

# A construction sector environmental climate change risk management system to achieve sustainable development goals

Kemala Hayati

kemala.hayati@itpln.ac.id

Institut Teknologi PLN

Nurunnashiha Nurunnashiha

Institut Teknologi PLN

Aryana Rachmad Sulistya

Institut Teknologi PLN

Irma Sepriyanna

Institut Teknologi PLN

Qurratuain Kamazuhra

Institut Teknologi PLN

Rachmad Ardianto

Institut Teknologi PLN

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## Research Article

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**A construction sector environmental climate change risk management system to achieve sustainable development goals**

<sup>1</sup>Kemala Hayati, <sup>2</sup>Nurunnashiha, <sup>3</sup>Aryana Rachmad Sulistya, <sup>4</sup>Irma Sepriyanna, <sup>5</sup>Qurratuain Kamazuhra, <sup>6</sup>Rachmad Ardianto

<sup>1,2,4</sup>Faculty of Regional and Infrastructure Technology, Department of Civil Engineering, Institut Teknologi PLN, Jakarta 11480, Indonesia

<sup>3,5</sup>Faculty of Regional and Infrastructure Technology, Department of Geography, Institut Teknologi PLN, Jakarta 11480, Indonesia

<sup>6</sup>Faculty of Regional and Infrastructure Technology, Department of Environmental Engineering, Institut Teknologi PLN, Jakarta 11480, Indonesia

Correspondent author: kemala.hayati@itpln.ac.id; rachmad@itpln.ac.id

## **Abstract**

The concept of "sustainable building and construction" refers to the approach of planning, designing, constructing, and managing buildings to foster environmentally sustainable built environments. This approach integrates sustainability considerations, encompassing environmental economic and social factors throughout the project's life cycle. Climate change presents a significant challenge to numerous industries, including construction. The construction sector must adapt to the increasing frequency of natural disasters, rising global temperatures, and shifting weather patterns to ensure the sustainability and safety of buildings. This study explores the risks and impacts of climate change on building construction and potential solutions. This study examines the relationship between climate change and construction, analysing the challenges, opportunities and strategies for advancing a more sustainable and eco-friendly future. This research adopts a qualitative approach employing an analytical risk management process (probability impact matrix). The objective is to contribute to the achievement of SDGs and the implementation of green construction practices, which construction professionals can use to address the challenges of achieving more sustainable development.

Keywords: Climate Change, SDGs, Construction, AHP, Risk Management

## **1. Introduction**

Climate change presents a substantial challenge to the construction industry, characterised by rising temperatures, altered precipitation patterns, and an increased frequency of hydrometeorological events such as floods and landslides. In Indonesia, these climatic changes have disrupted construction projects, escalated costs, and inflicted damage on infrastructure, thereby reducing the lifespan of assets and introducing numerous uncertainties. The construction sector contributes significantly to global climate change, with the building industry accounting for 38% of global energy-related emissions. Green buildings, which emphasise energy efficiency, eco-friendly materials, and climate adaptability, offer a potential solution; however, their implementation in Indonesia remains limited. Climate change is one of the most urgent challenges confronting the construction sector. According to B.I Jin et al. [[1], construction management professionals should be trained in climate management skills, adopt net-zero and climate-friendly technologies and procurement practices, develop green and climate-resilient projects, and retrofit existing buildings to withstand climate change.

Addressing the environmental and climate challenges facing the construction sector requires robust policies and regulations that prioritise the use of sustainable, low-impact materials, energy-efficient methods, and climate-responsive design principles throughout project lifecycles. Research indicates that adopting energy efficiency as a roadmap for carbon mitigation helps limit energy use and improve building performance, while sustainable materials can reduce embodied energy and resource consumption in construction projects, contributing to lower environmental impacts overall [2]. Integrating climate risk assessments into the early planning and design stages enables professionals to identify vulnerabilities and implement appropriate adaptation strategies that enhance resilience in the built environment, reflecting principles embedded in global sustainability frameworks [3]

Adopting a systematic approach is crucial for developing policies related to GIPs within the construction industry. The AHP is a valuable technique for pinpointing and ranking policy strategies. AHP facilitates structured decision-making by organising criteria and subcriteria into a hierarchy, drawing on the insights and experiences of stakeholders such as contractors, consultants and project owners. This method enables the creation of construction policies that address climate risks while also encouraging sustainable development practices and supporting the achievement of the Sustainable Development Goals [4],[5],[6] . Climate change presents two types of risks to construction: physical risks, such as damage from natural disasters, and nonphysical risks, including regulatory uncertainties, material price volatility, and social pressures. Three key pillars must be addressed to implement green or sustainable construction: economic, social, and environmental factors [7].

Previous studies have highlighted the critical role of the AHP in prioritising policies and strategies within the construction sector, particularly in the context of climate change and sustainable development. Johnsson et al. [8] emphasised the need for a structured approach to assess the sector's contribution to SDGs 9 and 13, with AHP facilitating complex multi-criteria decision-making. Ahram and Zakaria [2] identified imbalanced priorities, such as energy efficiency, cost, and regulation, as major barriers to green building adoption, which AHP helps clarify by integrating stakeholder perspectives. Mickovski [9] further stressed the need for multidisciplinary approaches to embed nature-based solutions in construction planning. Zhao et al. [10] applied AHP to flood mitigation strategies and found stakeholder engagement and local knowledge to be the most influential policy criteria. Flood mitigation planning employs decision-making tools based on multiple criteria to facilitate systematic policy development. The AHP has been extensively used to prioritise mitigation strategies by integrating technical, social, and environmental considerations. Nugraha et al. [11] applied AHP to rank urban flood mitigation measures, demonstrating its efficacy

in structuring complex decisions and enhancing policy priorities. Similarly, Caporale and Rinaldi [12] utilised AHP to evaluate adaptation strategies for flood and landslide risks, demonstrating that community perceptions and local knowledge influence intervention effectiveness, establishing stakeholder engagement as critical for disaster mitigation. The integration of social and environmental dimensions within multi-criteria frameworks has been emphasised in recent studies. Axelsson et al. [13] combined AHP with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to promote evidence-based decision-making and incorporate stakeholder preferences into urban flood adaptation planning. Zhang et al. [14] developed an extended watershed-based statistical model supported by AHP to estimate risk levels by accounting for environmental conditions, topography, and societal characteristics. These studies affirm that AHP functions as both a quantitative tool for comparing alternatives and a framework for integrating stakeholder perspectives and socio-environmental factors into flood mitigation policies. Consequently, AHP contributes to the development of adaptive strategies that are technically sound, socially inclusive, and responsive to local contexts, thereby enhancing disaster risk management initiatives.

This study proposes using the AHP to identify adaptive policy strategies for climate change in construction. AHP has not been widely applied in Indonesia's sustainable development context to derive actionable policy recommendations based on stakeholder perceptions. This study connects climate change risk management with achieving the SDGs. Climate change adaptation requires sustainable building practices that reduce environmental impact and enhance resilience. The industry can support carbon neutrality goals through green infrastructure development, carbon footprint reduction, and eco-friendly materials. Sustainable construction delivers physical facilities that fulfil economic, social, and environmental objectives. By incorporating sustainability into development processes, national infrastructure initiatives are crucial in meeting climate targets. The construction regulations must be revised to align with the environmental goals. The deployment of sustainable building materials and strategies, along with strategic planning and compliance mechanisms, is essential for mitigating climate risks. Evaluating the long-term impacts of construction projects through environmental impact assessments (EIAs) helps identify environmental risks and minimise adverse outcomes.

## 2. Materials and Methods Used

### 2.1. Data Gathering

This study identifies energy efficiency, water conservation, environmentally friendly materials, and indoor environmental quality as essential aspects of sustainable construction, connected to climate change risks and

sustainable development goals. The AHP is used to identify and prioritise key factors influencing adaptive policy implementation in construction. The study employs purposive sampling through nonprobability sampling, involving stakeholders and policymakers knowledgeable about the research topic. Data collection uses questionnaires with written questions for the respondents. The research stages involve constructing a hierarchy of elements for reducing climate change, designing paired comparison questionnaires for stakeholders, conducting AHP data analysis for priority weights, and testing response consistency. The AHP analysis results inform policy strategies to enhance the resilience of the construction sector to climate change impacts and promote the achievement of Sustainable Development Goals (SDGs). This approach provides a scientific basis for developing adaptive policies in the national construction sector. The analysis follows the established AHP framework, with data interpretation conducted both numerically through priority weight calculations and qualitatively through examining the context of the construction sector regarding climate change and SDGs. By analysing respondent assessments and comparing sub-criteria, this research reveals industry players' preferences regarding sustainability issues, providing insight into key factors for building construction sector resilience against climate risks.

## 2.2. Analytic Hierarchy Process

The AHP is a prominent MCDM methodology that facilitates decision-makers in structuring complex problems into a hierarchical framework comprising criteria, sub-criteria, and alternatives, thereby deriving quantitative priority weights through pair-wise comparisons. Developed by Saaty, AHP is a well-regarded method for addressing both qualitative and quantitative aspects of complex problems by converting subjective judgments into numerical values [15]. According to Dolan et al., the standard procedural steps of AHP include: (1) defining the decision goal and relevant criteria/sub-criteria, (2) conducting pair-wise comparisons of criteria to obtain relative priority weights, (3) calculating local and global weights, often using the eigenvector method, (4) aggregating alternative weights if applicable, (5) checking the consistency of judgments, and (6) performing sensitivity analysis of the results. Moreover, AHP is particularly effective in contexts involving multiple stakeholders, qualitative or intangible factors, and the necessity for group decision-making, such as in the construction sector, sustainable development, and risk management [16]. AHP has been extensively applied in the construction sector to evaluate sustainability performance, assess risk management alternatives, and prioritise strategic policy options. Its structured nature enables the integration of diverse expert opinions and technical indicators to produce transparent and rational policy outcomes [17]. By

employing this approach, construction policy can be formulated to address climate-related risks while promoting sustainable development practices, thereby contributing to the achievement of the Sustainable Development Goals (SDGs)—notably SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) [18], [19], [20].

Applying the AHP to formulate construction policy addressing climate risks and promoting sustainable development while contributing to the Sustainable Development Goals (SDGs), the methodology offers the following key advantages: (1) It facilitates the integration of climate risk criteria (e.g., emission reduction, adaptation, and regulatory compliance) with socioeconomic interests, bridging environmental and social dimensions [21]. It supports participatory decision-making by incorporating the expertise of multiple stakeholder groups in a structured manner [22]. The AHP hierarchy is constructed by identifying primary criteria through literature review and field findings (i.e., GHG emission reduction, infrastructure adaptation, environmental regulatory compliance, and socioeconomic impact). Each criterion was decomposed into subcriteria based on interviews with stakeholders and literature. The process includes: setting goals, building hierarchy, performing pairwise comparisons, computing weights, consistency checking, sensitivity analysis, and deriving prioritised criteria for policy formulation. This approach supports construction policies that address climate risks while promoting sustainable development and the achievement of SDGs. A pairwise comparison matrix is an  $n \times n$  square matrix that captures the relative judgments among elements and is constructed by comparing each criterion against others.

Matrix Normalisation:

$$a_{ij}^* = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (1)$$

Eigenvalue (Priority):

$$w_i = \frac{\sum_{j=1}^n a_{ij}^*}{n} \quad (2)$$

Consistency Index (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

Consistency Ratio

$$CR = \frac{CI}{RI} \quad (4)$$

Noted:  $\lambda_{max}$ : Maximum Eigen Value; n: Number of Criteria; RI: Random Index (random value based on the number of criteria); If  $CR < 0.1$ , then the matrix consistency is acceptable.

### 3. Results and Discussion

#### 3.1. Data Gathering

The use of the AHP to structure expert judgement and derive priority weights is consistent with prior sustainability decision-making studies in the construction domain, including recent open-access work that applies AHP to low-carbon management and carbon-emission control across the building life cycle. Such studies highlight the suitability of AHP for translating qualitative expert preferences into comparable weights for environmental and governance criteria [23]. Based on the questionnaire results, the respondents' assessments of the principal climate change factors contributing to the attainment of the Sustainable Development Goals (SDGs) have been analysed and summarised in the following **Table 1**.

**Table 1** Recapitulation of Respondents' Answers to the Main Criteria

| Criteria   vs                          | Greenhouse Gas<br>Emission<br>Reduction | Adaptation to<br>Climate Change | Environmental<br>Regulatory<br>Compliance | Socioeconomic<br>Impact |
|----------------------------------------|-----------------------------------------|---------------------------------|-------------------------------------------|-------------------------|
| Greenhouse Gas<br>Emission Reduction   | 1000                                    | 1221                            | 2698                                      | 1603                    |
| Adaptation to Climate<br>Change        | 0819                                    | 1000                            | 4027                                      | 1690                    |
| Environmental<br>Regulatory Compliance | 0371                                    | 0248                            | 1000                                      | 3393                    |
| Socioeconomic Impact                   | 0624                                    | 0592                            | 0295                                      | 1000                    |
| Total                                  | 2,81                                    | 3,06                            | 8,02                                      | 7,69                    |

**Table 1** shows the pairwise comparison matrix used in the AHP to assess the relative importance of four criteria: reduction of greenhouse gas emissions, adaptation to climate change, environmental regulatory compliance, and socioeconomic impact. Each value reflects how much more one criterion is preferred over another based on expert judgement. Several patterns can be observed in complex phenomena like this: some major regions of the world have experienced significant reductions in their GHG emissions, driven by increased efficiency and a reduction in the carbon intensity of energy supply, partly due to the implementation of climate change policies and the deindustrialisation of the economic matrix. This is important to become an effective tool for assessing global emission trends and monitoring climate change mitigation policies, especially during times of crisis [24]. Values greater than one (1) indicate higher importance, whereas values below 1 indicate lower importance. The totals at the bottom of

each column are used in the normalisation process to calculate the final priority weights for each criterion. The calculation of the EVV for the main criteria can be grouped in Table 2.

**Table 2** Main Criteria of The Vector Eigenvalue

| Criteria   vs                       | Greenhouse Gas Emission Reduction | Adaptation to Climate Change | Environmental Regulatory Compliance | Socioeconomic Impact | Average |
|-------------------------------------|-----------------------------------|------------------------------|-------------------------------------|----------------------|---------|
| Greenhouse Gas Emission Reduction   | 0355                              | 0399                         | 0336                                | 0209                 | 0325    |
| Adaptation to Climate Change        | 0291                              | 0327                         | 0502                                | 0220                 | 0335    |
| Environmental Regulatory Compliance | 0132                              | 0081                         | 0125                                | 0441                 | 0195    |
| Socioeconomic Impact                | 0222                              | 0193                         | 0037                                | 0130                 | 0145    |
| Eigenvector                         |                                   |                              |                                     |                      | 1000    |

**Table 2** presents the normalised pairwise comparison matrix and the resulting eigenvector values for the main criteria..Each normalised value indicates the proportional contribution of one criterion relative to others, based on expert assessments.The average column displays the mean value for each criterion, representing its final priority weight or eigenvector..These eigenvector values indicate that climate change adaptation (0.335) and greenhouse gas emission reduction (0.325) have the highest relative importance, followed by environmental regulatory compliance (0.195) and socioeconomic impact (0.145)..The total eigenvector value is equal to 1, confirming consistency in the weighting process..The main-criteria weights indicate that climate change adaptation (0.335) and greenhouse gas emissions reduction (0.325) are prioritised over environmental regulatory compliance (0.195) and socioeconomic impact (0.145)..this pattern aligns with the broader literature emphasising that the built environment simultaneously (i) requires strengthened resilience to escalating climate hazards and (ii) remains a key mitigation leverage point through efficiency and decarbonisation measures..open-access reviews underline the centrality of climate-responsive building adaptation strategies [[25], [26].in parallel, the syntheses of lifecycle carbon emissions stress the need to address multiple stages (materials, transport, construction, and operation) when prioritising mitigation actions [27].

Table 3 presents the normalised pairwise comparison matrix and the eigenvector results for the sub-criteria under the GGES reduction category.y. The subcriteria evaluated include Environmentally Friendly Materials, Energy Efficiency, Logistics Optimisation, and renewable energyy. The results demonstrate that certain sub-criteria, such as Energy Efficiency and Logistics Optimisation, hold relatively higher significance than others, emphasising their

crucial role in reducing GHG emissions in construction activities.s. The total eigenvector value is equal to one, confirming consistency and validity in the weighting process.

**Table 3** Recapitulation of Respondents' Answers to the Sub-Criteria Greenhouse Gas Emissions Reduction

| Criteria   vs                      | Environmentally friendly materials | Energy Efficiency | Logistics Optimisation | Renewable Energy |
|------------------------------------|------------------------------------|-------------------|------------------------|------------------|
| Environmentally friendly materials | 1000                               | 3563              | 1921                   | 2464             |
| Energy Efficiency                  | 0281                               | 1000              | 4877                   | 1239             |
| Logistics Optimisation             | 0521                               | 0205              | 1000                   | 1407             |
| Renewable Energy                   | 0406                               | 0807              | 0711                   | 1000             |
| Total                              | 2,21                               | 5,58              | 8,51                   | 6,11             |

**Table 4** illustrates the eigenvector values for the subcriteria under the GGES reduction criterion, reflecting the relative priorities assigned to each component based on expert and respondent evaluations. The subcriteria Environmentally include Friendly Materials, Energy Efficiency, Logistics Optimisation, and renewable energy. Innovative and adaptive material integration ensures that infrastructure systems evolve in accordance with ecological realities and societal needs. The framework developed in this regard emphasises the importance of bridging material science, policy, and practice [28]. The calculated eigenvector values represent the normalised weights derived from the pairwise comparison matrix. Among these, environmentally friendly materials demonstrate the highest priority with an average eigenvector value of 0.430, indicating that the selection and use of sustainable construction materials are considered the most influential in reducing emissions. This is followed by energy efficiency with a weight of 0.271, underscoring the importance of optimising energy use in project operations. Logistics Optimisation ranks third with 0.155, while renewable energy holds the lowest weight at 0.144, suggesting a comparatively smaller but still relevant role in reducing emissions. Overall, these findings reveal that respondents prioritise direct interventions in material selection and energy management over logistical and renewable energy aspects. The total eigenvector sum equals 1, confirming consistency and validity within the AHP framework.

Within the GHG emission reduction criterion, the highest sub-criterion weight is that of environmentally friendly materials (0.430), followed by energy efficiency (0.271), Logistics Optimisation (0.155), and renewable energy (0.144). The prominence of materials is consistent with lifecycle evidence that embodied emissions from material production and supply chains can represent a substantial share of total building emissions, motivating strong emphasis

on material selection and low-carbon substitutes [27]. Low-carbon materials and bioclimatic/efficiency-oriented design can deliver meaningful CO<sub>2</sub> reductions [29]. The relatively high role of energy efficiency is likewise supported by empirical and review findings that energy-efficiency measures in buildings directly contribute to climate and SDG objectives [25] and that material choices can significantly influence operational cooling and electricity demand [30]. Finally, the non-trivial weight assigned to Logistics Optimisation is consistent with recent studies highlighting that construction logistics and material transport can be an important emission hotspot and a practical target for optimisation and governance (the open-access review “Turning a spotlight on construction logistics for a sustainable urban environment—a review of current policy concepts and literature” [31]. The foundation of resilient construction is an infrastructure that adapts to climate change and provides ways to strengthen environmental protection while reducing the duration of prolonged and socioeconomic instability. As the risk of climate change increases in the form of drought, floods, storms, and land degradation, conventional materials can still be used to maintain infrastructure functionality. The integration of innovative, durable, and adaptable materials ensures that infrastructure systems evolve in accordance with ecological realities and community needs [28], [32].

**Table 4** Sub-Criteria Greenhouse Gas Emission Reduction Vector Eigen Values

| Criteria   vs                      | Environmentally friendly materials | Energy Efficiency | Logistics Optimisation | Renewable Energy | Average |
|------------------------------------|------------------------------------|-------------------|------------------------|------------------|---------|
| Environmentally friendly materials | 0453                               | 0639              | 0226                   | 0403             | 0430    |
| Energy Efficiency                  | 0127                               | 0179              | 0573                   | 0203             | 0271    |
| Logistics Optimisation             | 0236                               | 0037              | 0118                   | 0230             | 0155    |
| Renewable Energy                   | 0184                               | 0145              | 0084                   | 0164             | 0144    |
| Eigenvector                        |                                    |                   |                        |                  | 1       |

**Table 5** presents the recapitulation of respondents’ assessments for the subcriteria under Climate Change Adaptation, which include extreme climate-resilient design, sustainable drainage systems, and adaptive technologies. The data were derived from the pairwise comparison matrix used in the AHP to evaluate the relative importance of each adaptation measure. The results indicate that Extreme Climate-Resilient Design received the highest comparative weight, with total values of 1.894, 3.460, and 6.660 across the respective criterion columns. This suggests that the integration of climate-resilient structural design features is the most crucial approach for mitigating future climate risks in construction projects. Subsequently, sustainable drainage systems were rated moderately significant,

emphasising their role in managing stormwater and minimising flood risks. Lastly, ATS were also recognised for their importance, though ranked slightly lower, reflecting their emerging but growing role in enhancing resilience.

**Table 5** Recapitulation of Respondents' Answers to the Climate Change Adaptation Sub-Criteria

| Criteria   vs                    | Extreme climate–resilient design | Sustainable drainage systems | Adaptive Technologies |
|----------------------------------|----------------------------------|------------------------------|-----------------------|
| Extreme climate–resilient design | 1                                | 1474                         | 4647                  |
| Sustainable drainage systems     | 0679                             | 1                            | 1013                  |
| Adaptive Technologies            | 0215                             | 0987                         | 1                     |
| Total                            | 1894                             | 3460                         | 6660                  |

**Table 6** displays the eigenvector values for the subcriteria under climate change adaptation, illustrating the relative importance of each factor as determined through the AHP. The subcriteria evaluated include extreme climate-resilient design, sustainable drainage systems, and adaptive technologies. Among these, Extreme Climate-Resilient Design achieved the highest average eigenvector value of 0.551, indicating that it is the most critical component in enhancing infrastructure adaptability to climate impacts. This finding reflects the emphasis of stakeholders on strengthening building designs and materials to withstand extreme weather events. The next priority, Sustainable Drainage Systems, received an eigenvector value of 0.266, highlighting the importance of effective water management and flood mitigation strategies within climate adaptation planning. Lastly, adaptive technologies recorded a lower weight of 0.183, indicating a supporting but less dominant role in current adaptation measures, likely due to their relatively recent integration and technological cost considerations. Overall, the results confirm that structural resilience, complemented by environmental systems and technological innovation, remains the cornerstone of adaptation strategies to ensure comprehensive climate responsiveness. The eigenvector sum equals 1, indicating the internal consistency of the AHP computation. Continuous monitoring, evaluation, and adaptation are essential for maintaining effective constructions and guiding policymakers, managers, and communities in protecting assets from disasters induced by climate change. Similarly, fair procurement practices and strong political will are crucial to ensuring financial compliance and project success [33]. Under climate change adaptation, extreme climate–resilient design (0.551) dominates, followed by sustainable drainage systems (0.266) and adaptive technologies (0.183). The priority for resilient design is consistent with reviews noting that climate change is increasingly challenging building habitability and performance, requiring climate-responsive design and adaptation mechanisms [26]. The substantive weight on SUDS aligns with stormwater literature showing that SUDS are widely promoted as flexible, multi-benefit

solutions that improve flood management while supporting broader urban sustainability goals [34]. Meanwhile, adaptive technologies (e.g., data-driven monitoring, smart/IoT-enabled management) are increasingly positioned as enablers of risk-informed adaptation and resilience planning. For example, digital technologies, such as digital twins, play a role in sustainability performance and emissions reduction across the building life cycle [35].

**Table 6** Climate Change Adaptation Vector Eigen Values of Sub-Criteria

| Criteria   vs                        | Extreme climate–<br>resilient design | Sustainable<br>drainage systems | Adaptive<br>Technologies | Average |
|--------------------------------------|--------------------------------------|---------------------------------|--------------------------|---------|
| Extreme climate–<br>resilient design | 0528                                 | 0426                            | 0698                     | 0551    |
| Sustainable drainage<br>systems      | 0358                                 | 0289                            | 0152                     | 0266    |
| Adaptive<br>Technologies             | 0114                                 | 0285                            | 0150                     | 0183    |
| Eigenvector                          |                                      |                                 |                          | 1       |

**Table 7** presents the recapitulation of respondents’ evaluations for the subcriteria under Environmental Regulatory Compliance, which include Green Standards and Certification, Carbon Emissions Audit, and Incentives and Penalties. The three main tools in carbon emission reduction regulation include conducting environmental audits, enhancing the credibility of carbon emission reduction disclosures as imperative tools and controls (carbon emission standards), and market-based tools (carbon taxes and emission trading) that utilise stakeholder monitoring and accountability to address “government failure” or “market failure” in carbon emission reduction. The table summarises the results of pairwise comparisons used to assess the relative importance of these subcriteria within the context of SCG. Green Standards and Certification received the strongest comparative rating, with total values of 1.906, 3.789, and 4.896 across the matrix, respectively. The Carbon Emissions Audit ranks second, emphasising the need for systematic measurement and verification of carbon outputs to improve transparency and accountability. Finally, Incentives and Penalties hold a lower comparative value, indicating that regulatory mechanisms are important, but their influence is perceived as more indirect and dependent on consistent enforcement.

**Table 7** Recapitulation of Respondents’ Answers to the Environmental Regulatory Compliance Sub-Criteria

| Criteria   vs                        | Green Standards and<br>Certification | Carbon emissions<br>audit | Incentives and<br>Penalties |
|--------------------------------------|--------------------------------------|---------------------------|-----------------------------|
| Green Standards and<br>Certification | 1                                    | 1777                      | 2908                        |
| Carbon emissions audit               | 0563                                 | 1                         | 0989                        |
| Incentives and Penalties             | 0344                                 | 1012                      | 1                           |
| Total                                | 1906                                 | 3789                      | 4896                        |

**Table 8** presents the eigenvector values for the subcriteria under Environmental Regulatory Compliance, including Green Standards and Certification, Carbon Emissions Audit, and Incentives and Penalties. These eigenvector values reflect the normalised weights derived from the pairwise comparison matrix, indicating the relative importance of each subcriterion in achieving regulatory alignment and SCPs. Green Standards and Certification obtained the highest average eigenvector value of 0.529, confirming its position as the most influential factor in promoting environmental accountability within the construction industry. The carbon emissions audit follows with an eigenvector value of 0.254, emphasising the significance of systematically monitoring and verifying emissions to ensure transparency and performance improvement. Meanwhile, Incentives and Penalties recorded the lowest weight of 0.217, indicating that regulatory enforcement mechanisms, while important, are perceived as secondary to certification and auditing processes in driving compliance behaviour. Overall, the results highlight a clear prioritisation towards proactive compliance through standardised certification and quantitative assessment, rather than reactive enforcement. The total eigenvector value is equal to 1, confirming consistency and validity within the AHP analytical framework.

The leading role of Green Standards and Certification (0.529) in environmental regulatory compliance is consistent with the research that rating and certification systems operate as governance instruments that formalise sustainability indicators (energy, materials, and carbon) and provide market signals for adoption. Recent research and review work document the rapid growth in green building assessment research and highlight the increasing prominence of carbon- and efficiency-related indicators in rating systems [36]. A comparative analysis of major certification schemes (e.g., LEED, BREEAM, and WELL) also emphasised their alignment with the triple-bottom-line framing and SDG-related performance dimensions [37]. The non-negligible weight assigned to Carbon Emissions Audit (0.254) is supported by methodological work on carbon accounting and monitoring, including life-cycle-based carbon accounting methods for construction projects [38] and real-time monitoring frameworks that convert site-level data into verifiable emissions management insights [32].

**Table 8** Sub-Criteria Environmental Regulatory Compliance Vector Eigen Values

| Criteria   vs                        | Green Standards<br>and Certification | Carbon emissions<br>audit | Incentives and<br>Penalties | Average |
|--------------------------------------|--------------------------------------|---------------------------|-----------------------------|---------|
| Green Standards<br>and Certification | 0524                                 | 0469                      | 0594                        | 0529    |

|                          |        |        |      |        |
|--------------------------|--------|--------|------|--------|
| Carbon emissions audit   | 0295   | 0,2639 | 0202 | 0254   |
| Incentives and Penalties | 0,1804 | 0,2670 | 0204 | 0,2172 |
| Eigenvector              |        |        |      | 1      |

**Table 9** provides a recapitulation of respondents' evaluations for the subcriteria under Socioeconomic Impact, which include the cost of implementing green policies and technologies, creation of green jobs, and stakeholder awareness and engagement. The table summarises the results of the AHP questionnaire's pairwise comparisons, reflecting stakeholder perspectives on the social and economic dimensions of sustainable construction. The cost of implementing green policies and technologies holds the strongest comparative weight, with total values of 2.078, 3.648, and 5.081 across the evaluation matrix. This indicates that respondents perceive financial feasibility as the most critical factor influencing the successful implementation of sustainable practices. In contrast, the creation of green jobs and stakeholder awareness and engagement received relatively lower comparative values, although both remain significant in shaping long-term sustainability outcomes.

**Table 9** Recapitulation of Respondents' Answers to the Socioeconomic Impact of the Sub-Criteria

| Criteria   vs                                        | Cost of implementing green policies and technologies | Creation of green jobs | Stakeholder Awareness and Engagement |
|------------------------------------------------------|------------------------------------------------------|------------------------|--------------------------------------|
| Cost of implementing green policies and technologies | 1000                                                 | 2248                   | 1578                                 |
| Creation of green jobs                               | 0445                                                 | 1000                   | 2502                                 |
| Stakeholder Awareness and Engagement                 | 0634                                                 | 0400                   | 1000                                 |
| Total                                                | 2078                                                 | 3648                   | 5081                                 |

**Table 10** presents the eigenvector values for the subcriteria under Socioeconomic Impact, namely, Cost of Implementing Green Policies and Technologies, Creation of Green Jobs, and Stakeholder Awareness and Engagement. These eigenvector values represent the normalised weights derived from the pairwise comparison matrix, reflecting each socioeconomic factor's relative importance in supporting sustainable construction practices. The findings indicate that the cost of implementing green policies and technologies has the highest average eigenvector value of 0.469, highlighting its dominant influence in shaping sustainability decisions within the construction sector. The creation of green jobs ranks second with a weight of 0.327, emphasising the perceived value of employment generation and its contribution to social welfare and inclusive growth. Lastly, Stakeholder Awareness and Engagement has a

lower weight of 0.204, suggesting that community and stakeholder participation are viewed as supportive rather than primary drivers, although they are acknowledged as important. Overall, the results underline that economic viability remains the leading factor in sustainability implementation, followed by the social benefits of GJC, with awareness and engagement serving as essential enablers for long-term impact. The total eigenvector value is equal to 1, confirming the consistency of the AHP computation.

In the socioeconomic impact criterion, the dominance of the cost of implementing green policies and technologies (0.469) reflects a widely reported barrier: higher upfront or transaction costs can slow adoption even when long-term benefits exist. Other studies identified cost and regulatory stability as key determinants influencing the uptake of building energy-efficiency measures [25]. The substantial weight on Creation of Green Jobs (0.327) is consistent with research linking sustainability transitions to changing skill needs and employability in the construction labour market, emphasising training and competency development as part of a green economy shift [39]. Finally, Stakeholder Awareness and Engagement (0.204) aligns with the research showing that systematic stakeholder engagement is often necessary to translate sustainability targets into project decisions and PM [40].

**Table 10** Sub-Criteria Socioeconomic Impact Vector Eigen Values

| Criteria   vs                                        | Cost of implementing green policies and technologies | Creation of green jobs | Stakeholder Awareness and Engagement | Average |
|------------------------------------------------------|------------------------------------------------------|------------------------|--------------------------------------|---------|
| Cost of implementing green policies and technologies | 0481                                                 | 0616                   | 0311                                 | 0469    |
| Creation of green jobs                               | 0214                                                 | 0274                   | 0492                                 | 0327    |
| Stakeholder Awareness and Engagement                 | 0305                                                 | 0110                   | 0197                                 | 0204    |
| Eigenvector                                          |                                                      |                        |                                      | 1       |

**Table 11** presents the recapitulation of respondents' evaluations of the policy alternatives, including fiscal incentives for green projects, carbon audit regulations, workforce training, and Adaptive Design Standardisation. The table summarises the results of pairwise comparisons obtained from the AHP questionnaire, reflecting stakeholder preferences towards different policy strategies for promoting sustainable development. The results reveal that WT holds the highest comparative weight, with a total value of 6.934 across the evaluation matrix, indicating that respondents consider CB as the most influential policy measure. Adaptive Design Standardisation follows with a total value of 5.345, emphasising the importance of standardised and flexible design practices in supporting sustainability initiatives. Meanwhile, carbon audit regulations (4.661) and fiscal incentives for green projects (3.148) received

comparatively lower weights, suggesting that while regulatory and fiscal mechanisms are valued, stakeholders place greater emphasis on human resource development and adaptive design frameworks as key drivers of sustainable policy implementation.

**Table 11** Recapitulation of Respondents' Answers to Policy Alternatives

| Criteria   vs                        | Fiscal incentives for green projects | Carbon Audit Regulations | Workforce Training | Adaptive Design Standardisation |
|--------------------------------------|--------------------------------------|--------------------------|--------------------|---------------------------------|
| Fiscal incentives for green projects | 1000                                 | 2868                     | 1408               | 0918                            |
| Carbon Audit Regulations             | 0349                                 | 1000                     | 3885               | 1867                            |
| Workforce Training                   | 0710                                 | 0257                     | 1000               | 1560                            |
| Adaptive Design Standardisation      | 1090                                 | 0536                     | 0641               | 1000                            |
| Total                                | 3148                                 | 4661                     | 6934               | 5345                            |

**Table 12** presents the eigenvector values for the policy alternatives, namely Fiscal Incentives for Green Projects, Carbon Audit Regulations, Workforce Training, and Adaptive Design Standardisation. These eigenvector values represent the normalised weights derived from the pairwise comparison matrix, reflecting each policy option's relative importance in supporting sustainable development initiatives. The findings indicate that fiscal incentives for green projects hold the highest average eigenvector value of 0.327, underscoring their dominant role in promoting environmentally responsible investments through financial support mechanisms. Carbon Audit Regulations rank second with a weight of 0.309, emphasising the importance of regulatory oversight in ensuring transparency and accountability in ER efforts. Meanwhile, Adaptive Design Standardisation and Workforce Training register lower weights of 0.185 and 0.179, respectively, suggesting that while design adaptability and capacity building remain essential, they are perceived as complementary strategies rather than primary policy drivers. Overall, the results highlight that fiscal and regulatory measures are the most effective instruments for advancing sustainability policies, with training and design standardisation functioning as supportive components. The total eigenvector value equals 1, confirming the AHP computation's consistency and validity.

**Table 12** Policy Alternatives for the Vector eigenvalue

| Criteria/VS                                | Fiscal incentives<br>for green<br>projects | Carbon Audit<br>Regulations | Workforce<br>Training | Adaptive<br>Design<br>Standardisation | Rata-rata |
|--------------------------------------------|--------------------------------------------|-----------------------------|-----------------------|---------------------------------------|-----------|
| Fiscal<br>incentives for<br>green projects | 0318                                       | 0615                        | 0203                  | 0172                                  | 0327      |
| Carbon Audit<br>Regulations                | 0111                                       | 0215                        | 0560                  | 0349                                  | 0309      |
| Workforce<br>Training                      | 0226                                       | 0055                        | 0144                  | 0292                                  | 0179      |
| Adaptive<br>Design<br>Standardisation      | 0346                                       | 0115                        | 0092                  | 0187                                  | 0185      |
| Eigenvector                                |                                            |                             |                       |                                       | 1         |

### 3.2. Formation of Rankings in Priority Determination

The process of determining the priority of climate change mitigation and adaptation strategies in the construction sector follows a structured analytical approach based on the AHP. It begins by combining two sets of weights: the criterion weights, which are obtained from the pairwise comparison matrix of criteria, and the alternative weights, which are calculated from the pairwise comparison matrix of alternatives under each criterion. The weight of each alternative is multiplied by the corresponding criterion weight to produce a composite value representing its overall importance within the decision hierarchy. These composite scores are then arranged from the highest to the lowest to identify which strategies should be prioritised for implementation. The ranking provides a clear picture of the actions viewed as the most urgent and impactful in addressing climate-related challenges within the construction industry. The total sum of all composite weights—resulting from the multiplication of criteria and alternative weights—must equal one to ensure the results are accurate and consistent. This verification step confirms that the calculations are balanced and that no weighting bias has occurred. Finally, the ranking outcomes derived from the respondents' assessments are summarised in the table below. Table 13 presents a clear and data-driven representation of the relative priorities among the proposed mitigation and adaptation strategies, supporting decision-makers in developing effective and targeted sustainability policies for the construction sector.

Fiscal Incentives for Green Projects (0.327) marginally exceeds Carbon Audit Regulations (0.309), followed by Adaptive Design Standardisation (0.185) and Workforce Training (0.179). This ordering is consistent with evidence that fiscal incentives and reward/compensation mechanisms can accelerate green building uptake, particularly in early adoption phases [41], and subsidy design and phase-out strategies materially influence market equilibria in green building development [42]. Monitoring, reporting, and verification (including real-time data capture) is a critical

enabler for performance-based carbon management in construction [40]. The remaining priorities are also literature-consistent: standardisation of climate-adaptive design is emphasised [26], while workforce training and green employability are repeatedly identified as necessary complements to policy and technology deployment in construction sustainability transitions [39].

**Table 13.** Value of the main factor

| No | Factors                             | Percentage |  |
|----|-------------------------------------|------------|--|
| 1  | Greenhouse Gas Emission Reduction   | 42%        |  |
| 2  | Adaptation to Climate Change        | 24%        |  |
| 3  | Environmental Regulatory Compliance | 15%        |  |
| 4  | Socioeconomic Impact                | 5%         |  |

Based on the results of **Table 13**, the most prioritized areas for improvement are (1) Environmental Regulation Compliance and (2) Social and Economic Impact. The AHP hierarchy was initiated by identifying the main criteria based on literature review and field findings related to climate change risks in the construction sector, namely: Greenhouse Gas Emission Reduction, Infrastructure Adaptation, Environmental Regulation Compliance, and Socio-Economic Impact. Each of these criteria is then broken down into specific sub-criteria, for example, under "Infrastructure Adaptation," which includes Extreme Climate Resilient Design and Sustainable Drainage Systems based on input from experts and industry best practices. The sub-criteria selection process involves focus group discussions with academics and a literature review by the authors, so the resulting framework reflects a collaborative and comprehensive perception. After the criteria and sub-criteria were established, a hierarchical matrix was created to map the relationships between the research objectives (climate mitigation and adaptation priorities), criteria, sub-criteria, and policy alternatives. This hierarchy is then validated thru an initial consistency test using the Consistency Ratio (CR) to ensure the assessment structure is unbiased. The final result of the framework preparation.

The AHP evaluation is presented in the following hierarchy diagram, which visualizes the order and interconnections between the elements of the research assessment.

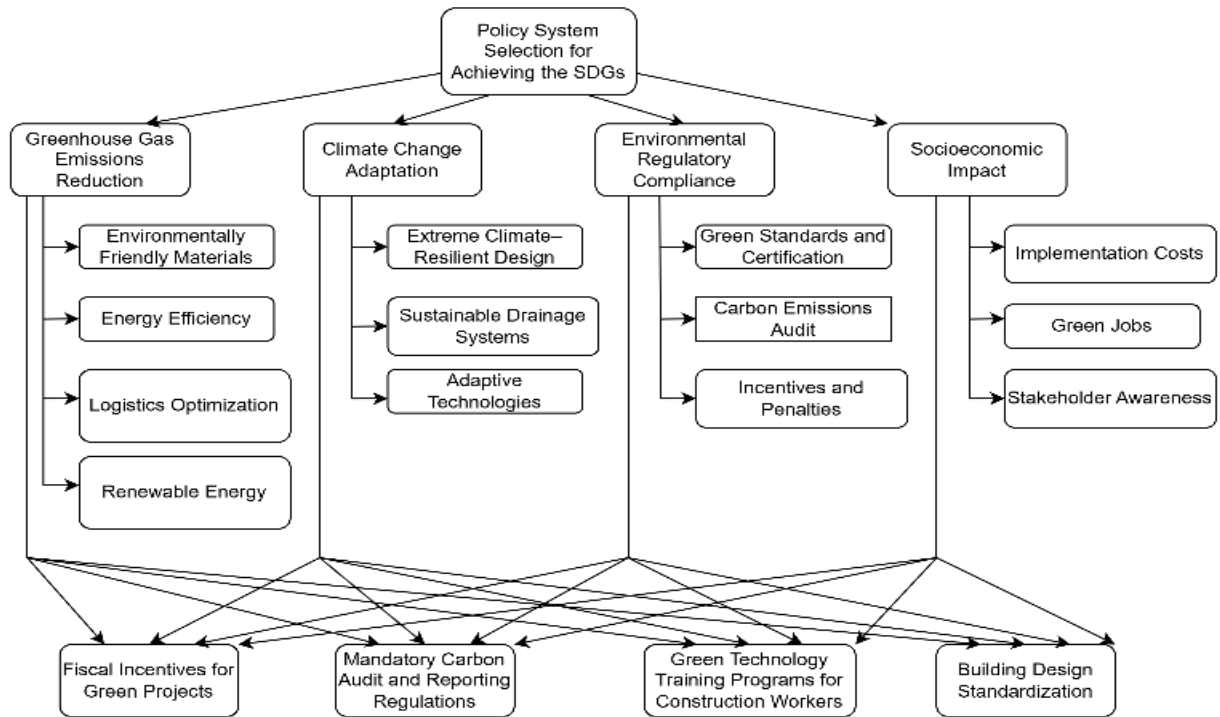


**Figure 1.** AHP evaluation

Based on the results obtained from the Analytic Hierarchy Process (AHP), Identification of potential climate change risks consisting of: greenhouse gas Emissions reduction, climate change adaptation, environmental regulatory compliance and socioeconomic impact. The importance of consistency in quality application in sustainable construction. Some Practical Implications that can be implemented are:

- Low Emission Focus: Contractors and project owners should adopt low carbon footprint materials and energy efficiency technologies as a first step.
- Emission Performance-Based Incentive Scheme: A tax reduction scheme for projects that successfully reduce emissions above a certain threshold.
- Climate-Resilient Design: Building design standards should reflect adaptation needs, such as sustainable drainage systems and flood-resistant designs and Issuance of new national standards for building designs resistant to extreme temperatures and floods, coordinated by the Ministry of Public Works and Housing (PUPR).
- Regulatory Compliance: Local governments need to tighten carbon audit mechanisms and provide fiscal incentives to encourage stakeholders to comply with regulations. And Requirement for annual emission reports for all Medium to Large Scale Construction projects, with penalties for non-compliance.
- Socio-Economic Management: Green jobs training programs and local community participation need to be expanded to minimize social impacts. Training and Certification of Green Skills, AHP-based training program for project managers and technicians, accompanied by official certification to enhance climate adaptation capabilities.

#### 4. Conclusion

The Analytic Hierarchy Process (AHP) identifies "Greenhouse Gas Emissions Reduction" as the top criterion (0.42), emphasising its role in sustainability performance in construction. This consensus reflects the impact of carbon emission mitigation on environmental sustainability, aligning with studies citing emission reduction as crucial for sustainable construction and climate goals. The second criterion, "Infrastructure Adaptation" (0.24) stresses the resilience of construction assets to climate-induced stresses, highlighting the role of adaptive infrastructure in long-term performance and risk reduction. Research shows that climate-resilient design enhances the robustness of built environments. The third criterion, "Environmental Regulatory Compliance" (0.15), highlights the role of regulatory frameworks in sustainable construction but suggests challenges due to institutional constraints, implying the need for compliance mechanisms, coordination, and incentive-based governance. "Socioeconomic Impact" (0.05) is the lowest priority, indicating that social and economic aspects are secondary to environmental priorities. This suggests a phased approach, focusing on emission reduction and adaptation first and then integrating social equity and economic welfare. Socioeconomic considerations are crucial for inclusive development. The hierarchy of sustainability priorities aligns with international frameworks, such as the Agreement UN SDGs, emphasising emission mitigation and infrastructure adaptation, while regulatory compliance and socioeconomic integration highlight the need for balanced policies in sustainable construction. Quality management encompasses all aspects related to construction, including the improvement of human resource quality. The need for evaluation regarding economic, social, and environmental benefits. Good organizational management becomes a key factor in the implementation of sustainable construction.

#### **Conflict of 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.

#### **Research Involving Human Participants and/or Animals**

This study did not involve human participants or live animals. All experimental procedures were conducted in accordance with applicable environmental and laboratory safety regulations.

#### **Informed Consent**

Not applicable, as this study did not involve human participants.

#### **Data availability statements**

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

#### **Author Contributions Statement**

**Kemala Hayati:** writing, original draft; reviewing and editing; resources; funding acquisition; data curation.

**Nurunnashila:** writing, editing, data curation, and conceptualisation. **Aryana Rachmad S:** Writing, data curation,

and conceptualisation. **Irma S**: writing, editing, data curation, and conceptualisation. **Qurratun Kamazuhra**: writing, and editing. **Rachmad Ardhinato**: writing, editing, data curation, and conceptualisation.

## References

- [1] B I A, Jin X and Osei-kyei R A Meta-analysis of Climate Risk Mitigation **1** 75–86
- [2] Hafez F S, Sa'di B, Safa-Gamal M, Taufiq-Yap Y H, Alrifay M, Seyedmahmoudian M, Stojcevski A, Horan B and Mekhilef S 2023 Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research *Energy Strategy Reviews* **45** 101013
- [3] Pietocha A 2024 The BREEAM, the LEED and the DGNB certifications as an aspect of sustainable development *Acta Scientiarum Polonorum. Architectura* **23** 121–33
- [4] Yaralioglu I and Kara C 2025 Sustainable Urban Design Approach for Public Spaces Using an Analytical Hierarchy Process ( AHP )
- [5] Soam S K, N S R, Bs Y, Balasani R, Rakesh S, Marwaha S, Kumar P and Agrawal R C 2023 AHP Analyser : A decision-making tool for prioritizing climate change mitigation options and forest management 1–14
- [6] Qian J 2024 Identifying Critical Criteria on Assessment of Sustainable Materials for Construction Projects in New Zealand Through the Analytic Hierarchy Process ( AHP ) Approach
- [7] Raymondo T, Marcelline S and Chengang Y 2022 Impact of Green Construction Procurement on Achieving Sustainable Economic Growth In fl uencing Green Logistic Services Management and Innovation Practices **9** 1–14
- [8] Johnsson F 2024 Emissions from building and construction can be halved with current technologies and practices Filip Johnsson and Ida Karlsson from Chalmers University of 4–7
- [9] Mickovski S B 2021 Re-Thinking Soil Bioengineering to Address Climate Change Challenges
- [10] Zhao J, Chen H, Liang Q, Xia X, Xu J, Hoey T, Barrett B, Renaud F G, Boshier L and Zhou X 2022 Large - scale flood risk assessment under different development strategies : the Luanhe River Basin in China *Sustain. Sci.* **17** 1365–84
- [11] Nugraha N B, Puspaningrum A and Santosa Y M 2025 Using AHP to prioritize flood mitigation measures in urban areas *E3S Web of Conferences* **605**
- [12] Caporale D and Rinaldi A 2025 The application of analytical hierarchy process to assess adaptation strategies for flood and landslides risks: A case study of a multi-risk area community *Environ. Sci. Policy* **163** 103959

- 503 [13] Axelsson C, Giove S and Soriani S 2021 Urban pluvial flood management part 1: Implementing an ahp-topsis  
504 multi-criteria decision analysis method for stakeholder integration in urban climate and stormwater adaptation  
505 *Water (Switzerland)* **13**
- 506 [14] Zhang H, Shao Z, Sun J, Huang X and Yang J 2022 An Extended Watershed-Based AHP Model for Flood  
507 Hazard Estimation: Constraining Runoff Converging Indicators via MFD-Derived Sub-Watershed by  
508 Maximum Zonal Statistical Method *Remote Sens. (Basel)*. **14**
- 509 [15] Saaty T L *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*  
510 (RWS Publications)
- 511 [16] Chen C-F 2006 Applying the Analytical Hierarchy Process (AHP) Approach to Convention Site Selection *J.*  
512 *Travel Res.* **45** 167–74
- 513 [17] Darko A, Chan A, Effah E, Owusu E, Pärn E and Edwards D 2018 Review of application of analytic hierarchy  
514 process (AHP) in construction *International Journal of Construction Management* **19**
- 515 [18] Tunji-Olayeni P, Afolabi A, Ojelabi R and Eshofonie E E 2019 Climate change mitigation and adaptation  
516 strategies for construction activities within planetary boundaries: Limitations of developing countries *J. Phys.*  
517 *Conf. Ser.* **1299** 12006
- 518 [19] Practices S, Oliveira I De and Barbosa J 2023 Construction Industry and Its Contributions to Achieving the  
519 SDGs Proposed by the UN : An Analysis of
- 520 [20] Fei W, Opoku A, Agyekum K, Oppon J A, Ahmed V, Chen C and Lok K L 2021 The Critical Role of the  
521 Construction Industry in Achieving the Sustainable Development Goals ( SDGs ): Delivering Projects for the  
522 Common Good
- 523 [21] Sreenivasan A, Suresh M, Nedungadi P and R R R 2023 Mapping analytical hierarchy process research to  
524 sustainable development goals: Bibliometric and social network analysis *Heliyon* **9** e19077
- 525 [22] Iradukunda P, Mwanaumo E M and Kabika J 2023 A review of integrated multicriteria decision support  
526 analysis in the climate resilient infrastructure development *Environmental and Sustainability Indicators* **20**  
527 100312
- 528 [23] Zheng J F, Lu Z P, Ding Y, Guo Z Z and Zhou S X 2025 Management of Carbon Emissions Throughout the  
529 Building Life Cycle Based on the Analytic Hierarchy Process *Buildings* **15** 1–18
- 530 [24] Oreggioni G D, Monforti Ferraio F, Crippa M, Muntean M, Schaaf E, Guizzardi D, Solazzo E, Duerr M, Perry  
531 M and Vignati E 2021 Climate change in a changing world: Socio-economic and technological transitions,  
532 regulatory frameworks and trends on global greenhouse gas emissions from EDGAR v.5.0 *Global*  
533 *Environmental Change* **70** 102350

- 534 [25] Di Foggia G 2018 Energy efficiency measures in buildings for achieving sustainable development goals  
535 *Heliyon* **4** e00953
- 536 [26] Saifudeen A and Mani M 2024 Adaptation of buildings to climate change: an overview *Front. Built Environ.*  
537 **10** 1–17
- 538 [27] Wang G, Luo T, Luo H, Liu R, Liu Y and Liu Z 2024 A comprehensive review of building lifecycle carbon  
539 emissions and reduction approaches *City and Built Environment* **2** 1–28
- 540 [28] Salah M, Elmasry M, Mashhour I M and Amer N 2023 A framework for assessing sustainability of  
541 construction projects *Clean. Eng. Technol.* **13** 100626
- 542 [29] Firoozi A A, Oyejobi D O and Firoozi A A 2025 Innovations in energy-efficient construction: Pioneering  
543 sustainable building practices *Clean. Eng. Technol.* **26** 100957
- 544 [30] Okonta D E 2023 Investigating the impact of building materials on energy efficiency and indoor cooling in  
545 Nigerian homes *Heliyon* **9** e20316
- 546 [31] Haag P and Jünger H C 2023 Turning a spotlight on construction logistics for a sustainable urban  
547 environment—a review of current policy concepts and literature *Front. Built Environ.* **9** 1–17
- 548 [32] Bai F, Cai Q, Zheng X, Lei Z, Wang W, Liang J, Guo J and Qi J 2025 An integrated framework for reducing  
549 construction carbon emissions using real-time monitoring and econometrics *Sci. Rep.* **15** 1–18
- 550 [33] Ilugbusi B S, Adisa O, Obi O C, Awonuga K F, Adelekan O A, Asuzu O F and Ndubuisi N L 2024 Urban  
551 Resilience To Climate Change: a Review of Adaptation Strategies and Infrastructure Innovations *Ecofeminism*  
552 *and Climate Change* **5** 18–23
- 553 [34] Zhou Q 2014 A review of sustainable urban drainage systems considering the climate change and urbanization  
554 impacts *Water (Switzerland)* **6** 976–92
- 555 [35] Zhang Z, Wei Z, Court S, Yang L, Wang S, Thirunavukarasu A and Zhao Y 2024 A Review of Digital Twin  
556 Technologies for Enhanced Sustainability in the Construction Industry *Buildings* **14** 1–23
- 557 [36] Mao J, Yuan H, Xiong L and Huang B 2024 Research Review of Green Building Rating System under the  
558 Background of Carbon Peak and Carbon Neutrality *Buildings* **14**
- 559 [37] Tsirovasilis E, Katafygiotou M and Psathiti C 2025 Comparative Assessment of LEED, BREEAM, and  
560 WELL: Advancing Sustainable Built Environments *Energies (Basel)*. **18** 1–23
- 561 [38] Wu Y, Zhang C, Liu Y, Deng W, Jike S and Liu F 2025 Carbon Accounting in Construction Engineering:  
562 Methodology and Applications *Sustainability (Switzerland)* **17** 1–38
- 563 [39] Silvestru C I, Lupescu M E, Ifrim A M, Silvestru R and Icoiciu C V 2024 The Impact of Sustainability on the  
564 Labour Market and Employability in the Construction Industry *Sustainability (Switzerland)* **16** 1–16

- 565 [40] Bal M, Bryde D, Fearon D and Ochieng E 2013 Stakeholder Engagement: Achieving Sustainability in the  
566 Construction Sector *Sustainability (Switzerland)* **5** 695–710
- 567 [41] Saka N, Olanipekun A O and Omotayo T 2021 Reward and compensation incentives for enhancing green  
568 building construction *Environmental and Sustainability Indicators* **11** 100138
- 569 [42] Zhao Y, Ma Y and Zhong F 2025 Sustaining Green Building Incentives: A Tripartite Evolutionary Game  
570 Analysis and the Synergistic “Technology–Reputation–Policy” Pathway *Buildings* **15** 1–34
- 571