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The Key Factors for Sustainability Reporting Adoption in the Semiconductor Industry Using the Hybrid FRST-PSO Technique and Fuzzy DEMATEL Approach

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Abstract: The proliferation of sustainability reporting (SR) is in response to environmental and social responsibility, but investors are increasingly concerned over the effects of sustainability reporting in corporate sustainability. The Sustainability Accounting Standard Board (SASB)'s sustainability standards are acknowledged as the main framework for implementing this activity, yet the influencing factors among sustainability reports highly correlate and are diverse and complicated, especially in the semiconductor industry, which is the key driving force for economic development in China. To exploit and evaluate those key factors, this research introduces a hybrid model that integrates fuzzy rough set theory with particle swarm optimization (FRST-PSO) and a fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL). FRST-PSO is adopted to filter out redundant and irrelevant factors, and the selected results are then inserted into fuzzy DEMATEL to depict the opaque relationships and set up a prioritization strategy for improvement among the factors. According to the findings on the magnitude of the impact, the priorities for improvement are environment, human capital, social capital, leadership and governance, and business model and innovation. Based on the results, an optimal and practical solution is proposed as the basis for information disclosure of sustainability reporting for the semiconductor industry.

Keywords: sustainability reporting (SR); sustainability accounting standard board (SASB); fuzzy rough set theory (FRST); particle swarm optimization (PSO); fuzzy decision-making trial and evaluation laboratory (DEMATEL)

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1. Introduction

Sustainability reporting (SR) has gained significant advancement in practice around the globe in the past two decades and is viewed as a useful channel for information disclosure [1]. SR enables organizations to focus exclusively on the impacts of sustainability topics and to be more responsible about the environment and social aspects they face. According to relevant studies [2–4], the vast majority of large companies across industries have developed their SRs on social/environmental impacts, which have become a necessary business practice for them. Johari and Komathy [5] pointed out the sustainability disclosure rate in Europe is 49% and is continuously increasing. As demonstrated by the Sustainability Accounting Standards Board (SASB), 83% of Securities and Exchange Commission (SEC)-registered companies in the U.S.A. provide sustainability information in their mandatory filings [6]. Obviously, SR has achieved greater popularity around the world and has raised the reliability of sustainability information disclosure [7].

Along with more attention in sustainability disclosure practices, several international organizations such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standard Board (SASB) have successively put forward a SR framework [8]. The GRI practical guidelines focus on the role of stakeholder participation, while the SASB standards

emphasize the investor-focused information demand [9]. To meet the needs of investors for information disclosure, SASB issued a conceptual framework in September 2019 for over 70 different industries to help them conduct appropriate investment decisions [10]. The 2019 version of the conceptual framework was viewed as an overarching standard to provide sustainability disclosure for investors and to create a good communication channel between corporates and investors [11]. The sustainability accounting standards of SASB help achieve the objectives of implementation in a global context.

The SASB standards have been used recently to highlight the materiality of ESG (environmental, social, and governance) disclosures by several studies. SASB's SR has the goal to develop industry-specific sustainability accounting standards that help public entities disclose environmental, social, and useful investment information to investors [10]. From an industry perspective, the SASB standards are recognized as the most favorable framework for the effectiveness of a firm's SR disclosure. After the advent of SASB reporting, many international well-known companies switched and adopted the SASB standards to revisit the impacts of ESG on corporate financial performance [11]. For example, the semiconductor company Intel has introduced the SASB framework and incorporated its accounting metrics to improve and deliver its own SR. The SASB framework not only serves as a benchmark of sustainability matters, but it also creates a useful decision-making support tool for investors, thereby enabling the transparency and the effectiveness of SR practices and expectations among international principles and standards.

Compared to the other leading worldwide standards, the SASB framework provides a platform to evaluate what material sustainability disclosures should be given based on the industry sector, and then the organizational sustainability performance can be improved and be beneficial to investors [12]. Thus, corporates appear to be moving in a new direction to progressively modify their SR based on the SASB framework in the near future. The SASB standards will supersede GRI SR guidelines as the main types of information disclosures for corporates. The main reason, however, why companies intend to adopt the SASB standards is that they expect to communicate with investors information that has a material financial impact on their long-term development by disclosing the quantitative metrics in the standards. Five sustainability dimensions and sub-criteria within separate dimension of industry-based SR have been issued by SASB from the global perspective [10]. Thus, meeting the requirements for such introductions is a new situation and a grand challenge. As such, the SASB framework as a benchmark of this study for evaluating key factors of sustainability reporting in the semiconductor sector is appropriate and in line with international trends.

However, in spite of the growing number of studies related to the corporate sustainability reporting, much of the attentions still focus on literature review studies. The main research goal herein is to provide a fully comprehensive and practical sustainable framework that can be adapted and applied to the semiconductor industry in China based on the SASB standards (e.g., industry-specific characteristics). As we know, the semiconductor industry is an important driver of the global technology revolution and the most important pillar of China's economic development. Therefore, the sustainable promotion of this industry is a top priority. This study analyzes the key factors of SR disclosure from the perspective of semiconductor corporates and auditing by certified public accountants (CPAs). More specially, this study shall give a holistic view on the construction of SR for a group decision problem, which corresponds with the specific expectation of investors. Despite the great contribution of SR practices in academic research for nearly a decade, there have been few empirical works done on identifying the specific factors that relate to SASB topics [7,13,14]. The dependence and feedback effects between multiple factors affecting SR reporting must be considered in order to construct a practical framework, yet they have not been observed in the current research. To overcome the complex issue, we propose an integrated evaluation model based on fuzzy rough set theory with particle swarm optimization (FRST-PSO) technique and the fuzzy decision making trial and evaluation laboratory (fuzzy DEMATEL) approach. FRSR-PSO screens key sustainability elements, and the fuzzy

DEMATEL method helps clarify the rankings of the determinants' contribution. Hence, we can provide a framework for semiconductor firms in China implementing and delivering SR principles and strategies.

The rest of this study is organized as follows. Section 2 provides an overview of the dimensions and criteria of SR based on SASB's conceptual framework in the existing literature. Section 3 describes the questionnaire design, data collection, and the introduced hybrid model. Section 4 analyzes the empirical results. Section 5 illustrates the application and discussion of the empirical findings. The final section concludes the paper.

2. Evaluation Matrix of Sustainability Reporting

What many corporate governance policies have in common these days is that they see SR as a critical part for implementing sustainability strategies efficiently and long-term value creation. SASB considers industry-specific sustainability aspects that have a long-term impact on the business. It assesses the financial and operational performance impact of corporate activities in ESG issues through five sustainability dimensions under the framework, which are recognized and expected by the global market. As such, the SASB materiality guidelines serve as the basis of the evaluation metrics of SR in this paper, and these five sustainability dimensions are [9,10]: environment (A), social capital (B), human capital (C), business model and innovation (D), and leadership and governance (E). A brief description of each dimension appears as follows.

2.1. Environment

Firms are experiencing immense pressure from environmental and social responsibility in recent years, facilitating the necessity and transparency for SR disclosure [15]. To achieve corporate responsibility due to the impact of operational strategy on the environment, Indian companies are required to provide a high-quality SR [10]. An environmental issue related to corporate sustainability should take precedence over capital market efficiency in developing economic and social interests [16]. In other words, environmental sustainability has received enormous attention and is the social tie that bind us to society [17]. Business activities could cause considerable increases in greenhouse gas (GHG) emisions and air pollution, which have negatively influenced the environment [18]. Effectively controlling global warming by mitigating GHG emissions is now a popular consensus [19]. SASA noted that an effective implementation of an energy management program in an organization has high importance for corporate sustainability development [20]. Corporates also have highlighted water and wastewater treatment in response to community residents' concerns, thereby promoting the environmental protection activities and robustness of SR [21]. A significantly greater number of concerns related to the discharge of waste and hazardous materials, especially in high-polluting industries, now affects business sustainability [22].

2.2. Social Capital

Business corporations have obligations to work towards achieving social interactions and provide social welfare for the public. There is increasing acceptance that given increased social capital, a corporate must not only adhere to sustainability development, but may in fact have to issue SR regularly [22]. According to Laskar [23], human rights are regarded as one of the evaluation factors of SR disclosure that can enhance firm performance by integrating into SR. Aggarwal and Singh [24] suggested that SR is a multi-dimensional structure, and that human rights have received greater attention from the international community and should be introduced into the evaluation metrics in a timely manner [25]. Furthermore, Lambrechts et al. [26] noted that the customer privacy involved in social relations is more valuable than other factors on SR by large firms around the world. Appropriate disclosure is viewed as a necessary component in the structure of SR content and is crucial in attracting investors and forming an organization-society relationship [27].

2.3. Human Capital

Human capital refers to workforce engagement and a diverse and inclusive workforce, which is the key source for long-term firm value [10]. It includes such things as fair labor practices, diversity and inclusion, and employee health, safety, and well-being. Mio et al. [28] noted that how to secure fair wages for laborers is one of the pillars of social performance and related to sustainability disclosures [29]. As pointed out by Jestratijevic et al. [30], the guarantee and assurance of fair labor practices should be developed, thereby maintaining the internal stickiness of SR. Additionally, GRI indicated that, while the reporting of labor productivity and a firm's competitiveness is beneficial for investors, workforce diversity and inclusion are to be included within the scope of corporate SR [9]. According to the sustainable development goals released by the United Nations in 2015, an effective policy promoting diversity and inclusion in labor hiring has become the necessary criterion for the disclosure of SR [31]. Piecyk and Björklund [32] confirmed that employee health and job safety, as well as labor welfare, are important to a corporate SR strategy [33].

2.4. Business Model and Innovation

To improve the sustainable development of a company, a sustainable business model and innovation that builds on economics, society, and the environment can contribute to SR quality [34,35]. Similarly, Demirkan et al. [36] posited that business model innovation is a feasible factor in gaining a competitive advantage and value, facilitating the sustainable development goals. Complying with the requirements of the disclosure of sustainability reporting practices is an indispensable work based on the UN [31], while business operations resulting in substantive social and environmental impact can affect corporate sustainability development. Companies have to provide a comprehensive view of business operations revolving around issues of the environment and society in support of ecosystem changes and the international development trend of corporate sustainability [37]. Many organizations have voluntarily included product quality and security in sustainability issues related to environmental involvement when they submit a SR [38]. According to a survey by Patel and Rayner [39], many big companies in India view products and services as a core value and integrate this indicator into their sustainability development practices.

2.5. Leadership and Governance

Senior leadership plays a pivotal role in corporate governance and corporate sustainability, driving high-quality content in SR [40]. In response to international expectations on International Financial Reporting Standards, South African companies have emphasized the importance and effectiveness of business leadership and sustainability [41]. According to Lozano and Huisingh [42], supply chain management in an organization is a key part towards sustainability and to attain a higher level of sustainable performance. The global areas have raised awareness about supply chain management for maintaining the necessary safe and smooth operations of production and to support the achievement of SR in an entity's business activities [43], particularly in the post-epidemic era. Accident and safety management has attracted growing attention as a sustainability issue in recent decades [44], and GRI considers this factor and stronger management for establishing a better measurement of SR [45]. Additionally, Kumar and Prakash [46] reported that sustainability practices such as environmental management and business ethics are the fundamental content of global sustainability frameworks and can be seen in GRI guidelines.

3. Research Methodology

This research develops FRST-PSO (fuzzy rough set theory-based particle swarm optimization) to identify the essential factors/criteria, and then adopts fuzzy DEMATEL to exploit the opaque relationships and to prioritize the essence among factors of SR in China's semiconductor industry. Figure 1 expresses the proposed decision framework, and the methodologies adopted are discussed in the following sections.

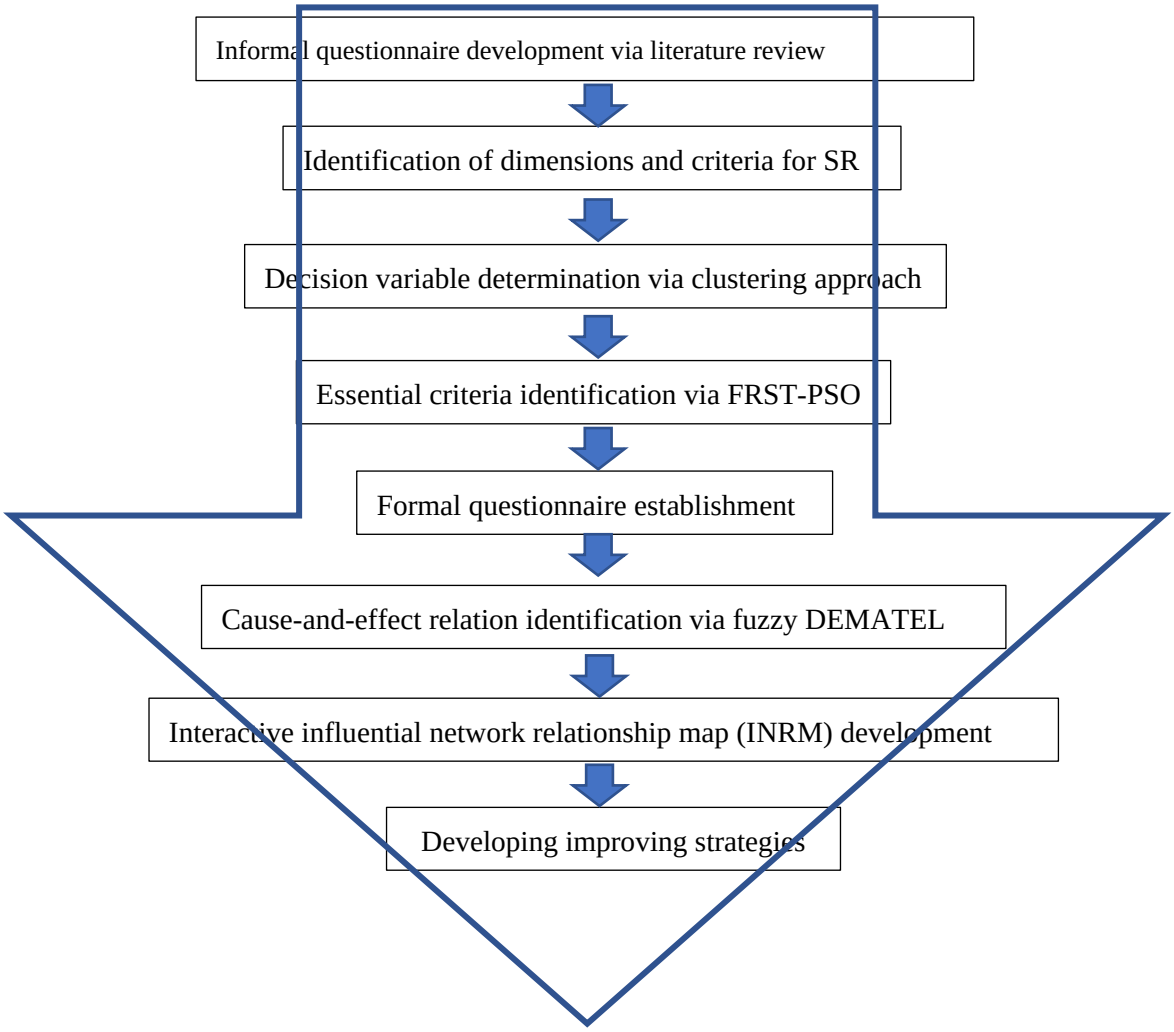


Figure 1. The introduced decision framework.

3.1. Fuzzy Rough Set Theory-Based Particle Swarm Optimization (FRST-PSO)

Many practical tasks in decision making procedures involve a large amount of input features. Unfortunately, not all collected input features are relevant and essential, and some are even contaminated by some degree of errors. When decision makers are surrounded by a considerable amount of input features, it will lead to a biased outcome, as well as cause decision making failure. To combat this, one may consider feature selection, which aims at identifying essential feature subsets without eliminating the original model's discriminant ability, as well as reducing the course of dimensionality [16]. Having the advantages of handling data comprising vagueness, impreciseness, and uncertainty, fuzzy rough set theory (FRST) is conducted to cope with feature selection tasks and is also proven remarkably popular and gained considerable success in recent years [47]. A brief illustration of FRST runs as follows.

FRST is developed by two fuzzy sets: fuzzy lower and upper approximation. In a crisp case, instances that belong to the lower approximation are viewed as falling into an approximated set preciseness. In a fuzzy case, instances may range between 0 and 1, thus providing more flexibility in handling uncertainty [48]. Equation (1) displays the fuzzy lower approximation, and the fuzzy indiscernibility relation is adopted to approximate a fuzzy concept X.

$$\alpha_{\underline{R_P}X}(x) = \inf_{y \in Q} \lambda(\alpha_{R_P}(x,y), \alpha_x(y)) \quad (1)$$

where λ denotes the fuzzy implicator, and R_P expresses the fuzzy similarity relation induced by feature subset P.

$$\alpha_{R_P}(x,y) = T_{a\in p}\{\alpha_{R_a}(x,y)\} \tag{2}$$

where $\alpha_{R_a}(x,y)$ represents to what degree the instances x and y are similar in regard to attribute a and T denotes the t-norm. Based on a similar procedure, the fuzzy positive region can be expressed in Equation (3).

$$\alpha_{pos_P(D)}(x) = \sup_{X\in U/D} \alpha_{\underline{R_P}}(x) \tag{3}$$

The fuzzy-rough degree of dependency of D on the feature P is shown in Equation (4), which can be used to illustrate the dependency between features [49].

$$\gamma'_P(D) = \frac{\sum_{x\in U} \alpha_{POS_P(D)}(x)}{|U|} \tag{4}$$

The reduct in FRST is the minimal feature subset that poses the whole dependency degree of the original dataset; i.e., $\gamma'_{REDUCT}(D) = \gamma'_C(D)$. A greater detailed illustration of FRST can be seen in Jensen and Parthaláin [47] and Jensen et al. [50].

How to determine the best reduct in FRST is an NP-complete task [51]. Chen et al. [52] indicated that a meta-heuristic algorithm can be an appropriate avenue to handle the aforementioned tasks. Genetic algorithm (GA), one type of a meta-heuristic algorithm, has been widely adopted to handle the optimization task and received much attention. The criticism of GA is that its inherent structure is too complicated (i.e., it includes mutation and crossover) and it is very easy to get stuck in a local optimum. To combat this, an emerging algorithm, named particle swarm optimization (PSO) [53], with the merit of no pre-assumption about the problem being optimized and a large search space, can be conducted. It begins with a population of random solutions, or particles. Each particle is located in a feature space S. The ith particle is denoted as $A_i = (a_{i1}, a_{i2}, \ldots, a_{iS})$, and the position of the ith particle is expressed as $P_i = (p_{i1}, p_{i2}, \ldots, p_{iS})$. The particle reaches the best position (that is, this position can let the particle have the best fitness value) in a prior operation, expressed as P_{best}. Here, G_{best} denotes the particle reaching the best performance among all particles. By modifying the velocity $V_i = (v_i, \ldots, v_{iS})$ of a particle, the search algorithm of PSO can be performed.

$$\begin{aligned} v_{id} &= w * v_{id} + c_1 * rand() * (p_{id} - x_{id}) + c_2 * rand() * (p_{Gd} - x_{id}) \\ x_{id} &= x_{id} + v_{id} \end{aligned} \tag{5}$$

A greater detailed illustration of PSO can be seen in Inbarani et al. [54].

3.2. The Fuzzy DEMATEL

DEMATEL [55,56], as a widely applicable technique in the MCDM (multi-criteria decision-making) field, effectively engages decision-makers into decision-making processes and provides them a practical solution. MCDM refers to the decision making of choosing among a limited (infinite) set of alternatives with conflicting and incommensurable degrees [57,58]. It is widely used in various fields and an important method and tool to address practical issues. The DEMATEL technique can help extract the mutual relations between all SR determinants by visualizing the cause–effect relationships among the selected determinants in graphs [59]. Based on this, the prioritization of SR elements in the structural model of the system/sub-system can be identified for developing and implementing a better strategic plan.

Despite the fact that DEMATEL is a powerful structural tool for analyzing criteria architecture, it should be expanded to capture ideal observations due to the subjectivity and fuzziness in human assessments [60]. In that case, fuzzy logic has been integrated

into the DEMATEL method to determine fuzzy DEMATEL for solving such an extremely difficult problem [61]. Fuzzy DEMATEL is a suitable method for addressing group decision making in an uncertain environment and has been applied in many fields, such as supplier selection [62], green supply chain management [63], strategy planning [64], and circular economy adoption barriers [65]. The computational procedures of this model are described in more detail below.

To provide a reasonable solution for the vagueness of human judgement, the degree of influence is expressed with five linguistic terms (very poor, poor, medium, good, very good) and their corresponding triangular fuzzy numbers (l_{ij}, m_{ij}, r_{ij}), left (l), medium (m), and right (r) scores [66], as shown in Table 1, and a weighted average can be achieved. By conducting a defuzzification technique, the fuzzy judgement is converted into crisp scores through the transformation of a fuzzy value [67]. As such, based on the experts' assessments for the criteria by using the estimation of linguistic terms, the fuzzy direct-influence matrix $\widetilde{A}$ is generated as follows.

$$\widetilde{A} = [\widetilde{a}_{ij}]_{n\times n}, \text{where} \widetilde{a}_{ij} = (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{r}) \tag{6}$$

Table 1. Fuzzy linguistic terms and corresponding values for evaluation.

Linguistic Terms	Triangular Fuzzy Numbers
Very poor	[0.0, 0.1, 0.3]
Poor	[0.1, 0.3, 0.5]
Medium	[0.3, 0.5, 0.7]
Good	[0.5, 0.7, 0.9]
Very good	[0.7, 0.9. 1.0]

The normalized fuzzy direct-influence matrix $\widetilde{X}$ can be computed as:

$$\begin{aligned} \widetilde{X} &= \widetilde{A}/\alpha, \text{ where } \alpha \\ &= \max_{i,j}\left\{\max_{i}\sum_{j-1}^{n} a_{ij}, \max_{j}\sum_{j-1}^{n} a_{ij}\right\},\ i,j \in \{1,\ldots,n\} \\ \widetilde{X} &= \left[\widetilde{x}_{ij}\right]_{n\times n},\ \widetilde{x}_{ij} = (x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{h}) \end{aligned} \tag{7}$$

where $\widetilde{X} = (X^{l}, X^{m}, X^{h})$, $X^{l} = [x_{ij}^{l}]_{n\times n}$, $X^{m} = [x_{ij}^{m}]_{n\times n}$, and $X^{h} = [x_{ij}^{h}]_{n\times n}$. However, the total fuzzy direct-influence matrix ($\widetilde{G}$) can be seen as:

$$\widetilde{G} = [\widetilde{g}_{ij}]_{n\times n}, \text{where } \widetilde{g}_{ij} = (g_{ij}^{l}, g_{ij}^{m}, g_{ij}^{h}) \tag{8}$$

where

$$G^{l} = [g_{ij}^{l}]_{n\times n} = X^{l}(I - X^{l})^{-1}, G^{m} = [g_{ij}^{m}]_{n\times n} = X^{m}(I - X^{m})^{-1},$$
$$\text{and} \quad G^{h} = [g_{ij}^{h}]_{n\times n} = X^{h}(I - X^{h})^{-1}$$

The CFCS (converting fuzzy data into crisp scores) defuzzification technique is finally used to produce more accurate crisp scores. The vectors of the total influence matrix $\widetilde{G}$ are the sum of rows ($\widetilde{D}$) and sum of columns ($\widetilde{R}$). The fuzzy DEMATEL structural model is now established, and INRM (influential network relationship map) is drawn by mapping the set of $(\widetilde{D}_i + \widetilde{R}_i, \widetilde{D} - \widetilde{R})$ for analyzing the casual relations on key factors of SR.

4. Data Analysis

4.1. Questionnaire Development

This study set up a questionnaire (see Figure 2), identified the dimensions and criteria, created a pre-test questionnaire creation, and finalized the official questionnaire. To obtain some insights regarding when SR is done in practice, we make use of the SASB disclosure items [6,9,10] and the relevant literature. Specifically, the SASB standards contain a "com-

prehensive assessment matrix", and is used in this study to examine how a SR disclosure mandate affects environmental and social consequences.

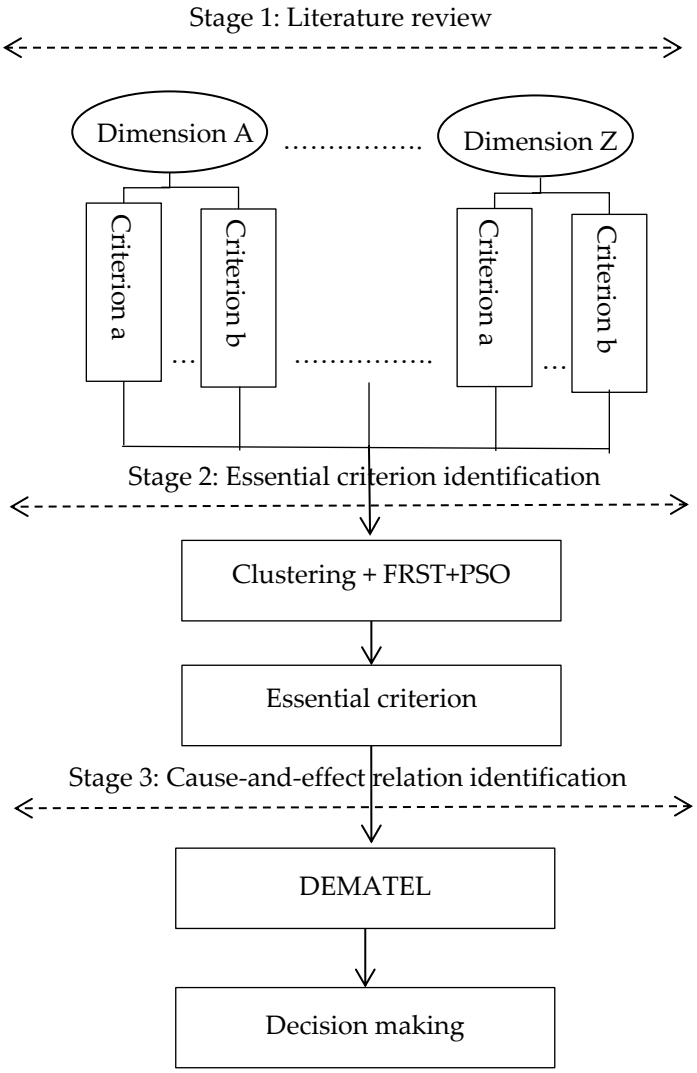


Figure 2. The procedure of formal questionnaire development.

Given the SASB framework, existing literature, and domain experts, the pre-test questionnaire involves five dimensions and thirty-three criteria (Table 2).

According to a survey among professionals who were experienced in the work of sustainability issues and was circulated among 10 certified public accountants (CPAs) at CPA firms and 10 heads of sustainability office at semiconductor companies. Respondents' scores ranged from 0 to 10 (0 = extremely unimportant, 10 = extremely important), and then the completed questionnaires were imported into FRST-PSO techniques to determine the crucial determinants and to formulate a new filtered/formal questionnaire. Because FRST-PSO is recognized as a supervised learning approach, the condition variable needs to be decided beforehand. In accordance with Thangavel et al. [68], the clustering approach (K-means) is adopted to determine the condition variable. We adopt an ELBOW method to determine the best number of clusters (see Figure 3). We can see that the cluster number is set to 3 to reach the best performance. This information is conjunction with FRST-PSO to selected feature subsets (see Tables 3–5).

Table 2. Criteria of disclosure of sustainability reporting for the pre-test questionnaire.

Dimension	Criterion
Environment	C1: GHG (greenhouse gas) emissions C2: Air quality C3: Energy management policy C4: Fuel management C5: Water and wastewater management C6: Waste and hazardous materials management C7: Biodiversity impacts
Social capital	C8: Human rights C9: Access and affordability C10: Customer welfare C11: Customer privacy C12: Fair disclosure C13: Fair marketing and advertising
Human capital	C14: Labor relations C15: Fair labor practices C16: Workforce diversity and inclusion C17: Employee health, safety, and well-being C18: Compensation and benefits
Business model and innovation	C19: Product packaging C20: Business operations C21: Environmental and social impacts on assets C22: Lifecycle impacts of services C23: Product quality and safety C24: Products and services
Leadership and governance	C25: Supply chain management C26: Systemic risk management C27: Accident and safety management C28: Political influence C29: Business ethics C30: Regulatory capture C31: Transparency of payments C32: Materials sourcing C33: Competitive behavior

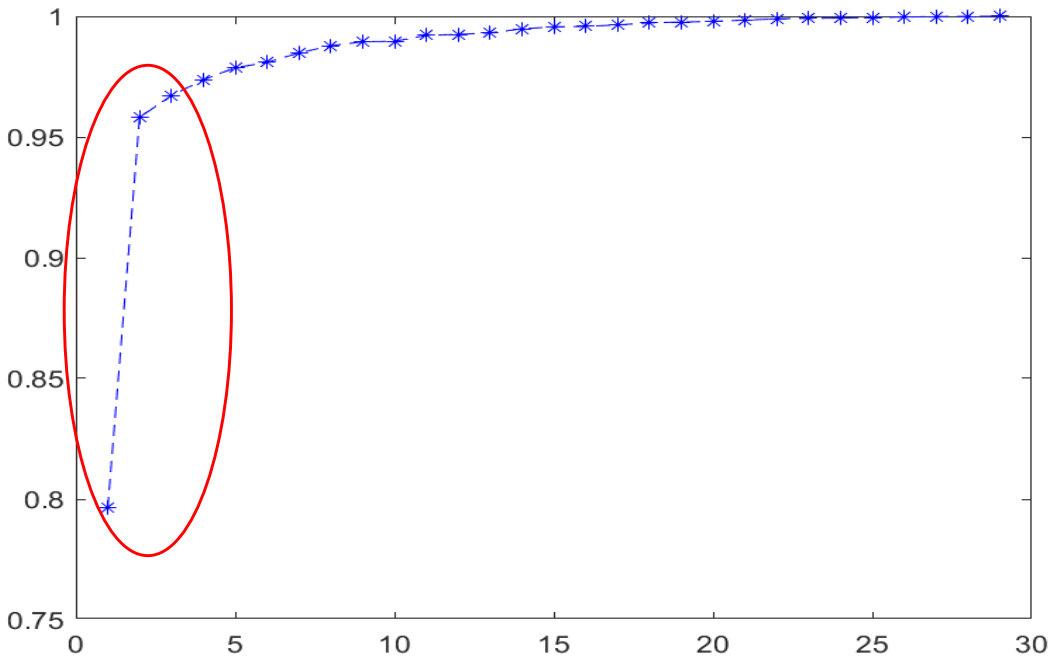


Figure 3. The number of clusters determination.

Table 3. The selected criteria by FRST-PSO technique.

Dimension	Criterion	(◆: Selection; ◇: No Selection)	
		Key Factors Generated from the FRST-PSO Method	
		New Code	Result
A	C1: GHG (greenhouse gas) emissions	a_1	◆
	C2: Air quality	–	◇
	C3: Energy management policy	a_2	◆
	C4: Fuel management	–	◇
	C5: Water and wastewater management	a_3	◆
	C6: Waste and hazardous materials management	a_4	◆
	C7: Biodiversity impacts	–	◇
B	C8: Human rights	b_1	◆
	C9: Access and affordability	–	◇
	C10: Customer welfare	–	◇
	C11: Customer privacy	b_2	◆
	C12: Fair disclosure	b_3	◆
	C13: Fair marketing and advertising	–	◇
C	C14: Labor relations	–	◇
	C15: Fair labor practices	c_1	◆
	C16: Workforce diversity and inclusion	c_2	◆
	C17: Compensation and benefits	–	◇
	C18: Employee health, safety, and well-being	c_3	◆
D	C19: Product packaging	–	◇
	C20: Business operations	–	◇
	C21: Environmental and social impacts on assets	d_1	◆
	C22: Lifecycle impacts of services	d_2	◆
	C23: Product quality and safety	–	◇
	C24: Products and services	d_3	◆
E	C25: Supply chain management	e_1	◆
	C26: Systemic risk management	–	◇
	C27: Accident and safety management	e_2	◆
	C28: Political influence	e_3	◆
	C29: Business ethics	–	◇
	C30: Regulatory capture	–	◇
	C31: Transparency of payments	–	◇
	C32: Materials sourcing	–	◇
	C33: Competitive behavior	–	◇

Note: A: environment; B: social capital; C: human capital; D: business model and innovation (D); E: leadership and governance.

Table 4. Feature selection from domain experts via the FRST-PSO technique.

Feature Subset	Accuracy	Coverage	AAC *
Subset 1: A2, A3, B1, B3, B4, C3, C4, D2, D3, D4, D6	0.86	0.83	1.69
Subset 2: A2, A3, A4, B1, B3, C1, C3, D1, D3, D4, D6	0.90	0.91	1.81
Subset 3: A1, A2, A4, B1, B3, B4, C1, C3, C4, D2, D3, D4	0.85	0.86	1.71
Subset 4: A1, A4, B1, B2, B4,C1, C2, C3, C4, D1, D5, D6	0.84	0.86	1.70
Subset 5: A1, A3, A4, B2, B4, C1, C4, D1, D3, D4, D5	0.83	0.84	1.67

* AAC: Aggregation of accuracy and coverage.

Table 5. Sustainability reporting assessment framework for the semiconductor industry.

Dimension/Criterion	Description	Source(s)
	Environment (*A*)	
GHG (greenhouse gas) emissions (a_1)	Measurement and announcement of carbon dioxide emission	Moses et al. [18]; Raghupathi and Raghupathi [19]
Energy management (a_2)	An optimizing energy management policy for corporate sustainability	Reimsbach et al. [13]
Water and wastewater management (a_3)	The supervision and management of water and wastewater treatment systems	Ike et al. [20]
Waste and hazardous materials management (a_4)	Assessment and adjustment of waste and hazardous materials management	Kozlowski et al. [21]
	Social capital (*B*)	
Human rights (b_1)	Advocacy and emphasis on human rights protection	Laskar [23]; Aggarwal and Singh [24]; Antonini et al. [25]
Customer privacy (b_2)	Any information associated with consumer products and services is protected.	Lambrechts et al. [26]
Fair disclosure (b_3)	An entity can fairly disclose necessary information to all stakeholders on the results of operations.	Tsalis et al. [27]
	Human capital (*C*)	
Fair labor practices (c_1)	Firms provide a good labor environment and working condition for employee.	Mio et al. [28]; Karagiannis et al. [29]; Jestratijevic et al. [30]
Workforce diversity and inclusion (c_2)	Non-discriminatory labor act and treatment	GRI [9]; UN General Assembly [31]
Employee health, safety, and well-being (c_3)	Firms focus on employee health, safety, and well-being	Hsueh [33]
	Business model and innovation (*D*)	
Business operations (d_1)	Environmental impact of negative products caused by business operations	UN [31]; Uyar et al. [37]
Product quality and security (d_2)	Product quality and safety are guaranteed by the enterprise	Al-Shaer and Zaman [38]
Products and services (d_3)	Sustainable product and service provision	Patel and Rayner [39]
	Leadership and governance (*E*)	
Supply chain management (e_1)	Effectively manage corporate supply chain to adapt to today's rapidly changing and technology-oriented business environment	Lozano and Huisingh [42]; Vieira and Radonjič [43]
Accident and safety management (e_2)	Corporates provide a safety management process for entire operation and handling mechanisms of accidents and disasters.	Khan et al. [44]; Corazza et al. [45]
Business ethics (e_3)	Business activities take into account the interests of society	Kumar and Prakash [46]

The formal questionnaire was established based on Table 4 and was sent to gather knowledge from 34 domain experts who specialize in sustainability issues, consisting of 10 CPAs from Big 4 public accounting firms (Deloitte, PricewaterhouseCoopers (PwC), KPMG, and Ernst & Young), 14 heads of sustainability departments at semiconductor companies, and 10 accounting scholars in the four first-tier cities (Beijing, Shanghai, Guangzhou, and Shenzhen) in China (see Table 6). All self-administered survey questionnaires were conducted through online and offline interviews that took approximately 2 h from May 2022 to December 2022. Additionally, a brief explanation on the purpose of this research for participants was performed, and those invited submitted a pairwise comparison matrix of the key factors with ratings on a five-point scale that ranges from 0 to 4 (from 0 [absolutely no impact] to 4 [very high impact]) based on their cognitions. At the same time, a performance questionnaire was evaluated based on the group of experts using a ten-point scale, whereby 0 indicates very great dissatisfaction and 10 for very high satisfaction. In a word, a total of 34 filled questionnaires were collected to serve as the basis for empirical analysis in this study.

4.2. Analysis of Evaluation Criteria

To provide an appropriate solution, a fuzzy DEMATEL approach was conducted—that is, the model helps achieve an influential relationship among dimensions/criteria and constructs an INRM for better decision making.

Based on the opinion of experts, the influence matrix by pairwise comparison is obtained and indicates the interaction among factors. The total fuzzy direct-influence matrix $\widetilde{G} = [\widetilde{g}_{ij}]_{n\times n}$ is achieved using Equation (8) and presented in Table 7.

Table 6. Experts' characteristics in this experiment and evaluation format.

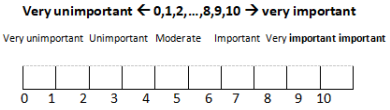
Category	No.	Job Title
Certified public accountants (More than 15 years of work experience)	1–2	A senior manager in PricewaterhouseCoopers (PwC), the Guangzhou office
	3–4	A senior manager in KPMG, the Guangzhou office
	5–6	A senior manager in Ernst & Young, the Guangzhou office
	7	A senior manager in Deloitte, the Guangzhou office
	8	A senior manager in KPMG, the Guangzhou office
	9	A senior manager in KPMG, the Shenzhen office
	10	A senior manager in PwC, the Shenzhen office
Heads of sustainability office at semiconductor companies (At least 10 years work experience on internal auditing departments)	11–13	Managers of sustainability office, XX company, Guangzhou
	14–17	Managers of sustainability office, XX company, Shenzhen
	18–19	Managers of sustainability office, XX company, Beijing
	20	A manager of sustainability office, XX company, Shanghai
Survey of the level of importance in evaluation dimensions and criteria		
Dimension	Criteria	Considering the important evaluation of the standard, enter 0–10 

Table 8 shows the influential relationships, which include five dimensions and sixteen key influence factors. Dimension A (Environment) gives the highest positive degree of influence ($\widetilde{d}_i - \widetilde{s}_i = 0.032$), whereas dimension C (Human capital) and dimension E (Leadership and governance) show the negative values to mean influenced by other dimensions. For criteria, criterion a_1 (GHG emissions) indicates the highest value of ($\widetilde{d}_i - \widetilde{s}_i$) among all factors, showing that this criterion has the highest influence on other criteria, whereas criterion a_3 (Water and wastewater management) has a minimum negative value, indicating that it is easily influenced in a whole system. Additionally, we observe the influence relationship ($\widetilde{d}_i + \widetilde{s}_i$) among the criteria, showing that criterion a_1 (GHG emissions) has the highest relation at 1.192, whereas the criterion e_3 (products and services) gives the weakest relation and the value is 0.713.

INRM is drawn according to Table 8 for measuring the mutual effects between dimensions/criteria, as shown in Figure 4. In Figure 4, the latitude axis ($\widetilde{d}_i + \widetilde{s}_i$) stands for the intensity of the total relationship among factors, and the longitude axis ($\widetilde{d}_i - \widetilde{s}_i$) stands for the causal effects among factors. INRM presents a view of the interdependence of the factors influencing SR quality in China's semiconductor industry. As can be seen, the direct impact of dimension A (Environment) is given on other dimensions; dimension C (Human capital) also has a direct impact on dimensions B (Social capital), E (Leadership and governance), and D (Business model and innovation). The cause group factors include dimensions A, C, and D, whereas the effect groups are dimensions E and D. The same effect in the individual dimensions, such as a_2 (GHG emissions), b_3 (Fair disclosure), c_3 (Employee health, safety, and well-being), d_2 (Product quality and safety), and e_3(Supply chain management) can be achieved for analyzing the dependent relationships among all criteria. In other words, a corporate in the manufacturing sector aims to present a robust SR in which these five factors should be prioritized.

Table 7. Fuzzy influence matrix on the average values of criteria.

Criterion	a_1	a_2	a_3	a_4	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3	e_1	e_2	e_3
a_1	0.131	0.180	0.178	0.176	0.177	0.176	0.166	0.174	0.179	0.169	0.176	0.175	0.179	0.168	0.181	0.175
a_2	0.137	0.111	0.141	0.138	0.140	0.136	0.130	0.139	0.140	0.132	0.140	0.135	0.139	0.131	0.140	0.142
a_3	0.128	0.133	0.106	0.127	0.131	0.132	0.127	0.128	0.135	0.126	0.131	0.133	0.133	0.125	0.135	0.132
a_4	0.130	0.134	0.138	0.107	0.136	0.135	0.126	0.135	0.138	0.128	0.134	0.135	0.139	0.129	0.141	0.135
b_1	0.123	0.129	0.127	0.127	0.103	0.128	0.120	0.126	0.134	0.124	0.127	0.125	0.131	0.115	0.131	0.127
b_2	0.121	0.127	0.128	0.126	0.127	0.102	0.122	0.126	0.128	0.123	0.130	0.125	0.131	0.121	0.131	0.129
b_3	0.158	0.164	0.159	0.160	0.163	0.161	0.118	0.161	0.165	0.156	0.162	0.158	0.164	0.156	0.159	0.157
c_1	0.124	0.130	0.131	0.128	0.130	0.127	0.122	0.102	0.131	0.120	0.135	0.129	0.138	0.123	0.136	0.130
c_2	0.129	0.134	0.132	0.129	0.132	0.128	0.116	0.122	0.107	0.137	0.131	0.136	0.140	0.126	0.139	0.136
c_3	0.159	0.166	0.166	0.157	0.167	0.163	0.157	0.161	0.165	0.121	0.165	0.160	0.165	0.156	0.165	0.158
d_1	0.119	0.123	0.125	0.126	0.125	0.124	0.114	0.118	0.122	0.120	0.099	0.121	0.125	0.114	0.122	0.124
d_2	0.145	0.153	0.153	0.150	0.152	0.150	0.140	0.142	0.151	0.140	0.144	0.116	0.149	0.140	0.152	0.148
d_3	0.120	0.124	0.126	0.122	0.124	0.121	0.115	0.122	0.120	0.112	0.117	0.122	0.100	0.116	0.123	0.121
e_1	0.155	0.159	0.161	0.156	0.159	0.158	0.152	0.159	0.162	0.148	0.155	0.159	0.161	0.117	0.162	0.158
e_2	0.121	0.124	0.122	0.119	0.123	0.120	0.112	0.122	0.124	0.116	0.123	0.123	0.126	0.117	0.101	0.125
e_3	0.123	0.125	0.129	0.125	0.125	0.125	0.119	0.125	0.128	0.121	0.121	0.126	0.130	0.117	0.133	0.101

Table 8. Cause ($\widetilde{d_i}$) and effect ($\widetilde{s_i}$) values among dimensions and criteria.

Dimension/Criterion	Row Sum ($\widetilde{d_i}$)	Column Sum ($\widetilde{s_i}$)	$\widetilde{d_i} + \widetilde{s_i}$	$\widetilde{d_i} - \widetilde{s_i}$
Environment (A)	0.714	0.682	1.396	0.032
GHG (greenhouse gas) emissions (a_1)	0.666	0.527	1.192	0.139
Energy management policy (a_2)	0.526	0.558	1.084	−0.032
Water and wastewater management (a_3)	0.495	0.562	1.057	−0.068
Waste and hazardous materials management (a_4)	0.509	0.562	1.072	−0.053
Social capital (B)	0.678	0.669	1.348	0.009
Human rights (b_1)	0.351	0.393	0.743	−0.042
Customer privacy (b_2)	0.351	0.391	0.742	−0.041
Fair disclosure (b_3)	0.442	0.360	0.802	0.083
Human capital (C)	0.693	0.673	1.366	0.020
Fair labor practices (c_1)	0.353	0.386	0.738	−0.033
Workforce diversity and inclusion (c_2)	0.366	0.402	0.768	−0.036
Employee health, safety, and well-being (c_3)	0.447	0.378	0.826	0.069
Business model and innovation (D)	0.639	0.687	1.326	−0.047
Business operations (d_1)	0.345	0.360	0.704	−0.015
Product quality and safety (d_2)	0.408	0.359	0.768	0.049
Products and services (d_3)	0.339	0.373	0.713	−0.034
Leadership and governance (E)	0.663	0.677	1.340	−0.013
Supply chain management (e_1)	0.437	0.352	0.789	0.086
Accident and safety management (e_2)	0.343	0.396	0.739	−0.053
Business ethics (e_3)	0.352	0.385	0.737	−0.033

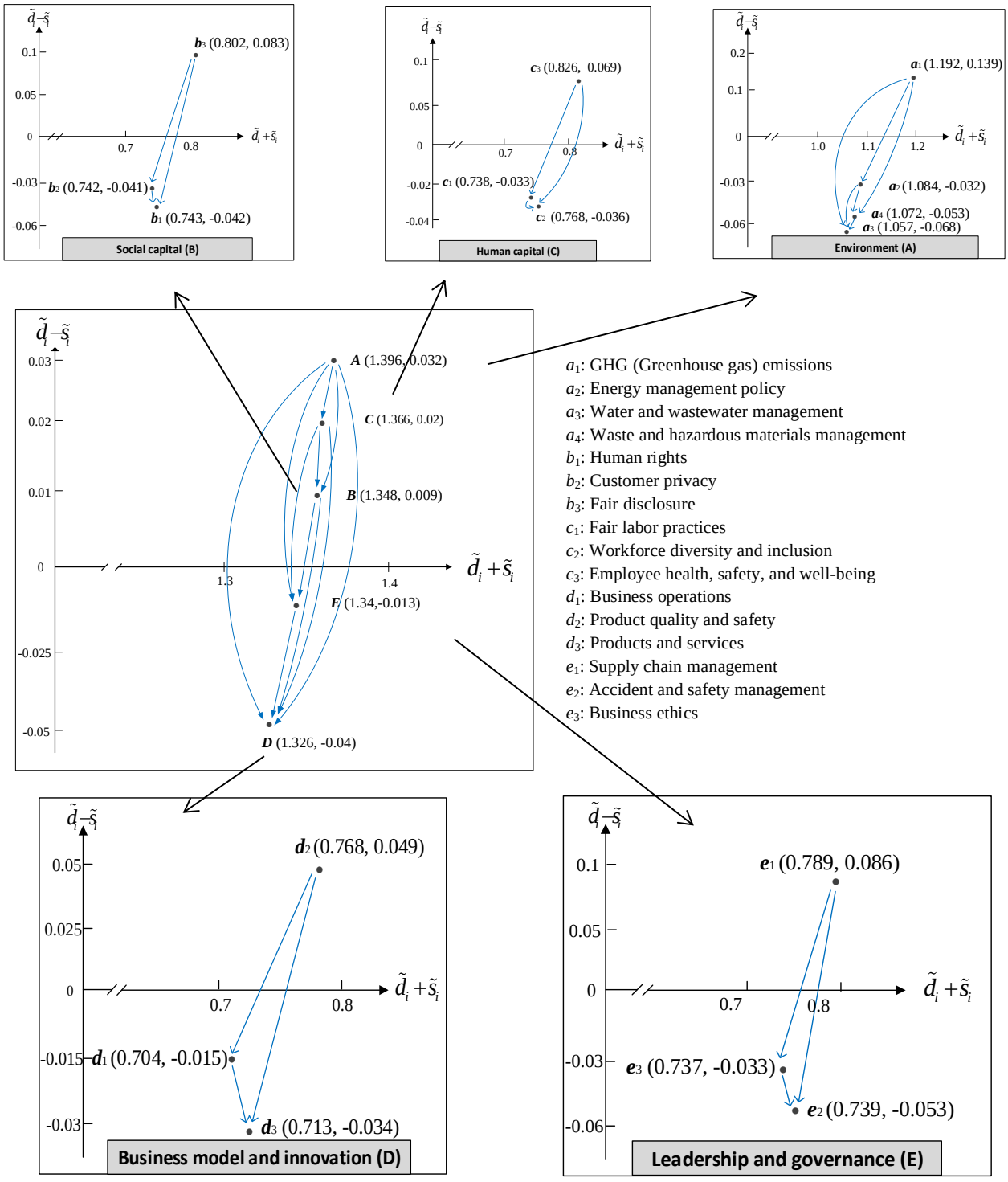


Figure 4. The INRM of influential relationships among factors.

5. Discussion

According to Figure 4, the results of fuzzy DEMATEL, the cause–effect relation between system and sub-systems, are visualized for identifying SR in the semiconductor sector. As such, we prioritize the aspects in the following order: environment (A), human capital (C), social capital (B), leadership and governance (E), and business model and innovation (D). Specifically, environment is a top-priority direction of optimizing SR in the semiconductor industry in China, because this activity affects other potential activities directly or indirectly to create a double effect of problem solving. Mio et al. [28] noted

that an environment factor is important for sustainability disclosures, so that environment sustainability issues have received a great deal of attention around the world. Enhancement of a corporate environmental strategy does not merely improve SR quality, but also helps a firm gain a competitive advantage in the market [69]. Similarly, de Villiers and van Staden [70] conducted an analysis to indicate that investors and shareholders require a certain quality of environmental information disclosure of corporates for facilitating value enhancement.

In the context of global warming, the responsibility for and protection of the environment is the foundation for sustainability value creation [71]. Oware and Awunyo-Vitor [72] suggested that the growing awareness of environmental responsibilities has become a global consensus, but open and transparent environmental information is a necessary condition for the composition of SR. According to a Brundtland report in 1987 [73], the environmental protection activities should be considered in SR, and are more likely to lead to the promotion of environment sustainability and an increase in firm value [74]. Such a concept of environmental sustainability has been valued and promoted by many international institutions after that, such as in the GRI framework. Management of companies should therefore understand that a well-structured environmental practice is important and should build environmental indicators into their SR [75]. At the top, global environmental issues are escalating stakeholders' concerns towards corporate sustainability disclosure for safeguarding their interests [76].

We can similarly see from Table 8 that GHG (greenhouse gas) emissions (a_1) are said to have the highest value of influence relation on other criteria. More specifically, it means that "GHG (Greenhouse gas) emissions" is the highly prioritized criterion when a firm intends to construct a SR. A company operating in Canada was required to report its GHG emissions based on Nazari et al. [77], who showed that GHG emissions are associated with enhanced SR, because of external pressures on corporate environmental protection and social responsibility. According to the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD), the greenhouse gas protocol has been formulated and integrated into an environmental sustainability framework to show that corporates are socially and environmentally responsible by adhering to sustainable reporting practices [78]. Chung and Cho [79] noted that a series of actions and initiatives are included in the environmental, social, and economic aspects of enterprises, which are inseparably related to GHG emissions.

Supply chain management is the second highest contributor among the criteria and a significant driver of leadership and governance (dimension E). In fact, SR issued by the manufacturing industry since 2003 has clearly disclosed supply chain information [25]. Bové and Swartz [80] indicated that supply chain management captures a key area for improvements to the environmental and social impacts of company activities, and is a necessary component of SR. Effective supply chain management not only involves manufacturing enterprise operations, but also helps strengthen the promotion of SR [81]. When creating SR, it is expected that a firm discloses supply chain operations to a variety of stakeholders, which is of critical importance for corporates to increase the achievement of their sustainable development. Therefore, supply chain management should be taken into account when determining the quality of SR during the process of achieving sustainable development. The results of this study provide a reference framework for the effectiveness and efficiency of SR in the semiconductor sector.

6. Conclusions

Using a SASB framework, this study makes several important contributions and extensions to the sustainability development and information disclosure literature. First, this paper extends prior studies based on the semiconductor industry in general and China in particular, as they mainly focus on the construction and disclosure of SR. Second, the comprehensive factors of SR in the semiconductor industry are considered and introduced into the evaluation model. To overcome information overload and concentrate on the most significant factors, the FRST-PSO hybrid algorithm is adopted. That is, the FRST-PSO is

applied to preliminarily filter the essential criteria among all criteria. We then use the fuzzy DEMATEL model to enable the prioritization of the selected criteria in considering their mutual relationship. A cause-and-effect analysis among criteria is conducted in accordance with the results received from fuzzy DEMATEL. It is easy to realize the essence of SR for corporates in the semiconductor industry via these results. It provides empirical findings to policymakers in China and other emerging markets that have already drawn up sustainability disclosure and are considering SR in their respective contexts. The importance of dimensions' influence by using the fuzzy DEMATEL provides the priority ranking as follows: environment, human capital, social capital, leadership and governance, and business model and innovation. GHG (greenhouse gas) emissions are the main core component of SR disclosure, which means firms must specifically strengthen this factor to improve their SR quality. Findings from the study help decision-makers as a benchmark for supporting practical actions and implementing them in different regions of the world.

This study contributes to the literature of the semiconductor industry in China, it also faces some challenges that need to be solved. Questionnaires are based on the experts' opinion from China, and other countries might give different views. The bio-inspired meta-heuristic optimization methods, such as artificial rabbits optimization [82], could provide a robust and reliable analysis. Additionally, multi-criteria group decision making for analyzing the hierarchy process [83] may have greater flexibility to handle data with fuzzy information and identify specific directions for semiconductor sectors.

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