Abstract: Sustainable development is the concept of coordinating people and the environment and achieves contemporary development without compromising the interests of the next generation. It can also be thought of as not exceeding the biosphere’s carrying capacity. Urban metabolism emphasizes resource recycling and use to achieve balance between resource input and product output in urban areas. However, the scale of cities has expanded rapidly in recent years along with resource and energy demands. Waste and pollution also cause major threats to the environment and ecology. Given increasingly serious environmental problems, the original linear metabolism must be converted into a cyclical one to ensure urban sustainability. From the policy implementation report of Taipei City, this study used the fuzzy Delphi method to develop evaluation factors and integrated this with the analytic network process decision-making tool to determine the priority weights of each policy and evaluate development strategies for urban development based on the metabolism concept. The study results reveal that natural environmental sustainability and sustainable energy strategies were prioritized plans for evaluating urban development with the metabolism concept, and the results can be used as a reference for future urban development strategies.

Keywords: urban metabolism; fuzzy Delphi method; analytic network process

1. Research Motivation and Objectives

Sustainable development can be interpreted as maintaining or expanding the production and use of resources, maintaining the integrity of the resource base so that natural resources are available to humans in perpetuity and are not depleted to the detriment of the production and livelihood of future generations. It can also be interpreted as developmental needs for material and energy not exceeding the regeneration capacity and waste absorption ability of the biosphere [1]. All countries regard sustainable development as the highest guiding principle for environmental problems [2]. In addition to environmental issues, human society must be committed to the sustainable development of cities and deeply understand urban systems for favorable urban management [3]. Cities are dynamic, complex, and large-scale areas that are centers of human production and consumption. Urban development can be divided into four major structures: substantive development, society and economics, the natural environment, and the living environment. From energy and material inputs, urban development produces numerous unsustainable phenomena, such as traffic congestion, air pollution, and massive energy consumption [4]. Given increasingly serious environmental issues, Wolman [5] proposed discussing pollution problems in urban environments from the perspective of urban metabolism, which aims “to maintain the materials and goods required by city residents at home, work, and leisure activities, which also include inputs for living and construction.” Wolman emphasized the resource–waste relationship, reminding residents that some pollution occurs from using each resource and that only proper use can reduce environmental harm.
Among studies promoting urban sustainable development, establishing a mechanism that measures the sustainability of urban development is a key task for understanding the developmental trend of cities. Agenda 21, proposed at the 1992 Earth Summit, noted that the indicator system is a method of evaluating whether the developmental trends of each country are consistent with sustainability [6]. Moreover, Chapter 40 of Agenda 21 invoked the establishment of national, regional, and global sustainable development indicators. With reference to the issues of urban sustainability in recent years, it can be found that some issues and indicators are established from the perspective of “metabolism”. The metabolism concept originated from biology studies on organisms and ecology studies on ecosystems. Due to similarities in structure and function between natural and social ecosystems, the metabolism concept has gradually been introduced into the study of social ecosystems, which mainly refers to the materials required by urban residents for living and wastes and pollutants produced by them. However, unlike biological systems, this metabolism is cyclical but not complete until waste generated during production and consumption is properly treated in cities.

Several foreign cities have gradually established their own urban metabolism indicators. For example, the European Environment Agency of the European Union released urban metabolism indicators in 2011, which were constructed and developed from four major aspects: urban mobility, urban type, urban life, and urban quality [7]. Few Taiwanese studies have explored urban metabolism [8–10]. Most have focused on analyzing cities by energy flow and few have focused on constructing urban metabolic indicators through social network analysis. Therefore, this study established evaluation indicators of urban metabolism in Taiwan to explore the urban development strategies of Taipei City through social network analysis of metabolism and compared both analysis methods. With this research motivation, the research objectives of this study were as follows:

1. Summarize appropriate evaluation criteria through literature review and data collection to establish urban metabolism indicators.
2. Evaluate Taipei City’s urban development strategies based on the metabolism concept.

2. Literature Review

The literature review introduces the definition of urban metabolism and identifies relevant Taiwanese and foreign studies that explore the indicator evaluation criteria. The second part discusses urban metabolism with sustainable development to clarify the relationship between sustainable development and urban metabolism.

2.1. Urban Metabolism

Urban metabolism evolved from the biological concept and was first proposed by Theodor Schwann in the 19th century. The researchers of urban metabolism have compared cities to biological organisms. Organisms need energy and resource inputs, transform them to do work, and produce waste, much like cities do [11,12]. The basis for Theodor Schwann’s proposal was derived from Marx’s economic philosophy [13,14]. Moreover, some contemporary critical urban theorists such as Sywngedeou, Kaika, and Heynen, among others, have approached urban metabolism from a neo-Marxist perspective, using Marx’s approach for “analyzing the dynamic internal relationships between humans and nature” [8]. Although the metabolism concept was proposed early on, it had not been studied until recently. First, Wolman [5] applied urban metabolism to examine rising pollution problems in the urban environment by using the city as an ecosystem metaphor and discussed the entry of materials and energy into the urban system. Due to shortages of resources and unreusable pollutants in urban environments, externalities affecting human health are generated. In addition, Girardet [9] asserted that a cyclical metabolism must be designed for ecocity development. Cyclical urban development refers to establishing a material and energy cycle in cities to reduce environmental burdens and allow city interiors to digest and metabolize themselves to not affect other environments [10]. Therefore, urban metabolism is the sum of technological and socio-economic processes that occur in urban areas and cause urban growth, energy production, and waste emission [15].
which indicates that metabolic actions are a form of cities [16]. It is also necessary to carry out material and energy metabolism in order to achieve the goal of sustainable development.

Urban metabolism emerged in the late twentieth century as a systems-based approach to know urban trajectories of resource use, waste production, and associated impacts on the environment. Although some have suggested that cities are more like ecosystems—the summing up of many metabolisms [12,17]. However, urban metabolism is the term of art in the industrial ecology community. It is increasingly in geography, planning, and other related disciplines and dimensions. Therefore, urban metabolism provides a metaphorical framework to examine natural–human systems [5,15,18,19] and provides a basis upon which to consider sustainability implications.

2.2. Sustainable Development Indicators

The sustainable development concept was proposed in 1987 to account for the environment, society, and the economy. All are indispensable and have no bias [20] The Seattle Comprehensive Plan [21] noted that sustainable cities use resources efficiently; constantly reuse, recycle, and use local resources as much as possible; minimize ecological damage from production and use; allocate resources fairly; balance growth and resilience needs; and use resources cautiously [20] Sustainable development has gradually become the guiding principle for development in various countries, and the importance of sustainable urban development to global sustainable development is mainly because cities are human consumption centers. In addition to the consumption of large amounts of resources, waste emission poses a major threat to the protection and production of ecosystems [22].

To enable cities to achieve sustainable development, urban governance must check urban development trends, overcome unsustainable urban development problems, and establish a mechanism to measure the sustainability of urban development [4] Evaluation of urban development mostly uses an indicator system to formulate criteria for evaluating resource use. The indicator system is a method that can be used to evaluate whether development trends in countries meet sustainability principles [6]. Without these standards, performance levels cannot be determined and policy decisions or resource reallocation cannot be revised. Sustainable development indicators include information on environmental, social, and economic elements [23]. They are simple, integrative, and forward looking and have gradually been widely used as an evaluation tool for urban sustainable development.

2.3. The Link between Sustainable Development Indicators for Urban Metabolism

Metabolism also has its own research indicators, such as water resources, noise, and waste disposal proposed in earlier stages. Newman [24] added social issues and characteristics, including residents’ health, employment rate, income, and education into the urban metabolism model, which is called “livability”. He integrated vitality into the general model of urban metabolism to expand discussion of it. He affirmed that a sustainable city should consider material flow amount and include human vitality (e.g., social environment and health). Pincetl [25] claimed that, in addition to conventional material flow and pollution, sustainable urban metabolism should focus on humans and society. The study determined that considering economics, health, accessibility or mobility, equity, community quality, policies and regulations, education, and employment is necessary to reflect local needs and provide information for decision makers. Furthermore, Rosales [26] agreed that urban metabolism can serve as a reference for sustainable development and noted that sustainable development indicators can be applied for early urban development. He also proposed that many current indicators are limited to specific areas (e.g., environment and economics) and a comprehensive indicator is required for urban sustainable development. For indicator evaluation, urban metabolism can be analyzed to understand the degree of flow between energy and resources [26]. Urban metabolism is widely applied in sustainable development. In addition to basic material flow analysis, many planners apply it to the sustainable community and urban development framework [27,28]. Kennedy [15] explored the relationship between neighborhood design and urban metabolism in a study that used the four aspects of urban metabolism to study the Toronto community, including whether the development
of energy-efficient buildings and mass transit affected the neighborhood metabolism. Moreover, he highlighted the need to evaluate whether unplanned factors affect other regions (e.g., climate change, because drastic climate change produces various global effects). Exploring climate change from the metabolism perspective can provide information regarding resource use. For example, Mediterranean cities may suffer from heat and water resource problems. By using urban metabolism, water use and energy demands can be understood to propose policies on increasing a city’s adaption and response to disasters. The European Environment Agency released urban metabolism indicators in 2011; constructed metabolism indicators from urban mobility, urban pattern, urban life, and urban quality; and used them as development guidelines [7] to propose strategies such as waste recycling. Another application was in the Hammarby Sjöstad district of Sweden. The development guiding principle of this district involves cyclical urban metabolism. Conke [29] used Curitiba, Brazil, as a research region to measure the changes in material and energy use that occurred in the city between the years of 2000 and 2010. The final results revealed for Curitiba (and any other city that supposedly takes sustainability seriously) that the need for continuous development should be considered together with the consequent environmental impact, both well measured by the urban metabolism approach. Urban metabolism has become an important tool to understand how the development of one city causes impacts to the local and regional environment and to support a more sustainable urban design and planning. D’Amico [30] explores existing international indicators using the concept of Smart Metabolism and identifies eight international indicator systems that meet their research objectives. The final results show that ISO 37122 and UNECE-ITU standards are the most balanced in terms of economic, environmental, and social aspects of urban metabolism. The ISO 37122 [31] indicators include economics, education, energy, environment and climate change, finance, governance, health, housing, population, and social conditions, recreation, security, solid waste, sports and culture, telecommunications, transport, agriculture, urban planning, wastewater, and water. As for UNECE-ITU, it is a framework of smart sustainable indicators developed by the UN in cooperation with the International Telecommunication Union, and others stakeholders evaluate the urban smartness and the metabolism of urban contexts to comply with the Sustainable Development Goals [32]. To balance between development and environmental management, cities must aim for sustainable development to prevent the continuous expansion of problems between ecology and the environment. This study defined urban metabolism according to the circular urban metabolism mentioned by van Broekhoven [10] including the cycle of material, energy and social issues [24] to reduce the burden on the city. Previous studies have indicated that urban metabolism is a type of sustainable development but differs from the comprehensive nature of sustainable development. Early studies on urban metabolism have focused on the relationship between materials and energy. However, recent studies have incorporated other social relationships into urban metabolism theory. The importance of current urban metabolism research lies in the study of urban metabolic parameters. Experts can evaluate the influence of urban development on the environment through studying parameters. With clear data, relevant parameters can become a standard for sustainable development indicators and a reference for urban development policies [13,33,34]. Therefore, this study classified sustainable development into social, environmental, and economic areas as preliminary indicators. Moreover, this study referred to early-stage basic material flow metabolic indicators in the literature, such as research by Conke [29], Rosales [26], Kennedy [13], and Newman [24], who discuss water resources, air pollution, noise pollution, and social and economic characteristics such as health, population, infrastructure, and urban space. These factors were added to form comprehensive metabolism indicators. A total of 18 indicators were finally summarized. (Figure 1) In particular, three major indicator classifications in this study were only for the convenience of developing preliminary indicators through the fuzzy Delphi method and were not used for comparison in subsequent studies.
3. Research Methods and Procedures

This study explored metabolism and strategic development for urban areas. According to Taiwan’s urban development process, Taipei City (which is heavily urbanized) was selected as the research scope, and its urban development strategies were used for empirical analysis. This study first used the fuzzy Delphi method to identify the urban metabolism factors and conduct policy evaluations from expert consensus guidelines. Because urban development policy involves multicriteria decision-making considerations, the evaluation was analyzed through the analytic network process (ANP) to obtain a suitable reference plan. The research framework is as displayed in Figure 2.

![Research framework](image)

**Figure 2.** Research framework.

3.1. Fuzzy Delphi Method

The fuzzy Delphi method is the conventional Delphi method combined with fuzzy set theory. Ishikawa et al. [35] introduced and improved fuzzy theory into the Delphi method (i.e., concepts from cumulative frequency distribution and fuzzy integrals were used to integrate experts’ opinions into fuzzy numbers), which is called the fuzzy Delphi method. The fuzzy Delphi method proposed by Jeng [36] is more objective and reasonable than the general single-triangular fuzzy number used to obtain geometric mean. Therefore, this study adopted Jeng’s double triangular fuzzy numbers to integrate experts’ opinions, used a gray zone test to check whether experts’ opinions reached convergence, and screened urban metabolism evaluation indicators. The expert questionnaire contains conservative and optimistic values. Experts are asked to check the conservative and optimistic values for maximum and minimum acceptable range, and then the conservative and optimistic values obtained for all indicators are checked to achieve a consensus value and to filter the indicators. (Figure 3) In...
this study, 18 urban metabolism-related indicators were compiled through a literature review and screened through the fuzzy Delphi method. In this study, 18 urban metabolism-related indicators were compiled through a literature review and screened through the fuzzy Delphi method. The indicators selected using the fuzzy Delphi method will be discussed at an expert meeting and each indicator will be explicitly defined to enable the next step of the ANP method to identify interactions between the indicators and their weights.

\[ C^i : \text{Conservative value} \]
\[ C^i_L : \text{Minimum conservative cognitive value} \]
\[ C^i_M : \text{Conservative cognitive mean value} \]
\[ C^i_U : \text{Maximum conservative cognitive value} \]
\[ O^i : \text{Optimistic value} \]
\[ O^i_L : \text{Minimum optimistic cognitive value} \]
\[ O^i_M : \text{Conservative optimistic mean value} \]
\[ O^i_U : \text{Maximum optimistic cognitive value} \]
\[ G^i : \text{Expert consensus value} \]

3.2. Analytic Network Process

The ANP method was proposed by Saaty [37] and is mainly based on the assumption that the early analytic hierarchy process (AHP) must have independent restrictions between hierarchical elements. The ANP includes concepts of dependence and feedback and is a modification of the AHP, which can be regarded as a special case of the ANP. The ANP is a systematic method of confirming organizational goals and priority weight values to reach decisions. The network relationship of the ANP can present correlations between criteria and calculate limiting influence between each control criterion to form a supermatrix. (Figure 4) This study explored nine indicators screened from the fuzzy Delphi method. The interdependence between indicators was determined using expert meetings and a literature review. Super Decision 3.20 was used as an operating tool to obtain interdependent weights between indicators, compare these with the six urban development strategies summarized, and finally select a strategy suitable for evaluating urban development with the metabolism concept.
According to the literature review, indicator selection was based on 18 indicators initially proposed for urban metabolism, followed by an expert questionnaire combined with the fuzzy Delphi method and referring to the relevant literature. Studies such as those by Lo [38], Wu and Ho [39], and Chiang and Wu [40] have mentioned that the threshold is typically set at 6.0–7.0 if the questionnaire range value is 0–10. The threshold value setting is generally based on the geometric mean of expert consensus [41] 2017. This study also selected appropriate factor items by referring to the method proposed by Ishikawa [35] (1993), in which geometric mean is used to represent the consistency of expert consensus (Gi) as the threshold.

Nine valid questionnaires were collected in this study, and participants comprised experts from the industry, government, and academia who majored in urban planning and urban design and understood urban development. This study used the geometric mean of expert consensus (Gi = 6.93) as the threshold value and finally selected nine evaluation indicators as vital criteria influencing Taipei City’s urban development strategy for the next ANP stage. A total of nine indicators obtained a high consensus value by the fuzzy Delphi method (Table 1), namely resource reuse, water resources, waste disposal, and green coverage rate in the environmental dimension; open space, health, and infrastructure in the social dimension; and green transportation and energy use efficiency in the economic dimension. This signified that the experts reached a consensus for the nine indicators and considered that these indicators were more crucial than other factors in evaluating urban development with the concept of urban metabolism. For a detailed description of the indicators, please see Table A1 in Appendix A.

### Table 1. Statistical analysis results of selected evaluation indicators.

| Evaluation Indicators       | Min (Ci) | Max (Oi) | Min Max | Min Max | Min Max | Min Max | Ci | Oi | Singular Value (a) | Geometric Mean | Singular Value | Test Value (Zi) | Expect Consensus (Gi) |
|-----------------------------|----------|----------|---------|---------|---------|---------|----|----|-------------------|----------------|---------------|----------------|---------------------|
| Resource reuse              | 5 7      | 8 10     | 6 8     | 6.07    | 8.84    | 7.34    | 3.77| 7.46 | 6.93              |                |               |                | 6.93                |
| Energy use efficiency       | 2 8      | 7 10     | 5 9     | 5.12    | 8.81    | 7.37    | 2.69| 7.39 | 6.93              |                |               |                | 6.93                |
| Green transportation        | 3 7      | 8 10     | 7 8     | 5.68    | 8.99    | 7.74    | 4.31| 7.33 | 6.93              |                |               |                | 6.93                |
| Infrastructure              | 3 8      | 7 9      | 5 9     | 4.58    | 8.34    | 6.41    | 2.77| 7.28 | 6.93              |                |               |                | 6.93                |
| Waste disposal              | 5 7      | 8 9      | 7 8     | 5.71    | 8.74    | 7.12    | 4.03| 7.23 | 6.93              |                |               |                | 6.93                |
| Green coverage rate         | 2 8      | 8 10     | 7 9     | 5.61    | 8.84    | 7.56    | 3.23| 7.23 | 6.93              |                |               |                | 6.93                |
| Water resources             | 5 7      | 7 10     | 6 8     | 5.69    | 8.58    | 7.22    | 3.12| 7.14 | 6.93              |                |               |                | 6.93                |
| Health                      | 4 8      | 8 10     | 6 9     | 5.45    | 8.73    | 7.57    | 3.28| 7.09 | 6.93              |                |               |                | 6.93                |
| Open space                  | 2 8      | 8 10     | 6 8     | 5.33    | 8.73    | 7.22    | 4.39| 7.03 | 6.93              |                |               |                | 6.93                |
| Air quality                 | 3 8      | 6 10     | 5 9     | 5.38    | 8.20    | 6.79    | 0.81| 6.91 |                |                |               |                |                   |
| Energy self-sufficiency rate| 2 8      | 6 10     | 4 9     | 4.77    | 8.29    | 6.72    | 1.52| 6.83 |                |                |               |                | 6.83                |
| Population structure        | 2 7      | 8 9      | 7 8     | 5.05    | 8.61    | 7.36    | 4.56| 6.83 |                |                |               |                | 6.83                |
| Alternative energy use efficiency | 3 7      | 8 9      | 6 8     | 4.98    | 8.36    | 6.85    | 4.38| 6.67 |                |                |               |                | 6.67                |
| Ecosystem diversity         | 3 7      | 6 9      | 5 8     | 4.84    | 7.80    | 6.26    | 1.96| 6.45 |                |                |               |                | 6.45                |
| Cultural/artistic facilities| 2 7      | 7 10     | 5 8     | 4.59    | 8.19    | 6.42    | 3.61| 6.39 |                |                |               |                | 6.39                |
| Working population          | 2 6      | 7 9      | 6 7     | 4.44    | 7.85    | 6.48    | 4.42| 6.14 |                |                |               |                | 6.14                |
| Urban design                | 3 6      | 7 10     | 5 9     | 4.38    | 7.82    | 6.39    | 4.45| 6.30 |                |                |               |                | 6.30                |
| Noise                       | 2 6      | 5 9      | 4 8     | 3.88    | 7.09    | 5.84    | 2.20| 5.50 |                |                |               |                | 5.50                |
| Geometric mean              |          |          | 6.93    |         |         |         | 6.93| 6.93 |                |                |               |                |                   |

Note: Gray highlighted values are evaluation indicators that passed a threshold of 6.935. Empirical analysis of Taipei City.
This study selected Taipei City, which is highly urbanized, as the research scope. Because the literature review mentioned that urban metabolism indicators affect planners’ decision-making considerations, a case study and analysis were performed referring to various policies in the policy implementation report of Taipei City over the past 3 years. The 2016–2018 Taipei City development strategies [42] were summarized, and the plans of six major selected strategies were sorted and divided into “S1 Natural Environment Sustainability”, “S2 Improving Man-made Environment”, “S3 Transportation Development”, “S4 Revitalizing Urban Space”, “S5 Energy Sustainability Policy”, and “S6 Health”. Subsequently, an expert questionnaire combining with the AHP and ANP was used to explore plan weights. Natural environment sustainability policy included resource reuse items such as establishing sewage treatment and systems, strengthening water resource treatment in the Tamsui River system, food waste recycling, furniture recycling, and establishing recycling boxes for second-hand books. In addition, improving the man-made environment included monitoring air quality, reducing noise, and enhancing environmental quality. A capital monitoring network can be constructed and indoor air quality in public places can be controlled through promoting air quality maintenance zones. The transportation development strategy mainly encouraged green vehicles, increased the number of bicycle stations and lanes, subsidized electric vehicle and bicycle purchases, set up smart bus stop signs, and combined smart card transaction data to estimate the number of distributed bus trips. Moreover, urban space revitalization increased the number of sidewalks and permeable pavements and green resource areas in parks to create a convenient mountain-friendly leisure environment and link large green spaces in parks with green corridors. Greening the roofs and facades of buildings can also enhance greenery and air quality for healthy living. Furthermore, energy sustainability focused on using green and renewable energy, such as improving waste incineration efficiency for power and hydropower generation and encouraging the establishment of solar photovoltaic energy for buildings, parks, and green spaces. Finally, health strategies included building a sports city, optimizing sports complexes, and promoting diversified sports activities to enhance community health, create elder-friendly environments, and improve long-term care for older adults.

Nine metabolism indicators obtained through the fuzzy Delphi method and six aforementioned strategies were compared and evaluated to identify an appropriate development strategy. (Figure 5)

This study collected nine valid questionnaires completed by experts from various fields in industry, government, and academic sectors who majored in urban planning and urban design and understood urban development in August 2019. The geometric mean of the criteria was obtained from results selected by each expert. With the geometric mean, the interdependence and importance between criteria can be clearly understood. The mean obtained was essential for future analysis of inputs in Super Decisions (v3.20). During data input, note that when the indicators were compared with each other, the diagonal elements in matrix Aij (i = j) were the maximum value in the same rows, indicating that the indicator itself had the most crucial influence on the target under this criterion. For example, when C1 was compared with C2 and C9, C1 was the most crucial item because it was a standard for considering the possibility of being affected or affecting other indicators. Hence, the geometric mean of C1–C1 was the largest. The matrix calculation results are presented in Tables 2 and 3.
Figure 5. Hierarchical structure of urban metabolism and urban development evaluation items. An urban development strategy is a multicriteria decision analysis, and each indicator is interdependent. The interdependence between the evaluation criteria was not pre-established, and an interdependent relationship was generated between criteria obtained from an experts’ round table forum (e.g., C3 waste disposal criterion affected C1 resource reuse) (Figure 6). Remaining criteria were considered noninterdependent because they did not directly affect resource reuse. Therefore, only after confirming the interdependence between criteria, this relationship could be analyzed through interactive connectivity operations with the analytic network process (ANP) network method (operating in a supermatrix manner). Finally, the weights of each plan could be obtained accordingly.

Table 2. Weighted supermatrix of urban development strategies.

| Indicator | C1   | C2   | C3   | C4   | C5   | C6   | C7   | C8   | C9   |
|-----------|------|------|------|------|------|------|------|------|------|
| C1        | 0.454| 0.000| 0.417| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|
| C2        | 0.358| 0.822| 0.000| 0.000| 0.000| 0.246| 0.000| 0.319| 0.000|
| C3        | 0.000| 0.000| 0.350| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|
| C4        | 0.000| 0.000| 0.000| 0.554| 0.206| 0.000| 0.000| 0.000| 0.000|
| C5        | 0.000| 0.000| 0.000| 0.000| 0.378| 0.000| 0.000| 0.000| 0.000|
| C6        | 0.000| 0.000| 0.000| 0.000| 0.276| 0.560| 0.000| 0.000| 0.000|
| C7        | 0.000| 0.178| 0.000| 0.000| 0.140| 0.193| 1.000| 0.000| 0.000|
| C8        | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.519|
| C9        | 0.187| 0.000| 0.233| 0.446| 0.000| 0.000| 0.000| 0.000| 1.000|

| Policy  | S1   | S2   | S3   | S4   | S5   | S6   |
|---------|------|------|------|------|------|------|
| S1      | 0.246| 0.385| 0.415| 0.159| 0.180| 0.320|
| S2      | 0.123| 0.134| 0.172| 0.138| 0.236| 0.214|
| S3      | 0.204| 0.080| 0.059| 0.395| 0.080| 0.053|
| S4      | 0.109| 0.122| 0.075| 0.109| 0.340| 0.256|
| S5      | 0.264| 0.222| 0.190| 0.133| 0.050| 0.084|
| S6      | 0.054| 0.057| 0.088| 0.067| 0.114| 0.074|
Figure 6. Interdependence among metabolism indicators.

Table 2 is the weighted supermatrix established to comply with the column-stochastic principle (i.e., column sum value = 1), and multiple self-multiplications of the weighted supermatrix gradually converged to present equal numbers in each row. This matrix with a fixed weight value is the limit supermatrix or irreducible matrix, and weights in the matrix are relative weight values that consider interdependencies (Table 2). According to Table 3, the matrix exhibited convergence, stability, and consistency after long-term equalization. The dependence gradually converged to obtain a fixed value after the supermatrix was multiplied multiple times. The limit value was fixed to obtain the overall relative weight of each evaluation factor [43].

Table 3. Limit supermatrix of urban development strategies.

| Indicator | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|-----------|----|----|----|----|----|----|----|----|----|
| C1        | 0.059| 0.059| 0.059| 0.059| 0.059| 0.059| 0.059| 0.059| 0.059|
| C2        | 0.470| 0.470| 0.470| 0.470| 0.470| 0.470| 0.470| 0.470| 0.470|
| C3        | 0.035| 0.035| 0.035| 0.035| 0.035| 0.035| 0.035| 0.035| 0.035|
| C4        | 0.068| 0.068| 0.068| 0.068| 0.068| 0.068| 0.068| 0.068| 0.068|
| C5        | 0.037| 0.037| 0.037| 0.037| 0.037| 0.037| 0.037| 0.037| 0.037|
| C6        | 0.075| 0.075| 0.075| 0.075| 0.075| 0.075| 0.075| 0.075| 0.075|
| C7        | 0.126| 0.126| 0.126| 0.126| 0.126| 0.126| 0.126| 0.126| 0.126|
| C8        | 0.048| 0.048| 0.048| 0.048| 0.048| 0.048| 0.048| 0.048| 0.048|
| C9        | 0.080| 0.080| 0.080| 0.080| 0.080| 0.080| 0.080| 0.080| 0.080|

| Policy | S1 | S2 | S3 | S4 | S5 | S6 |
|--------|----|----|----|----|----|----|
|         | 0.294| 0.150| 0.112| 0.140| 0.195| 0.108|
| S2     | 0.150| 0.150| 0.112| 0.140| 0.195| 0.108|
| S3     | 0.112| 0.112| 0.112| 0.140| 0.195| 0.108|
| S4     | 0.140| 0.140| 0.140| 0.140| 0.195| 0.108|
| S5     | 0.195| 0.195| 0.195| 0.195| 0.195| 0.108|
| S6     | 0.108| 0.108| 0.108| 0.108| 0.108| 0.108|

Table 2 is the weighted supermatrix established to comply with the column-stochastic principle (i.e., column sum value = 1), and multiple self-multiplications of the weighted supermatrix gradually converged to present equal numbers in each row. This matrix with a fixed weight value is the limit supermatrix or irreducible matrix, and weights in the matrix are relative weight values that consider interdependencies (Table 2). According to Table 3, the matrix exhibited convergence, stability, and consistency after long-term equalization. The dependence gradually converged to obtain a fixed value after the supermatrix was multiplied multiple times. The limit value was fixed to obtain the overall relative weight of each evaluation factor [43].

Because Super Decisions can obtain the geometric mean limit weight of the supermatrix and the sum of this weight is not necessarily equal to 1, normalization was used to represent the final weight.
value. The results of the strategy weights were 0.294, 0.195, 0.150, 0.140, 0.112, and 0.108 for strategies S1, S5, S2, S4, S3, and S6, respectively, in descending order. Therefore, for overall evaluation options, natural environment sustainability and energy sustainability policies should be the highest priorities in urban development under the metabolism concept, and this does not mean that the other four policies have not contribute to the criteria.

Regarding current Taipei City development strategies, the Taipei City government adopted “Sustainable Taipei Eco-City” as its planning vision in recent years to focus on the strategies for natural environment sustainability and energy sustainability. Under this vision, the government proposed corresponding strategies aimed at environmental ecology, water resource treatment, resource reuse, and flood control. Various departments have suggested numerous action plans, such as the “Reborn Festival” held in 2019, which included a music festival and second-hand market with the theme of “free from waste”. Recyclable materials or those with low environmental impact were used from the stage design to the layout of the music festival, with expectations of reusing them in the future. The second-hand market was open to the public for goods exchanges. In addition, the Department of Environmental Protection, Taipei City Government, also organized a points collection event, in which people can earn points by taking public transportation or recycling resources, and the points can be exchanged for goods. Government agencies should strengthen key performance indicators with regular monitoring and tracking and encouraging citizens to participate in activities such as seminars or family activities. The environmental protection concept can be introduced into daily life by providing environmental education to elementary school students and, through experience activities, encouraging people to care for environmental problems and to understand the importance of natural ecology and coexistence with the environment, thereby protecting the environment.

Regarding energy sustainability strategies, energy conservation has always been a key strategy of Taipei City and is mainly promoted to the public through events, mobile billboards, and videos. In addition, green energy tends to focus on solar energy, such as by expanding renewable energy applications, establishing biomass energy plants, building energy-saving smart public houses, establishing smart grids for institutions and schools, and encouraging enterprises and private sector to invest in green energy to create a livable and sustainable “Sunshine Capital.” The Department of Environmental Protection promoted the “Taipei Energy Hill” project and built the first landfill solar power plant in the Fudekeng Environmental Restoration Park, Wenshan District. For the continuous implementation of solar photovoltaic systems, the Taipei City government will also apply a public–private partnership model to build solar photovoltaic systems on the roofs of public institutions, schools, public houses, and residential houses. Recently, landfill in Nangang district was converted into a solar power generation area that generates biogas power, and this successfully transformed into a green energy environmental protection and education park integrating environmental education, ecological protection, and green energy generation. The government should strengthen the promotion of smart grids and solar panels, organize regional seminars or events to communicate with the people, and use incentive measures to encourage people to participate and move toward sustainable development together.

5. Discussions

The fuzzy Delphi method and ANP were used to construct metabolism evaluation indicators and to identify the policy priority value among urban development strategies evaluated based on the metabolism concept, hoping to consider various levels and obtain objective results. Because of the interdependent characteristics of urban development strategy selection, objective and reasonable reference information for decision making is necessary to obtain complete results. The selected plan in this study was expected to correspond with the actual situation and have an accurate reference value for urban development strategies. The results and conclusions of the study are summarized as follows:

(1) Through a literature review and fuzzy Delphi calculations on expert questionnaires, evaluation indicators for urban metabolism were developed. The indicators were divided into economic,
social, and environmental aspects, including resource reuse, energy use efficiency, green transportation, infrastructure, waste disposal, green coverage rate, water resources, health, open space, air quality, energy self-sufficiency rate, population structure, alternative energy use efficiency, ecosystem diversity, cultural/artistic facilities, working population, urban design, and noise, and were used as a preliminary structure to conduct expert questionnaires. Analysis of the fuzzy Delphi method revealed that expert consensus was high. Experts discussed the importance of evaluation indicators according to designated thresholds. Based on the geometric mean of 6.93, a consensus value of 7.00 was set as a threshold to screen out indicators. Nine indicators were finally selected: resource reuse, energy use efficiency, green transportation, infrastructure, waste disposal, green coverage rate, water resources, health, and open space.

(2) Expert questionnaires with the fuzzy Delphi method in the first stage were the basis of the second stage at which the ANP was performed. According to the policy implementation report of Taipei City over the past 3 years, six strategies were summarized: Natural Environment Sustainability, Energy Sustainability, Improving Man-Made Environment, Revitalizing Urban Space, Transportation Development, and Health. The actual importance weight was obtained through the matrix statistical operation for the second-stage AHP questionnaire. After considering the interdependencies of indicators, actual weights \( W_c \) were acquired: \( C_1 \) resource reuse = 0.059, \( C_2 \) water resources = 0.470, \( C_3 \) waste disposal = 0.035, \( C_4 \) green transportation = 0.068, \( C_5 \) open space = 0.037, \( C_6 \) green coverage rate = 0.075, \( C_7 \) health = 0.126, \( C_8 \) infrastructure = 0.048, and \( C_9 \) energy use efficiency = 0.080. Indicators with high importance level comprised water resources, followed by health and then energy use efficiency.

(3) Regarding urban development policy evaluation based on the metabolism concept, the study results (Figure 7) reveal that S1 Natural Environment Sustainability (29.4%) and S5 Energy Sustainable Development (19.5%) were crucial and prioritized plans. These results were consistent with the analysis results of selected indicators, and S2 Improving Man-Made Environment (15.0%), S4 Revitalizing Urban Space (14.0%), and S3 Transportation Development (11.2%) exhibited small differences in values, which were secondary urban development policy considerations.

![Figure 7. Strategy-selected weights through the ANP method.](image)

(4) Natural environment sustainability obtained the highest weight value. Because Taipei City planned a “Sustainable Taipei Eco-City” for environmental sustainability, this study proposed corresponding strategies under its vision for environmental ecology, water treatment, resource reuse, and flood control. The government should strengthen the establishment of key performance indicators with regular monitoring and tracking, encourage citizens to participate in activities (e.g., seminars or family activities), and introduce the environmental protection concept into
people’s daily lives. Moreover, environmental education can be conducted for elementary school students. Energy sustainability strategies can be initiated in public institutions, such as by building smart grids and solar panels and converting idle waste landfills into solar power parks to expand green energy generation. In addition, the government can strengthen the promotion of smart grids and solar panels, organize regional seminars or events, communicate with the public, and use incentive measures to encourage people to participate and move toward sustainable development together.

Circular metabolism is essential to reducing urban material flows and social processes that cause urban growth, energy production, and waste emission and achieving sustainable development. The research results on urban metabolism can be incorporated as future guiding principles and planning indicators of early-stage urban development, such as in foreign countries that use the metabolism concept as a guiding principle for waste and pollution handling or to evaluate urban development policies. Moreover, the metabolism concept can be an evaluation indicator in overall reviews to check whether urban development aligns with the urban metabolism viewpoint.

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**Appendix A**

| Evaluation factor | Description |
|-------------------|-------------|
| C1 | Resource reuse | All urban resources should be conserved to prevent environmental damage caused by excessive use of them, such as through resource recycling promotion and reuse activities. |
| C2 | Water resources | The use and treatment of water resources involves major environmental impact assessment projects and is an essential part of metabolism. |
| C3 | Waste disposal | Waste is the product of activity, disposal methods affect the environment, and waste is the most crucial part affecting metabolism. |
| C4 | Green transportation | Cities should have environmentally friendly transportation, which includes cycling and walking in addition to mass transportation. |
| C5 | Open space | Open spaces are where residents can rest and relax. Most open spaces improve residents’ living environments and may attract visitors to the city. |
| C6 | Green coverage rate | This refers to urban areas covered by green vegetation, including parks and flower gardens that provide leisure activities in urban life and allow for the development of beautiful landscapes to improve residents’ quality of life. |
| C7 | Health | This refers to urban residents’ physical and mental health levels and the number of health facilities. |
| C8 | Infrastructure | This refers to basic pipelines in the city, including tap water, sewers, gas, and water conservancy. |
| C9 | Energy use efficiency | This is the ratio of effectively used energy to actual consumed energy. Efficient energy use can reduce waste output and increase metabolism. |
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