduce the risks associated with natural disasters. Apparently, hard infrastructure within the SEZ should be constructed, including flood control measures and improved drainage systems, and an early warning system for flood-related emergencies. The vulnerability to climate hazards could also be reduced by increasing the dissemination of knowledge related to disaster prevention.

There are several limitations to this study, the recording of the amount of historical data being the preliminary limitation. With regards to factor analysis, a larger number of samples contribute to more robust results [52]. Comprehensively, as the geographical scope of this study was restricted to district level boundaries, the data pertaining to the collection of long and continuous historical time-series was assiduously challenging in nature. Thus, the study defined the probable availability of long-term historical data as one criterion in selecting the indicators to avoid a large amount of missing value.

5. CONCLUSIONS

The current findings have identified several driving factors, including economic, industrial, and urban development, that are associated with climate-related issues in the Tak SEZ. The path coefficient of the driving factors and the impact factors is -0.062, indicating that economic, industrial, and urban development have a negative effect on water resources, natural disasters, and GHG emissions. Contrarily, the pressure and state factors have significant positive impact on the climate related issues (PC = 0.721, 0.359 respectively), while the influence is low between the response and the impact (PC = 0.050). The identification of these factors should help policy-makers, evaluators, and the public understand the potential impacts of SEZ development on sustainability, especially with regards to water resources, natural disaster risks, and GHG emissions. These findings simultaneously highlight several mitigation strategies that may help to minimize the environmental risks associated with SEZ development.

The indicators presented in the current study will be helpful for future investigators working on identifying potential variables for the evaluation of other types of development zones that have a variety of socio-economic activities. The integration of holistic thinking using DPSIR framework together with PLS-SEM technique to explore the relationship among multiple sustainability indicators contributes to the existing methodology for assessing large scale area-based development, like SEZs. Future studies could also use the PLS-SEM model to estimate the dynamic effects of socio-economic development on dependent variables in these systems in order to prevent/ mitigate potential impacts that may occur from the proposed development by dealing with the main development factors related to the outcomes. Directions for the future could then be suggested through development modification. The results of this study may further assist in planning more effectively, which would then lead to greater sustainability in any regional development.

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APPENDIX: DPSIR indicator selection

Label	Name	N		Median	Mode	Std. Deviation	Percentiles		
		Valid	Missing				25	50	75
DE1	Income/capita	12	2	5.00	5	0.900	4.25	5.00	5.00
DE2	Registered of juristic person	13	1	4.00	3[a]	0.870	3.00	4.00	4.00
DE3	Border trade value	12	2	4.50	5	1.193	4.00	4.50	5.00
DE4	Investment value	12	2	5.00	5	0.622	5.00	5.00	5.00
DI1	Investment in infrastructure	14	0	4.50	5	0.914	4.00	4.50	5.00
DI2	Profitability of infrastructure	13	1	3.00	4	1.256	2.00	3.00	4.00
DI3	Construction land	12	2	3.50	3	1.243	3.00	3.50	4.75
DN1	Gross value of fixed assets	11	3	4.00	4	1.168	3.00	4.00	5.00
DN2	Registered factory	14	0	4.50	5	0.825	3.75	4.50	5.00
DN3	Industry electricity demand	14	0	4.50	5	1.269	3.75	4.50	5.00
DU1	Population growth	11	3	4.00	4	0.647	4.00	4.00	5.00
DU2	Urbanization rate	14	0	4.50	5	0.949	3.00	4.50	5.00
DU3	Urban growth rate	11	3	4.00	4[a]	0.831	3.00	4.00	5.00
DU4	Urban employment rate	14	0	5.00	5	0.852	4.00	5.00	5.00
DU5	Household electricity demand	12	2	4.50	5	1.505	3.25	4.50	5.00
PP1	Population density	11	3	5.00	5	0.505	4.00	5.00	5.00
PI1	Road density	12	2	4.00	4	0.793	3.00	4.00	4.75
PT1	Traffic density	14	0	4.50	5	0.975	3.75	4.50	5.00
PT2	Volume-to-Capacity Ratio	14	0	4.50	5	1.177	3.00	4.50	5.00
PT3	VKT/VMT	13	1	4.00	5	0.927	4.00	4.00	5.00
PE1	Total energy consumption	13	1	5.00	5	0.650	4.00	5.00	5.00
PE2	Energy consumption/capita	12	2	4.50	4[a]	0.522	4.00	4.50	5.00
PW1	Water consumption	12	2	5.00	5	0.669	4.00	5.00	5.00
PW2	Water use rate	12	2	5.00	5	0.905	4.00	5.00	5.00
PL1	Land use intensity	11	3	4.00	4[a]	0.905	4.00	4.00	5.00
PL2	Land cover area	11	3	3.00	3[a]	1.362	2.00	3.00	5.00
PF1	Forest cover	12	2	4.00	4[a]	1.115	3.00	4.00	5.00
PA1	Waste generated from household	13	1	5.00	5	0.855	5.00	5.00	5.00
PA2	Waste generated from industry	13	1	5.00	5	0.376	5.00	5.00	5.00
PA3	Waste accumulated	11	3	5.00	5	0.924	5.00	5.00	5.00
PA4	Communities complaints	13	1	5.00	5	1.115	3.00	5.00	5.00
PG1	Carbon emission	13	1	5.00	5	0.776	4.00	5.00	5.00
PG2	AADT	14	0	4.50	5	1.167	3.75	4.50	5.00
PC1	Days of extreme rainfall	14	0	4.50	5	1.359	3.50	4.50	5.00
PC2	Maximum precipitation	14	0	4.50	5	1.122	4.00	4.50	5.00
PC3	Total precipitation in rainy season	14	0	4.50	5	1.122	4.00	4.50	5.00
PC4	Max. value of daily max. temp.	14	0	4.00	4	1.267	3.75	4.00	4.25
SD1	Total population	11	3	5.00	5	0.688	4.00	5.00	5.00
SD2	Urban population	11	3	5.00	5	0.505	4.00	5.00	5.00
SD3	Household size	11	3	4.00	4[a]	1.136	3.00	4.00	5.00
SD4	Household number	11	3	4.00	5	0.982	4.00	4.00	5.00
SB1	Water budget	11	3	5.00	5	0.688	4.00	5.00	5.00
SW1	WQI	13	1	5.00	5	0.439	4.50	5.00	5.00
SW2	Wastewater discharged	12	2	4.50	5	1.206	3.00	4.50	5.00
SW3	Complaints of wastewater	13	1	5.00	5	1.068	3.00	5.00	5.00
SA1	AQI	11	3	5.00	5	1.206	4.00	5.00	5.00
SA2	PM2.5 & PM10	13	1	5.00	5	0.877	4.00	5.00	5.00
SA3	Days with air quality exceed std.	13	1	5.00	5	1.013	3.50	5.00	5.00
SA4	Complaints about air pollution	13	1	4.00	5	1.080	3.00	4.00	5.00
SP1	Rainfall	14	0	4.50	5	1.167	3.75	4.50	5.00
SO1	Flood	14	0	4.50	5	0.825	3.75	4.50	5.00
SO2	Drought	14	0	4.00	3[a]	0.877	3.00	4.00	5.00
IF1	People affected by flood	12	2	4.00	4	0.793	3.25	4.00	5.00
IF2	Household affected by flood	11	3	5.00	5	0.905	3.00	5.00	5.00
IF3	Economic loss	11	3	5.00	5	1.009	4.00	5.00	5.00
IF4	Water-borne diseases	12	2	4.00	5	0.996	3.25	4.00	5.00
IF5	Vulnerability Index	14	0	5.00	5	0.756	4.00	5.00	5.00
IW1	Freshwater shortage	11	3	5.00	5	1.206	4.00	5.00	5.00
IW2	Water stress	11	3	5.00	5	0.688	4.00	5.00	5.00
IW3	Groundwater level	11	3	4.00	5	0.982	4.00	4.00	5.00
IG1	Total GHG emissions	13	1	5.00	5	0.439	4.50	5.00	5.00
IG2	People exposed by pollutants	12	2	4.00	5	1.044	3.00	4.00	5.00
RE1	Energy efficiency	14	0	4.50	4[a]	0.519	4.00	4.50	5.00
RE2	Clean production process	14	0	4.50	5	0.646	4.00	4.50	5.00

Label	Name	N		Median	Mode	Std. Deviation	Percentiles		
		Valid	Missing				25	50	75
RW1	Agricultural water use efficiency	11	3	5.00	5	0.688	4.00	5.00	5.00
RW2	Reuse wastewater	11	3	5.00	5	0.467	4.00	5.00	5.00
RW3	Safely treated wastewater	11	3	5.00	5	0.522	4.00	5.00	5.00
RS1	Envi. protection investment	14	0	5.00	5	0.514	4.00	5.00	5.00
RS2	Water infrastructure investment	14	0	4.50	5	0.745	4.00	4.50	5.00
RM1	Proper disposal	11	3	5.00	5	0.505	4.00	5.00	5.00
RM2	Recycling rate	12	2	5.00	5	0.651	4.25	5.00	5.00
RA1	Growth rate of forest cover rate	11	3	5.00	5	1.168	4.00	5.00	5.00
RA2	Afforest in built-up area	11	3	4.00	5	1.433	2.00	4.00	5.00
RL1	Green space	11	3	4.00	4[a]	0.905	4.00	4.00	5.00
RL2	Ecological protection	11	3	5.00	5	1.168	4.00	5.00	5.00
RL3	Urban envi. infra. investment	11	3	4.00	4	0.944	4.00	4.00	5.00

Note: a. Multiple modes exist. The smallest value is shown.

Source: Expert judgment, statistical analysis, using SPSS® Statistics 26.0.