

A Multi-Criteria Sustainability Assessment Model for Micro-Infrastructure in Residential Areas: Evidence from Bekasi City, Indonesia

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Abstract

Rapid urban growth has increased the demand for reliable and sustainable micro-infrastructure in residential areas, particularly in rapidly developing cities. However, existing assessment approaches often emphasize technical performance while providing limited integration of environmental, social, economic, and governance dimensions. This study aims to develop a multi-criteria sustainability assessment model for micro-infrastructure in residential areas using Bekasi City, Indonesia, as a case study. The proposed model was constructed through a comprehensive literature review, expert consultations, and stakeholder engagement to identify relevant sustainability indicators and evaluation criteria. The indicators were organized into four sustainability dimensions: environmental, social, economic, and institutional. A weighting and scoring mechanism were then developed to measure the sustainability performance of residential micro-infrastructure systems, including local roads, drainage networks, water supply facilities, wastewater systems, and solid waste management facilities. The model was validated through its application to selected residential areas in Bekasi City to assess its practicality, consistency, and decision-support capability. The results demonstrate that the developed model effectively captures the multidimensional characteristics of infrastructure sustainability and provides a transparent framework for comparing sustainability performance across residential areas. Furthermore, the model enables the identification of critical improvement priorities and supports evidence-based planning and resource allocation. The study contributes a practical and adaptable assessment tool that can assist local governments, planners, developers, and policymakers in promoting sustainable residential infrastructure development. The framework may also be adapted to other urban contexts facing similar sustainability challenges in rapidly growing metropolitan regions.

Keywords

Sustainability assessment, Micro-infrastructure, Residential areas, Multi-criteria decision-making, Urban sustainability.

1. Introduction

Rapid urbanization has significantly transformed the demand and complexity of urban infrastructure systems, requiring cities to provide services that are not only technically reliable but also environmentally sustainable, socially inclusive, economically feasible, and institutionally resilient. Urban expansion, population growth, and increasing resource pressures have intensified challenges related to infrastructure capacity, environmental degradation, and unequal access to essential services. Consequently, infrastructure sustainability assessment has evolved beyond conventional engineering-based evaluation toward integrated approaches that consider multiple sustainability dimensions throughout infrastructure planning, development, operation, and maintenance processes (Sharifi, 2022; Ahmad et al., 2023).

Residential micro-infrastructure represents a fundamental component of sustainable urban development because it directly influences daily community activities and quality of life. Infrastructure systems such as local roads, drainage networks, water supply facilities, wastewater systems, and solid waste management services determine neighborhood accessibility, public health conditions, environmental quality, and residential resilience. However, unlike large-scale infrastructure projects that generally receive substantial planning attention, neighborhood-scale infrastructure often faces challenges related to limited investment, inadequate maintenance, fragmented management, and uneven service provision. Recent studies emphasize that deficiencies in micro-infrastructure can significantly affect urban vulnerability, particularly in rapidly growing cities where infrastructure development does not always match population and housing expansion (Wang et al., 2022; Zhang et al., 2023).

The sustainability assessment of residential micro-infrastructure is complex because these systems involve multiple objectives, stakeholders, and decision-making considerations. Infrastructure performance is influenced not only by technical conditions but also by environmental impacts, affordability, community needs, governance capacity, and long-term operational feasibility. Therefore, assessing infrastructure sustainability requires a multidimensional framework that can integrate diverse criteria and support balanced decision-making. Previous studies have demonstrated that multi-criteria decision-making (MCDM) approaches are increasingly applied in sustainability evaluation because they allow the integration of quantitative and qualitative indicators, stakeholder preferences, and competing sustainability objectives (Siksnyte-Butkiene et al., 2022; Govindan et al., 2023).

Although numerous sustainability assessment frameworks have been developed, several limitations remain. Existing infrastructure assessment models are frequently designed for large-scale infrastructure projects and emphasize technical, environmental, or project-level performance indicators. These approaches may not adequately represent the specific characteristics of residential micro-infrastructure, where localized conditions, community requirements, institutional capacity, and service accessibility play important roles in determining sustainability outcomes (Lützkendorf et al., 2022; Siew et al., 2023). Furthermore, many existing frameworks provide limited integration between environmental, social, economic, and institutional dimensions, resulting in an incomplete understanding of infrastructure sustainability performance (Rezaei et al., 2023).

The limitations become more significant in rapidly developing urban areas in emerging economies, where infrastructure challenges are shaped by accelerated residential growth, limited resources, and varying institutional capacities. Sustainability assessment models developed in advanced urban contexts cannot always be directly applied to developing cities due to differences in governance structures, socioeconomic conditions, infrastructure availability, and local priorities (Sharifi, 2022; Ahmad et al., 2023). Therefore, context-specific assessment models are required to support sustainable infrastructure planning in cities experiencing rapid transformation.

Bekasi City, Indonesia, provides an appropriate context for examining these challenges. As part of the Jakarta Metropolitan Area, Bekasi has experienced substantial residential expansion and increasing demand for neighborhood infrastructure services. Despite continuous infrastructure improvement efforts, challenges related to drainage systems, road conditions, water supply reliability, wastewater management, and solid waste services remain evident across residential areas. These conditions demonstrate the need for an integrated assessment framework capable of identifying sustainability performance and supporting evidence-based infrastructure improvement strategies.

This study addresses the existing research gap by developing a multi-criteria sustainability assessment model specifically designed for residential micro-infrastructure systems. The proposed framework integrates four sustainability dimensions: environmental, social, economic, and institutional. Through a combination of indicator identification, weighting, and scoring mechanisms, the model provides a systematic approach for evaluating infrastructure sustainability performance and identifying priority improvement areas. Unlike conventional assessment approaches that primarily focus on technical performance, this study emphasizes a holistic evaluation of residential infrastructure sustainability within a rapidly urbanizing developing-city context.

The objectives of this study are to (1) identify relevant sustainability indicators for residential micro-infrastructure assessment through literature review, expert consultation, and stakeholder engagement; (2) develop a multi-criteria evaluation framework incorporating indicator weighting and scoring mechanisms; and (3) validate the applicability of the proposed model through its implementation in selected residential areas in Bekasi City. The study contributes both methodologically and practically by providing an adaptable decision-support tool for local governments, planners,

developers, and policymakers seeking to improve sustainable residential infrastructure planning and resource allocation.

2. Literature Review

2.1 Sustainable Infrastructure and Residential Micro-Infrastructure

Sustainable infrastructure has become an essential approach in urban development as cities face increasing pressures from population growth, climate change, resource constraints, and rising demands for public services. Unlike conventional infrastructure assessment that mainly emphasizes technical reliability and economic efficiency, sustainable infrastructure considers broader impacts throughout the infrastructure life cycle, including environmental protection, social benefits, economic feasibility, and institutional capacity (Sala et al., 2021; Sharifi, 2022). Recent studies emphasize that infrastructure systems should be evaluated as interconnected socio-technical systems because their performance is influenced by interactions between physical conditions, environmental processes, governance mechanisms, and community characteristics (Xia et al., 2023).

Within urban environments, residential micro-infrastructure plays a critical role in determining the sustainability and resilience of communities. Local roads, drainage networks, water supply facilities, wastewater systems, and solid waste management services directly influence accessibility, public health, environmental quality, and residents' quality of life. However, these neighborhood-scale infrastructures often receive less attention than large-scale infrastructure projects despite their direct impacts on daily urban activities (Sharifi, 2022). Infrastructure failures at the residential level, such as inadequate drainage, poor waste management, or unreliable water services, can increase environmental risks and social vulnerability, particularly in rapidly growing urban areas.

Assessing residential micro-infrastructure sustainability is challenging because infrastructure performance depends on multiple interconnected factors. Technical improvements alone may not guarantee sustainable outcomes without considering affordability, community acceptance, institutional coordination, and long-term maintenance capacity. Therefore, sustainability assessment requires a multidimensional framework capable of integrating environmental, social, economic, and institutional criteria to represent the actual conditions of residential infrastructure systems (Rezaei et al., 2023). This perspective highlights the need for assessment models specifically designed for neighborhood-scale infrastructure rather than relying exclusively on frameworks developed for larger infrastructure projects.

2.2 Sustainability Assessment Frameworks for Infrastructure Systems

Various sustainability assessment frameworks have been developed to support infrastructure planning and decision-making. These frameworks generally aim to evaluate infrastructure performance through a combination of environmental, economic, social, and management indicators. Existing approaches have contributed significantly by encouraging decision-makers to consider sustainability objectives beyond conventional engineering performance (Siew et al., 2023). Recent research also indicates that infrastructure sustainability assessment frameworks are increasingly moving toward integrated models that evaluate multiple sustainability dimensions simultaneously (Sánchez et al., 2023).

Despite these developments, several limitations remain. Many established assessment frameworks were originally developed for large-scale infrastructure projects and rely on extensive technical data, specialized expertise, and project-level information. Such characteristics may reduce their applicability for residential micro-infrastructure, where sustainability performance is strongly influenced by local conditions, community needs, service accessibility, and institutional capacity. Consequently, assessment approaches developed for major infrastructure systems may not fully capture the complexity of neighborhood-scale infrastructure sustainability.

Another limitation concerns the balance among sustainability dimensions. Previous studies indicate that infrastructure assessment frequently prioritizes environmental and technical indicators, while social, economic, and institutional factors receive comparatively less attention (Sala et al., 2021; Rezaei et al., 2023). However, residential infrastructure systems operate within social and governance contexts where community participation, affordability, maintenance practices, and institutional effectiveness significantly affect long-term performance. Therefore, sustainability assessment models should incorporate a broader range of indicators to support more comprehensive and context-sensitive evaluations.

2.3 Multi-Criteria Decision-Making in Sustainability Assessment

Multi-Criteria Decision-Making (MCDM) has become an increasingly applied approach for sustainability assessment because infrastructure decisions commonly involve multiple objectives, conflicting criteria, and diverse stakeholder preferences. MCDM methods enable researchers and decision-makers to integrate qualitative and quantitative indicators, establish criterion priorities, and evaluate sustainability performance through structured weighting and scoring mechanisms (Mecca, 2023; Xu et al., 2023).

Various MCDM techniques, including Analytic Hierarchy Process (AHP), TOPSIS, Best-Worst Method (BWM), and hybrid approaches, have been applied in sustainable infrastructure research. These methods support decision-making by allowing the integration of expert knowledge and contextual priorities into assessment models (Štilić & Puška, 2023). In infrastructure planning, MCDM approaches have been used to prioritize investments, compare alternatives, and evaluate sustainability performance under complex decision environments (Bošnjak & Jajac, 2023).

For residential micro-infrastructure, MCDM provides advantages because neighborhood systems involve diverse components with different sustainability implications. For example, drainage infrastructure relates strongly to environmental resilience, while waste management depends on technological, economic, institutional, and behavioral factors. A multi-criteria framework allows these interconnected aspects to be evaluated simultaneously rather than through fragmented sector-based assessments. Nevertheless, existing MCDM applications have largely focused on selecting alternatives or evaluating individual infrastructure solutions rather than developing integrated sustainability assessment models for residential infrastructure systems.

2.4 Research Gap and Study Contribution

The literature indicates that significant progress has been made in developing infrastructure sustainability assessment frameworks and applying MCDM approaches for complex decision-making. However, three major gaps remain. First, existing models are predominantly oriented toward large-scale infrastructure projects and provide limited guidance for evaluating neighborhood-level infrastructure systems. Second, many assessment approaches do not fully integrate environmental, social, economic, and institutional dimensions within a single framework. Third, existing MCDM applications commonly focus on infrastructure selection or prioritization rather than measuring the overall sustainability performance of existing residential micro-infrastructure.

This study addresses these gaps by developing a multi-criteria sustainability assessment model specifically designed for residential micro-infrastructure systems. The proposed framework integrates four sustainability dimensions—environmental, social, economic, and institutional, through indicator identification, weighting, and scoring mechanisms. Unlike conventional infrastructure assessment approaches, the model emphasizes neighborhood-scale evaluation and incorporates contextual considerations relevant to rapidly developing urban areas.

Recent studies have increasingly emphasized the importance of integrated sustainability assessment frameworks to address the complexity of urban development challenges. Urban sustainability is no longer evaluated solely based on environmental performance or infrastructure availability but through interconnected dimensions involving ecological resilience, social well-being, economic feasibility, technological capability, and governance effectiveness. The transition toward multidimensional assessment approaches reflects the increasing recognition that urban systems operate as complex socio-technical environments where infrastructure performance is influenced by interactions between physical systems, communities, and institutional arrangements. Previous studies have demonstrated that sustainability assessment frameworks require comprehensive indicators capable of capturing diverse urban characteristics, particularly in rapidly growing cities experiencing pressures from population expansion, land-use change, and increasing infrastructure demands (Bibri & Krogstie, 2021; Fang et al., 2021; Yigitcanlar & Cugurullo, 2022; Dong et al., 2024).

Multi-criteria decision-making (MCDM) approaches have become increasingly applied in sustainability evaluation because they enable researchers and decision-makers to integrate multiple criteria, stakeholder perspectives, and competing priorities within a structured analytical framework. Various studies have applied MCDM methods, including the Analytic Hierarchy Process (AHP), to evaluate infrastructure systems, urban development alternatives, and sustainability performance indicators. These approaches provide transparency in weighting criteria and support evidence-based prioritization of improvement strategies. Recent applications have shown that hybrid assessment models combining sustainability indicators with decision-support techniques can improve the reliability of urban

infrastructure evaluation and provide more practical guidance for policy interventions (Gulcimen et al., 2023; Jiang et al., 2022; Macchiaroli et al., 2023; Wang et al., 2023; Taheri & Khosravi, 2024; Zhou et al., 2024).

Despite the increasing development of sustainability assessment frameworks, several limitations remain. Existing approaches frequently focus on city-scale sustainability, building performance, or major infrastructure systems, while neighborhood-scale micro-infrastructure has received comparatively limited attention. Furthermore, many assessment models emphasize environmental or technical indicators but provide insufficient integration of social, economic, and institutional dimensions within residential contexts. Therefore, there is a need for an integrated and practical assessment framework capable of evaluating residential micro-infrastructure sustainability through a multidimensional perspective.

By applying the model to Bekasi City, Indonesia, this research provides empirical evidence on the applicability of multidimensional sustainability assessment in a rapidly urbanizing metropolitan context. The framework is expected to support local governments, planners, developers, and policymakers in identifying infrastructure improvement priorities and allocating resources more effectively. Thus, this study contributes both methodologically and practically by providing an adaptable decision-support tool for sustainable residential infrastructure development.

3. Method

This study employed a multi-stage research design to develop a multi-criteria sustainability assessment model for residential micro-infrastructure in Bekasi City, Indonesia. The methodological framework was developed based on the principle that infrastructure sustainability requires an integrated evaluation approach capable of incorporating environmental, social, economic, and institutional dimensions rather than relying solely on technical performance indicators. Previous studies emphasize that sustainability assessment models should combine multiple criteria, stakeholder perspectives, and structured evaluation mechanisms to support transparent and evidence-based decision-making (Sala et al., 2021; Sharifi, 2022).

The research process consisted of four main stages: sustainability indicator identification, indicator refinement through expert and stakeholder involvement, development of weighting and scoring mechanisms, and empirical validation of the proposed model. Initially, relevant sustainability indicators were identified through a comprehensive review of recent literature on sustainable infrastructure assessment and urban sustainability evaluation. Indicator selection followed the principle that effective sustainability indicators should represent measurable aspects of infrastructure performance while capturing broader environmental, social, economic, and governance considerations (Singh et al., 2022; Xia et al., 2023). Based on the literature synthesis, the indicators were categorized into four sustainability dimensions: environmental, social, economic, and institutional.

Following the indicator identification stage, expert consultation and stakeholder engagement were conducted to evaluate the relevance, applicability, and contextual suitability of the proposed indicators for residential micro-infrastructure conditions in Bekasi City. The involvement of experts and stakeholders is widely recognized as an important component of sustainability assessment because infrastructure performance is influenced by technical conditions as well as local knowledge, management practices, and community needs (Mardani et al., 2021; Siksnielyte-Butkiene et al., 2022). This process aimed to refine the indicator framework, remove overlapping criteria, and ensure that the assessment model reflected practical challenges associated with neighborhood-scale infrastructure systems.

The validated indicators were subsequently incorporated into a multi-criteria assessment framework through a weighting and scoring mechanism. Weighting was used to determine the relative importance of each sustainability criterion, while scoring was applied to evaluate the performance of residential micro-infrastructure components based on the established assessment indicators. The application of weighting and scoring approaches is commonly used in sustainability assessment because infrastructure decisions often involve multiple criteria with different levels of importance and potential trade-offs (Govindan et al., 2023; Rezaei et al., 2023). The assessment framework evaluated five major residential micro-infrastructure components: local roads, drainage networks, water supply facilities, wastewater systems, and solid waste management facilities.

Finally, the developed model was validated through its application to selected residential areas in Bekasi City. The validation process examined the practicality, consistency, and decision-support capability of the assessment framework in representing sustainability performance across different residential infrastructure systems. Empirical validation is an essential stage in developing sustainability assessment models because it demonstrates whether

theoretical indicators and evaluation mechanisms can effectively support real-world planning and management decisions (Sala et al., 2021). Through this approach, the proposed model aims to provide a transparent and adaptable tool for identifying infrastructure improvement priorities and supporting sustainable residential infrastructure development.

4. Data Collection

This study employed a mixed-method data collection approach combining secondary data analysis, field observations, community surveys, and expert judgement to develop and validate the sustainability assessment model for residential micro-infrastructure. This approach was selected because neighborhood-scale infrastructure sustainability is influenced by interconnected technical, environmental, social, economic, technological, and institutional factors. Previous sustainability assessment studies emphasize that integrated evaluation requires combining objective infrastructure information with stakeholder perspectives and expert knowledge to capture the complexity of urban residential systems (Sala et al., 2021; Sharifi, 2022).

Secondary data were collected through a comprehensive review of scientific literature, urban planning documents, and relevant institutional reports. These data were used to identify initial sustainability indicators and establish the conceptual framework of the assessment model. Based on previous studies on sustainable settlements and infrastructure evaluation, the indicators were structured into multidimensional criteria representing environmental, social, economic, and institutional aspects of residential micro-infrastructure sustainability (Xia et al., 2023; Rezaei et al., 2023).

Primary data collection was conducted in eight selected residential areas in Bekasi City, Indonesia. The selected locations were evaluated based on the characteristics and performance of neighborhood-scale infrastructure components, including local roads, small-scale drainage systems, micro-open spaces, pedestrian facilities, public lighting, water supply facilities, wastewater systems, and solid waste management facilities. Field observations were conducted to assess the physical condition, availability, accessibility, and operational performance of these infrastructure components. Field-based evaluation is important for micro-infrastructure assessment because actual infrastructure conditions and maintenance practices directly influence sustainability performance at the residential scale. Community perceptions were collected through a survey involving 178 residents from the selected residential areas. The survey aimed to capture users' perceptions regarding infrastructure accessibility, service quality, safety, environmental conditions, and satisfaction with existing neighborhood facilities. Community-based assessment is particularly relevant for residential infrastructure because sustainability outcomes are directly associated with user experience, social acceptance, and the effectiveness of infrastructure services in supporting daily activities (Siksnyte-Butkiene et al., 2022).

Expert judgement was incorporated to validate sustainability indicators and determine their relative importance within the assessment framework. A total of nine experts participated in the Delphi process, representing academic, governmental, and professional perspectives. The expert panel consisted of specialists from civil engineering, urban and regional planning, environmental engineering, and architecture disciplines; representatives from local government institutions, including the Housing, Settlement and Land Agency, Environmental Agency, and Regional Development Planning Agency (Bappeda); as well as infrastructure consultants, residential developers, and neighborhood management practitioners.

The Delphi method was applied to achieve expert consensus regarding indicator relevance and assessment criteria. Delphi is widely utilized in sustainability research because it provides a structured mechanism for integrating expert knowledge and reducing uncertainty in complex decision-making processes (Mardani et al., 2021). After indicator validation, the Analytic Hierarchy Process (AHP) using pairwise comparison was applied to determine the relative weights of sustainability criteria. AHP has been widely adopted in multi-criteria sustainability assessment because it enables decision-makers to prioritize indicators systematically based on expert judgement while maintaining a transparent evaluation structure (Saaty, 1980; Govindan et al., 2023).

The combination of literature-based indicator development, Delphi-based expert validation, AHP weighting, community surveys, and field observations provided a comprehensive dataset for constructing the sustainability assessment model. This integrated approach enabled the study to evaluate residential micro-infrastructure performance by combining technical conditions, stakeholder perceptions, and expert-based priorities, thereby supporting the development of a practical decision-support framework for sustainable residential infrastructure planning.

5. Results and Discussion

5.1 Results

The development of the multi-criteria sustainability assessment model resulted in a comprehensive framework for evaluating residential micro-infrastructure performance based on four sustainability dimensions: environmental, social, economic, and institutional. The framework development process began with the identification of relevant sustainability indicators through an extensive literature review and was subsequently refined through a Delphi consultation process involving nine experts from multidisciplinary backgrounds, including civil engineering, urban and regional planning, environmental science, architecture, government agencies, and infrastructure practitioners.

The Delphi validation process ensured that the selected indicators were relevant, measurable, and applicable for assessing neighborhood-scale infrastructure sustainability. The final assessment framework consisted of 34 indicators distributed across four sustainability dimensions. The environmental dimension included nine indicators related to drainage capacity, flood mitigation, solid waste management, wastewater management, water efficiency, water availability, micro green space provision, and environmental cleanliness. The social dimension consisted of eight indicators representing accessibility, pedestrian safety, public lighting, community participation, communal facilities, and residential comfort. The economic dimension comprised eight indicators focusing on maintenance affordability, operational efficiency, infrastructure durability, investment effectiveness, and long-term feasibility. Meanwhile, the institutional dimension included nine indicators related to maintenance programs, monitoring mechanisms, regulatory implementation, stakeholder coordination, institutional capacity, and long-term sustainability planning.

The established indicator framework provided the foundation for the subsequent analytical stages, including the determination of sustainability dimension priorities using the Analytic Hierarchy Process (AHP), performance evaluation of residential areas, calculation of sustainability indices, and identification of priority improvement strategies. The AHP analysis was conducted to determine the relative importance of the four sustainability dimensions based on expert judgement. The pairwise comparison process showed that environmental sustainability was considered the most influential dimension in determining residential micro-infrastructure sustainability. The resulting weights indicated that the environmental dimension obtained the highest priority with a weight of 0.466, followed by the social dimension with 0.277, the institutional dimension with 0.160, and the economic dimension with 0.097. The total weight of all dimensions reached 1.000, confirming that the four dimensions were successfully integrated into the assessment model. The reliability of expert judgement was evaluated through the consistency test of the AHP matrix. The calculation produced a maximum eigenvalue (λ_{max}) of 4.067, a consistency index (CI) of 0.022, a random index (RI) of 0.900, and a consistency ratio (CR) of 0.024. Since the obtained CR value was below the recommended threshold of 0.10, the expert comparison process was considered consistent and acceptable for sustainability weighting analysis.

Following the weighting process, the developed model was applied to evaluate eight residential areas in Bekasi City. The assessment combined field observations and community perception data collected from 178 respondents to capture both physical infrastructure conditions and user experiences. Each residential area was assessed based on environmental, social, economic, and institutional performance dimensions. The assessment results revealed variations in sustainability performance among the evaluated residential areas. Area 6 demonstrated the highest overall performance, with environmental, social, economic, and institutional scores of 3.90, 4.10, 3.70, and 3.80, respectively. These results indicate that Area 6 achieved relatively balanced performance across all sustainability dimensions. Area 2 also showed strong performance, with environmental, social, economic, and institutional scores of 3.65, 3.80, 3.55, and 3.60, respectively. In contrast, Area 3 and Area 8 demonstrated relatively lower performance, particularly in environmental and institutional dimensions. Area 3 obtained environmental and institutional scores of 2.40 and 2.60, while Area 8 obtained scores of 2.55 and 2.75 for the same dimensions.

The differences in performance among residential areas indicate that sustainability outcomes are influenced by variations in infrastructure conditions, maintenance practices, community involvement, and institutional management capacity. Therefore, the assessment demonstrates that residential micro-infrastructure sustainability cannot be represented by a single technical parameter but requires an integrated evaluation of multiple interacting dimensions. The sustainability index was subsequently calculated by combining the AHP-derived weights and performance scores using the following equation:

$$SI = (0.466ENV) + (0.277SOC) + (0.097ECO) + (0.160INS)$$

The calculation results showed that Area 6 achieved the highest sustainability index with a value of 0.812 and was classified as having high sustainability performance. Area 2 also achieved a high sustainability category with an index value of 0.742. The remaining six residential areas were categorized as having moderate sustainability performance, including Area 4 (0.651), Area 7 (0.626), Area 1 (0.606), Area 5 (0.566), Area 8 (0.548), and Area 3 (0.521).

The sustainability index results demonstrate that most assessed residential areas have achieved basic infrastructure functionality; however, improvements are still required to enhance sustainability performance. Areas with moderate sustainability levels require targeted interventions focusing on their weakest dimensions rather than applying identical improvement strategies across all locations. The final stage of the assessment involved identifying priority improvement components using an importance-performance analysis. The results showed that drainage systems represented the highest priority intervention because of their very high importance and relatively low-to-moderate observed performance. Solid waste management was identified as the second priority due to its significant influence on environmental quality and residential conditions. Micro open spaces were also identified as an important improvement component because of their contribution to environmental quality, ecological balance, and residential livability. Pedestrian facilities were categorized as a medium priority because their performance was moderate, while public lighting and water supply systems demonstrated relatively satisfactory conditions and were classified as components requiring continuous maintenance rather than major intervention.

Overall, the results confirm that the proposed multi-criteria sustainability assessment model successfully integrates environmental, social, economic, and institutional perspectives to evaluate residential micro-infrastructure performance. The model provides a systematic approach for identifying sustainability gaps, comparing residential areas, and determining priority improvement strategies to support sustainable infrastructure planning in rapidly developing urban areas.

5.2 Discussion

The findings of this study demonstrate that residential micro-infrastructure sustainability represents a complex and multidimensional concept that cannot be adequately evaluated through conventional technical performance assessment alone. The developed assessment model integrates four sustainability dimensions, namely environmental, social, economic, and institutional aspects, to provide a comprehensive evaluation framework for neighborhood-scale infrastructure systems. This approach recognizes that micro-infrastructure functions within a broader socio-environmental system, where infrastructure effectiveness is influenced not only by physical conditions but also by environmental resilience, community interaction, financial feasibility, and governance capacity. The integration of multiple sustainability dimensions provides a more realistic representation of residential infrastructure performance, particularly in rapidly urbanizing areas where infrastructure challenges are interconnected. Residential micro-infrastructure such as local roads, drainage systems, waste facilities, water services, pedestrian facilities, and small-scale green spaces directly affect residents' daily activities and environmental conditions. Therefore, evaluating these systems requires an assessment framework that captures both infrastructure functionality and the broader sustainability context in which infrastructure operates.

The results indicate that the environmental dimension represents the most influential factor in determining residential micro-infrastructure sustainability. This finding highlights the critical role of environmental infrastructure components, including drainage systems, waste management facilities, water services, and micro green spaces, in maintaining residential resilience and quality of life. The high priority assigned to environmental sustainability reflects the challenges experienced by rapidly developing urban areas, where population growth, land-use transformation, and increasing pressure on natural resources create significant demands on neighborhood infrastructure systems. In the context of Bekasi City, environmental infrastructure has become increasingly important due to the rapid expansion of residential areas and the resulting pressure on urban service systems. Inadequate drainage capacity may increase flood vulnerability, inefficient waste management may contribute to environmental degradation, and limited green spaces may reduce ecological quality and residential comfort. Therefore, improving environmental performance should not only focus on physical infrastructure upgrades but also incorporate maintenance strategies, environmental management practices, and community participation mechanisms to ensure long-term effectiveness.

The findings further demonstrate that the social dimension represents an important determinant of sustainability performance. Residential infrastructure is ultimately designed to serve communities; therefore, infrastructure quality must be evaluated based on accessibility, safety, inclusiveness, and user satisfaction. Infrastructure systems that are technically functional but inaccessible or unsuitable for residents may fail to achieve sustainable outcomes. The

importance of social sustainability emphasizes that residents should be considered not only as infrastructure users but also as active participants who influence infrastructure performance through daily practices and community-based management. The role of social factors is particularly significant for neighborhood-scale infrastructure because many micro-infrastructure systems depend on collective behavior. Waste separation, environmental cleanliness, infrastructure maintenance, and community monitoring require active participation from residents. Consequently, sustainable residential development requires integration between physical infrastructure provision and social capacity building. Infrastructure interventions that involve communities during planning, implementation, and maintenance stages are more likely to achieve long-term sustainability outcomes.

The institutional dimension also plays an essential role in maintaining infrastructure performance over time. Although infrastructure conditions represent visible indicators of sustainability, their long-term effectiveness depends strongly on governance mechanisms, maintenance programs, monitoring systems, and stakeholder coordination. Residential infrastructure often experiences performance decline not because of inadequate initial construction but because of limited maintenance capacity, unclear management responsibilities, and insufficient coordination between relevant actors. The findings suggest that institutional capacity should be considered as a fundamental component of sustainability assessment rather than a supporting factor. Effective collaboration between local governments, developers, community organizations, and residents is required to ensure continuous infrastructure management. Strengthening institutional mechanisms can improve accountability, optimize maintenance processes, and support adaptive responses to changing urban conditions.

Although the economic dimension received the lowest relative priority in the weighting process, it remains an important factor supporting long-term infrastructure sustainability. Economic sustainability determines whether infrastructure systems can be maintained, operated, and improved throughout their service life. Infrastructure planning that focuses only on initial investment costs may overlook future operational requirements and maintenance challenges. For residential micro-infrastructure, economic considerations should include maintenance affordability, operational efficiency, durability, and resource optimization. Therefore, economic sustainability should not be interpreted only as cost reduction but rather as ensuring that infrastructure investments generate long-term benefits while remaining financially manageable for responsible stakeholders. This perspective is particularly important for urban areas where limited resources require effective prioritization of infrastructure improvement programs.

The variation in sustainability performance among the eight residential areas demonstrates that infrastructure sustainability is strongly influenced by local conditions. Differences in environmental quality, infrastructure maintenance practices, community participation, and institutional capacity resulted in different sustainability outcomes among assessed areas. These findings indicate that a standardized infrastructure improvement approach may not effectively address sustainability challenges across diverse residential contexts. Instead, infrastructure interventions should be based on specific sustainability gaps identified through multidimensional assessment. Areas with lower environmental performance require targeted improvements in drainage systems, waste management, and environmental quality. Meanwhile, areas with weaker institutional performance require strengthening of maintenance systems, monitoring mechanisms, and stakeholder coordination. This approach enables more efficient allocation of resources because improvement strategies are directed toward the most critical weaknesses.

The importance-performance analysis further confirms that drainage systems represent the most urgent improvement priority. Drainage infrastructure plays a central role in maintaining urban resilience, particularly in densely developed residential areas vulnerable to rainfall variability and surface runoff problems. Improving drainage capacity, maintenance frequency, and monitoring practices should therefore become key components of sustainable residential infrastructure strategies. Solid waste management was identified as another important intervention area. Although waste collection services may already exist, sustainability performance depends on management efficiency, waste reduction practices, separation behavior, and community participation. Strengthening waste management systems requires not only service improvements but also behavioral changes and institutional support.

The identification of micro green spaces as an improvement priority highlights the increasing importance of small-scale ecological infrastructure within residential environments. Although limited in physical size, micro green spaces contribute to environmental quality, thermal comfort, biodiversity support, and residential livability. Integrating pocket parks and other small-scale green infrastructure into residential planning can therefore support broader urban sustainability objectives. The proposed multi-criteria sustainability assessment model provides both theoretical and practical contributions. From a scientific perspective, the study contributes to the development of sustainability

assessment approaches by focusing specifically on residential micro-infrastructure, which is often overlooked compared with buildings, large-scale infrastructure, or city-level sustainability assessments. The integration of expert judgement, community perception, field observation, and multi-dimensional indicators provides a comprehensive framework for evaluating infrastructure sustainability at the neighborhood scale.

From a practical perspective, the model provides decision-support capabilities for local governments, planners, developers, and infrastructure managers. By identifying sustainability performance levels and priority improvement areas, the framework can support evidence-based planning, resource allocation, and infrastructure management decisions. The model is also adaptable to other rapidly urbanizing cities experiencing similar challenges related to infrastructure demand, environmental pressure, and governance capacity. Overall, the findings confirm that sustainable residential micro-infrastructure requires an integrated approach that combines environmental resilience, social functionality, economic feasibility, and institutional capacity. Infrastructure sustainability is not determined solely by physical conditions but by the interaction between infrastructure systems, communities, and governance structures. Therefore, achieving sustainable residential development requires coordinated strategies that integrate infrastructure improvement with environmental management, community engagement, and institutional strengthening.

5.3 Proposed Improvements

Based on the sustainability assessment results, several improvement strategies are proposed to enhance the performance of residential micro-infrastructure in Bekasi City. The proposed interventions are formulated based on the identified sustainability gaps, particularly those related to environmental performance, infrastructure management, and community-oriented services. Rather than applying uniform improvement strategies across all residential areas, the proposed actions emphasize a targeted approach that considers the specific weaknesses identified through the multi-criteria assessment model. The priority improvement focuses on strengthening neighborhood drainage systems. The assessment results indicate that drainage performance represents the most critical infrastructure component requiring intervention due to its high sustainability importance and relatively lower observed performance. Improvement strategies should include routine drainage maintenance, capacity enhancement in flood-prone locations, removal of sediment accumulation, improvement of drainage connectivity, and implementation of nature-based drainage solutions where applicable. In addition, drainage management should be integrated with climate adaptation strategies to improve residential resilience against increasing rainfall intensity and urban flooding risks.

The second priority improvement concerns solid waste management systems. Although waste collection services are generally available in residential areas, sustainability performance depends on the effectiveness of waste reduction, separation, collection, and processing practices. Improvement strategies should include strengthening community-based waste management programs, promoting household waste separation, improving recycling participation, and enhancing coordination between residents and local waste management authorities. The involvement of community organizations is particularly important because waste management sustainability is strongly influenced by behavioral factors and local participation. The third improvement priority relates to the provision and enhancement of micro-green spaces within residential environments. The assessment identified limited availability of small-scale green infrastructure as one of the factors affecting environmental quality and residential comfort. Therefore, residential areas should consider integrating pocket parks, community gardens, green corridors, and other small-scale ecological features into existing urban spaces. These interventions can provide multiple benefits, including improved thermal comfort, enhanced environmental quality, increased social interaction, and better residential livability.

Improvement of pedestrian facilities represents another important strategy for strengthening social sustainability. Although pedestrian infrastructure was not identified as the highest priority, moderate performance conditions indicate opportunities for improvement, particularly regarding accessibility, safety, and inclusiveness. Proposed interventions include improving pedestrian connectivity, enhancing walking safety through better surface conditions and lighting, and ensuring accessibility for elderly residents, children, and vulnerable groups. These improvements can support more inclusive and human-oriented residential environments. In addition to physical infrastructure improvements, strengthening institutional capacity is essential to ensure long-term sustainability performance. The assessment results indicate that governance mechanisms influence the ability of residential areas to maintain infrastructure quality. Therefore, improvement strategies should include establishing clearer maintenance responsibilities, improving monitoring systems, strengthening coordination among government agencies and communities, and developing periodic infrastructure evaluation mechanisms.

Community participation should also become an integral component of future improvement strategies. Residents play an important role in maintaining neighborhood infrastructure through daily practices, reporting mechanisms, and collective management activities. Establishing participatory management approaches can improve infrastructure sustainability by increasing community ownership and reducing dependence solely on government-based maintenance systems. At the policy level, local governments should consider adopting a sustainability-based infrastructure planning approach that prioritizes interventions according to measurable performance indicators.

The proposed assessment model can support this process by identifying infrastructure components with high importance but low performance, allowing decision-makers to allocate resources more effectively. Such an approach can improve the efficiency of infrastructure investment while ensuring that development programs address the most critical sustainability challenges. Overall, the proposed improvements emphasize that sustainable residential micro-infrastructure requires a combination of physical upgrading, environmental management, social participation, and institutional strengthening. The implementation of these strategies can enhance infrastructure resilience, improve residential quality of life, and support the transition toward more sustainable urban development in rapidly growing cities.

6. Conclusion

This study developed a multi-criteria sustainability assessment model for evaluating residential micro-infrastructure performance in rapidly growing urban areas, using Bekasi City, Indonesia, as a case study. The proposed model integrates four sustainability dimensions, namely environmental, social, economic, and institutional aspects, to overcome the limitations of conventional infrastructure assessments that primarily focus on technical performance. Through the integration of literature review, expert validation, AHP weighting, field observation, and community perception assessment, the study provides a comprehensive framework for measuring sustainability performance at the neighborhood scale. The results demonstrate that the developed framework successfully captures the multidimensional characteristics of residential micro-infrastructure sustainability. A total of 34 indicators were established and validated through a Delphi process involving nine experts, providing a structured basis for evaluating infrastructure performance.

The AHP analysis identified the environmental dimension as the most influential sustainability factor, followed by social, institutional, and economic dimensions. This finding highlights the critical importance of environmental infrastructure components, such as drainage systems, waste management facilities, water services, and micro green spaces, in determining residential sustainability performance. The application of the model in eight residential areas in Bekasi City revealed variations in sustainability performance among locations. The sustainability index results showed that two residential areas achieved high sustainability performance, while the remaining areas were categorized as moderate. These variations indicate that residential infrastructure sustainability is strongly influenced by local environmental conditions, infrastructure quality, maintenance practices, community involvement, and institutional capacity. Therefore, sustainability improvement strategies should be tailored to specific infrastructure weaknesses rather than applying uniform interventions across different residential contexts.

The study also identified key improvement priorities for enhancing residential micro-infrastructure sustainability. Drainage systems emerged as the highest priority intervention due to their significant influence on environmental resilience and flood mitigation capacity. Solid waste management, micro green spaces, pedestrian facilities, and institutional strengthening were also identified as important components requiring continuous improvement. These findings demonstrate that sustainable residential infrastructure development requires a balanced approach combining physical infrastructure enhancement, environmental management, community participation, and governance improvement. The main contribution of this study lies in the development of an adaptable assessment framework specifically designed for residential micro-infrastructure systems. Unlike assessment approaches that focus primarily on buildings, large-scale infrastructure, or city-level sustainability indicators, the proposed model emphasizes the importance of neighborhood-scale infrastructure as a fundamental component of sustainable urban development. The framework provides a practical decision-support tool for local governments, planners, developers, and infrastructure managers to identify sustainability gaps, prioritize interventions, and support evidence-based infrastructure planning.

Despite its contributions, this study has several limitations. The assessment was conducted in eight residential areas within Bekasi City; therefore, the results reflect the characteristics of the selected study context. Future research may expand the application of the model to different urban settings with varying socio-economic, environmental, and governance conditions. Further studies may also incorporate dynamic monitoring approaches, advanced data analytics,

and spatial modelling techniques to improve the accuracy and adaptability of sustainability assessment. Overall, this study confirms that achieving sustainable residential development requires an integrated understanding of infrastructure systems, environmental conditions, community needs, economic feasibility, and institutional capacity. The proposed multi-criteria sustainability assessment model provides a practical and transferable approach to support sustainable micro-infrastructure planning in rapidly urbanizing cities and contributes to broader efforts toward resilient and inclusive urban development.

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