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Research article

A comparison on the critical success factors of MSW and RDF power plant development in Thailand: Using an interpretive structural modelling and cross-impact matrix multiplication applied to classification analysis

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ABSTRACT

Waste-to-energy (WtE) power plants, supplied mainly with municipal solid waste (MSW) and refuse-derived fuel (RDF), which convert waste into electricity, have emerged as a solution to Thailand's waste management problems. This study focused on identifying and studying the critical success factors (CSFs) that influence the success of MSW and RDF power plants in Thailand. This study employed interpretive structural Modelling and cross-impact matrix multiplication applied to a classification analysis to evaluate the impact of these CSFs on the development of WtE projects. The results showed that, for MSW, most CSFs were related to energy and waste management policies, followed by waste quality for electricity generation. In addition, strong financial resources and appropriate power plant locations are important for MSW management success. Conversely, for RDF, most CSFs were sufficient waste quality for electricity generation and performed well according to licensing conditions. In this study, high-level CSFs indicated that these factors were crucial for MSW and RDF development. CSFs differ based on specific technologies and regulations. However, sufficient waste quality (heating value and moisture content) is a common CSF in the MSW and RDF technologies. This study provides valuable insights into the CSFs that affect the development of WtE. Understanding and addressing these CSFs is essential for the development and operation of WtE power plants in Thailand and other countries with similar conditions. Thus, policy-makers and other stakeholders can make informed decisions to ensure the success of WtE projects.

1. Introduction

Thailand has experienced slow economic development in recent years; however, urbanization and population growth have increased. Consequently, the country is facing a growing waste management problem. This leads to environmental degradation and poses health risks to the public. In response to this challenge, the Thai government developed the comprehensive National Waste Management Action Plan No. 2 (2022–2027) to address waste management and promote sustainable practices. This policy focuses on various aspects of waste management, including waste reduction, recycling, and safe disposal, and aims to ensure that waste is managed in a manner that protects public health and the environment. The application of waste-to-energy (WtE) technology is

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increasingly being recognized as an important solution to Thailand's waste management problem, because it addresses the following issues [1–8].

- Conversion of waste into valuable energy sources. The WtE technology can generate electricity or heat from waste, which can be used to power residents, businesses, and industries. This can help reduce a country's reliance on fossil fuels and increase its energy security.
- Reducing the volume of waste that needs to be disposed of and landfill space. With limited landfill space in Thailand, converting WtE can help reduce the volume of waste that needs to be disposed of in landfills. This can extend the lifespan of existing landfills and reduce the need for new landfills.
- Mitigating greenhouse gas emissions. Because landfills are a significant source of methane emissions, which is a potent greenhouse gas, WtE technology can help reduce methane emissions by capturing gas and using it as a fuel source.
- Promoting circular economy. WtE technology can be integrated into a circular economy approach, in which waste is viewed as a resource rather than a problem. By converting waste into energy, wasted materials can be used to create value and contribute to the economy.
- Supporting sustainable development. WtE technology aligns with Thailand's commitment to sustainable development goals (SDGs) and can help promote environmental protection, social responsibility, and economic growth.

WtE technology can play a critical role in Thailand's waste management and energy landscapes. With this technology, waste collection, transportation systems, and sanitary facilities can be improved, leading to a reduction in illegal waste dumping, open burning, and municipal solid waste (MSW) leakage into the environment, because it has become a valuable energy source for WtE power plants [1,2]. By adopting this technology, a country can improve its waste management practices, reduce its environmental impact, and contribute to sustainable development. The government's community waste management policy, under the National Economic and Social Development Plan, stipulates that waste management in the form of resource utilization must focus on the management system and be environmentally friendly.

In 2022, the amount of MSW generated in Thailand was approximately 25.70 million tons. The generation was as follows: Central (17,511 tons/day), Northeast (16,882 tons/day), Bangkok (12,890 tons/day), South (8684 tons/day), North (4585 tons/day), East (6565 tons/day), and West (3294 tons/day). The average waste disposal per person in Thailand is approximately 1.07 kg daily [9]. Although the government has constructed MSW disposal systems, they are not adequate, because the quantity of MSW tends to increase annually owing to the climate, seasons, and economic behavior of life in each community or city. However, waste characteristics from various provinces in Thailand still reveal similar elements and properties, and are categorized into general, recyclable, organic, or hazardous waste. Approximately 40 % of the MSW collected is organic waste. Notably, plastic bags were found to be highly prevalent, constituting over 60 % of the general waste category.

In 2022, Thailand had 2074 operating waste disposal facilities and 33 waste transfer stations, according to a survey of local governments and private sector facilities countrywide. Among the waste disposal facilities, 1990 were operated by local government organizations, of which 81 followed proper waste disposal practices, whereas the remaining were found to be noncompliant with waste disposal regulations. Additionally, 84 facilities are managed by private companies or local government organizations in partnership with the private sector. Of these, 30 facilities were compliant with waste disposal regulations, whereas the rest were non-compliant [9]. The Alternative Energy Development Plan (AEDP2018) 2018–2037 has set targets for promoting the use of renewable energy sources in Thailand. One key objective is to harness electricity from MSW sources. The plan aims to produce 900 MW by 2037 [10]. There are two options: direct combustion and refuse-derived fuel (RDF) [11,12].

Based on information from the Energy Regulatory Commission (ERC) of Thailand, there are currently approximately 30 projects; 400 MW selling contracts have been approved by the power purchase agreement (PPA) license of MSW power plants. From these projects, approximately 60 % is MSW power plants, and 40 % is RDF power plants. However, many WtE projects have been unsuccessful after receiving PPA. These scenarios can be classified into three main types. (1) The projects were unsuccessful because they were unable to complete the construction of power plants and did not achieve a Commercial Operation Date (COD) before the due date indicated in the PPA. The two main reasons for this are that local socials/communities opposed WtE projects, and the projects were not economically feasible. (2) The projects completed the construction and achieved COD; however, the projects were later unsuccessful because of incorrect selection of technology and wrong system design from the beginning of the project implementation. This leads to low efficiency of WtE power plants and a lower income than expected. (3) The projects completed construction and achieved COD; however, the projects were unsuccessful because the amount and/or quality of waste in the power plant locations was lower than expected. Consequently, the power plant operation was under the potential capacity, leading to a longer payback period for the projects than determined.

In addition, MSW and RDF power plants have different factors and implementation constraints. MSW power plants depend on the project location, local amount, and quality of waste. The lower heating value (LHV) range of MSW suitable for WtE power plants is 1100–2000 kcal/kg [13]. LHVs owing to high moisture content make the quality of power plant generation difficult to operate and control. MSW cannot be transported across the approval location boundary, and is imported from other locations for use in MSW power plants. Notably, according to the Public Health Act (No. 2) 2007, MSW is the responsibility of the state. Without approval, no one can use it. Under this condition, those who would like to develop an MSW power plant project need to receive official approval from the local state agencies. For RDF power plants, this also depends on the project location. The cost of RDF is high; however, it provides a high heating value (the suitable RDF LHV for WtE power plants is 2200–4500 kcal/kg) [13]. Hence, it is easier to operate and control the quality of power plant generation compared with the direct use of MSW. For waste management regulations, RDF is not a state asset, and anyone can access it. Additionally, it is easy to transport, and there is no boundary constraint. However, the cost of RDF is unstable and varies depending on the market price. Consequently, the return on investment in these projects is also unpredictable.

All these factors have direct negative effects on driving country policies on waste reduction using WtE. Environmental conservation in Thailand and the rest of the world cannot be achieved. Therefore, the success of WtE project development practices should be concrete and sustainable to support the policies of these countries. Owing to the significant technical constraints of MSW and RDF power plant development and non-technical constraints, such as government regulations and economic and social aspects, this study aimed to (a) identify the key factors influencing the success of MSW and RDF power plant technology in Thailand and (b) analyze and compare the causes that could affect the implementation of MSW and RDF power plant technology in Thailand. When the factors are identified and prioritized, the success of MSW and RDF projects has a high potential for achievement and sustainability. Environmental issues, including the impact of climate change on the country related to waste management problems, can be solved using the findings of this research.

To ascertain this, this study conducted a comprehensive analysis of the critical success factors (CSFs) that can influence the success of WtE power plants by comparing MSW and RDF power plants in Thailand. The CSFs were derived from a thorough examination of the relevant literature and discussions with reliable agencies and experts in the WtE field. This study employed Interpretive Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis, supported by Microsoft Excel software, to assess the impact of these factors on WtE project development in Thailand. A structural self-interaction matrix (SSIM) was also used to identify issues that could affect success and failure.

This research provided significant contributions as follows.

- This study identified nine CSFs of WtE power plants: energy and waste management policy, sufficient amount of waste, sufficient waste quality for electricity generation, sophistication of WtE technology, efficiency in plant operation and management, strong financial resources, awareness and active involvement of the public, strategic location with the community, and good performance according to the licensing conditions.
- Priority CSFs that influence the success of WtE power plants, specifically MSW and RDF power plants in Thailand, differ based on their specific technology requirements, including regulations. Sufficient waste quality for electricity generation is a common CSF of MSW and RDF power plants.
- The results of this study highlight the importance of understanding CSFs and their associated risks when considering the implementation of MSW and RDF technologies. Considering these factors, policymakers and other stakeholders can make informed decisions to ensure the successful development and operation of WtE projects.

2. MSW and RDF power plant technology

2.1. MSW power plants

MSW power plants, also known as WtE plants, are facilities designed to convert solid waste materials into electricity and heat (Fig. 1 (a)). These plants play a crucial role in waste management by reducing the volume of waste, minimizing landfill usage, and harnessing energy from waste that would otherwise be lost. Specific details of the MSW plants are presented below [14,15].

- Waste collection: MSW is collected from residential, commercial, and industrial areas.
- Waste sorting: The collected waste is sorted to remove recyclable materials such as plastic, paper, metal, and glass. Non-recyclable waste, chemical characteristics of LHV >1500 kcal/kg, moisture content <50 %, ash <18 %, S <0.12 %, and Cl <0.40 % are expected.
- Combustion: The remaining non-recyclable waste is burnt at high temperatures of 700–1200 °C in specially designed incinerators.
- Heat generation: The combustion process produces high temperatures, which are used to generate steam by heating water in a boiler (thermal efficiency ≥79 %). In some cases, the waste heat generated during the process is captured and utilized in industrial processes. This enhances the overall efficiency of the plant.
- Steam power generation: A steam outlet temperature of 400 °C is then directed to a turbine, which drives the generator to produce electricity.

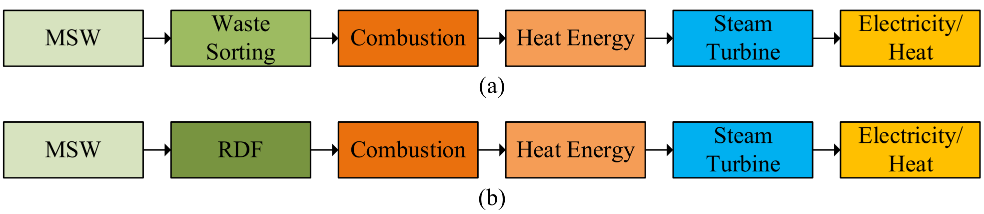

Fig. 1. The overview process of WtE power plant technology (a) MSW process and (b) RDF process.

- Electricity: The primary output of a MSW power plant is electricity. It can be supplied to the local grid for distribution in residential, commercial, and industrial areas.
- Pollution control: Various pollution control technologies are employed to minimize the emission of pollutants such as particulate matter, sulfur dioxide, nitrogen oxides, and heavy metals.

2.2. RDF power plants

RDF refers to the solid waste/municipal waste that has undergone various processes to increase the heating value of MSW. RDF power plants are specifically designed to convert RDF, a processed form of MSW, into electricity or heat (Fig. 1 (b)). The specific details of the RDF plants are presented below [16–18].

- Waste sorting and preparation: MSW is collected and transported to RDF plants, where it undergoes sorting and preparation to remove recyclable materials such as plastic, paper, metal, and glass. The remaining non-recyclable waste is further processed to create RDF. The RDF produced from non-recyclable waste is shredded, crushed, or pulverized to reduce its size and increase its energy density. Magnetic separators, eddy current separators, and other technologies are employed to remove ferrous and nonferrous metals from waste streams. The obtained RDF is a dry and homogeneous fuel with higher energy content than raw MSW. The RDF chemical characteristic expectations are LHV $>$3400 kcal/kg, moisture content $<$30 %, ash $<$18 %, S $<$0.21 %, and Cl $<$1.30 %.
- Combustion: RDF is fed into a specially designed combustion chamber or furnace. The fuel is burnt at high temperatures, typically between 800 and 1100 °C, in the presence of excess air. The combustion process releases heat energy from the RDF.
- Heat recovery and energy generation: The heat generated from RDF combustion is transferred to a water-filled boiler (thermal efficiency $\geq$82 %). The heated water produces high-pressure steam. The high-pressure steam outlet temperature of 455 °C is directed to a steam turbine, which drives a generator to produce electricity. Alternatively, steam can be used for industrial processes or district heating.
- Pollution control: RDF power plants are equipped with pollution control technologies to minimize emissions. Air pollution control devices, such as electrostatic precipitators, fabric filters, and selective catalytic reduction systems, are employed to remove particulate matter, gases, and pollutants. Flue gas treatment systems are used to reduce sulfur dioxide (SO_2), nitrogen oxides (NOx), and other harmful emissions.

2.3. Difference between MSW and RDF power plants

MSW and RDF power plants are both used to generate electricity from waste; however, they differ in the type of waste used and the processes involved. Below are some key differences between the two power plants [19–21].

- Waste input: RDF power plants use processed waste derived from non-combustible materials in the MSW. Conversely, MSW power plants use unprocessed MSW.
- Processing: RDF power plants require a processing facility to sort and remove noncombustible materials from MSW. This involves the shredding, grinding, and screening of waste to create RDF. MSW power plants do not require separate processing facilities, because the waste is fed directly into the combustion chamber.
- Combustion: RDF power plants typically use a fluidized bed combustion process in which the RDF is burnt in a bed of heated sand. This process facilitates efficient combustion and reduces emissions. MSW power plants use mass-burn combustion, in which unprocessed waste is burned in a large furnace.
- Energy output: RDF power plants generally have a higher energy output than MSW power plants, because RDF is a more consistent fuel source with a higher calorific value. MSW power plants may have a lower energy output owing to the variability of the waste feedstock.
- Emissions: RDF and MSW power plants produce emissions; however, RDF power plants generally produce lower emissions because of the use of a more efficient combustion process and the removal of non-combustible materials. MSW power plants may produce higher emissions owing to the presence of contaminants in the waste streams [22].

Overall, MSW and RDF power plants both effectively generate electricity from waste; however, the choice between these two power plants depends on factors such as the availability and quality of waste feedstock, desired energy output, and environmental considerations.

3. Materials and methods

3.1. The development of ISM for MSW and RDF power plants

This study aimed to investigate the CSFs that influence the success of WtE power plants, specifically MSW and RDF power plants, in Thailand. This study compiled CSFs from credible sources, including the literature, documents, and expert interviews and consultations. These factors were then analyzed using ISM and MICMAC to determine their impact on WtE project development in Thailand. In addition, an SSIM was developed to identify and analyze obstacles that could hinder success or lead to failure. Microsoft Excel was used to implement ISM (including SSIM) and MICMAC processes. The analyzed results of the MSW and RDF power plant technologies were compared in terms of technical and financial aspects, as well as overall project success. The methods and procedures used in this study are outlined in Fig. 2, which provides a clear overview of the methodology.

A systematic literature review of WtE projects was conducted and insights from experts in WtE development in Thailand were gathered to identify preliminary ideas and CSFs. To achieve this research objective, a qualitative methodology was considered most suitable. This study employed ISM with MICMAC analysis, as mentioned above. The ISM has been widely used in research for several decades and offers unique advantages over other techniques [23,24]. It can accommodate non-numeric and numeric research models, making it highly beneficial for conducting interviews, questionnaires, and literature reviews for explanation, investigation, and analysis. The ISM is a versatile modelling method that enables researchers to approach complex issues carefully. It utilizes logical thinking and results in interpretations that are easily understandable. The ISM process involves several steps: (1) identifying the key variables, which in this case were the success factors affecting WtE development; (2) creating an SSIM to identify the relationships among these success factors; (3) developing a reachability matrix (RM) method; (4) testing transitivity in the subsequent step; (5) setting the derived model levels using the RM; (6) translating the relationships and constructing the ISM model; and (7) reviewing and revising any inconsistencies found in the model. Following this process, the research analyzed and evaluated the CSFs for WtE projects in Thailand, specifically focusing on MSW and RDF technologies. The insights gained from this analysis contribute to a better understanding of the factors that drove the success of this research, and could help in decision-making and project development in the WtE sector.

3.2. *Identifying the CSFs of MSW and RDF power plants*

Table 1 presents the sources of the CSFs, which are based on an extensive review of the relevant literature and insights from WtE

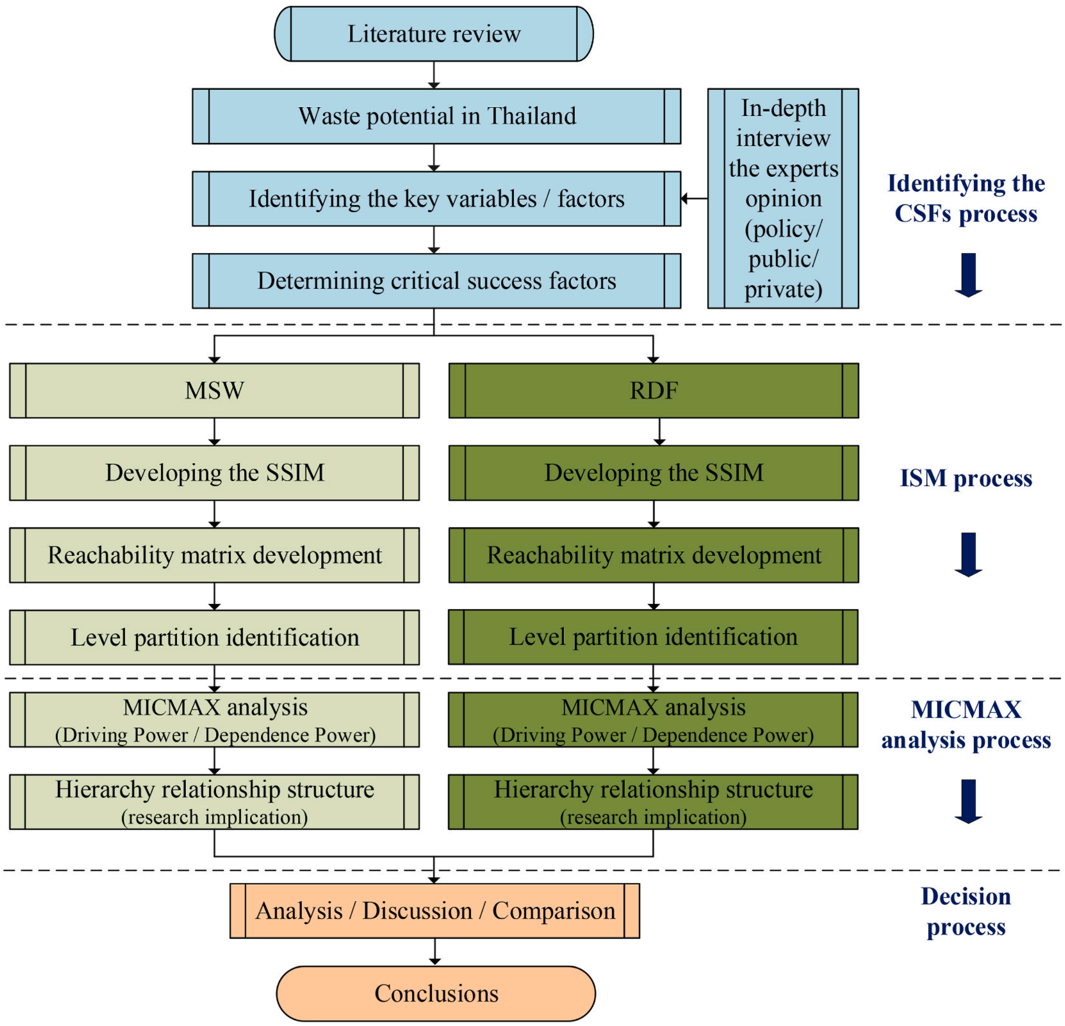

Fig. 2. The overview (process) of this study.

expert interviews. This study identified CSFs that significantly impacted the development of RDF and MSW power plants because there is no available information on CSFs for RDF and MSW power plants in Thailand. The steps for finding the CSFs in this study were as follows. First, based on a literature review, all the CSFs related to this study were gathered. From a literature perspective, CSFs are the key to a project's success. Hence, many CSFs could not be considered important. Therefore, the frequent CSFs found in the literature are of interest, and approximately 15 CSFs were selected. They were then analyzed and regarding their suitability in Thailand. In this process, the customization of the initial 15 CSFs was listed in the questionnaire; the CSFs were categorized into six aspects: national waste policy, potential of waste, technology, project management, finance, and social and environmental issues. An in-depth consultation with experts was conducted to identify the most important factors. Some factors were removed because of their irrelevance and others were combined because of their similarities. Finally, nine CSFs were selected and classified into six categories as listed in Table 2.

3.3. Description of the CSFs

CSFs are key elements or factors that contribute significantly to the success of a particular project in Thailand. Below are the nine CSFs studied to assess the impact of success on MSW and RDF projects [25–36].

- *CSF1: Energy and waste management policy*

National waste and waste management policies have a significant impact on the development of WtE projects in Thailand because a clear and supportive regulatory framework is crucial for WtE project development. National waste policies establish guidelines, standards, and procedures for permitting, licensing, and compliance with environmental and health regulations. This framework provides certainty and facilitates the planning and implementation of WtE facilities. National waste policies can provide grants, subsidies, tax benefits, or feed-in tariffs for renewable energy generated from waste. These measures could attract private investment and foster growth in the WtE sector. Overall, a comprehensive and supportive national waste policy framework is essential to foster the development of WtE projects. By addressing the regulatory, financial, environmental, and social aspects, these policies create an environment that promotes sustainable waste management practices and waste utilization as valuable resources for energy generation.

- *CSF2: Sufficient amount of waste*

The sufficient amount of available waste directly impacts the viability and efficiency of WtE projects. A sufficient amount of waste is essential to ensure a consistent and reliable feedstock supply for WtE facilities. A steady stream of waste is necessary to maintain optimal operation and energy generation. WtE projects often require a certain amount of waste to achieve economic viability. In summary, a sufficient amount of waste directly affects WtE projects in terms of operational efficiency, project viability, energy generation potential, waste diversion, and the overall environmental sustainability of waste management practices. Policymakers, waste management authorities, and project developers must assess and plan WtE initiatives based on the availability of an adequate and consistent supply of waste feedstock.

- *CSF3: Sufficient waste quality for electricity generation*

Waste quality has a significant impact on its suitability for electricity generation through WtE processes. The key factors affecting waste quality include the calorific value, moisture content, physical characteristics, contaminants, consistency, and pretreatment. Waste with a higher calorific value, lower moisture content, and homogeneous physical characteristics is preferred for efficient energy conversion. Contaminants and impurities should be minimized to comply with environmental regulations and to protect equipment. The consistency and predictability of waste quality are crucial for stable electricity generation. Waste sorting, pretreatment, and appropriate waste management practices can improve waste quality. The availability of adequate and consistent waste feedstock is vital for continuous electricity production. Overall, the consideration and optimization of waste quality are essential for effective and sustainable electricity generation through WtE.

- *CSF4: The sophistication of WtE technology*

The sophistication of the WtE technology refers to the level of advancement and complexity of the processes, systems, and

Table 1
Sources of CSFs of this research.

Type of sources	Sources	Number	Remarks
Literature related to factors in this research	Scopus database, related agencies reports	25 docments	CSFs identify based on literature review [1–8,14–18, 25–36]
In-depth interview/ consultation	Experts (>10 years in WtE field from policy, public, and private sector	6 persons (approximately 1 h per person)	Questions for identification and categorization of CSFs of MSW and RDF power plant development in Thailand

Table 2
CSF identification and categorization.

Aspects	Symbols	Critical Success Factors	Remark
1. National waste policy	CSF1	Energy and waste management policy	[25,28,30,31,35,36]
2. Waste Potential	CSF2	Sufficient amount of waste	[26,27,29,30,32,33,36]
	CSF3	Sufficient waste quality for electricity generation	[28–36]
3. WTE Technology	CSF4	The sophistication of WtE technology	[25,27,28,30–32,34]
4. Project Management	CSF5	Efficiency in plant operation and management	[28–31,33,35]
5. Finance	CSF6	Strong financial resources and financial viability	[25–27,29,31,32]
6. Social and environment issues	CSF7	Awareness and active involvement of the public	[25,26,28,31,32,34,35]
	CSF8	Strategic location with community (and public approval/satisfaction)	[27–29,31,33,34]
	CSF9	Performing well according to the licensing conditions	[25–27,29–32,34]

equipment used to convert waste into energy. The sophistication of WtE technology focuses on enhancing the energy recovery efficiency, emission control, waste pretreatment, resource recovery, control and automation, and integration with renewable energy systems. Advancements in WtE technology have contributed to sustainable waste management practices, reduced dependence on fossil fuels, and promoted the efficient utilization of waste as a valuable resource for energy generation.

- *CSF5: Efficiency in plant operation and management*

Plant operation and management efficiencies are crucial for the successful implementation of WtE projects. Efficient plant operation begins with a well-designed layout that optimizes the flow of waste, energy-conversion processes, and material-handling systems. The layout should minimize operational bottlenecks, ensure proper waste segregation, and facilitate efficient equipment placement. Efficiency in WtE plant operation and management involves optimizing plant design, waste feedstock management, energy recovery, emission control, equipment maintenance, data monitoring, operator training, and fostering a culture of continuous improvement. By implementing efficient practices, WtE plants can maximize energy generation, reduce environmental impacts, and contribute to sustainable waste management.

- *CSF6: Strong financial resources*

Strong financial resources are crucial for successful implementation of WtE projects. Strong financial resources provide the necessary funding to develop and execute WtE projects. Sufficient capital enables the acquisition of land, construction of facilities, installation of equipment, and implementation of necessary infrastructure, and ensures the project's viability from inception to completion. In summary, strong financial resources provide the necessary foundation for successful development, operation, and expansion of WtE projects. They enable technology investment, risk mitigation, timely execution, long-term operation, revenue generation, investment attraction, and economic and environmental benefits. By ensuring their financial strength, WtE projects can thrive, promote sustainable waste management, and contribute to cleaner and more efficient energy production.

- *CSF7: Awareness and active involvement of the public*

Public awareness and active involvement are essential to the success of WtE management projects. Public awareness plays an important role in waste reduction and segregation. When the public is educated on the importance of waste minimization, recycling, and proper waste segregation practices, they are more likely to actively participate in separating recyclables from non-recyclables. This improves the quality and quantity of waste feedstock available for energy generation in WtE facilities. Public awareness and active involvement are crucial for successful WtE management. Public engagement promotes sustainable waste management practices, supports policy development, encourages collaboration and partnerships, drives behavioral change, and influences public perceptions and acceptance. The success and effectiveness of WtE initiatives can be significantly enhanced by empowering individuals and communities to actively participate in waste management.

- *CSF8: Strategic location with community (social aspects)*

The strategic location of a WtE project and its impact on the surrounding community are crucial factors that contribute to its success. WtE projects should ensure convenient access to waste feedstock. Proximity to urban centers or areas with high waste generation rates reduces transportation costs and logistical challenges associated with waste collection and transportation. In addition, a steady and sufficient supply of waste is essential for the continuous operation and economic viability of a project. The strategic location of a WtE project, considering factors such as waste accessibility, environmental and health considerations, stakeholder engagement, job creation, local energy demand, waste management integration, and environmental sustainability, is crucial for its success. By addressing these aspects, a strategically located WtE project can optimize its operations, gain community support, minimize potential negative impacts, and contribute to sustainable waste management and renewable energy generation in the region.

- *CSF9: Performing well according to the licensing conditions*

Performing well according to the licensing conditions is essential for the successful operation of a WtE project. Adhering to licensing conditions ensures compliance with the relevant laws, regulations, and permits associated with waste management and energy generation. This includes meeting environmental standards, emission limits, waste disposal guidelines, and operational requirements set by regulatory authorities. By performing well according to licensing conditions, a WtE project can operate within a legal framework, minimize environmental impacts, ensure safety, engage with the community, and demonstrate responsible waste management practices. Compliance with licensing conditions fosters project credibility, regulatory compliance, and sustainability. This contributes to the long-term success of the WtE initiative.

3.4. Developing SSIM of RDF and MSW

ISM is a powerful methodology employed to analyze complex systems and uncover the relationships between various components or elements within a system [37,38]. It serves as a valuable tool for comprehending the interdependencies and hierarchical structures among different factors or elements. By providing a structured framework, ISM facilitates the analysis and understanding of relationships and dependencies within a complex system. This methodology aids in the identification of key drivers and driving elements, which supports decision-making and strategic planning processes. One of the primary advantages of ISM is its ability to visualize the hierarchy and interconnections among the factors or elements within a system. This visual representation enhances our understanding of the system dynamics and assists in the development of effective interventions and policies. In the context of this research, SSIM was developed to specifically analyze the CSFs associated with the development of RDF and MSW power plants in Thailand.

The RM is an important process in SSIM analysis. The RM is a representation of the SSIM in a binary matrix form. This helps to identify the reachability set for each CSF within a system. Below is a step-by-step approach for developing the RM [39–42].

- Listing the CSFs: First, all the CSFs identified for the MSW and RDF WtE technologies were analyzed. These CSFs should capture the key factors influencing the success of WtE projects.
- Constructing the RM: We created a matrix with rows and columns representing each CSF. Each cell in the matrix indicates the reachability relationship among CSFs. The value "1″ represents a direct reachability relationship, indicating that CSF i directly influences CSF j. The value "0″ indicates that there is no direct reachability relationship. Table 3 describes the RM relationship represented by a binary number system.
  V: CSF i will help to achieve CSF j
  A: CSF j will help to achieve CSF i
  O: CSF i and j are unrelated
  X: CSF i and j will help to achieve each other
- Determining reachability relationships: We analyzed the relationships among the CSFs and populated the RM accordingly. Experts' opinions, literature reviews, and empirical evidence were considered to determine direct reachability relationships.
- Assessing indirect reachability relationships: After establishing direct reachability relationships, the indirect reachability relationships among the CSFs were assessed. Indirect reachability refers to the influence of one CSF on another CSF. This can be identified by examining direct reachability relationships in the matrix. Tables 4 and 5 list the RM results of the MSW and RDF technologies, respectively.
- Populating the matrix: The RM cells were filled based on the determined reachability relationships. Mark a "1″ if there is a direct reachability relationship among the CSFs, and a "0″ if there is no direct reachability relationship.
- Interpreting the RM: The RM was analyzed to understand the reachability set for each CSF. The reachability sets of CSFs include all the CSFs that can be reached directly or indirectly from a particular CSF.

The cause-effect relationship of each pair of key successes was determined, and all data were used to create an SSIM table, as shown in Tables 6 and 7. In addition, all the data were used to develop the RM-level partition matrix, as shown in Tables 8–12. For example, from Table 8, the reachability set of CSF1 transitioned from Table 6 (CSF1-row) is CSF3–CSF8. The antecedent sets in the CSF1-column are CSF4, CSF7, and CSF8. The intersection sets of CSF1 that matched between the reachability and antecedent sets were CSF4, CSF7, and CSF8. This process was repeated for each CSF sample. Level 1 is identified by complete matching between the reachability and intersection sets, and the subsequent levels are obtained by iterating the same method.

The RM provides valuable insights into the relationships and dependencies among the CSFs in the system. This helps identify the

Table 3
RM relationship with binary number symbol.

Symbol	Relationship i to j (i, j)	Relationship j to i (j, i)
V	1	0
A	0	1
O	0	0
X	1	1

Table 4
RM of MSW technology.

Code	Critical Success Factor	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9
CSF1	Energy and waste management policy	–	O	V	X	V	V	X	X	O
CSF2	Sufficient amount of waste (MSW)	O	–	X	V	V	V	X	O	V
CSF3	Sufficient waste quality for electricity generation	A	X	–	O	V	X	X	X	X
CSF4	Sophistication of WtE technology (MSW)	X	A	O	–	O	X	V	X	A
CSF5	Efficiency in plant operation and management	A	A	A	O	–	V	O	O	A
CSF6	Strong financial resources	A	A	X	X	A	–	X	X	A
CSF7	Awareness and active involvement of the public	X	X	X	A	O	X	–	O	V
CSF8	Strategic location with community	X	O	X	X	O	X	O	–	A
CSF9	Performing well according to the licensing conditions	A	A	X	V	V	V	A	V	–

Table 5
RM of RDF technology.

Code	Critical Success Factor	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9
CSF1	Energy and waste management policy	–	O	V	X	V	V	X	X	V
CSF2	Sufficient amount of waste (RDF)	O	–	X	V	V	V	X	O	V
CSF3	Sufficient waste quality for electricity generation	A	X	–	O	V	X	X	X	X
CSF4	Sophistication of WtE technology (RDF)	X	A	O	–	O	X	V	X	A
CSF5	Efficiency in plant operation and management	A	A	A	O	–	V	O	X	A
CSF6	Strong financial resources	A	A	X	X	A	–	X	X	A
CSF7	Awareness and active involvement of the public	X	X	X	A	O	X	–	O	V
CSF8	Strategic location with community	X	O	X	X	X	X	O	–	A
CSF9	Performing well according to the licensing conditions	A	A	X	V	V	V	A	V	–

Table 6
SSIM of MSW technology.

Code	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9	Driving Power
CSF1	–	0	1	1	1	1	1	1	0	6
CSF2	0	–	1	1	1	1	1	0	1	6
CSF3	0	1	–	0	1	1	1	1	1	6
CSF4	1	0	0	–	0	1	1	1	0	4
CSF5	0	0	0	0	–	1	0	0	0	1
CSF6	0	0	1	1	0	–	1	1	0	4
CSF7	1	1	1	0	0	1	–	0	1	5
CSF8	1	0	1	1	0	1	0	–	0	4
CSF9	0	0	1	1	1	1	0	1	–	5
Dependence Power	3	2	6	5	4	8	5	5	3	

Table 7
SSIM of RDF technology.

Code	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9	Driving Power
CSF1	–	0	1	1	1	1	1	1	1	7
CSF2	0	–	1	1	1	1	1	0	1	6
CSF3	0	1	–	0	1	1	1	1	1	6
CSF4	1	0	0	–	0	1	1	1	0	4
CSF5	0	0	0	0	–	1	0	1	0	2
CSF6	0	0	1	1	0	–	1	1	0	4
CSF7	1	1	1	0	0	1	–	0	1	5
CSF8	1	0	1	1	1	1	0	–	0	5
CSF9	0	0	1	1	1	1	0	1	–	5
Dependence Power	3	2	6	5	5	8	5	6	4	

CSFs that have the highest influence and impact on the success of MSW and RDF WtE projects.

3.5. MICMAC analysis

MICMAC analysis is a technique used in decision-making and strategic management, and it is used to assess the interdependencies and driving power of factors within a system [43,44]. It provides a structured approach that helps understand the relative importance and influence of various factors and helps in identifying key drivers and dependent factors. The nine CSFs of MSW and RDF power plant

Table 8
RM level partition matrix 1 of MSW power plants.

CSF	Reachability set	Antecedent set	Intersection set	Level
CSF1	3,4,5,6,7,8	4,7,8	4,7,8	
CSF2	3,4,5,6,7,9	3,7	3,7	
CSF3	2,5,6,7,8,9	1,2,6,7,8,9	2,6,7,8,9	
CSF4	1,6,7,8	1,2,6,8,9	1,6,8	
CSF5	6	1,2,9		
CSF6	3,4,7,8	1,2,3,4,5,7,8,9	3,4,7,8	1
CSF7	1,2,3,6,9	1,2,3,4,6	1,2,3,6	
CSF8	1,3,4,6	1,3,4,6,9	1,3,4,6	1
CSF9	3,4,5,6,8	1,2,3,7	3	

Table 9
RM level partition matrix 2 of MSW power plants.

CSF	Reachability set	Antecedent set	Intersection set	Level
CSF1	3,4,7	4,7	4,7	
CSF2	3,4,7,9	3,7	3,7	
CSF3	2,7,9	1,2,7,9	2,7,9	2
CSF4	1,7	1,2,9	1	
CSF7	1,2,3,9	1,2,3,4	1,2,3	
CSF9	3,4	1,2,3,7	3	

Table 10
RM level partition matrix 3 of MSW power plants.

CSF	Reachability set	Antecedent set	Intersection set	Level
CSF1	4,7	4,7	4,7	3
CSF2	4,6,7,9	7	7	
CSF4	1,7	1,2,9	1	
CSF7	1,2,9	1,2,4	1,2,3	
CSF9	4,5	1,2,7	3	

Table 11
RM level partition matrix 1 of RDF power plants.

CSF	Reachability set	Antecedent set	Intersection set	Level
CSF1	3,4,5,6,7,8,9	4,7,8	4,7,8	
CSF2	3,4,5,6,7,9	3,7	3,7	
CSF3	2,5,6,7,8,9	1,2,6,7,8,9	2,6,7,8,9	
CSF4	1,6,7,8	1,2,6,7,8,9	1,6,7,8	1
CSF5	6,8	1,2,3,7,9		
CSF6	3,4,7,8	1,2,3,4,5,7,8	3,4,7,8	1
CSF7	1,2,3,6	1,2,3,4,6	1,2,3,6	1
CSF8	1,3,4,5,6	1,3,4,5,6,9	1,3,4,5,6	1
CSF9	3,4,5,8	1,2,3,7	3	

Table 12
RM level partition matrix 2 of RDF power plants.

CSF	Reachability set	Antecedent set	Intersection set	Level
CSF1	3,9			
CSF2	3,9	3	3	
CSF3	2,9	1,2,9	2,9	2
CSF9	3	1,2,3	3	2

development were evaluated and classified based on their driving and dependence powers. All success factors were introduced into a square matrix, where the rows and columns represent the identified factors. Each cell of the matrix indicates the impact of one factor on another. The effects were assessed using expert opinions, and all factors were classified into the following four categories.

- Autonomous factors: These factors have low driving and dependence powers. They slightly influenced the other factors.
- Dependent factors: These factors have high dependence but low driving power. These factors are strongly influenced by others.
- Linking factors: These factors have a high driving power and high dependence. They strongly influenced and were strongly influenced by other factors.
- Independent factors: These factors have a high driving power and low dependence power. They strongly influenced other factors and were only slightly influenced by others.

The data extracted from the RM, as described earlier, were utilized to classify the CSFs of MSW and RDF project development into partitions of different levels. These factors were divided into two sets: reachability and antecedents. By employing the MICMAC method, the relationship data from Tables 6 and 7 were analyzed to determine the driving and dependence power values associated with each factor. This analysis facilitated a graphical representation of the factors into four distinct groups: autonomous, dependent, linked, and independent.

3.6. Limitation of this research

One limitation of this study is the ISM technique, as it demonstrates high visibility when those who use it understand and have significant experience interpreting the obtained data. The interpretation of the results can differ because it sometimes depends on who uses the ISM. Another limitation is that this study was conducted based on Thailand's practices and conditions, such as policies, regulations, and social aspects. Therefore, in other countries, these techniques can be applied by identifying CSFs based on specific local contexts, and the results obtained can be different.

4. Results and discussions

Based on the significant technical constraints of MSW and RDF power plant development, including government regulations and economic, environmental, and social aspects, this research aimed to identify the factors influencing the success of MSW and RDF power plants and analyze and compare the factors that could affect the implementation of two WtE power plant technologies, namely MSW and RDF power plants. This study conducted a comparative analysis of the CSFs to examine the factors influencing the successful development of WtE power plants. The CSFs were identified through a thorough survey of relevant literature documents, discussions, and interviews with reliable agencies and experts in the WtE field.

The analysis revealed nine CSFs covering six sectors: national waste policy, waste potential, technology, project management, finance, and social and environmental issues. The aim was to determine the technology that best aligns with these CSFs. The study's findings and analysis were organized sequentially, starting with the MICMAC analysis and progressing step-by-step to level partitioning.

4.1. MSW and RDF power plants comparison using MICMAC analysis

Regarding the MICMAC analysis of the MSW power plant (Fig. 3) and regarding that of RDF power plants below (Fig. 4), both power plants were examined within the context of the conditions prevailing in Thailand.

Fig. 3, referred from Table 6, illustrates the classification of the nine CSFs into different quadrants based on the MICMAC analysis of MSW power plant development. The classification is as follows:

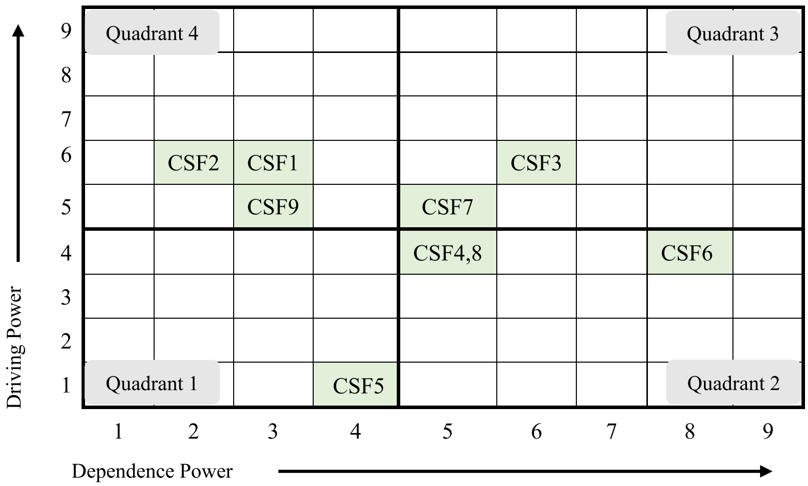

Fig. 3. MICMAC analysis of MSW power plants.

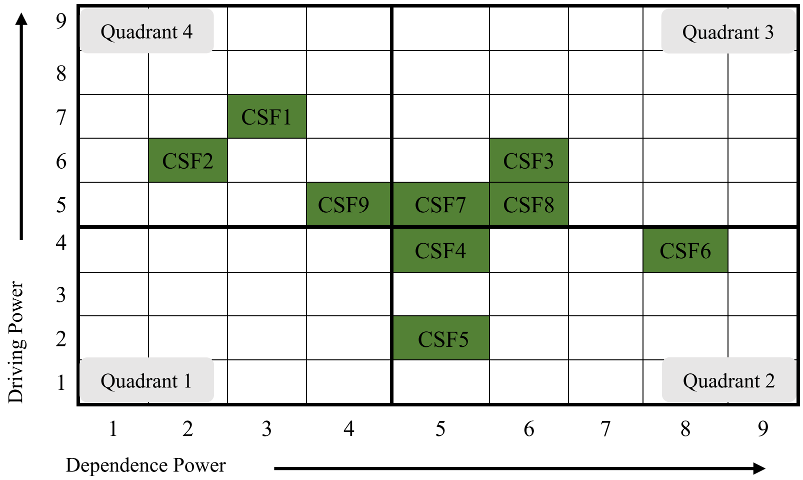

Fig. 4. MICMAC analysis of RDF power plant.

Quadrant 1 (Autonomous Group): This quadrant comprises the factor “efficiency in plant operation and management (CSF5).” It exhibits a relatively low level of dependence and driving power, indicating that it has a limited impact on other factors, while being slightly influenced by others.

Quadrant 2 (Dependence Group): This quadrant includes the factors “sophistication of WtE technology (CSF4), strong financial resources (CSF6), and strategic location with community (CSF8).” These factors demonstrate a high level of dependence, but relatively low driving power. These factors are strongly influenced by others.

Quadrant 3 (Linkage Group): This quadrant includes the factors “sufficient waste quality for electricity generation (CSF3) and awareness and active involvement of the public (CSF7).” These factors exhibit a high dependence and driving power. They have a strong impact on other factors while being strongly influenced by others.

Quadrant 4 (Independence Group): This quadrant comprises the factors “energy and waste management policy (CSF1), sufficient amount of waste (CSF2), and performing well according to the licensing conditions (CSF9).” These factors demonstrate relatively high driving power and low dependence. They have a strong influence on other factors but are only slightly influenced by others.

Through the MICMAC analysis, the factors were classified into quadrants based on their driving and dependence powers. For the MICMAC analysis of the MSW power plant, all nine CSFs were distributed in every quadrant; however, the quadrant with the most influencing factors was Quadrant 3, which consisted of CSF3 and CSF7.

Fig. 4, referred from Table 7, provides a visual representation of the CSFs categorized into different quadrants based on the MICMAC analysis of RDF power plant development. The classification of nine CSFs is as follows:

Quadrant 2: This quadrant comprises the factors “sophistication of WtE technology (CSF4), efficiency in plant operation and management (CSF5), and strong financial resources (CSF6).” These factors exhibit a high level of dependence, but relatively low driving power. These factors are strongly influenced by others.

Quadrant 3: This quadrant comprises the factors “sufficient waste quality for electricity generation (CSF3), awareness and active involvement of the public (CSF7), and strategic location with community (CSF8).” These factors exhibit a high dependence and driving power. They have a strong impact on other factors while being strongly influenced by others.

Quadrant 4: This quadrant includes the factors “energy and waste management policy (CSF1), sufficient amount of waste (CSF2), and performing well according to the licensing conditions (CSF9).” These factors exhibit a relatively high driving power and low dependence. They have a strong influence on other factors but are only slightly influenced by others.

For the MICMAC analysis of the RDF power plants, all nine CSFs were distributed in three quadrants; however, the quadrant with the most influencing factors was Quadrant 3, which consisted of CSF3, CSF7, and CSF8.

As previously explained, the MICMAC analysis is a decision-making and strategic management technique used to evaluate the interdependencies and influential factors within a system. This study focused on assessing MSW and RDF power plants by using nine CSFs across six aspects. The results of the MICMAC analysis for MSW and RDF plants are summarized in Table 13.

A comparative analysis was conducted between MSW and RDF plants in Quadrant 1. In this quadrant, MSW exhibited efficiency in

Table 13
MICMAC analysis summary.

Quadrants	MSW power plant	RDF power plant
Quadrant 1	CSF5	
Quadrant 2	CSF4, CSF6, CSF8	CSF4, CSF5, CSF6
Quadrant 3	CSF3, CSF7	CSF3, CSF7, CSF8
Quadrant 4	CSF1, CSF2, CSF9	CSF1, CSF2, CSF9

plant operation and management (CSF5), whereas the RDF did not demonstrate any CSFs. This factor has low driving and dependence powers. However, for an MSW, the key considerations are to begin with a good design and optimize the operation and management of the plant, as these are fundamental requirements.

The Quadrant 2 analysis clearly indicates that the "sophistication of the WtE technology (CSF4)" factor is relevant for MSW and RDF power plants. Although CSF4 has a limited impact on the other factors, it is sufficient to conclude that WtE technology should be tailored to match the waste quantity and quality in Thailand. For both technology implementations, success is impossible without "strong financial resource (CSF6)" to support the project. In addition to CSF4 and CSF6, the MSW plants also included CSF8, whereas the RDF plants included CSF5. These factors contribute to the overall assessment of the sophistication of WtE technology and project financial resources in alignment with specific requirements in the context of MSW and RDF power plants.

Quadrant 3 in the MICMAC analysis was referred to as the linkage factor. These factors strongly influenced each other and were strongly influenced by others. MSW and RDF power plants share two common factors in this group: sufficient waste quality for electricity generation (CSF3), and awareness and active involvement of the public (CSF7). The presence of these factors in Quadrant 3 highlights their importance, as they hold strong sway over themselves and significantly impact the success factors of WtE projects in Thailand. In addition, RDF power plants specifically incorporate an additional factor (i.e., CSF8), which also falls into Quadrant 3. CSF8 acts as a driving force that affects the overall performance of RDF power plants. Consequently, it is imperative to thoroughly analyze and consider CSF8 during the development stages of RDF power plants in Thailand.

Quadrant 4 was significantly influenced by other factors, while being slightly influenced by others. In this group, the three key success factors were similar in the MSW and RDF power plants. These factors are the energy and waste management policy (CSF1), sufficient amount of waste (CSF2), and performance according to licensing conditions (CSF9). CSF1, CSF2, and CSF9 have a profound impact on the other parameters because they are directly linked to national waste policies, the availability of an adequate amount of waste, and performance according to licensing conditions. These three factors are the foremost CSFs that must be considered when developing WtE projects.

4.2. MSW and RDF power plants comparison using RM-level partition analysis

The ISM technique serves as a comprehensive structural model that combines visual representations and mathematical comparisons to address complex numerical and nonnumerical problems. By incorporating direct and indirect analyses within an interactive and structured learning process, this approach aids in understanding the significance of each parameter's connection to the research objectives. The RM-level partition analysis examines the key parameters that are critical for the development of WtE power plants, specifically MSW and RDF technologies. The objective of this analysis is to identify the most influential parameters that impact WtE project development in Thailand, and subsequently rank their levels of importance in a step-by-step manner. This study reveals the significance of advancing WtE power plants and waste management practices, particularly in the conversion of waste into electricity and overall waste management in the country. The RM-level partition study of the MSW power plants is shown in Fig. 5.

The nine CSFs were evaluated step-by-step through SSIM and MICMAC analyses, which led to the RM-level partition. This comprehensive process enables us to understand the parameters that are significant in decision-making for the development of WtE projects in Thailand. From the analysis of MSW power plants, the factors influencing project development were divided into three levels. The analysis revealed three levels of partitioning: Levels 1, 2, and 3. The RM-level partition analysis indicates that Level 3, which includes the energy and waste management policy (CSF1), signifies a higher complexity in the development of MSW projects compared to RDF projects because of the increasing number of layers in the level partition. Level 2 identifies sufficient waste quality for

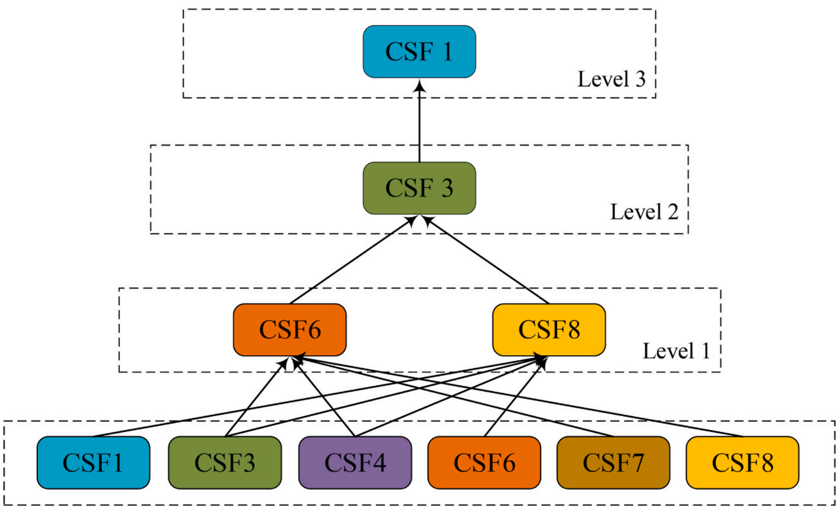

Fig. 5. The RM-level partitions of MSW technology analysis.

electricity generation (CSF3) as a significant factor for MSW power plants. Level 1 comprises CSF6 and CSF8, demonstrating their importance for the successful development of MSW plants. The analysis further revealed that CSF1, located at Level 3, is a CSF due to the diverse management approaches and involvement of various parties and local agencies in MSW disposal. The existence of clear policies at the national level is crucial for the success of MSW power plant projects. Without clear policies, investment may be hindered, and conflicts may arise because of the inability to manage waste effectively. The second most important factor at Level 2 is CSF3, which is related to waste quality (for electricity generation, it mainly focuses on heating value and moisture content). Because MSW mainly comes from communities, the quality of waste varies, and it may have beneficial and harmful effects when converted into electricity using MSW technology. Finally, at Level 1, CSF6 and CSF8 pertain to financial considerations and appropriate selection of power plant locations. The locations of power plants must be suitable for waste collection, such as proximity to residential, commercial, or industrial areas with significant waste generation. Financial management is crucial for successful waste collection and plant operation.

The analysis of MSW plants revealed a significant correlation between the parameters and the level of importance for each CSF, as determined by the RM-level partition analysis. Similarly, an analysis was conducted for RDF plants by employing the RM-level partition methodology and utilizing the same nine CSFs as in the MSW plants. The RM-level partition analysis of RDF technology is illustrated in Fig. 6.

As shown in Fig. 6, the CSFs at Level 1 comprise CSF4, CSF6, CSF7, and CSF8. These factors were ranked as the second most important because of their interconnections with reachability and antecedent sets. In the evaluation process based on the RM-level partitioning methodology, these parameters were identified as having similarities and significant interdependencies that affected each other. However, the parameters at the highest level are of utmost importance for the development of RDF power plants. According to the RM-level partition analysis, sufficient waste quality for electricity generation (CSF3) and adherence to licensing conditions (CSF9) were the most crucial. This indicates that there is no higher partition level beyond partition Level 2 for RDF power plants. This aligns with the requirement that RDF technology relies on appropriate waste quality for efficient power generation. Compliance with licensing conditions is another key factor at the highest level, and is of significant importance for RDF power plants. In Thailand, the ERC is responsible for monitoring power plants that have obtained electricity production licenses and ensuring compliance with the stipulated conditions. When RDF power plants violate these conditions or receive complaints from the public regarding issues such as air pollution, water pollution, or noise, the ERC has the authority to revoke or suspend licenses based on the severity of the pollution caused by the facility. Therefore, based on the level partition analysis of RDF power plants, CSF3 and CSF9 were identified as the most common CSFs, followed by CSF4, CSF6, CSF7, and CSF8. Consequently, public or private sectors planning to develop RDF power plant projects in Thailand should carefully consider these CSFs and their respective importance levels, as indicated in the level partition analysis, during their decision-making process.

From the analysis of the MICMAC- and RM-level partitioning of MSW and RDF power plants, there are distinct factors that contribute to their success. In the case of RDF power plants, the priority CSFs identified in the RM-level partition 2 were CSF3 and CSF9 (Fig. 7). These factors include sufficient waste quality and compliance with the conditions specified in the licenses. RDF power plants require higher-quality waste compared to MSW because most of the waste comes from well-managed sorting and preparation with reduced moisture content in the expected range of 25–30 %. Therefore, having an adequate quantity of waste and ensuring compliance with licensing conditions are the primary success factors for RDF power plants. However, MSW power plants are more complex, as indicated by their RM-level partitions, which extend to Level 3. In the case of MSW waste, the policy and regulatory considerations represented by CSF1 have become CSF. Waste quality was the second most important factor. Consequently, the quality of MSW can vary depending on its source. Hence, it is crucial to consider CSF1 and CSF3 for the successful development of MSW power plant projects (Fig. 8).

4.3. Policy recommendations

Based on these research findings, it is evident that the success factors for developing WtE power plants, whether MSW or RDF, differ. Therefore, policymakers, public and private sectors, and other stakeholders interested in such ventures should conduct a thorough risk assessment associated with each CSF discussed in this research for MSW and RDF power plant technologies. To translate the findings into action, it is recommended that policymakers utilize these results as WtE project development guidelines of the country to achieve higher project success rate and sustainability. The proposed policy recommendations are as follows.

- *Energyand waste management policy reformulation*

According to the AEDP2018 plan, over 500 MW of waste power plants are the remaining targets, and there are also existing WtE projects that have been demonstrated as unsuccessful, as mentioned in the Introduction. Reformulating related regulations from various government agencies is strongly recommended to succeed in the waste reduction policy through electricity production. This is consistent with expert interviews showing that most unsuccessful WtE projects are due to policy and regulation issues. One main cause is the silo working structures of government ministries/departments and stakeholders, which remain barriers. All related regulations of every agency should be indicated from the beginning to achieve the project's goal. These regulations must be analyzed to minimize the necessary number of regulations by reducing, combining, and repealing them. New regulations can be issued if necessary. National WtE policies should formulate the guidelines, standards, and procedures to permit licensing. This requires compliance with

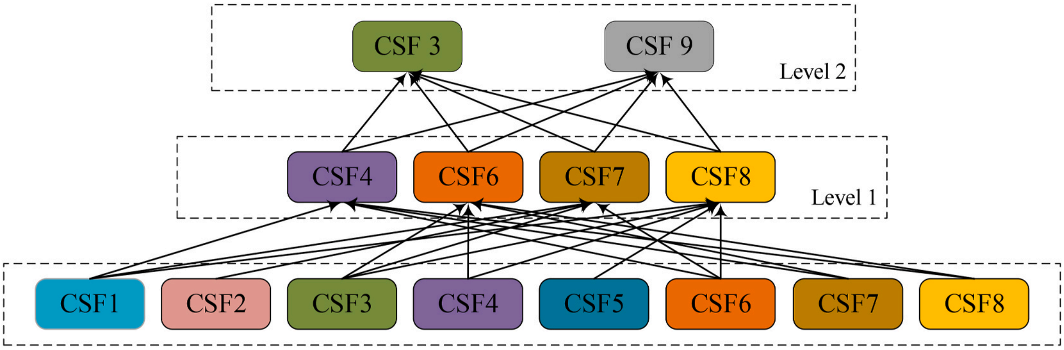

Fig. 6. The RM-level partitions of RDF WtE power plants.

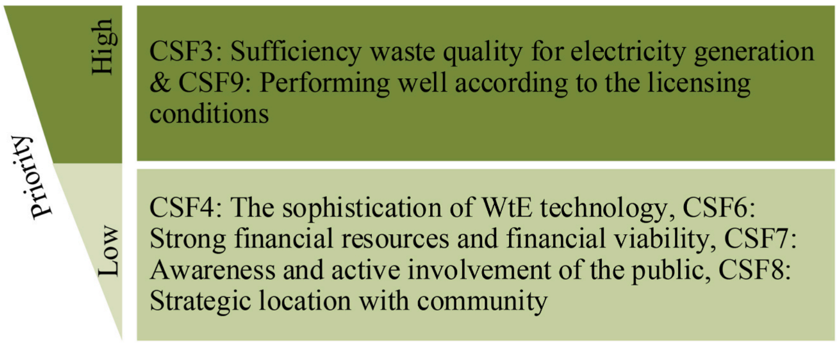

Fig. 7. The priority CSFs of RDF power plant development.

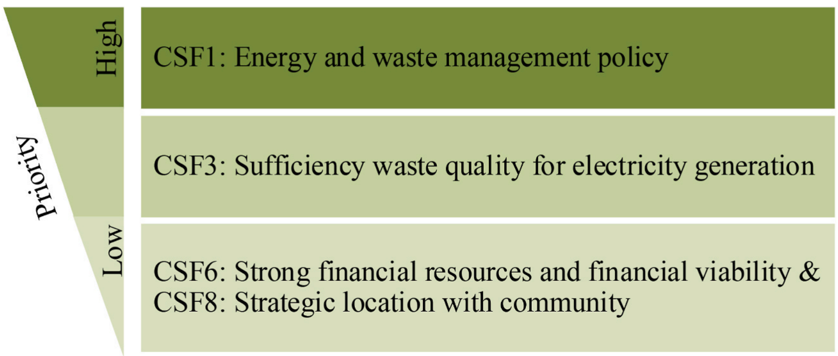

Fig. 8. The priority CSFs of MSW power plant development.

environmental and health regulations. By addressing regulatory reforms, these proposed recommendations create an environment that promotes sustainable waste management practices and the utilization of waste as a valuable resource for energy generation.

- *Balance of country energy trilemma*

Additionally, the integration of waste management and energy policies helps to balance the three dimensions of the country's energy trilemma: energy affordability and access, energy security, and environmental sustainability [45]. By adopting WtE technology, a country can improve its waste management practices, reduce environmental impacts, and contribute to global SDGs.

- *Waste database*

The results showed that "sufficient waste quality for electricity generation" is a common CSF in MSW and RDF power plants. The government should develop waste databases for the public that indicate the waste storage areas around the country (i.e., MSW or RDF), amount of waste, and type of waste. These should be formal and accurate data that must be updated properly and frequently. With this information, suitable WtE technology can meet the requirements and increase the success rate of projects.

- *Specific financial resources for WtE projects*

As mentioned previously, "strong financial resources and financial viability" are crucial for successful WtE projects. The government should encourage and provide specific financial resources for WtE projects rather than only providing incentive schemes such as feed-in tariff programs. According to this study, one reason for the unsuccessful MSW and RDF power plants is the lack of financial support. Strong financial resources provide the necessary foundation for successful development, operation, and expansion of WtE projects. By ensuring financial strength, WtE projects can promote sustainable waste management and contribute to cleaner and more efficient energy production.

- *WtE zoning strategic*

The findings revealed that "strategic location" is a common CSF for MSW and RDF projects because it directly affects the surrounding community. This is a critical factor contributing to project success. To support this success factor, "WtE zoning strategy" can be developed by integrating with "energy and waste management policy reformulation" and "waste database." With the proposed recommendation, WtE projects can ensure convenient access to waste feedstock. Moreover, it reduces transportation costs and the logistical challenges associated with waste collection and transportation. Moreover, it increases the supply of waste, which is essential for the continuous operation and economic viability of projects. By addressing this issue, a strategically located WtE project can help optimize its operations, gain community support, minimize potential negative impacts, and contribute to sustainable waste management and energy generation locally.

5. Conclusion

Thailand is facing a growing waste management problem owing to urbanization and population growth, which have led to environmental degradation and health risks. To address this challenge, the Thai government has implemented a comprehensive waste policy that includes waste reduction, recycling, and safe disposal. WtE technology, such as MSW and RDF power plants that convert waste to electricity, is recognized as an important solution to Thailand's waste management problem. This study utilized the ISM technique and MICMAC analysis to evaluate the CSFs of MSW and RDF technologies in Thailand. The analysis focused on their impact on the WtE project development based on MSW and RDF power plant requirements. The identified CSFs were derived from a comprehensive analysis of relevant literature, reputable agencies, and the expertise of industry professionals in the field of WtE. This study identified nine CSFs, categorized into six aspects: national waste policy, potential for waste, technology, project management, finance, and social and environmental issues. The ISM analysis further examined the critical parameters for the development of WtE power plants, specifically MSW and RDF technologies.

For MSW power plants, most CSFs are based on energy and waste management policies (CSF1), followed by waste quality (heating value and moisture content) for electricity generation (CSF3). In addition, factors such as financial considerations (CSF6) and appropriate power plant locations (CSF8) are important for the successful development of MSW power plants. However, for RDF power plants, most CSFs had sufficient waste quality for electricity generation (CSF3) and performed well according to licensing conditions (CSF9). These factors were identified as having the highest importance and were crucial for the development of RDF power plants. The CSFs for MSW and RDF plants differ based on their specific technology requirements. MSW power plants require policy considerations and waste quality management, whereas RDF power plants focus on waste quality and licensing compliance.

In conclusion, this research provides valuable insights into the CSFs that impact the development of WtE power plants. Understanding and addressing these CSFs is essential for the development and operation of WtE power plants in Thailand and other countries with similar conditions. These findings highlight the importance of understanding CSFs and their associated risks when considering the implementation of MSW and RDF technologies. By considering these factors, policymakers and other stakeholders can make informed decisions to ensure successful development and operation of WtE projects. Overall, the adoption of WtE technology is crucial for the waste management and energy landscapes in Thailand and other countries. This helps improve waste management practices, reduces environmental impacts, and contributes to sustainable social development.

Using this ISM and MICMAC analysis, future studies on the sensitivity analysis of the RM can be conducted. By doing so, we aim to determine what will occur if there is a small change in the RM matrix elements. In addition, this could include more experts to determine whether the final-level partitioning changes.

Data availability statement

The data that support the findings of this study are available within the article and additional data are available from the corresponding author upon reasonable request.

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CRediT authorship contribution statement

Nitad Jaisue: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nipon Ketjoy:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Malinee Kaewpanha:** Writing – review & editing, Validation, Methodology, Conceptualization. **Prapita Thanarak:** Writing – review & editing, Validation, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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