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Advancing Sustainability: Development of an ESG Evaluation Framework for Taiwan's Science Parks

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Abstract: Research on Taiwan's science parks has frequently concentrated on isolated aspects, often neglecting the interplay between diverse indicators and the multifaceted dynamics influencing the development of these parks. Additionally, existing applications of environmental, social, and governance (ESG) frameworks in science parks have been found to inadequately capture the complexity of their performance metrics. This study aims to establish a comprehensive ESG evaluation framework tailored to the unique characteristics of Taiwan's science parks. Through the integration of the Fuzzy Delphi Method (FDM) and cluster analysis, a classification system was developed, demonstrating operational feasibility. The proposed evaluation framework is structured around two primary dimensions-Environmental Resource Management and Socioeconomic Resilience-encompassing ten critical indicators. Findings indicate that indicators under the Environmental Resource Management dimension, including water resource utilization, air quality management, greenhouse gas (GHG) emissions, renewable energy adoption, and waste management, exert the most significant impact on the sustainable development of science parks. In contrast, indicators under the Socioeconomic Resilience dimension, such as transportation planning, labour rights protection, public facility services, and financial sustainability, are deemed moderately influential yet essential to fostering balanced development. Indicators related to high-tech talent cultivation and gender equality in decision-making were determined to have limited relevance to the immediate operational needs of science parks. Consequently, it is suggested that these indicators be excluded from resource allocation priorities in resource-constrained settings. Emphasis is placed on prioritizing investments in the Environmental Resource Management dimension to ensure sustainability and compliance with global environmental standards. Additional resources, if available, should be allocated based on the specific contextual needs of individual science parks. The proposed framework not only provides actionable insights into resource allocation strategies but also establishes a robust, comparable basis for evaluating the ESG performance of science parks in Taiwan and beyond. By addressing the interdependencies among critical indicators, the framework enhances the capacity of science parks to contribute to sustainable industrial development.

Keywords: Environmental, social, and governance (ESG) evaluation framework; Science parks; Fuzzy Delphi Method (FDM); Cluster analysis; Sustainable development

1. Introduction

Since the 1980s, due to shifts in the global industrial chain, the Taiwanese government foresaw a significant rise in labor costs, which would affect Taiwan’s labor-intensive industries, predominantly focused on light industry at the time. Consequently, the government decided to develop modernized industrial capabilities, prioritizing the development of capital-intensive and technology-intensive industries, particularly in the high-tech sectors. Since the establishment of the Hsinchu Science Park in 1979, Taiwan has developed three major science parks: Hsinchu, Central Taiwan, and Southern Taiwan Science Parks. The development of science parks has become the driving force behind various industries in Taiwan. In 2020, science parks reached historical highs in revenue, employment, and export figures (Ministry of Foreign Affairs, 2021). However, alongside economic growth, many began to reflect on the potential costs of such growth, particularly in the context of science park development.

Due to the global industrial division, the industries developed within Taiwan's Science Parks primarily include integrated circuits, optoelectronics, computers and peripherals, communications, precision machinery, and biotechnology, most of which remain high-energy-consuming sectors that focus on production. In addition to requiring large land areas, these industries also need substantial resources. This is in contrast to advanced countries, which emphasize knowledge-intensive science parks. For instance, European countries like the United Kingdom and France emphasize the importance of research and development and talent cultivation, but their capacity for mass production is clearly not on par with that of Asian countries (Chen et al., 2016).

In recent years, most studies on Taiwan's science parks have focused on environmental issues. For example, Chen et al. (2013) used an ecological footprint calculation framework to assess the ecological footprint of science parks, arguing that industrial transformation is necessary to promote the development of low-energy, low-pollution green industries. Lu et al. (2017) examined the risks of environmental management and resilience building in policy planning through the lens of flooding and urban heat island effects. Lee et al. (2024) developed a model to assess the impact of climate change on reservoir inflow, outflow, and storage, finding that future water resource availability will directly affect the stability of Taiwan's semiconductor manufacturing process and the global semiconductor component supply. Huang et al. (2019) analyzed the influence of R&D funding and operational performance on the air pollution index (PSI), revealing a long-term stable relationship between R&D funding, operational performance, and air pollution levels. Kao et al. (2023) collected ambient air total suspended particle (TSP) concentrations and dry depositions at the Taichung Science Park sampling site and discussed the possible pollutant sources.

In addition, some studies have focused on the economic aspects of science parks. For instance, Chang et al. (2010) aimed to establish indicators to measure regional innovation and entrepreneurship in science parks. Lee et al. (2017) discussed the impact of industrial clustering effects on the economic growth of science parks.

However, it can be observed that the studies mentioned above tend to focus on specific aspects, primarily addressing environmental and economic issues, while neglecting other indicators and the interactions between them, as well as the potential for other factors to significantly influence the future development of science parks.

In 2004, the United Nations' report Who Cares Wins first introduced the concept of ESG, aiming to establish a framework for integrating environment, social, and governance issues into asset management and securities brokerage services. By linking environment, social, and governance factors with investment decisions, the report sought to align these factors with the objectives of UNGC (the United Nations Global Compact). ESG represents environment, social, and governance issues, which are used to assess a company's non-financial performance, closely related to ethical or socially responsible investment (Lee & Kim, 2022).

While ESG has primarily been used to evaluate the practices and outcomes of corporate social responsibility (CSR), providing investors with both quantitative and qualitative insights into how these factors affect portfolio construction and risk-reward characteristics, it has traditionally been applied to corporate organizations. However, in recent years, the principles of ESG have gradually extended to the public sector or public infrastructure. As frontline entities responsible for many public affairs—including leisure and cultural facilities, waste management, household and community services, and land use—governments are, theoretically, the best candidates for ESG evaluations (Alatagi, 2021; Armstrong & Li, 2022).

Silicon Valley is the world's first high-tech cluster, and the tech hub it pioneered has become an important model for the development of high-tech industrial parks. Its key characteristic is the integration of universities and research institutions with industry, where academic and research achievements are rapidly commercialized, creating a comprehensive high-tech ecosystem. The development model of Silicon Valley is primarily market-driven, while Taiwan's first science park, Hsinchu Science Park, is mainly state-led (Wang et al., 2021). Nevertheless, due to the agglomeration advantages in regions such as Hsinchu, Taichung, and Tainan, a highly innovative industrial chain effect has been formed, creating a robust and stable industrial network through collaboration among universities, research institutions, and enterprises. Over time, the government has transitioned from a leading role to a supporting one (Yen et al., 2020). Notably, the development of Central Taiwan and Southern Taiwan Science Parks, along with local government participation, differs from the Hsinchu model, which was primarily led by central government (Jou, 1998). As seen, Taiwan's science parks exhibit a "dual characteristic" of government governance and corporate profitability, emphasizing both public interest and the creation of an investment-friendly environment. Hsinchu, Central Taiwan, and Southern Taiwan Science Park Administrations have also published their respective sustainability reports, highlighting the efforts made by the science parks in these areas.

However, the application of ESG in science parks has also presented several challenges. For example, sustainability reports from science parks reveal instances where some indicators are not applicable. Additionally, each park's administration uses different metrics and emphasizes varying degrees of importance each year, making it difficult to compare ESG performance across parks, even when measured. Therefore, it is highly challenging to use ESG indicators as a reference for policymaking and resource allocation in Taiwan's science parks. As Taiwan's primary industrial engine, science parks must position sustainability and the SDGs as one of their main objectives. In recent years, controversies surrounding the development of science parks have prompted more attention on how they align with sustainability and the SDGs. While the SDGs are overarching goals, ESG can be viewed as one of the evaluation tools for achieving these goals. ESG is more specific and operational, which helps promote the implementation of sustainable development.

FDM is derived from the traditional Delphi method, enhanced by fuzzy theory. It involves collecting expert opinions through questionnaires. Through their professional knowledge, insights, and experience, experts establish consensus. Since Zadeh introduced fuzzy mathematics in 1965, its application has been widespread, often in combination with the Delphi Method. It addresses the fact that human problem-solving thought processes cannot always be clearly explained by binary logic. Most existing studies on indicator selection adopt the FDM. Cluster analysis, a quantitative research method, classifies similar entities based on the concept of distance. In addition to the aforementioned indicator selection, this study attempts to apply the FDM to assign quantitative characteristics to various qualitative indicators. By integrating this approach with cluster analysis, the study categorizes the indicators to understand their relationship with the different dimensions of ESG.

The research questions of this study are (1) What are the indicators that will influence the future sustainability of science parks? (2) How can the concept of ESG be applied to science parks? (3) How can the indicators of science parks be made comparable across different parks? In order to solve these questions, this study aims to (1) employ the FDM to select ESG indicators for Taiwan's science parks, serving as an essential foundation for evaluating science parks. Furthermore, in related studies using the FDM, the classification of indicators has generally been based on researchers' subjective judgments, which can lead to inconsistent classification standards and potentially overlook the integrated impact of the indicators. Thus, this study (2) employs the FDM combined with cluster analysis to scientifically categorize the selected indicators. (3) After that, understanding the differences between the various indicators and their performance across the different dimensions of ESG, ultimately contributing to more effective policymaking and resource allocation for Taiwan's science parks.

In this study, we first discussed the existing gaps in current research on Taiwan's science parks. Through the collection of relevant literature, we aimed to identify ESG indicators suitable for assessing Taiwan's science parks and provide definitions for them. Subsequently, a framework for evaluation was established using the FDM and cluster analysis, followed by the proposal of policy recommendations.

Through this study, we identified the classification results from the combination of the FDM and cluster analysis to demonstrate operational feasibility. And a system for evaluating future science parks is divided into two major dimensions with ten indicators.

The study found environmental resource management issues, such as water resource utilization, air quality, GHG emissions, renewable energy use, and waste management, to be highly impactful for the future development of science parks. Transportation planning, labor rights protection, enhanced public facility services, and financial sustainability fall under the socioeconomic resilience dimension and are considered less important than those under environmental resource management, but they are still crucial to science parks. High-tech talent cultivation and gender equality in decision-making are viewed as less closely related to science park development in this study. Therefore, resources in science parks should exclude these two indicators.

From these findings, it is recommended that, under limited resources, science parks should first allocate resources to the Environmental Resource Management dimension. If more resources become available, they can be distributed based on the specific needs of the science park.

The ESG evaluation system established in this study can serve as a decision-making reference during the development of science parks, helping to reduce development and operational risks while improving performance. Besides, this research provides a comparable basis for the ESG evaluation system for Taiwan's science parks.

Finally, this study did not consider the interdependencies between the various indicators. Future research can provide a detailed discussion on the interdependencies among these indicators, which would help in more effective allocation of resources in science parks.

2. ESG System

Since the concept of ESG was introduced in the United Nations' Who Cares Wins report in 2004, a global ESG system has gradually taken shape, which can generally be discussed from three different perspectives: ESG disclosure frameworks, ESG ratings, and ESG investment (Zheng, 2023).

The ESG disclosure frameworks aim to provide guidance and standards for information disclosure, thereby reducing risks (Dye et al., 2021). When companies disclose their information based on these frameworks and guidelines, the content is often qualitative in nature and varies depending on the framework used, making it difficult for investment institutions or investors to comprehensively determine whether the disclosed information aligns with ESG principles. This has led to the emergence of third-party rating agencies that serve as auxiliary decision-makers in the investment process. These agencies provide ESG rating results for major investment institutions, and an increasing number of investors and investment firms rely on these third-party evaluations to assess a company's ESG performance (Berg et al., 2022). Although different ESG rating agencies may have varying assessments of the same company and there is still a lack of a unified scope and standards for evaluating the environment, social, and governance dimensions, these ratings generally follow the three primary categories of environment, social, and governance for evaluation and classification. There is no universally accepted definition for ESG investment, but it is generally understood as a non-traditional financial investment approach that involves selecting and managing investment portfolios based on ESG (Lopez et al., 2020). In addition, because an increasing amount of evidence proves that sustainability-related activities are material to the financial success of a company over time, more and more investors are placing greater emphasis on a company's ESG performance (Unruh et al., 2016). By disclosing ESG information and undergoing third-party evaluation, investment institutions or investors interested in sustainable investment can make more informed investment decisions and strategies.

Compared to ESG disclosure frameworks, rating agencies have a more structured ESG evaluation system for assigning ESG scores. Therefore, this study will use the criteria of ESG rating agencies to identify indicators that align with the evaluation of Taiwan's science parks, establishing a benchmark for assessing the ESG performance of Taiwan's science parks.

3. Literature on ESG Indicators

3.1 ESG Rating Agencies

ESG serves as a framework for evaluating the sustainability of companies and provides a reference for investors. However, the standards for ESG ratings are not clearly defined, and the evaluation lacks uniformity and consistency. Due to these varying standards, it is difficult for investors to compare ESG products. The main reasons for differences in ESG ratings include data discrepancies, the selection of assessment variables, scope, as well as data sources and standards (Zhang et al., 2024). Currently, there are over 600 ESG rating agencies worldwide (Li et al., 2022). Although there are numerous evaluation standards, certain ratings from specific agencies have been widely adopted by scholars and researchers as primary benchmarks. This study, drawing from relevant literature, selects the following agencies as the basis for establishing ESG indicators: *Asset4, Sustainalytics, S&P Dow Jones (RobecoSAM), Moody's ESG (Vigeo-Eiris), MSCI (KLD)*, and *FTSE Russell* (Berg et al., 2022; Billio et al., 2021; Dorfleitner et al., 2015; Escrig-Olmedo et al., 2019; Kimbrough et al., 2022; Lopez et al., 2020; Muñoz-Torres et al., 2019; Zumente & Lāce, 2021).

3.2 Related Research on the Application of ESG in Other Fields

In recent years, the concept of ESG has gradually shifted toward the public sector and public infrastructure. For example, Senkova & Earnest (2020) focused on state-owned enterprises, surveying 489 companies in Europe and finding that whether a company is state-owned is one of the main factors affecting ESG scores. Initially, there was a significant difference in ESG ratings between state-owned and non-state-owned enterprises, with state-owned companies rated much higher. However, over time, this gap has narrowed. In other words, the influence of the public sector on ESG has become considerable.

Armstrong & Li (2022) examined local government in Victoria, Australia. The Victorian Auditor General's Office published an audit report in 2021, revealing issues such as conflicts of interest, manipulation of land deals, lacking independence, and captured by their CEOs. In response, the Victorian Government introduced a Local Government Act (VIC) to address the poor organizational culture within these councils. Unlike previous reform measures that focused on the financial sustainability of councils, the new legislation emphasized the "system" of local government, considering long-term sustainability in governance, the roles, responsibilities, capabilities, and organizational culture of councils and councilors. They argued that good ESG practices could contribute to the future well-being and growth of local governments in society. If well-designed social indicators are implemented, they can also measure local government performance, identify significant shortcomings, and enhance financial performance.

Esmailpour et al. (2021) explored the new concept of ESG using qualitative and cross-national methods to explain effective urban governance models. Due to the lack of updated theories and sufficient foundations regarding ESG in urban governance programs, they employed grounded theory and semi-structured interviews with university faculty experts and managers with at least 15 years of experience in urban planning and policy. They proposed a concept of good urban governance, defined as an integration of efforts between citizens and governments to improve environmental, economic, and social conditions in urban areas, allowing them to participate in local and regional development processes. Thus, institutions such as government, civil society, and the private sector form a fundamental part of good urban governance.

Although this research did not explicitly identify indicators for evaluating government agencies, it highlighted the relationship between ESG and governmental bodies.

Additionally, in response to the COVID-19 crisis, the goal of carbon neutrality by 2050, environmental pollution, and natural disasters, green infrastructure has become a new objective in South Korea. As the concept of ESG has been widely applied in various fields, Lee & Kim (2022) aimed to explore trends in the application of ESG in green infrastructure from a government-level perspective. They used Moody ESG as a basis to select 98 related studies on green infrastructure both domestically and internationally. Among these, Lee & Kim (2022) identified relevant indicators for measuring green infrastructure, which included environmental aspects such as carbon and GHG reductions, climate change reduction, water management, air quality management, conservation and construction of natural capital, and energy management. The social aspects included community welfare, health, safety, education, residential and living environment, and community contributions, while governance aspects included policies, systems, and participation. They found that although there was considerable alignment between the goals of green infrastructure and ESG management, no studies had connected green infrastructure with ESG perspectives.

Alatagi (2021) directly attempted to apply ESG to urban local bodies. The Ministry of Housing and Urban Affairs (MoHUA) in India encourages cities to establish their credibility with potential investors for self-financing. Good ESG ratings signify effective fund usage and low investment risk, making it easier to borrow from banks. Unlike previous studies that referred to indicators from rating agencies, she referenced renowned international indicators and domestic policies in India to develop a standardized ESG evaluation system suitable for governments.

Furthermore, ESG has also been assessed at the national level. For example, RobecoSAM has proposed a national-level sustainability performance rating, measuring the environment, social, and governance performance of 150 countries worldwide biannually. This rating aims to analyze the sustainability status of various nations. They designed 15 major categories and a total of 40 ESG indicators based on the three ESG dimensions (Rebeco, 2024).

Kao (2023) explored the operational performance of industrial zones in Taiwan from an ESG perspective. This study focused on 61 industrial zones under the Ministry of Economic Affairs, utilizing FDM for expert questionnaires to establish indicators. Subsequently, data envelopment analysis (DEA) was employed to assess performance, and the Mann-Whitney U test was used to determine significant differences in the factors influencing the operational and management performance of various industrial zones. In this research, the established ESG indicators for the operational and management performance of industrial zones included environmental aspects such as renewable energy purchase, green energy capacity, GHG emissions, suspended particulate matter, volume of garbage clearance, gas and diesel sales, electricity/water consumption, and sewer line/discharge; the social aspects were divided into internal factors (such as development costs, land prices, industrial park area, unused land, number of employees, total salary, and number of factories announced to be discontinued) and external factors (such as government input funding and output value); governance aspects included factory size, factory capital amount , number of factories, factory operating revenue, net factory sales, actual foreign capital utilization, and patent applications.

3.3 Establish ESG Indicators Applicable to Taiwan's Science Parks

3.3.1 Define ESG in Taiwan's science parks

Considering that this research requires the classification of indicators through expert questionnaires, definitions for the three dimensions of ESG must be established to guide experts during the classification process.

Based on definitions from the United Nations and the Swiss Foreign Ministry regarding ESG, the environmental dimension includes risks associated with climate change, efforts to reduce environmental pollution and waste, strengthening environmental regulations on products and services, risk of reputation of civil society for performance, transparency, and responsible management, and responding to new markets for environmental services and green products. The social dimension encompasses workplace safety and health, local communities and relationships, respect for human rights in contracts with suppliers and partners, government and local community relationships in developing countries, and the risk of the reputation of civil society for performance, transparency, and responsible management. The governance dimension includes board structure and accountability, accounting transparency, structure of audit committee and independence of audit, managerial compensation, and management of corruption and bribery (Lee & Kim, 2022).

Esmailpour et al. (2021) contend that the environmental dimension signifies any environmental risks faced by companies and how those companies manage these risks, while the social dimension focuses on business relationships. This includes whether a company collaborates with suppliers that share similar values, whether it donates a portion of its profits to local communities or encourages employees to volunteer locally, and whether working conditions adequately consider employee health and safety, as well as the interests of other stakeholders. The governance dimension refers to whether companies use accurate and transparent accounting methods, allow shareholders to vote on significant issues, avoid conflicts of interest in selecting board members, refrain from using political donations to gain undue advantages, and avoid illegal activities.

Armstrong (2020) believes that "environment" refers to the awareness of climate change, population growth, and the impact on the natural environment. "Society" refers to CSR, which responds to issues such as climate change, population growth, and the impact of corporate activities on the communities they operate in. "Corporate governance" has several different definitions depending on the context in which it is applied, but it focuses on the leadership of the company, particularly the role of the board of directors in guiding and controlling the company. Governance can be divided into "external governance mechanisms" and "internal governance mechanisms". External governance refers to factors that influence the company but are beyond the direct control of the board of directors, such as laws, regulations, and the actions of various stakeholders. Internal governance mechanisms refer to the structures and processes that ensure the board's independence and accountability through reporting, transparent disclosure, risk management, and the prevention of corruption and bribery.

Billio et al. (2021) argue that in the environmental aspect, the primary focus is on a company's energy efficiency, GHG emissions, waste, water, and resource management, which highlights the relationship between environmental and financial performance. The social aspect focuses on factors that influence employee satisfaction. As for governance, attention is given to the independence of the board of directors, shareholder rights, executive compensation, control procedures, anti-competitive measures, and adherence to legal standards. Additionally, some studies emphasize the positive impact of these practices on a company's profitability.

MacNeil & Esser (2022) argue that with the rise of sustainability concepts, ESG has become a key factor for investors to mitigate ESG risks, as these risks can impact long-term investment performance. They believe that the environmental aspect primarily focuses on climate change, while the social aspect centers on human rights. However, they provide limited discussion regarding the governance aspect.

Peng & Isa (2020) argue that the environmental aspect represents the impact of a company's performance on the environment, while the social aspect refers to how a company's performance enhances the trust and loyalty of stakeholders, which include customers, society, and government agencies. The governance aspect focuses on the interests and welfare of management and shareholders, as well as CSR.

Trahan & Jantz (2023) recognized that the environmental aspect of ESG has become overly complex, encompassing many unrelated factors. This has blurred the goals and meaning of ESG investing, leading to misunderstandings among investors about its true objectives and benefits. As a solution, they proposed narrowing the environmental focus to carbon reduction measures aimed at addressing climate change. They also introduced five key criteria for evaluating the environmental aspect, emphasizing electrification while considering energy efficiency, social context, costs, and other relevant factors.

Considering that the definitions provided previously are primarily aimed at corporations and may not fully apply to science parks, the following modified definitions have been proposed:

1. Environment: Refers to the perspective of science parks on environmental protection, awareness of environmental risks, and the measures taken to mitigate the impacts of climate change.

2. Social: Encompasses human rights in a broad sense, the connections between science parks and society, and the relationships with the public, social organizations, and government agencies. Science parks are dedicated to maintaining the stability of these relationships to enhance the investment environment within the parks.

3. Governance: Pertains to the efficiency and transparency of policies within science parks, the oversight and management of internal operations, relationships between science parks and enterprises, actions and policies that support a healthy and friendly environment for incoming businesses, and practices aimed at enhancing the value of the science parks.

3.3.2 Merge similar indicators

Through the analysis of the aforementioned indicators, many of them share similar characteristics or are highly correlated. However, this research must consider the complexity of indicators and its potential impact on the practical operation of expert questionnaires, thereby diminishing the quality and efficiency of responses, which in turn could affect the accuracy and conclusions of the research.

To simplify the questionnaire design and enhance the effectiveness and reliability of expert assessments, this study has decided to merge similar indicators in the initial analysis phase. By simplifying the data structure, we aim to reduce unnecessary redundancy while retaining the critical information of the indicators. This approach will also optimize the implementation process of subsequent research methods, ultimately improving the interpretability and applicability of the research results.

3.3.3 Preliminarily screen indicators

Given the diverse range of indicators, it is important to note that Taiwan's science parks function as public institutions, which presents significant differences from typical corporate structures. Many ESG indicators may not fully align with the management systems and operational modes of science parks. Therefore, this research will conduct a preliminary screening based on the characteristics of science parks to ensure that the indicators used in the subsequent stages of the study are more applicable. This step aims to enhance the accuracy and relevance of the research findings.

After reviewing related studies, a total of 12 potential indicators have been identified, which include water resource utilization, air quality, GHG emissions, waste management, green buildings, renewable energy use, transportation planning, high-tech talent cultivation, labor rights protection, enhanced public facility services, gender equality in decision-making, and financial sustainability. However, regarding the content of each indicator, it is limited by the lack of clarity in publicly available data from most rating agencies concerning detailed descriptions of the indicators, and relevant research has not clearly defined each indicator. Therefore, this study refers to issues related to science parks to provide descriptions of the evaluation indicators, facilitating subsequent expert judgments.

In recent years, the global demand for semiconductors has been steadily increasing, and Taiwan's science parks have prioritized semiconductors as a key industry. Artificial intelligence, 5G, the Internet of Things, and everyday devices such as smartphones, TVs, computers, and various home appliances all rely on semiconductor components. Since semiconductor manufacturing requires significant amounts of water, finding stable and continuous alternative water sources during shortages will be crucial (Lee et al., 2024). In addition to new science parks that are subject to environmental impact assessments and required to use reclaimed water, many companies in existing parks also expect diversified water supply options to ensure stable production and sustainable development. For water resource utilization, the focus includes strengthening wastewater treatment capabilities, producing and using reclaimed water, and smart water management to improve water quality (Central Taiwan Science Park, 2021; Lee et al., 2024).

Regarding air quality in Taiwan’s science parks, Taiwan used to rely on the Pollutant Standard Index (PSI) to measure air pollution. This index primarily monitored pollutants such as O_3, CO, SO_2, NO_2, and PM_{10} to assess their impact on human health (Chen, 2018). Since 2017, Taiwan has adopted the Air Quality Index (AQI) system, which also includes monitoring of fine particulate matter (PM2.5), resulting in a more comprehensive air quality assessment. Therefore, science park development should minimize air pollution to reduce potential harm to human health.

As the development of Taiwan’s science parks typically involves large-scale construction, it may lead to the clearing of existing forests, which in turn reduces the number of trees. However, forests play a crucial role in carbon sequestration and maintaining biodiversity (Masolele et al., 2024). Besides, science parks often have large parklands that require irrigation and fertilization, but they often use synthetic fertilizers, pesticides, and herbicides. However, the use of synthetic fertilizers has been identified as major contributor to GHG emissions (Xu et al., 2023). For GHG emissions, the government has declared its goal of achieving net-zero carbon emissions by 2050. According to Article 4 of the Climate Change Response Act, "The long-term national GHG emission reduction goal is achieving GHG net-zero emission by 2050. To achieve the goal set in the foregoing paragraph, all levels of government shall implement GHG reduction, develop negative emission technologies, and facilitate international cooperation together with citizens, entities, and organizations." In accordance with these regulations, Taiwan’s science parks have also made GHG reduction one of their primary goals to help mitigate global warming and address the climate crisis. (Hsinchu Science Park, 2024).

Regarding waste management, the waste produced in science parks differs from general domestic waste, primarily consisting of general industrial waste and hazardous industrial waste, which must be properly treated before incineration or recycling. The current waste management policy in science parks is primarily focused on promoting a circular economy. For instance, Hsinchu Science Park has linked upstream, midstream, and downstream manufacturers to create a resource recycling industrial chain, minimizing waste generation (Hsinchu Science Park, 2024). Similarly, the Central Taiwan Science Park has worked with TSMC and six other companies to establish a “Zero Waste Center” aimed at promoting waste reduction and the circular economy by recycling secondary isopropanol, silicon-containing waste, industrial-grade fluorine-containing sludge, and silicon-containing sludge (Chen, 2023). In other words, the circular economy, as a policy objective for Taiwan’s science parks, prioritizes source reduction and recycling. Only waste that cannot be reused is processed through incineration or landfill methods.

In terms of green buildings, research has shown that science parks have adopted green building certification as a policy objective (Hsieh, 2022). The certifications applicable to science parks include the "EEWH-EC Green Building Label for Ecological Communities," Taiwan's Green Building Label, and the U.S. LEED Green Building Certification.

Regarding renewable energy, given the significant power consumption of science parks, they also play a key role in supporting renewable energy development policies. Taiwan is working toward its 2025 "Nuclear-Free Homeland" goal, which encourages and promotes the installation of renewable energy sources, including solar photovoltaics and energy storage systems, within the science parks (Central Taiwan Science Park, 2023; Chen, 2023).

In terms of transportation planning, the development of science parks brings in a large influx of people, which has raised transportation issues in many parks. Research has proposed various solutions, such as optimizing traffic signal design or implementing cross-regional governance to integrate resources from different government agencies and park businesses (Chen & Shih, 2015; Cho, 2008). These measures aim to internalize transportation challenges within the parks, reducing local traffic issues caused by park expansion or new developments.

The establishment of science parks aims to attract high-tech industries and scientific talent, thereby enhancing regional innovation capacity. Human capital is crucial for companies in the park, and thus human capital should be highly valued. In this study, human capital is divided into two key indicators: high-tech talent cultivation and labor rights protection. High-tech talent cultivation focuses on attracting a diverse pool of talent, facilitating the return of overseas professionals to Taiwan to share their expertise, and actively nurturing high-quality R&D personnel. Labor rights protection includes promoting occupational safety and health initiatives, overseeing various labor inspection plans and addressing complaints within the park, and ensuring the fair and legal resolution of labor disputes. Additionally, it incorporates a variety of activities designed to protect labor rights, improve worker health, and maintain a safe, healthy, and humane working environment (Central Taiwan Science Park, 2020).

Regarding enhancing public facility services, various rating agencies focus on public access to open spaces, the availability of public service facilities, and access to essential services. In science parks, this concept aligns with parks and green spaces under the "Science Park Public Space Maintenance and Management Regulations." Therefore, science park development should ensure adequate public facilities, such as parks and green spaces, to provide quality living environments and open spaces.

In terms of gender equality in decision-making, public affairs management has long shown gender segregation, with women less likely to hold decision-making positions and fewer opportunities to participate in decision-making. Taiwan's "Gender Equality Policy Guidelines" promote gender equality in decision-making, with strategies to narrow the gender gap in leadership positions. The United Nations Sustainable Development Goals (SDGs) also emphasize the importance of women's participation in public life and decision-making and include the goal of ensuring women have equal opportunities to participate in decision-making at all levels of leadership (Gender Equality Policy Committee of the Executive Yuan, 2024). Thus, to enhance gender participation in public policies, science park development should ensure equal decision-making opportunities for both genders.

Finally, many rating agencies highlight financial indicators, as the core principle of ESG is that a company should still be profitable while complying with ESG conditions. Therefore, finance remains a crucial aspect. The primary objective of "The Science Park Proprietary Fund," a non-profit operational fund, is to manage and coordinate financial resources across various science parks in order to maintain balanced financial conditions (Liao, 2004). During the planning phase, financial assessments are necessary to ensure self-sufficiency. In other words, the development of science parks should emphasize development costs and operational revenues to achieve financial balance, making financial sustainability a key evaluation indicator in this study.

4. Methodology

This study is divided into two main parts. The first involves the selection of future science park indicators to understand which indicators are more crucial for the development of science parks. The second part aims to identify how these indicators correspond to ESG criteria, providing insights into which areas should be targeted for improvement in science parks focusing on ESG.

In the first part, indicator selection is carried out using the FDM, while in the second part, indicator classification is conducted using cluster analysis. The following sections introduce the methods applied in each part.

4.1 FDM

Fuzzy mathematics was introduced in 1965 by Lotfi Zadeh. It addresses the fact that human problem-solving thought processes always be imprecise, vague, or uncertain. A key feature of fuzzy mathematics is the introduction of the membership function, which is used to represent the degree of fuzziness in a set, helps to quantify the degree of uncertainty and allows for a more nuanced approach to reasoning (Gupta et al., 2023). This approach helps address the binary thinking in human problem-solving. Generally, the most commonly used fuzzy numbers are triangular and trapezoidal fuzzy numbers. Due to the simplicity and ease of understanding associated with the construction and calculation of triangular fuzzy numbers (Chang & Tsai, 2012), they are frequently used in relevant research.

The FDM currently adopted is mostly based on the method proposed by Ishikawa et al. (1993), who developed the Max-Min method and fuzzy integration to derive expert opinions collected and calculate predictive values. Cheng adopted the Gray Zone Testing Method and the double triangular fuzzy number to improve Ishikawa's theory. The advantages of this approach include (Cheng, 2001):

1. It addresses the limitation of the traditional Delphi Method, which only provides information from the middle 50%, better capturing human cognitive fuzziness and uncertainty.
2. The gray zone testing method enhances the rigor and reasonableness of the FDM's results.
3. The use of the "maximum and minimum values of the possibility range" concept instead of Ishikawa et al.'s "most likely" and "least likely" concept improves the practical applicability of the FDM.
4. This model generally requires only one round of surveys, avoiding the time, effort, and costs associated with multiple rounds.

However, Jeng (2001) argued that in practice, Cheng’s Gray Zone Testing Method may consider a lack of convergence in cases where the double triangular fuzzy numbers show no gray zone, though this should actually indicate consensus. Therefore, Jeng improved upon this method.

For the indicator selection process, the FDM questionnaire was distributed to the expert panel. Each expert was asked to assign quantitative scores regarding the importance of each indicator for Taiwan's science parks based on three values: "maximum value," "minimum value," and "optimal value." These three numbers will become dual-triangular fuzzy numbers for each indicator, the Grey Zone Test Method will be used to examine whether the experts have reached a consensus. The consensus value will be represented by G^i.

FDM is widely applied in indicator selection studies. FDM operates through a series of questionnaire processes, calculating the consensus values for each indicator from expert opinions. The higher the consensus value, the greater the agreement among experts, indicating that the indicator is of higher importance to them.

This study intends to adopt the FDM proposed by Ishikawa et al. (1993) as the foundation and will incorporate the supplementary research of Cheng (2001) and Jeng (2001) in the design of the Fuzzy Delphi questionnaire.

4.2 Cluster Analysis

Cluster analysis is based on using quantitative data to calculate the similarity or dissimilarity between observations. It can generally be classified into hierarchical methods, non-hierarchical methods, and the Two-Step method, which combines both approaches.

The main difference between hierarchical and non-hierarchical clustering methods lies in whether the number of clusters is predetermined and the number of observations involved. In some studies, researchers must subjectively decide the number of clusters in advance, but this approach is often questioned. Moreover, determining the number of clusters through multiple trials can be time-consuming. Therefore, if the number of clusters is unknown, the Two-Step method can be employed. This involves first using hierarchical methods to determine the number of clusters, followed by applying non-hierarchical methods (Hair et al., 1995).

In hierarchical clustering, Ward's method is the most widely used approach to calculate the distance between observations. This method initially assigns each observation as its own cluster, then sequentially merges them. The merging order is determined by minimizing the total within-cluster variance after each merger. In non-hierarchical methods, K-means is the most prominent example. This method first divides the entire sample into k groups. Then, it calculates the distance from a sample to the center of each group. The sample is then assigned to the group with the closest center, and the centers of all groups are recalculated. This process is repeated until no samples need to be reassigned to different groups. (Wu & Liu, 2013).

As mentioned above, cluster analysis requires quantification for effective analysis. In this study, since the indicators do not possess inherent quantifiable characteristics for classification, the FDM was employed to assign quantitative attributes to each indicator. The concept is to define the indicators and dimensions (as discussed in Section 3.3) and ask experts, "To what extent do you believe a particular indicator belongs to a specific dimension (E, S, G)?" This helps establish quantifiable characteristics. By consulting different experts and using FDM to calculate the consensus values, the degree of each expert's agreement on the alignment of an indicator with a particular dimension can be obtained. This process provides the quantifiable characteristics of each indicator within the ESG dimensions, enabling classification through cluster analysis.

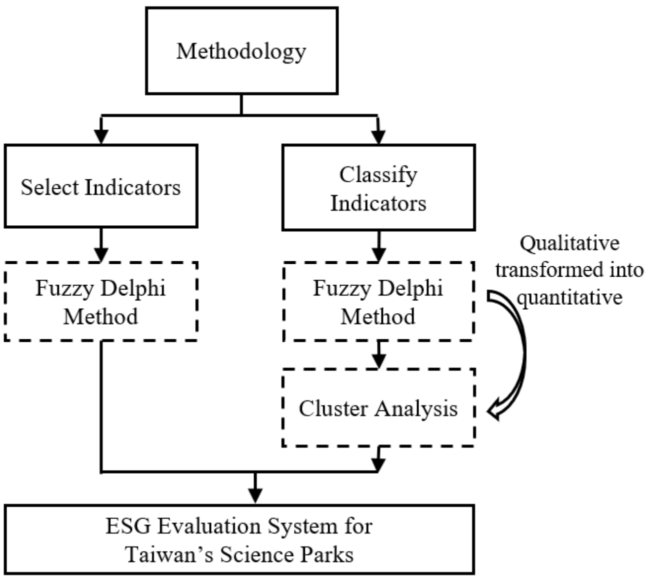

Figure 1. Research method flow

Considering the selected indicators and the fact that the number of clusters is unknown, this study will adopt the Two-Step clustering method, using SPSS for the analysis. The research method flow of this study can generally be illustrated as shown in Figure 1.

4.3 Select Experts

According to related research, the number of experts for the FDM should range between 15 and 30 if the group is highly homogeneous and between 5 and 10 if the group is more diverse (Klir & Folger, 1988). Therefore, in this study, considering that government officials are more familiar with the development of Taiwan's science parks, the selection of experts will include professionals from the following fields: 2 from academia, 3 from government agencies, and 2 from industry, totaling 7 experts.

5. Results

5.1 Select Indicators

In the indicator screening section, this study utilized Fuzzy Delphi questionnaire to establish expert consensus values for each evaluation indicator, as shown in Table 1. Based on the questionnaire results, all final test values were positive, indicating that the responses reached convergence. The geometric mean of the expert consensus values (Gi) for all indicators was 5.52, and the arithmetic mean was 5.63. Typically, the threshold for screening is determined using methods such as the geometric mean, arithmetic mean, or steep slope analysis, supplemented by the researcher's subjective judgment. However, if too few indicators remain after filtering, the threshold should be lowered to avoid impacting the study's results (Chang & Chang, 2010; Peng et al., 2022; Yang & Chiang, 2022). Generally, the threshold falls between 5 and 7. Therefore, the geometric and arithmetic means of the consensus values meet the standard.

Table 1. Results of the FDM questionnaire for indicator selection

Indicators	Test Value	Gi
Water resource utilization	2.80	7.43
Air quality	3.61	6.59
GHG emissions	4.56	6.48
Waste management	4.00	6.39
Green buildings	0.59	5.47
Renewable energy use	2.76	6.40
Transportation planning	3.56	5.43
High-tech talent cultivation	1.27	3.93
Labor rights protection	0.72	5.77
Enhance public facility services	1.88	4.53
Gender equality in decision-making	1.11	3.74
Financial sustainability	0.80	5.40
	Geometric mean	**5.52**
	Arithmetic mean	**5.63**

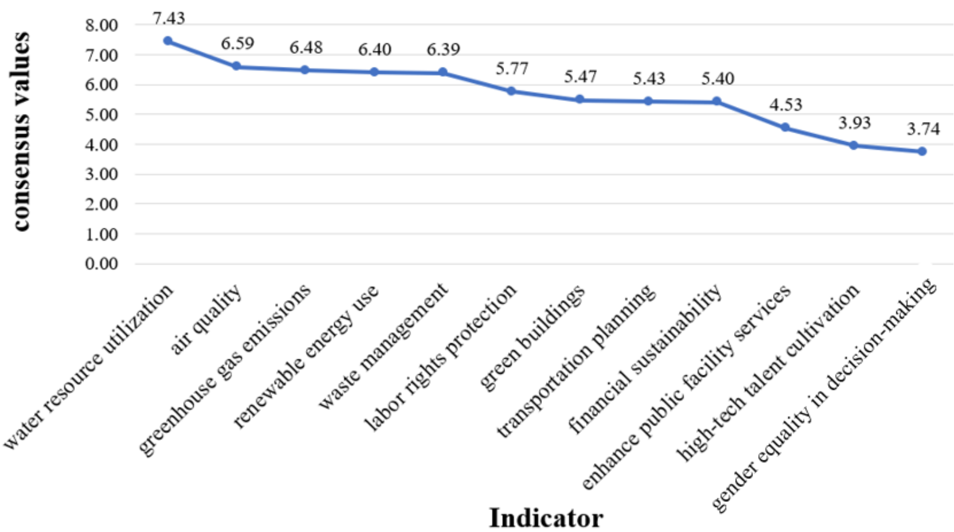

Figure 2. Steep slope analysis for indicator selection

Observing the steep slope threshold of expert values, a significant difference can be seen between “financial sustainability" (5.40) and "enhance public facility services" (4.53) (Figure 2). In theory, financial sustainability should serve as the screening threshold based on the steep slope analysis. However, the indicator for enhancing public facility services refers to the requirement that science park development should include adequate public facilities, such as parks and green spaces, to provide a good living environment and open spaces. Some studies point out the importance of this indicator for Taiwan's science parks (Huang, 2003). Therefore, this study will include this indicator in the overall analysis.

5.2 Classify Indicators

In the indicator classification process, some indicators did not reach convergence during the Fuzzy Delphi questionnaire. For these non-converged items, the geometric means of the maximum and minimum values were provided to the experts for reference. The experts were then asked to reassess these items in a second round. The final test values were all positive, and the questionnaire results reached convergence. As a result, we obtained three consensus values for each indicator, summarized in Table 2.

After obtaining the consensus values, a non-hierarchical clustering method was initially used for grouping, and the analysis was performed using SPSS. The dendrogram (Figure 3) revealed that dividing the data into two or three clusters seemed more reasonable. To further examine the grouping, the K-means method from hierarchical clustering was applied. When divided into three clusters, an ANOVA analysis showed that the p-values for the S and G dimensions were greater than 0.05, indicating no significant differences between the clusters. However, when divided into two clusters, the p-values for the E, S, and G dimensions were all less than 0.05, showing significant differences between the clusters (Table 3). Therefore, the two-cluster solution was deemed more reasonable.

The first cluster includes indicators such as water resource utilization, air quality, GHG emissions, waste management, green buildings, and renewable energy. The second cluster covers transportation planning, labor rights protection, enhance public facility services, and financial sustainability (Table 4). Based on their characteristics, we can name these two clusters as *Environmental Resource Management* and *Socioeconomic Resilience*, respectively. The final cluster centers are shown in Table 5.

Table 2. Results of the FDM questionnaire for indicator classification

Indicators	Dimensions	Test Value	Gi
Water resource utilization	E	3.32	8.25
	S	1.44	4.67
	G	1.25	5.39
Air quality	E	1.63	8.35
	S	1.23	4.71
	G	1.05	5.41
GHG emissions	E	2.03	8.38
	S	1.73	4.96
	G	1.02	5.39
Waste management	E	0.37	7.82
	S	0.12	5.14
	G	1.18	5.48
Green buildings	E	1.95	5.92
	S	0.70	4.77
	G	1.67	5.51
Renewable energy	E	1.58	7.58
	S	0.07	5.04
	G	1.35	5.35
Transportation planning	E	3.15	5.34
	S	0.58	5.37
	G	0.86	6.17
Labor rights protection	E	1.62	2.73
	S	2.00	6.41
	G	1.75	5.54
Enhance public facility services	E	0.65	4.47
	S	0.41	5.29
	G	2.29	6.35
Financial sustainability	E	0.02	3.66
	S	0.93	5.23
	G	0.16	6.90

Table 3. K-means cluster analysis (2 clusters)

	F Test	Significance
E	31.798	.000
S	8.210	.021
G	13.378	.006

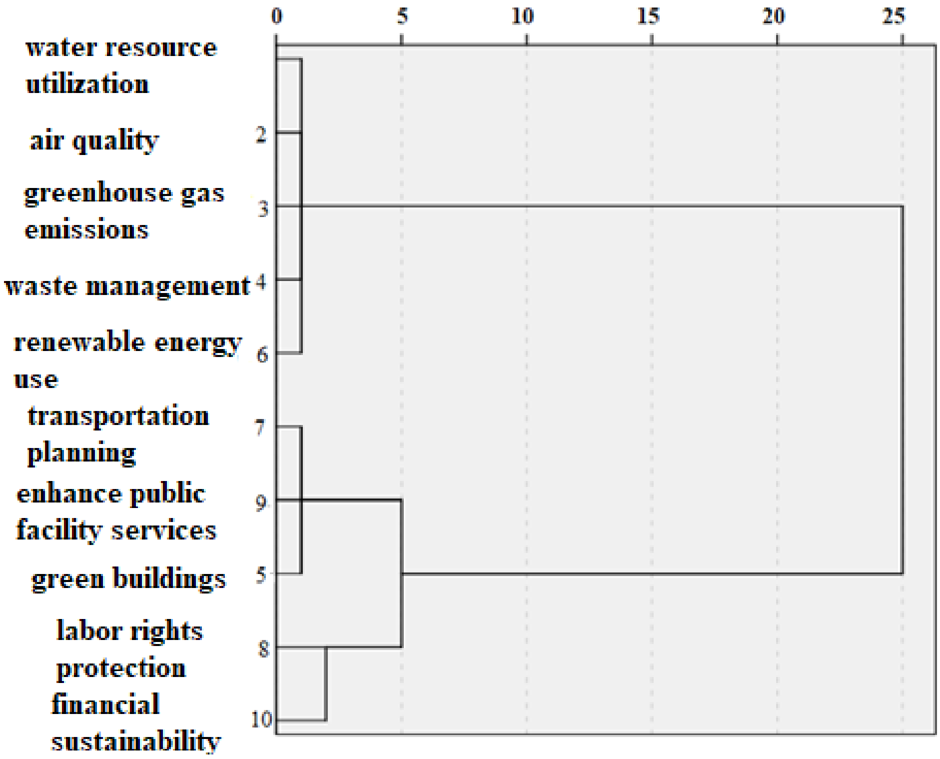

Figure 3. Dendrogram of non-hierarchical clustering

Table 4. Results of k-means cluster analysis

Indicator	Cluster	Distance
Water resource utilization	1	.575
Air quality	1	.656
GHG emissions	1	.669
Waste management	1	.284
Green buildings	1	1.802
Renewable energy use	1	.221
Transportation planning	2	1.308
Labor rights protection	2	1.712
Enhance public facility services	2	.519
Financial sustainability	2	.841

Table 5. Final cluster centers

	Cluster	
	1	2
E	7.7167	4.0500
S	4.8817	5.5750
G	5.42	6.24

5.3 Analysis and Discussion

Through the fuzzy Delphi questionnaire, we observed that indicators such as water resource utilization, air quality, GHG emissions, renewable energy use, and waste management have consensus values ranging from 6 to 8, indicating a high level of consensus. This reflects the experts' recognition of the high importance of these indicators for Taiwan's science parks. In contrast, indicators such as labor rights protection, green buildings, transportation planning, and financial sustainability scored between 5 and 6. While their importance is somewhat lower, they are still considered significantly important. Finally, indicators like enhance public facility services, high-tech talent cultivation, and gender equality in decision-making had lower importance scores, ranging from 3 to 5. However, the consensus value for enhance public facility services was not much lower than 5, and related research suggests this indicator still holds some importance, so it has been included in the evaluation system to avoid omission.

Therefore, based on the characteristics of Taiwan's science parks, the indicators suitable for the evaluation of these parks are: water resource utilization, air quality, GHG emissions, renewable energy use, waste management, labor rights protection, green buildings, transportation planning, financial sustainability, and enhance public facility services—totaling 10 indicators.

Additionally, from the classification questionnaire, we see that expert consensus divides these indicators into two main categories: environmental resource management, which covers water resource utilization, air quality, renewable energy use, GHG emissions, waste management, and green buildings; and socioeconomic resilience, which includes labor rights protection, transportation planning, financial sustainability, and enhance public facility services. Upon reviewing the characteristics of these two groups, it was found that the p-values for E, S, and G were all less than 0.05, indicating significant differences. Further examination of the final cluster centers showed that environmental characteristics were stronger in environmental resource management, whereas social and governance characteristics were more prominent in socioeconomic resilience. This suggests that, if the aim is to improve the environmental aspects of Taiwan's science parks, more attention should be given to measures related to environmental resource management. To enhance socioeconomic resilience, policies should focus on labor rights protection, transportation planning, financial sustainability, and enhance public facility services.

Moreover, from the combined results of the indicator selection and classification, the consensus for environmental resource management was generally higher, with the highest reaching 7.43 (water resource utilization) and even the lowest consensus (green buildings) being 5.47. In contrast, within the Socioeconomic Resilience, the highest consensus was for labor rights protection, with a score of only 5.77. This indicates that, compared to socioeconomic resilience, environmental resource management is a topic of greater concern among the experts.

Through the aforementioned content, it can be observed that in past research, studies on environmental aspects primarily focused on carbon emissions (Chen et al., 2013; Lu et al., 2017), air pollution (Huang et al., 2019; Kao et al., 2023), and water resource usage (Lee et al., 2024). Through the indicator selection of the FDM, we found that, in addition to the aforementioned topics, renewable energy use, waste management, and green buildings were also important indicators. In the other section, we found that past research mostly focused on the role of science parks within the industrial chain and how they innovate (Chang et al., 2010; Lee et al., 2017). However, through the ESG-established indicators, the socioeconomic resilience dimension focuses on achieving harmony within and outside the science park, which may be related to the essence of ESG—how it helps to reduce operational risks.

In summary, the following conclusions can be drawn from this study:

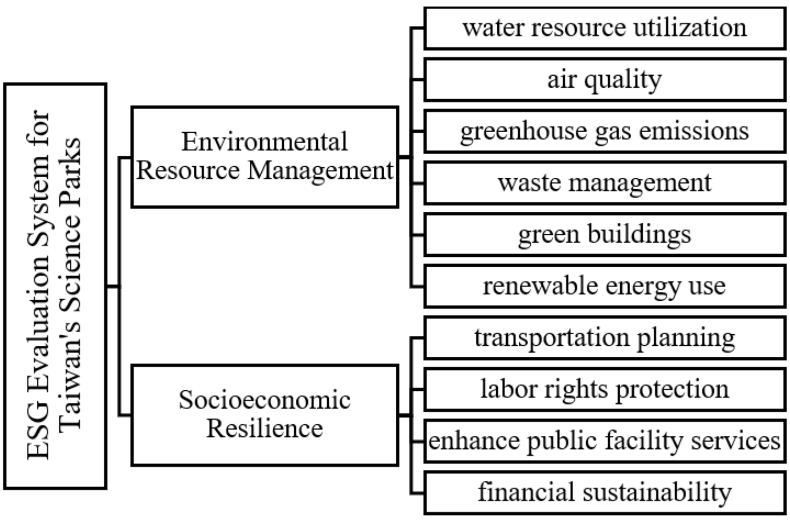

Figure 4. ESG evaluation system for Taiwan's science parks

(1) The study successfully identifies a framework for evaluating future science parks, consisting of two primary dimensions with a total of 10 indicators. The combination of the FDM and cluster analysis categorizes indicators

such as water resource utilization, air quality, GHG emissions, renewable energy use, waste management, and green buildings into one group, while transportation planning, labor rights protection, enhance public facility services, and financial sustainability are grouped into another (Figure 4). This classification aligns with general perceptions, demonstrating the operability of combining these two methods.

(2) Experts believe that most issues related to environmental resource management—such as water resource utilization, air quality, GHG emissions, renewable energy use, and waste management—have a significant impact on the future development of science parks.

(3) Transportation planning, labor rights protection, enhancement of public facility services, and financial sustainability fall under the socioeconomic resilience dimension. While the indicators under the socioeconomic resilience dimension are seen as less crucial than those in the environmental resource management dimension, they still have a significant impact.

(4) High-tech talent cultivation, often considered one of the objectives of science parks, is viewed as less closely related to science park development in this study. The reason for this could be that the development of technological talent requires collaboration with academic and research institutions as well as industrial clusters and is not the primary task of science parks themselves. Generally, technological talent primarily comes from higher education institutions and industry players. However, industries tend to prioritize efficiency and are accountable to shareholders and employees, placing greater emphasis on the practical contributions of research and development outcomes to company growth and profitability. As a result, talent cultivation and theoretical research remain primarily the responsibility of universities (Chien et al., 2013; Hu et al., 2005). The gender equality in decision-making, which is currently emphasized by various levels of government, is also perceived by experts and scholars as having minimal impact on science parks. A possible reason for this is that science park management is typically a government agency, and public servants are subject to established norms and systems regarding organizational culture and performance. Consequently, promotion channels are less likely to differ based on gender (Lin & Yang, 2016).

(5) In terms of the impact on ESG dimensions, if a science park prioritizes the Environmental (E) dimension, resources should be focused on the indicators under Environmental Resource Management. On the other hand, if the focus is on the social (S) and governance (G) dimensions, resources should be allocated to the indicators under socio-economic resilience. Notably, the indicators under socio-economic resilience show no significant differences between the S and G classifications.

6. Conclusions

Taiwan's science parks play a crucial role in the overall industrial development of the country, serving as a driving engine for Taiwan's industries. However, in recent years, the continuous expansion of science parks has sparked reflection on the establishment or expansion of these parks.

In the research on science parks, although some previous studies in Taiwan have pointed out the numerous challenges faced by these parks, most have focused on environmental and economic issues caused by their development. These research topics tend to discuss single issues or one-dimensional aspects, with limited literature approaching Taiwan's science parks from a holistic perspective. And some science park administrations have also published their respective sustainability reports, highlighting the efforts made by the science parks in these areas. However, the application of ESG in science parks has also presented several challenges. This makes it difficult to compare the sustainability reports produced by each science park administration, thus losing the significance of using ESG as a measure for evaluating science parks.

Therefore, this study adopts a more macro-level approach, providing policy recommendations for science parks, addressing gaps in existing research, and allowing different science parks to have a common basis for comparison in terms of ESG.

As for the research methodology, this study attempts to establish an evaluation system for Taiwan's science parks based on the widely discussed ESG indicators by the FDM. In previous Fuzzy Delphi studies, the classification of indicators was often based on subjective judgment, which may lead to inconsistencies in classification standards and overlook the comprehensive impacts between indicators. By applying the FDM combined with cluster analysis, this study provides a more scientific classification of the selected indicators, helping to understand the differences between indicators and their performance in the different ESG dimensions, thereby enabling more effective policy formulation and resource allocation.

The findings and conclusions of this study are as follows:

(1) Compared to previous FDM studies, this study establishes an objective method for classifying indicators that effectively considers the comprehensive impact of various indicator characteristics.

(2) Through a review of relevant literature and interviews with experts, this study identifies a two-dimensional, 10-indicator ESG evaluation system for Taiwan's science parks. The environmental resource management dimension includes six indicators: water resource utilization, air quality, renewable energy use, GHG emissions, waste management, and green buildings. The socioeconomic resilience dimension includes four indicators: labor

rights protection, transportation planning, financial sustainability, and enhance public facility services.

(3) The various environmental resource management issues emphasized in most current studies are also highly regarded by experts in this research, thus the findings align broadly with existing research directions.

(4) Transportation planning, labor rights protection, enhance public facility services, and financial sustainability are part of the socioeconomic resilience dimension. While indicators under the socioeconomic resilience dimension are seen as less crucial than those in the environmental resource management dimension, they still have a significant impact.

(5) High-tech talent cultivation, which is considered one of the goals of science parks, is perceived as less related to science park development. This may be because the training of technological talent is still seen as the responsibility of academic and research institutions, rather than that of the science park. Similarly, gender equality in decision-making has a relatively small impact on science parks, possibly because gender issues are not prioritized in decision-making circles within public sectors.

(6) In the evaluation system of Taiwan's science parks, the importance of the environmental resource management dimension is generally higher than that of the Socioeconomic Resilience dimension. If we aim to enhance the impact of the environment (E), resources should be focused on the indicators within the environmental resource management dimension. Conversely, to strengthen the social (S) and governance (G), resources should be concentrated on the indicators within the Socioeconomic Resilience dimension. It is recommended that, under limited resources, science parks should first allocate resources to the environmental resource management dimension. If more resources become available, they can be distributed based on the specific needs of the science park.

The ESG evaluation system established in this study can serve as a decision-making reference during the development of science parks, helping to reduce development and operational risks while improving performance. Besides, this research provides a comparable basis of ESG evaluation system for Taiwan's science parks.

Due to limitations in research resources, this study did not consider the interdependencies between the various indicators. In other words, improvements in one indicator might effectively enhance the performance of another. Future research can provide a detailed discussion on the interdependencies among these indicators, which would help in more effective allocation of resources in science parks.

Author Contributions

Conceptualization, Hao-Wei Chang; methodology, Hao-Wei Chang and Wann-Ming Wey; validation, Hao-Wei Chang; investigation, Hao-Wei Chang; resources, Hao-Wei Chang; data curation, Hao-Wei Chang; writing—original draft preparation, Hao-Wei Chang.; writing—review and editing, Hao-Wei Chang and Yi-Li Lin; visualization, Hao-Wei Chang; supervision, Wann-Ming Wey. All authors have read and agreed to the published version of the manuscript.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability

Data sharing is not applicable as the study is a review article.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Alatagi, A. (2021). *Possibilities of using environmental, social, and governance (ESG) framework for urban local governments*. https://cwas.org.in/resources/file_manager/Possibilities_of_using_ESG_Framework_for_Urban_Local_Governments_report.pdf

Armstrong, A. (2020). Ethics and ESG. *Australas. Account. Bus. Finance J., 14*(3), 6-17. http://doi.org/10.14453/aabfj.v14i3.2.
Armstrong, A. & Li, Y. (2022). Governance and sustainability in local government. *Australas. Account. Bus. Finance J., 16*(2), 12-31. https://doi.org/10.14453/aabfj.v16i2.3.
Berg, F., Koelbel, J. F., & Rigobon, R. (2022). Aggregate confusion: The divergence of ESG ratings. *Rev. Finance, 26*(6), 1315-1344. https://doi.org/10.1093/rof/rfac033.
Billio, M., Costola, M., Hristova, I., Latino, C., & Pelizzon, L. (2021). Inside the ESG Ratings: (Dis) agreement and performance. *Corp. Soc. Responsib. Environ. Manag., 28*(5), 1426-1445. https://doi.org/10.1002/csr.2177.
Central Taiwan Science Park. (2020). https://ctspcsr.com.tw/download/2020_en.pdf
Central Taiwan Science Park. (2021). https://ctspcsr.com.tw/download/2021_en.pdf
Central Taiwan Science Park. (2023). https://www.ctsp.gov.tw/files/1812e9aa-6d20-44c8-b1d6-bcffb8d3192f.pdf
Chang, C. C. & Tsai, C. W. (2012). Development of a knowledge management behavior scale for digital learning portfolios using network fuzzy Delphi and fuzzy analytic hierarchy process. *J. Educ. Media Libr., 50*(1), 103-133.
Chang, S. C. & Chang, D. (2010). The study of evaluation criteria of school-based mentor teacher program. *J. Educ. Taipei Munic. Univ. Educ., 37*, 19-66.
Chang, Y. C., Chen, M. H., Lin, F., & Gao, Y. S. (2010). Measuring regional innovation and entrepreneurship: The case of Taiwan science parks. In *PICMET 2010 Technology Management for Global Economic Growth, Phuket, Thailand* (pp. 1-9).
Chen, F. H. (2023). Assessing sustainable development initiatives in Central Taiwan Science Park: A study of residents' opinions and the impact on the urban ecosystem. *Buildings, 13*(5), 1202. https://doi.org/https://doi.org/10.3390/buildings13051202.
Chen, H. S., Chien, L. H., & Hsieh, T. (2013). A study of assessment indicators for environmental sustainable development of science parks in Taiwan. *Environ. Monit. Assess., 185*, 7001-7012. http://doi.org/10.1007/s10661-013-3080-z.
Chen, P. L., Yen, Y. C., & Kung, S. F. (2016). A policy network analysis for the formation of innovation platform in southern Taiwan science parks. *J. Archit., 17*(1), 25-52.
Chen, Y. C. (2018). Evaluation of greenhouse gas emissions from industrial parks using criteria air pollutants: A case study of Taiwan. *Int. J. Glob. Warm., 15*(1), 1-18. https://doi.org/10.1504/IJGW.2018.091949.
Chen, Y. T. & Shih, C. K. (2015). A Research of solution planning for traffic problem of Hsinchu science park. *J. Chin. Public Adm., 17*, 119-135. https://doi.org/10.6712/jcpa.201512_(17).0007.
Cheng, J. H. (2001). Indexes of competitive power and core competence in selecting Asia-pacific ports. *J. Chin. Inst. Transp., 13*(1), 1-25.
Chien, C. F., Peng, J. T., & Hsu, C. Y. (2013). Research on framework of university-industry collaboration for enhancing sustainable growth for NSC science park. *J. Manag. Syst., 20*(1), 27-54.
Cho, H. J. (2008). *Static signal design-a case study of HsinChu Science Park network* [Mastersthesis]. National Chiao Tung University, Taiwan.
Dorfleitner, G., Halbritter, G., & Nguyen, M. (2015). Measuring the level and risk of corporate responsibility – An empirical comparison of different ESG rating approaches. *J. Asset Manag., 16*(7), 450-466. https://doi.org/10.1057/jam.2015.31.
Dye, J., McKinnon, M., & Byl, C. V. D. (2021). Green gaps: Firm ESG disclosure and financial institutions' reporting requirements. *J. Sustain. Res., 3*(1), e210006. https://doi.org/10.20900/JSR20210006.
Escrig-Olmedo, E., Fernández-Izquierdo, M. Á., Ferrero-Ferrero, I., Rivera-Lirio, J. M., & Muñoz-Torres, M. J. (2019). Rating the raters: Evaluating how ESG rating agencies integrate sustainability principles. *Sustainability, 11*(3), 915. https://doi.org/10.3390/su11030915.
Esmailpour, N., Goodarzi, G., & Esmailpour Zanjani, S. (2021). The model of good sustainable urban governance based on ESG concepts. *J. Urban Manag. Energy Sustain., 3*(1), 96-107. https://doi.org/10.22034/jumes.2021.249506.
Gender Equality Policy Committee of the Executive Yuan. (2024). https://gec.ey.gov.tw/File/DA8692C4E2E58A1F?A=C
Gupta, S., Chatterjee, P., Rastogi, R., & Gonzalez, E. D. R. S. (2023). A Delphi fuzzy analytic hierarchy process framework for criteria classification and prioritization in food supply chains under uncertainty. *Decis. Anal. J., 7*, 100217. https://doi.org/10.1016/j.dajour.2023.100217.
Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1995). *Multivariate Data Analysis (4th ed.): With Readings.* Prentice-Hall, Inc.
Hsinchu Science Park. (2024). https://web.sipa.gov.tw/CSRWeb/eng/column01.jsp
Hsieh, Y. L. (2022). *The study on key factors of smart and ecological planning of science park* [Mastersthesis]. National Chengchi University, Taiwan.
Hu, T. S., Lin, C. Y., & Chien, H. T. (2005). The effects between technological communities interaction and

industrial clustering on innovation activity: A case of Hsinchu district. *J. Archit. Plan.*, *6*(1), 43-61. https://doi.org/10.30054/jap.200506.0003.

Huang, J. S. (2003). *The research of park & green land planning and design on science-based industrial park* [Mastersthesis]. Chung Hua University, Taiwan.

Huang, S., Chau, K., Shen, H., & Li, J. (2019). A relationship between economic performance and air pollution of a science park: A case study of Hsinchu Science Park in Taiwan. *Appl. Ecol. Environ. Res.*, *17*(1).

Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., & Mieno, H. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy Sets Syst.*, *55*(3), 241-253. https://doi.org/10.1016/0165-0114(93)90251-C.

Jeng, T. B. (2001). *Fuzzy assessment model for maturity of software organization in improving its staff's capability* [Mastersthesis]. National Taiwan University of Science and Technology, Taiwan.

Jou, S. C. (1998). Another version of the science park development in Taiwan: The Tainan science-based industrial park. *Taiwan*: *Radic. Q. Soc. Stud.*, *32*, 125-163.

Kao, C. L., Fang, G. C., & Chen, Y. H. (2023). Applying principal component, health risk assessment, source identification for metallic elements of ambient air total suspended particulates at Taiwan Scientific Park. *Environ. Geochem. Health*, *45*, 809-824. https://doi.org/10.1007/s10653-022-01222-y.

Kao, L. L. (2023). ESG-based performance assessment of the operation and management of industrial parks in Taiwan. *Sustainability*, *15*(2), 1424. https://doi.org/10.3390/su15021424.

Kimbrough, M. D., Wang, X. F., Wei, S., & Zhang, J. I. (2022). Does voluntary ESG reporting resolve disagreement among ESG rating agencies? *Eur. Account. Rev.*, *33*(1), 15-47. https://doi.org/10.1080/09638180.2022.2088588.

Klir, G. J. & Folger, T. A. (1988). *Fuzzy Sets, Uncertainty, and Information.* Prentice Hall.

Lee, E. & Kim, G. (2022). Analysis of domestic and international green infrastructure research trends from the ESG perspective in South Korea. *Int. J. Environ. Res. Public Health*, *19*(12), 7099. https://doi.org/https://doi.org/10.3390/ijerph19127099.

Lee, S., Lin, G. T., & Hsi, P. (2017). Industrial cluster development and its contribution to economic growth in Taiwan-Hsinchu Science and Industrial Park (HSIP). *J. Sci. Ind. Res.*, *76*, 273-278.

Lee, T. Y., Lai, Y. P., Teng, T. Y., & Chiu, C. C. (2024). Impact assessment of climate change on water supply to Hsinchu Science Park in Taiwan. *Water*, *16*(12), 1746. https://doi.org/10.3390/w16121746.

Liao, C. W. (2004). *Applications of securitization in financing —An illustration of science park proprietary fund* [Mastersthesis]. National Chiao Tung University, Taiwan.

Lin, K. L. & Yang, D. Y. (2016). A study on the relationships between organizational culture and job performance-with Kaohsiung public servants as example. *J. Glob. Bus. Oper. Manag.*, *8*, 125-136.

Li, S., Yin, P., & Liu, S. (2022). Evaluation of ESG ratings for chinese listed companies from the perspective of stock price crash risk. *Front. Environ. Sci.*, *10*. https://doi.org/10.3389/fenvs.2022.933639.

Lopez, C., Contreras, O., & Bendix, J. (2020). ESG ratings: The road ahead. *SSRN Electron. J.* https://doi.org/10.2139/ssrn.3706440.

Lu, P., Shen, Y. T., & Lin, T. H. (2017). Environmental risks or costs? Exploring flooding and the urban heat Island effect in planning for policymaking: A case study in the Southern Taiwan Science Park. *Sustainability*, *9*(12), 2239. https://doi.org/10.3390/su9122239.

MacNeil, I. & Esser, I. M. (2022). From a financial to an entity model of ESG. *Eur. Bus. Organ. Law Rev.*, *23*(1), 9-45. http://doi.org/10.1007/s40804-021-00234-y.

Masolele, R. N., Marcos, D., De Sy, V., Abu, I., Verbesselt, J., Reiche, J., & Herold, M. (2024). Mapping the diversity of land uses following deforestation across Africa. *Sci. Rep.*, *14*(1), 1681. https://doi.org/10.1038/s41598-024-52138-9.

Ministry of Foreign Affairs. (2021). Taiwan science park revenues break NT$3 trillion for first time. https://nspp.mofa.gov.tw/nsppe/news.php?post=195554&unit=379&unitname=&postname=Taiwan-science-park-revenues-break-NT$3-trillion-for-first-time

Muñoz-Torres, M. J., Fernández-Izquierdo, M. Á., Rivera-Lirio, J. M., & Escrig-Olmedo, E. (2019). Can environmental, social, and governance rating agencies favor business models that promote a more sustainable development? *Corp. Soc. Responsib. Environ. Manag.*, *26*(2), 439-452. https://doi.org/10.1002/csr.1695.

Peng, L. S. & Isa, M. (2020). Environmental, social and governance (ESG) practices and performance in Shariah firms: Agency or stakeholder theory? *Asian Acad. Manag. J. Account. Finance*, *16*(1). http://doi.org/10.21315/aamjaf2020.16.1.1.

Peng, L. Y., Lu, J., Luo, J. J., & Wang, Y. X. (2022). A combination of FDM, DEMATEL, and DANP for disclosing the interrelationship of influencing factors in rural homestay business: Empirical evidence from China. *Sustainability*, *14*(16), 10341. https://doi.org/10.3390/su141610341.

Rebeco. (2024). *Country sustainability ranking*. https://www.robeco.com/en-int/glossary/sustainable-investing/country-sustainability-ranking/

Senkova, T. A. & Earnest, S. (2020). *Government owned firms' emphasis on ESG* [Mastersthesis]. Government

owned firms' emphasis on ESG.
Trahan, R. T. & Jantz, B. (2023). What is ESG? Rethinking the "E" pillar. *Bus. Strateg. Environ., 32*(7). https://doi.org/10.1002/bse.3371.
Unruh, G., Kiron, D., Kruschwitz, N., Reeves, M., Rubel, H., & Zum Felde, A. M. (2016). Investing for a sustainable future: Investors care more about sustainability than many executives believe. *MIT Sloan Manag. Rev., 57*(4).
Wang, K., Yeh, S. Y., & Yen, H. M. (2021). How the innovation strategy and the network relationship in industrial clusters affect the firm's performance: A case study of Hsinchu Science Park. *J. Manag. Syst., 24*(4), 375-405. https://doi.org/10.29416/JMS.202110_28(4).0001.
Wu, C. N. & Liu, W. C. (2013). Watershed water quality assessment in the taipei water management district using multivariate statistical techniques. *J. Taiwan Agric. Eng., 59*(2), 29-50. https://doi.org/10.29974/JTAE.201306_59(2).0002.
Xu, Y., Xu, X., Li, J., Guo, X., Gong, H., Ouyang, Z., Zhang, L., & Mathijs, E. (2023). Excessive synthetic fertilizers elevate greenhouse gas emissions of smallholder-scale staple grain production in China. *J. Clean. Prod., 430*, 139720. https://doi.org/10.1016/j.jclepro.2023.139720.
Yang, T. S. & Chiang, M. H. (2022). The study on the construction of social impact assessment indicators. *Public Adm. Policy*, *74*, 35-68. https://doi.org/10.29865/PAP.202206_(74).0002.
Yen, L. K., Wang, J. H., Hsieh, C. C., We, B. K., & Lee, Y. T. (2020). Exploring the state role of collaborative governance on science park development: The cases of Taiwan and Russia. *Reg. Soc. Dev. Res., 11*, 99-127.
Zhang, H., Cao, C., & Zhao, Q. (2024). Addressing ESG rating divergence: A group decision-making approach with individual preferences. http://doi.org/10.2139/ssrn.5003802.
Zheng, M. (2023). Literature review on the correlation between ESG performance and corporate value. *Finance, 13*(3), 461-467. http://doi.org/10.12677/FIN.2023.133044.
Zumente, I. & Lāce, N. (2021). ESG rating-Necessity for the Investor or the Company? *Sustainability, 13*(16), 8940. https://doi.org/10.3390/su13168940.