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Contents

REVIEW NOTES

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Applying Delphi method to develop sustainable city indicators

A case study of Chiang Mai, Thailand

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Abstract

Cities around the world have expanded and consumed many resources. The expansion of these cities has had a huge impact on our planet. There are many ideas about sustainable urban development around the world to slow down or stop the destruction of the environment. Sustainable urban development is a concept that allows the economy, society, and environment to grow together in a balanced and sustainable manner. Chiang Mai in Thailand is considered a city with much potential. It currently has good city planning. However, indicators to evaluate the potential of sustainable cities are still lacking. Hence, this work aims to develop appropriate indicators for assessing the sustainability of Chiang Mai city using the Delphi method of panel surveys. At least 20 experts in various fields were selected to take the Delphi surveys conducted in three rounds. The results of the Delphi processes showed that there were 35 indicators suitable for assessing Chiang Mai's potential as a sustainable city and helping with the development planning of Chiang Mai in the future.

Keywords

Clean energy; Sustainability; Sustainable city; Delphi; Chiang Mai.

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1. Introduction

Expansion of urban society is one of the major trends and challenges that the world will face (Shaobo & Xiaolong, 2022; Wei et al., 2022; Do et al., 2022; Zeng et al., 2023). In the 21st century, the United Nations estimated that by 2050, the world will have an urban population of about 2.4 billion people, or 66% of the world's population (Amoushahi et al., 2022; Sun et al., 2021). Especially, Asia and Africa are showing rapid urbanization (Duan et al., 2022; Luo et al., 2022). For Thailand, there has been a continuous expansion of urbanization since the 1957s. Currently, Thailand has an urban population of about 55%, and it is estimated that by 2050, Thailand will account for 73% of the urban population. The growth of medium and small regional city centers and medium-sized cities will see a marked increase in population density. The economy of many regional cities will grow at a higher rate than Bangkok and above the national average (Chunark et al., 2021). Urbanization is both an opportunity and a challenge. Urban communities generate more than 80% of the world's gross domestic product while consuming more than 70% of their energy and carbon emissions (Hashmi et al., 2021; Margiotta et al., 2021; Rahman & Alam, 2021; Wang et al., 2022). Urbanization can drive an economy that benefits businesses from population density. Efficient use of land means low cost of transportation of goods, and it is also a source of innovation and technology. At the same time, recent urbanization has caused many problems (Pellicelli et al., 2022; Li et al., 2023), including directionless urbanization, environmental degradation, social inequality, inconsistent basic service, and housing shortages due to mass immigration. In addition, the changing situations in the world and Thailand have created a context that affects current and future urban development, including climate change and increased risk of disasters, rise of the middle class, an aging society, and technological advances and the transition to the digital economy (Spadaro et al., 2022; Szabó et al., 2022; Zhong & Chen, 2022). Therefore, it is imperative that the future development and management of cities rely on knowledge to create opportunities from urbanization and deal with problems that may arise from urbanization under the changing context (Boglietti & Tiboni, 2022). It can be said that the long-term sustainable development of a country will depend on the ability to develop cities and the indicators that will guide the cities of the future to be sustainable (Adshead et al., 2019; Franco, 2021; Henderson & Loreau, 2023).

Chiang Mai is currently undergoing continuous development. The development has been determined to align with the National Economic and Social Development Plan, and the northern region plan has been developed as a master plan for axial development. North-South Economic Corridor has a policy that emphasizes the importance of Chiang Mai as the center of the country and the sectors of business, trade, investment, administration, air transport, travel services, food, and health with international standards (Zhang et al., 2021), (Pongruengkiat et al., 2022). Due to its potential and role, Chiang Mai has many development projects from both the public and private sectors. However, no project has yet been able to measure the sustainability of Chiang Mai city development. Chiang Mai has much potential: it is the economic center of the North and the cultural capital of a country with a continuous influx of tourists as it is included in the preliminary list of UNESCO World Heritage Sites. In addition, Chiang Mai is also designated as a pilot area for developing smart cities, thus being a development base in digital technology. Moreover, Chiang Mai has the potential to be the center of education, medicine, and travel in the North; also, it has a beautiful natural environment. This makes Chiang Mai a livable city and worthy of sustainable urban development (Pongruengkiat et al., 2022).

Based on literature reviews and research papers on Chiang Mai's sustainable development, there are no indicators for assessing and monitoring sustainable urban development. Therefore, this work aims to facilitate, evaluate and choose suitable indicators to determine the potential of Chiang Mai city as a sustainable city through the Delphi method, with experts in various fields selecting and evaluating the indicators ideal for the city of Chiang Mai. To acquire relevant indicators for assessing the viability of Chiang Mai as a sustainable city, further investigation is necessary. Sustainable development consists of three main considerations: economic, social, and environmental (Zhao et al., 2019; Niemets et al., 2021; Al-Badi & Khan, 2022). Relevant

development must have the overlapping alternatives of these keywords, such as the interaction between socioeconomic dimensions and environment to social needs (Tanguay et al., 2010; Future, 2011; Winter & Knemeyer, 2013; Gosling et al., 2017). Economic development must avoid destroying ecosystems and losing nonrenewable resources (Tanguay et al., 2010). Sustainable city indicators must include not only the environmental dimension but also the social and economic dimensions (Lai, 2021). Therefore, this research studied the indicators from the Chiang Mai city development plan, Chiang Mai smart city strategy plan 2019, the master plan for the development of the Chiang Mai transportation system, bio-circular-green (BCG) economic model, transit-oriented development (TOD), and the United Nations' sustainable development goals (SDGs) (Franco, 2022) to cover all dimensions of the search for appropriate indicators to assess sustainable cities. From the aforementioned references, the researchers are interested in finding indicators used to evaluate the sustainable city potential of Chiang Mai. They intend to develop new indicators that are relevant to the specific context of Chiang Mai by integrating key indicators from various sources. The aim is to create a set of indicators that are tailored to the unique characteristics and circumstances of Chiang Mai as much as possible.

Developing sustainable city indicators for Chiang Mai would be highly relevant to the scope of TeMA Journal. This topic falls within the journal's focus on urban and regional planning, architecture, engineering, technology, and management, and addresses the challenges and opportunities related to the development, management, and sustainability of urban areas. Some potential sustainable city indicators for Chiang Mai could include green space, energy, Waste management, Transportation and Social equity. Developing sustainable city indicators for Chiang Mai could help identify areas where the city is doing well and areas where improvements are needed. This information could be used by policymakers, urban planners, and community stakeholders to guide decisions about resource allocation, infrastructure development, and sustainability initiatives.

2. Materials and methods

2.1 Delphi Method

Delphi techniques are widely accepted and popular research techniques in business, politics, health, economy, and education (Spranger et al., 2022; Chan & Lee, 2019; Drumm et al., 2022). The Delphi technique is a process or tool used to make decisions or draw conclusions on a matter systematically without the direct confrontation of a group of experts by gathering and asking for the experts' opinions. It is a technique that seeks input from experts' opinions on a particular subject by answering the questionnaire (OLADEGA et al., 2021). Henceforth, the designated experts must respond to the questionnaires presented by the researcher in a diligent and judicious manner, ensuring both precision and clarity in their responses. An expert, in this context, is an individual who possesses a wealth of knowledge and expertise in the particular subject under investigation. It is also a technique in which each expert involved in the research does not know who is and who has an opinion and does not know how each person views each item. This eliminates the influence of the group that affects their opinions. The Delphi technique was derived from questionnaires or other forms that do not require experts to meet. Experts are required to answer all the questionnaire steps to get the correct opinion. Therefore, it is necessary to use multiple rounds of questionnaires. In general, the questionnaire in Round 1 is open-ended, and in subsequent rounds, it is closed-ended (A. Y. P. Chan et al., 2013). A rating scale allows each expert to answer the questionnaire in a more carefully scrutinized and harmonious way. The experts agreed with the researchers' opinions, which were consistent with each answer to the previous questionnaire expressed in statistical terms, i.e., the median and the interquartile range. Then, they return the questionnaires to each expert to determine whether they want to keep the same answers or change them. The statistics used in the analysis are the basic statistics: the measure of the central tendency, namely, mode, median, and mean, and the measure of the distribution of the data, which is interquartile (P. Chan & Lee,

2019). The Delphi consensus method is a structured approach to reaching a consensus among experts or stakeholders on a particular topic or problem. It is a process that typically involves several rounds of data collection and analysis, aiming to refine opinions and converge toward a consensus view. The Delphi consensus method is a powerful tool for bringing together diverse perspectives and reaching a consensus on complex topics or problems. It can help ensure that all voices are heard and considered, leading to more robust and comprehensive results that inform policy decisions, research agendas, and other critical activities (Humphrey-Murto et al., 2017; Chan, 2022).

The 6-point Likert method was used to weigh the indicators chosen by the experts for further statistical analysis of the obtained values. In general, a 6-point Likert scale may provide a more nuanced response than a 5-point Likert scale, as it allows for an additional response option in the middle of the scale. This can help to reduce response bias and provide more precise measurements of attitudes and opinions. Additionally, having an odd number of response options prevents respondents from choosing the neutral option, which can encourage more thoughtful and meaningful responses (Dolnicar et al., 2011; Taherdoost, 2019). The Delphi technique used in conjunction with this 6-point Likert method collects the first round of data using an open-ended questionnaire. The next round will use a closed end. The first round of data collection using an open-ended questionnaire was intended to collect general opinions from experts for the second round of questionnaires, developed from the responses to the first round. All expert opinions are synthesized into an open-ended questionnaire of estimator type and sent to experts to prioritize or predict trends in each item. Each item obtained from the second round of questionnaires was calculated for statistical values. An issue to consider in the preparation of the questionnaire is the selection of statistical values used as feedback consisting of aggregated expert opinions. These values may be represented by mean, median, baseline, or percentage to represent the idea of most people and a statistical value showing the distribution of expert opinions. The most common statistics are standard deviation, quartile deviation, or the frequency or percentage distribution in each answer group to show the degree of consistency of the experts' thinking. The second group is a number that shows the experts' answers in the previous round to compare the consistency or differences of opinions of individual experts with the opinions of groups (Sourani & Sohail, 2015).

2.2 Relevant indicator selection, review, and classification

From previous research, the indicators are compiled as follows: Chiang Mai city development plan, Chiang Mai smart city strategy plan 2019, the master plan for the development of the Chiang Mai transportation system, BCG economic model (Otwong et al., 2021), transits city, transit-oriented development (TOD) (Sung & Oh, 2011), and SDGs (Bogers et al., 2022). All indicators were selected under the concept of sustainable development. Based on the previous research [The 12th International Conference on Logistics & Transport 2022: Identifying Suitable Indicators to Assess Chiang Mai as A Sustainable City Using Delphi Method], the indicators affecting the sustainable development of Chiang Mai can be divided into 18 groups, 64 indicators with additional groups and indicators from the experts who completed the questionnaire. The expert group is comprised of individuals with diverse backgrounds and expertise, including four city planners, seven local government officials, six representatives from the private sector, two energy experts, two social science experts, and two environmental experts. All group members were selected based on their extensive experience and held trusted positions in their respective fields. Such positions include membership in the National Planning Board, former deputy governor, and university professors with high academic standing. In the first round, these indicators were analyzed and used to prepare the questionnaire rounds 2 and 3. The details of the indicators are shown in Tab.1.

Category	Indicator	SDGs	Master plan	CNX plan 65	CNX smart	TOD	BCG
Energy	I1 Consumption of electricity per capita			✓	✓		✓
	I2 Consumption of fuel per capita		✓	✓	✓	✓	
	I3 The use of renewable energy in Chiang Mai area			✓	✓		✓
	I4 Projects and research on promoting the use of renewable energy	✓		✓	✓		✓
	I5 Energy conservation work	✓		✓	✓		✓
Environment quality	I6 Air quality	✓	✓	✓	✓	✓	✓
	I7 Emissions in transportation	✓	✓	✓	✓	✓	✓
	I8 Water	✓		✓	✓		✓
	I9 Waste	✓		✓	✓		✓
Land use	I10 Population density		✓	✓	✓	✓	✓
	I11 Integrated town plan		✓	✓	✓	✓	✓
	I12 Expansion pattern of the city	✓	✓	✓	✓	✓	✓
Transportation	I13 Type of transport (public, individual)		✓	✓	✓	✓	
	I14 Number of personal vehicles		✓				
	I15 Number of public vehicles		✓				
	I16 Vehicle usage rate	✓	✓			✓	
Health and wellbeing	I17 Number of beds in the hospital			✓	✓		
	I18 Number of hospitals and rehab centers through the Ministry of Health	✓	✓	✓			
	I19 Number of doctors			✓			
	I20 The potential of the hospital			✓	✓		
	I21 Sickness rate	✓		✓	✓		
	I22 Duration and ease of access to the public health system			✓			
	I23 Population health	✓		✓	✓		
	I24 Number of exercise locations and health promotion places			✓			
	I25 Average age of the population	✓		✓	✓		
Population	I26 Population	✓	✓	✓	✓	✓	✓
	I27 Birth rate			✓			
Labor	I28 Unemployment and Employment Rate	✓		✓	✓	✓	
	I29 Average income per capita	✓		✓	✓		
	I30 Level of knowledge and expertise of workers			✓			
Housing	I31 Number of residences		✓	✓	✓	✓	✓
	I32 The cost of buying or renting	✓	✓	✓		✓	
	I33 Distance/duration To travel for activities		✓	✓		✓	
Education	I34 Number of universities, schools, colleges	✓	✓	✓	✓	✓	
	I35 Graduation rate from bachelor's degree			✓	✓		
	I36 Number of students		✓	✓	✓		
	I37 Literacy rate	✓		✓			
	I38 The rate of employment in different areas / different areas After graduating at all levels and institutions		✓	✓			
Violence	I39 Number of crimes			✓	✓		
	I40 Number of police			✓	✓		
	I41 Number of police stations			✓	✓		
	I42 Amount of crime-risk areas (dark areas)	✓			✓		
Culture	I43 Number of ethnicities living in Chiang Mai			✓			
	I44 Number of festival management			✓	✓		
	I45 Number of recreational activities			✓			
	I46 Number of traditions			✓	✓	✓	
	I47 Income from cultural activities			✓			
Convenience	I48 Number of department stores and convenience stores	✓	✓	✓	✓	✓	✓
	I49 Number of markets		✓	✓	✓	✓	✓
	I50 Number of entertainment businesses		✓	✓	✓	✓	✓
	I51 Number of restaurants		✓	✓	✓	✓	✓
GPP	I52 Total product value in Chiang Mai	✓	✓	✓	✓	✓	✓
Creativity	I53 Number of creative courses	✓			✓		
	I54 Number of Creative Events and Exhibitions	✓		✓			
	I55 Income from Creative events and exhibitions	✓		✓			
Innovation	I56 Amount of innovation research	✓		✓	✓		
	I57 Income from research and innovation	✓		✓			

	I58 Innovation success rate	✓		✓			
Trade	I59 Amount of Trade Value	✓		✓	✓		✓
	I60 Income for each sector	✓		✓	✓		✓
Tourism	I61 Number of tourists		✓	✓	✓	✓	
	I62 Tourist spending rate			✓			
	I63 Currency exchange rate			✓			
Service	I64 Number of service businesses		✓	✓		✓	

Tab.1 Indicator review and classification

2.3 Questionnaire Development

The Delphi polling process involved three rounds of data collection. It is important to note that the questionnaire was not administered on a single occasion but was developed over multiple iterations, as illustrated in Fig.1. The details are as follows:

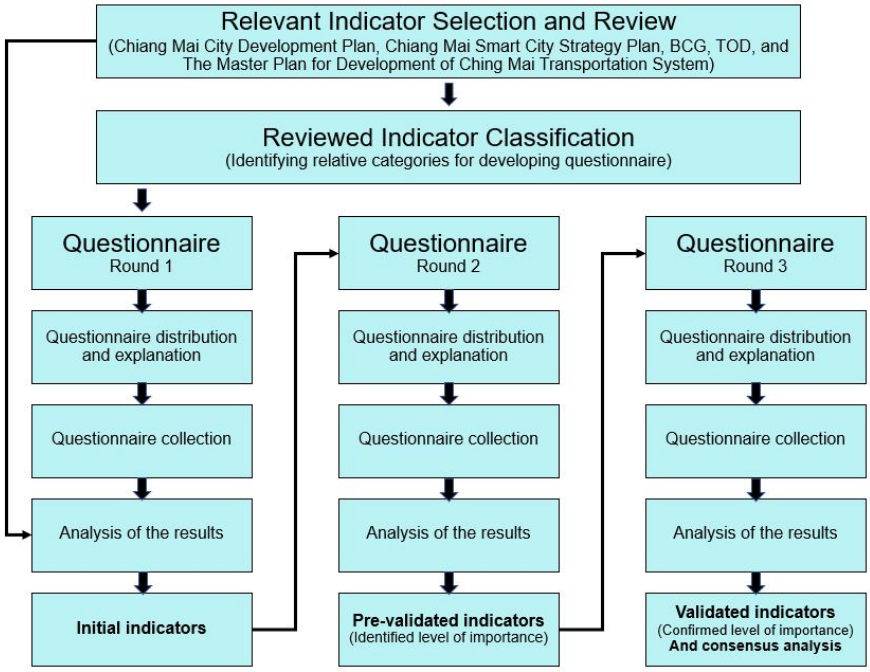

Fig.1 Research flow

Round 1: In Round 1, a validated questionnaire was used, and the indicators of sustainable urbanization were selected based on the previously mentioned data. Because sustainable city indicators are complex and numerous, the researcher has developed a questionnaire divided into 18 categories, with gaps for the participants to add information that they consider important. In order to streamline the questionnaire completion process for participants, it may be necessary to simplify and reduce the complexity of the questions. A sample questionnaire is shown in Fig.2.

Indicator Selection	
Indicator	Explanation
.....	.....

Fig.2 Delphi example Round 1

Round 2: In the second round, the indicators from the first questionnaire were used to determine the level of importance of the indicators using the 6-point Likert method, as shown in Fig.3.

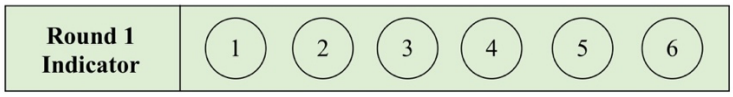

Fig.3 Delphi example Round 2

Round 3: In Round 3, a questionnaire in Round 2 was used to confirm the importance of the indicator. The mean values were added to the questionnaire, as shown in Fig.4.

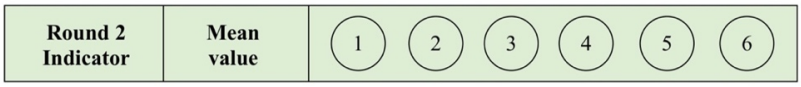

Fig.4 Delphi example Round 3

2.4 Conducting panel surveys

Panelist selection, invitation, and participation

Generally, the Delphi method defines the number of respondents differently depending on the suitability of the job (Sourani & Sohail, 2015). The number of participants involved in a study depends on the topic being considered, and in most cases, more than eight participants are included (Weidman et al., 2011). However, most studies have surveyed 8–16 participants or more, as appropriate (Hallowell & Gambatese, 2010). Based on previous literature studies, the majority of studies involved 8–16 participants (Pongruengkiat et al., 2022). Therefore, over 20 participants with expertise in each field were selected for this study. All the experts worked in fields related to the city's sustainability, city planners, local managers/governmental officers, private sectors, energy experts, transport experts, social science experts, and environmental experts, with 2-5 experts invited in each field.

Panel survey processes

Before completing the questionnaire, the participants were briefed on the objectives of this research, including the Delphi method of polling, where the lecture focuses on filling out additional questionnaires for the spaces provided in Fig.4. Participants were asked to identify at least five indicators of Chiang Mai's sustainability. There was a gap for participants to add groups of indicators they saw as relevant, with the most important being a sustainable city. This method must meet the guidelines of Chan & Lee (2019), Sourani & Sohail (2015).
In the second round, the questionnaire was designed with regard to the indicators acquired from the first round. In this round, the significance level of the indicator was added by a 6-point Likert-type scale. The details are as follows: 6 means strongly agree, 5 means agree, 4 means slightly agree, 3 means slightly disagree, 2 means disagree, and 1 means strongly disagree (Dolnicar et al., 2011; Taherdoost, 2019).
In the third round, the questionnaire was similarly developed with reference to the indicators obtained from the second round of questionnaires. Here, the mean value was added to examine the level of significance of the identified indicators because each participant can change their opinion according to the mean value received from Round 2.

2.5 Consensus analysis and investigation

This work did not have a consensus analysis of Round 2, as the significance of the Round 2 indicators has not been confirmed. However, the average value of Round 2 has helped the contributors. The final decision was made in Round 3 to conclude the level of importance of the indicator. Therefore, in this study, consensus analysis was conducted in Round 3 based on data from Chiang Mai. The results of identifying the level of importance of the agreed-upon indicators were more than 83% of the responses voted on the pointer. The scales were most important, very important, and important. Sourani and Sohail (Sourani & Sohail, 2015) reported the percentage of respondents who agreed on the criterion rankings. On the 6-point Likert category, consensus can be determined based on 75% or more respondents agreeing on a mean value of 4.50. Consequently, in this work, the consensus was determined based on the importance of a voted indicator equal to or higher than 4.50 and the percentage of panelists who agreed that a given rating of 4 to 6 was equal to or higher. Over 75% of the accredited indicators that achieve this consensus will be selected as the sustainable

cities indicator for Chiang Mai. The consensus sustainable city indicator is also based on audits and agreements, which is suitable for Chiang Mai for sustainable urban development.

3. Results and discussion

3.1 Developing indicators in Delphi round 1

In previous studies in [The 12th International Conference on Logistics & Transport 2022: Identifying Suitable Indicators to Assess Chiang Mai as A Sustainable City Using Delphi Method], it was found that after Delphi Round 1 of 20participants, 29 indicators were left with a choice frequency greater than 75%, measured from all 64 initial indicators. In addition, 25 indicators have been guided by experts, and another group of indicators was "Facility." Thus, there were 54 indicators obtained from Delphi Round 1. All of these indicators will be used for weighting in Delphi Round 2. Fig.5 shows the frequency of selecting indicators. Tab.2 shows indicators selected from the initial indicators and Tab.3 shows indicators from expert recommendations.

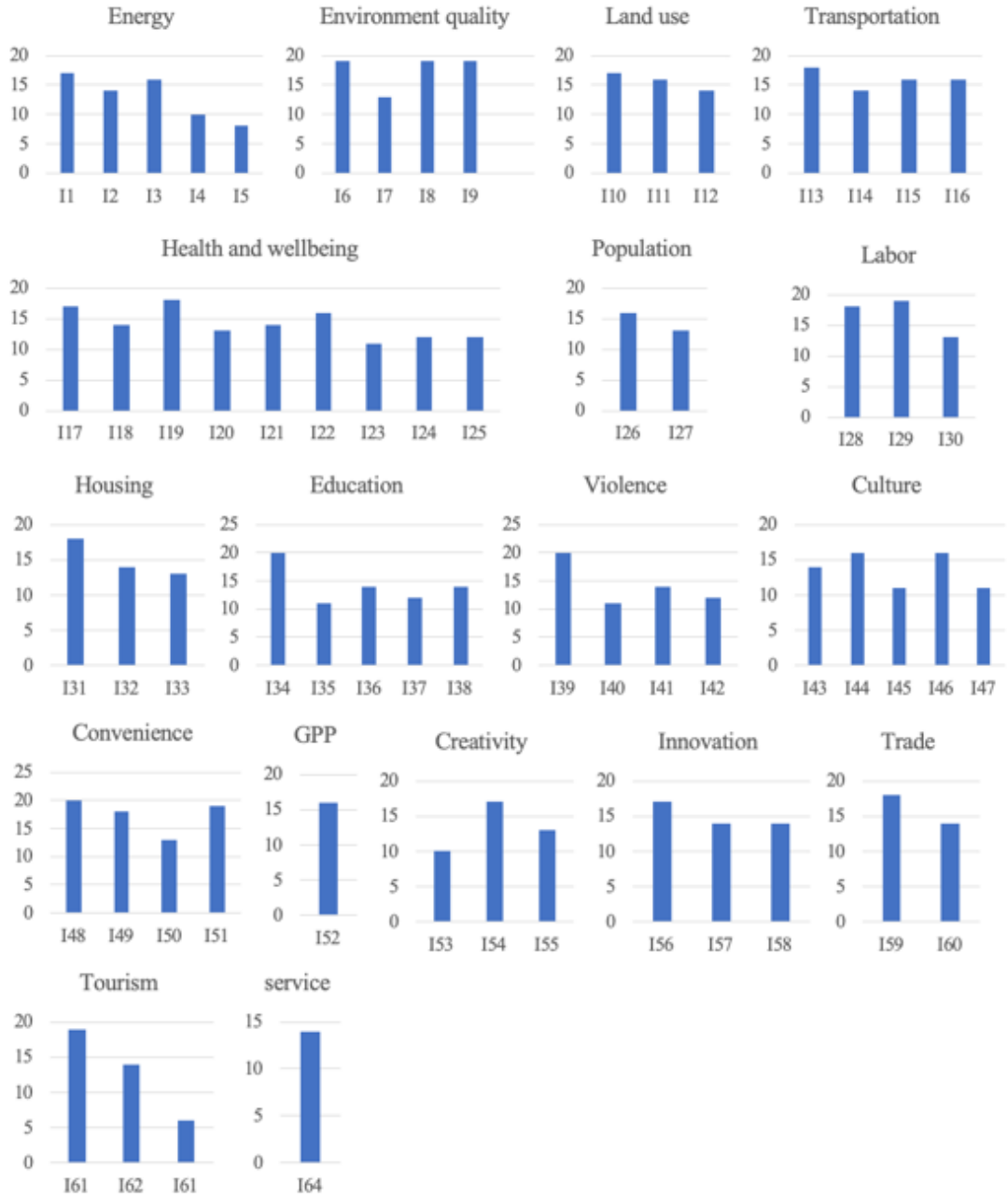

Fig.5 The frequency of selecting indicators

Category	Indicator	Category	Indicator
Energy	I1 Consumption of electricity per capita	Labor	I28 Unemployment and Employment Rate
	I3 The use of renewable energy in Chiang Mai area		I29 Average income per capita
Environment quality	I6 Air quality	Housing	I31 Number of residences
	I8 Water	Education	I34 Number of universities, schools, colleges
	I9 Waste	Violence	I39 Number of crimes
Land use	I10 Population density	Culture	I44 Number of festival management
	I11 Integrated town plan		I46 Number of traditions
Transportation	I13 Type of transport (public, individual)	Convenience	I48 Number of department and convenience stores
	I15 Number of public vehicles		I49 Number of markets
	I16 Vehicle usage rate		I51 Number of restaurants
Health and wellbeing	I17 Number of beds in the hospital	GPP	I52 Total product value in Chiang Mai
	I19 Number of doctors	Creativity	I54 Number of Creative Events and Exhibitions
	I22 Duration and ease of access to the public health system	Innovation	I56 Amount of innovation research
Population	I26 Population	Trade	I59 Amount of Trade Value
		Tourism	I61 Number of tourists

Tab.2 The indicators obtained from round 1 of Delphi by selected

Category	Indicator	Category	Indicator
Energy	Proportion of using renewable energy in the organization	Culture	Database-number of local experts/craftsmen/artists
Land use	Ratio of green area to total area		The number of museums that provide knowledge of the local culture
	Road area per total area		Statistics on the number of tourists who come during the festival
Transportation	Number of stops and distribution of public transport	Creativity	Number of local creative businesses
	Average travel per capita in different modes is connected to different fuel consumption	Innovation	Number of agencies that support innovation research
Health and wellbeing	Ratio of the elderly to the population		Number of start-ups
	Death rate	Tourism	Number of accommodations
Population	Latent population		Statistics of foreign tourists and Thai people
Housing	Residential building type		Objectives of foreign tourism
Education	Proportion of the undereducated population to the educated population		Number of days of provincial tourism for foreign and Thai tourists
Violence	Area per number of CCTV cameras		Number of tourist attractions by type
Facility	Utilities consumption rate	Service	Service business type
			Service business income per total provincial income

Tab.3 The indicators obtained from Round 1 of Delphi by expert recommended

3.2 Prevalidation of Indicators in Delphi Round 2

After analyzing the indicators obtained from Round 2 of Delphi, it was found that the passing indicators with a mean value greater than or equal to 75% were 35 indicators. The highest mean value is 5.6, and the lowest mean value is 4.0 as shown in Tab.4.

From Tab.4, it can be observed that the cut-out indicators are those with a mean value lower than 4.5, causing the group of Facility and Convenience indicators to be cut off, so the group of indicators will be reduced to 17 groups, and the indicators obtained the prevalidated indicators (SI), as shown in Tab.5.

3.3 Validation of Indicators in Delphi Round 3

After analyzing the results of Delphi Round 3, some metrics were renamed for greater clarity: "Water" was changed to "Water quality," "Waste" was changed to "Waste management," and "Total product value in Chiang Mai" changed to "Gross provincial products of Chiang Mai." The highest mean value is 5.55, and the lowest mean value is 4.68. The indicators with the highest mean were those in the Environment quality group (SI4, SI5, SI6), followed by the Energy group (SI2), shown in Tab.6.

3.4 Consensus Analysis

Indicators developed need to be confirmed based on a significance level equal to or above 4.5, so the percentage rating must be at levels 6, 5, or 4 equal to or above 75%. Referring to the consensus analysis, the proportion of panelists voting as 6, 5, or 4 for the 35 validated indicators is 100% for 14, 95% for 14, and 90% for 7. Hence, all of the 35 indicators reached consensus, as shown in Tab.7.

Category	Mean	Indicator	Category	Mean	Indicator
Energy	5.2	Consumption of electricity per capita	Education	4.7	Number of universities, schools, colleges
	5.2	The use of renewable energy in the Chiang Mai area		4.6	Proportion of the undereducated population to the educated population
	5.1	Proportion of using renewable energy to total energy	Violence	4.9	Number of crimes
Environment quality	5.6	Air quality		4.6	Area per number of CCTV cameras
	5.3	Water	Culture	4.6	Number of festivals and traditions
	5.4	Waste		4.4	Database-number of local experts/craftsmen/artists
Land use	4.8	Population density		4.4	The number of museums that provide knowledge of the local culture
	5	Integrated town plan		4.3	Statistics on the number of tourists who come during the festival
	5.2	Ratio of green area to total area		4.4	Number of traditions
	4.3	Road area per total area	Convenience	4.1	Number of department stores and convenience stores
Transportation	5	Type of transport (public, individual)		4.2	Number of markets
	4.4	Number of public vehicles		4.3	Number of restaurants
	4.3	Vehicle usage rate	GPP	4.8	Total product value in Chiang Mai
	4.2	Number of stops and distribution of public transport	Creativity	4.5	Number of creative events and exhibitions
	4	Average travel per capita in different modes is connected to different fuel consumption		4.7	Number of local creative businesses

Facility	4.3	Utilities consumption rate	Innovation	4.7	Amount of innovation research
Health and wellbeing	4.7	Number of beds in the hospital		4.6	Number of agencies that support innovation research
	4.6	Number of doctors		4.4	Number of start-ups
	5.0	Duration and ease of access to the public health system	Trade	4.5	Amount of trade value
	4.5	Ratio of the elderly to the population	Tourism	4.6	Number of tourists
	4.2	Death rate		4.5	Number of accommodations
Population	4.8	Population		4.3	Statistics of foreign tourists and Thai people
	4.4	Latent population		4.3	Objectives of foreign tourism
Labor	4.6	Unemployment and employment rate		4.5	Number of days of provincial tourism for foreign and Thai tourists
	4.9	Average income per capita		4.5	Number of tourist attractions by type
Housing	4.5	Number of residences	service	4.5	Service business type
	4.0	Residential building type		4.6	Service business income per total provincial income

Tab.4 The mean value of indicators obtained from Round 2 of Delphi

Category	**Indicator**	**Category**	**Indicator**
Energy	SI1 Consumption of electricity per capita	Education	SI19 Number of universities, schools, colleges
	SI2 The use of renewable energy in the Chiang Mai area		SI20 Proportion of the undereducated population to the educated population
	SI3 Proportion of using renewable energy to total energy	Violence	SI21 Number of crimes
Environment quality	SI4 Air quality		SI22 Area per number of CCTV cameras
	SI5 Water	Culture	SI23 Number of festivals and traditions
	SI6 Waste		
Land use	SI7 Population density	GPP	SI24 Total product value in Chiang Mai
	SI8 Integrated town plan	Creativity	SI25 Number of creative events and exhibitions
	SI9 Ratio of green area to total area		SI26 Number of local creative businesses
Transportation	SI10 Type of transport (public, individual)	Innovation	SI27 Amount of innovation research
Health and wellbeing	SI11 Number of beds in the hospital		SI28 Number of agencies that support innovation research
	SI12 Number of doctors	Trade	SI29 Amount of Trade Value
	SI13 Duration and ease of access to the public health system	Tourism	SI30 Number of tourists
	SI14 Ratio of the elderly to the population		SI31 Number of accommodation
Population	SI15 Population		SI32 Number of days of provincial tourism for foreign and Thai tourists
Labor	SI16 Unemployment and Employment Rate		SI33 Number of tourist attractions by type
	SI17 Average income per capita	Service	SI34 Service business type
Housing	SI18 Number of residences		SI35 Service business income per total provincial income

Tab.5 The indicators obtained the prevalidated indicators

Category	Mean	Indicator	Category	Mean	Indicator
Energy	5.09	SI1 Consumption of electricity per capita	Education	4.91	SI19 Number of universities, schools, colleges
	5.36	SI2 The use of renewable energy in the Chiang Mai area		5.14	SI20 Proportion of the undereducated population to the educated population
	5.23	SI3 Proportion of using renewable energy to total energy	Violence	5.09	SI21 Number of crimes
Environment quality	5.55	SI4 Air quality		5.05	SI22 Area per number of CCTV cameras
	5.55	SI5 Water quality	Culture	4.91	SI23 Number of festivals and traditions
	5.55	SI6 Waste management			
Land use	5.09	SI7 Population density	GPP	5.05	SI24 Gross provincial products of Chiang Mai
	5.27	SI8 Integrated town plan	Creativity	4.95	SI25 Number of creative events and exhibitions
	5.27	SI9 Ratio of green area to total area		5.14	SI26 Number of local creative businesses
Transportation	4.95	SI10 Type of transport (public, individual)	Innovation	5.27	SI27 Amount of innovation research
Health and wellbeing	4.86	SI11 Number of beds in the hospital		5.09	SI28 Number of agencies that support innovation research
	5.05	SI12 Number of doctors	Trade	5.09	SI29 Amount of trade value
	5.27	SI13 Duration and ease of access to the public health system	Tourism	5	SI30 Number of tourists
	4.68	SI14 Ratio of the elderly to the population		4.95	SI31 Number of accommodation
Population	4.91	SI15 Population		4.95	SI32 Number of days of provincial tourism for foreign and Thai tourists
Labor	4.95	SI16 Unemployment and Employment Rate		4.86	SI33 Number of tourist attractions by type
	5.09	SI17 Average income per capita	service	5	SI34 Service business type
Housing	4.82	SI18 Number of residences		5.05	SI35 Service business income per total provincial income

Tab.6 The mean value of indicators obtained from Round 3 of Delphi

Category	Indicator	Mean	Percentage of panelists voting for indicators as							
			6	5	4	3	2	1	6 or 5 or 4	3 or 2 or 1
Energy	SI1	5.09	41	27	32	0	0	0	100	0
	SI2	5.36	45	45	10	0	0	0	100	0
	SI3	5.23	32	59	9	0	0	0	100	0
Environment quality	SI4	5.55	68	22	5	5	0	0	95	5
	SI5	5.55	50	45	5	0	0	0	100	0
	SI6	5.55	50	45	5	0	0	0	100	0
Land use	SI7	5.09	32	45	23	0	0	0	100	0
	SI8	5.27	40	50	5	5	0	0	95	5
	SI9	5.27	55	22	18	5	0	0	95	5
Transportation	SI10	4.95	32	40	18	10	0	0	90	10

Health and wellbeing	SI11	4.86	23	45	27	5	0	0	95	5
	SI12	5.05	27	50	23	0	0	0	100	0
	SI13	5.27	45	36	18	0	0	0	100	0
	SI14	4.68	18	40	32	10	0	0	90	10
Population	SI15	4.91	27	41	27	5	0	0	95	10
Labor	SI16	4.95	23	50	27	0	0	0	100	0
	SI17	5.09	23	64	14	0	0	0	100	0
Housing	SI18	4.82	23	45	22	10	0	0	90	10
Education	SI19	4.91	23	50	22	5	0	0	95	10
	SI20	5.14	40	40	10	10	0	0	90	10
Violence	SI21	5.09	45	23	27	5	0	0	95	5
	SI22	5.05	36	36	32	0	0	0	100	0
Culture	SI23	4.91	32	32	31	5	0	0	100	0
GPP	SI24	5.05	32	41	27	0	0	0	100	0
Creativity	SI25	4.95	32	32	36	0	0	0	100	0
	SI26	5.14	32	55	8	5	0	0	95	5
Innovation	SI27	5.27	45	41	9	5	0	0	95	5
	SI28	5.09	45	27	23	0	5	0	95	5
Trade	SI29	5.09	36	41	18	5	0	0	95	5
Tourism	SI30	5	27	55	8	10	0	0	90	10
	SI31	4.95	27	50	13	10	0	0	90	10
	SI32	4.95	23	58	14	0	5	0	95	5
	SI33	4.86	22	50	18	10	0	0	90	0
Service	SI34	5	18	68	9	5	0	0	95	5
	SI5	5.05	32	45	18	5	0	0	95	5

Tab.7 Consensus analysis

3.5 Development, validation, and consensus

From Round 1 of Delphi analysis, it was found that 54 indicators were obtained from the selection of the initial indicators and the indicators recommended by the experts. A new group of indicators was added from the experts' recommendations, the group of "Facility" totaling 19 indicator groups. These changes are based on preliminary indicators and expert recommendations. After the second Delphi analysis, the group of indicators and indicators was reduced to 17 and 35 indicators, respectively. The group of indicators that were excluded was the Facility and Convenience group. After the third Delphi analysis, it was found that the number of indicator groups and the number of indicators were 17 groups and 35 indicators, respectively. The indicator is still the same as that from the second Delphi, but some indicators were renamed to increase clarity of that indicator. In addition, it was found that the group of indicators with the highest mean value was the group of Environment quality indicators; all three indicators in this group had a mean value of 5.55. The next high mean value was the Energy indicator group, where the SI2 indicator had a mean of 5.36.

According to consensus, the indicators developed were confirmed, taking into account significance levels equal to or greater than 4.5 and a 6, 5, or 4 score equal to or greater than 75% based on the consensus analysis. The fraction of experts voting 6, 5, or 4 for 35 verified indicators was 100% for 14 indicators, 95% for 14, and 90% for 7; hence, all 35 indicators reached a consensus.

This research follows the Delphi method to identify and validate sustainable city indicators for Chiang Mai. Through the initial study, 64 indicators were initially acquired. Through the validation process, 54 indicators were reduced to 35 after specifying the importance level. In addition, 35 verified indicators remained the same after confirming the priority (prevalidated). All 35 reviewed indicators reached a consensus. The two most important indicators are "Environment quality" and "Energy." Therefore, these indicators may be used to evaluate the potential of Chiang Mai as a sustainable city.

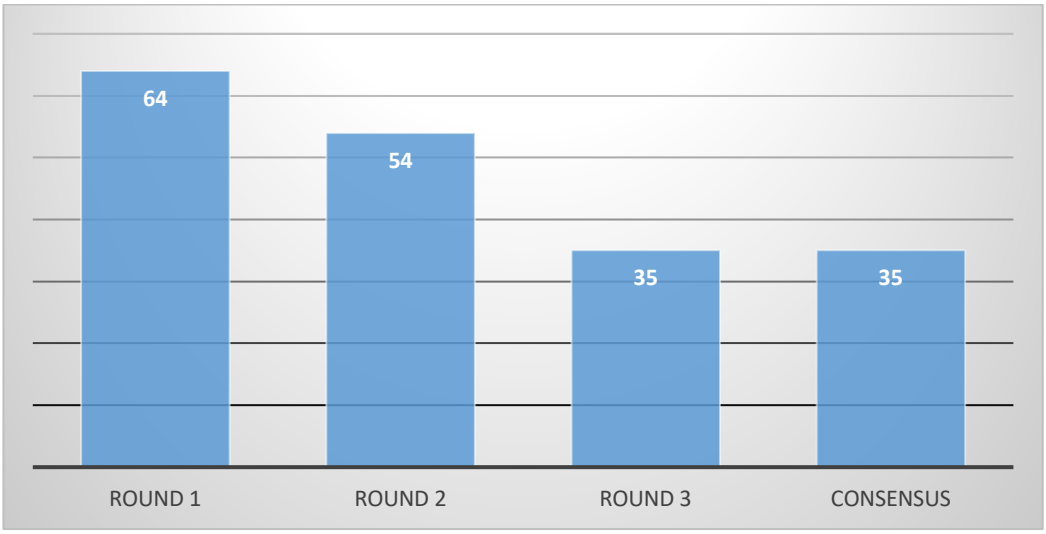

Fig.6 Number of indicators in each round

In future research, to use the indicators developed in this study to assess the sustainable city of Chiang Mai, a comprehensive assessment framework needs to be developed (Chan & Lee, 2019b; Chan & Lee, 2019a; Chan, 2020). This framework should incorporate the 35 identified indicators and other relevant indicators based on the specific needs and context of the city. Here are some steps that can be taken to use the developed indicators for assessing the sustainable city of Chiang Mai:

1. Identify the relevant sustainability dimensions - The sustainability dimensions that need to be assessed should be identified, such as environmental quality, social equity, economic growth, and governance;
2. Develop a comprehensive list of indicators - Based on the identified sustainability dimensions, a comprehensive list of indicators should be developed, including the 35 indicators identified in this study and other relevant indicators;
3. Collect data - Data should be collected for each indicator to evaluate the sustainability of the city. This data can be obtained from various sources, including government agencies, nongovernmental organizations, and academic research;
4. Analyze the data - The collected data should be analyzed to evaluate the sustainability of the city in relation to the identified sustainability dimensions and indicators;
5. Develop a sustainability report - The results of the analysis should be compiled into a sustainability report, which should include an overview of the sustainability status of the city, the identified strengths and weaknesses, and recommendations for improvement;
6. Develop a sustainability action plan: Based on the findings of the sustainability report, a sustainability action plan should be developed to guide the implementation of strategies and actions that will improve the sustainability of the city.

It is important to note that the developed indicators are specific to Chiang Mai and may not directly apply to other cities. Therefore, when using these indicators to assess the sustainability of other cities, adjustments and customization may be necessary to suit each city's specific needs and circumstances.

4. Conclusions

The study described here is an essential contribution to the field of urban development and sustainability, as it focuses specifically on identifying the indicators that impact sustainable urbanization in Chiang Mai. The use of multiple data sources and the Delphi method for data collection and analysis provide a robust framework for identifying these indicators and their applicability to the city. The study found that most indicators related to sustainable urbanization in Chiang Mai were related to environmental quality and energy. This suggests that efforts to promote sustainable urbanization in the city should focus on these areas. The indicators identified in this study can be used to evaluate the potential for sustainable urbanization in Chiang Mai. They can inform the development of a conceptual framework for planning a livable and sustainable city in the region. However, it is important to note that the indicators identified in this study may not be directly applicable to other cities. Each city's local context and specific conditions need to be considered when using these indicators to evaluate sustainable urbanization potential in other places. This requires careful adjustment and customization of the indicators to suit each city's specific needs and circumstances. Overall, this study provides a valuable contribution to the field of sustainable urban development and can be used to guide future efforts to promote sustainable urbanization in Chiang Mai.

The findings of this study can have practical implications for urban planners and policymakers in Chiang Mai, providing a roadmap for promoting sustainable urbanization and improving the overall livability of the city. The indicators identified in this study can inform the development of policies and strategies to enhance the quality of the environment, energy efficiency, and other key factors that contribute to sustainable urbanization. For future research, this study can serve as a foundation for further investigations into sustainable urbanization in Chiang Mai and other cities. Researchers can build upon the identified indicators and use them as a framework for evaluating the sustainability of other cities and identifying areas for improvement. This research can also include a more comprehensive assessment of other sustainability dimensions, such as social equity, economic growth, and governance. In summary, the findings of this study provide a valuable contribution to the field of sustainable urbanization and can inform efforts to promote livable and sustainable cities in Chiang Mai.

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