# Assessing barriers to the adoption of green technologies in developing countries by using an integrated decision-making system

Muhammad Ikram[a], Jinane Es-sadki[a]

[a]School of Business Administration, Al Akhawyan University in Ifrane, Avenue Hassan II, P.O. Box 104, 53 000 Ifrane, Morocco

**Abstract**

The United Nations Sustainable Development Goals (SDGs) set a global agenda to advance sustainability by exerting environmental pressures and promoting cleaner production. Achieving these targets depends heavily on the adoption of green technologies, yet several persistent barriers continue to impede the effective implementation of green technologies. Therefore, this study develops an integrated decision support system to assess Green Technology Adoption (GTA) barriers and explore potential strategies to overcome them effectively. After reviewing the literature and consulting with field experts, seven major categories of barriers of institutional, financial, market, technological, regulatory, environmental, and social barriers and twenty-six sub-barriers were identified and analyzed. A Fuzzy Analytic Hierarchy Process (FAHP) was applied to rank the main and sub barriers and, then used the Fuzzy VIekriterijumsko KOmpromisno Rangiranje (FVIKOR) method to prioritize the eleven potential solution strategies. The results reveal that financial barriers (FB), technological barriers (TB), and regulatory barriers (RB) are the most pressing, whereas natural resource dependency (EB1), limited institutional capacity (IB3) and climate challenges (EB2) were ranked the most influencing sub-barriers. Moreover, resilience programs for green tech jobs (SO7) and investment in digital technologies (SO6) ranked the top potential strategic solutions to mitigate the GTA barriers. This study provides actionable guidance for developing economies pursuing green transitions under economic and governance constraints, offering policymakers and practitioners a clear, systematic roadmap for designing resilient sustainability strategies.

***Keywords:*** Green technologies barriers; sustainable development goals; climate change; cleaner production; green investment; decision making



## 1. Introduction

Over the past few years, the growing urgency of climate change and environmental degradation has made the adoption of green technologies not just desirable but indispensable. Achieving the United Nations Sustainable Development Goals (SDGs) largely depends on how effectively countries are able to integrate such innovations into their development strategies (Ikram et al., 2021). According to the International Energy Agency (IEA, 2023) improving the efficiency of infrastructure, promoting cleaner transportation, and greening energy systems can substantially reduce greenhouse gas emissions making it an important step in the global fight against climate change.

Beyond their environmental benefits, green technologies also generate positive social and economic outcomes, which explains the reason why they are increasingly seen as pillars of sustainable development. As global temperatures continue to rise, many nations have intensified their own initiatives to confront the climate crisis, leading to accelerated progress in renewable energy innovation (Belaïd et al., 2023). The growing reliance on renewable electricity not only lessens dependence on finite natural resources but also helps maintain ecological balance and supports the ongoing transition toward a low-carbon global economy. These enhancements are necessary in order to reduce greenhouse gas emissions, ease energy shortages, and address broader issues of environmental deterioration (X. Zhao et al., 2024).

The sharp rise in carbon dioxide ($CO_2$) emissions which is largely driven by the expansion of non-renewable energy sources such as fossil fuels has become one of the most pressing global challenges of our time. The world's continued dependence on fossil fuels has not only fueled rapid growth in energy consumption but has also intensified $CO_2$ emissions, heightening environmental concerns (Miao et al., 2025). This trend contributes directly to global warming and is amplified by broader social and economic shifts, including industrial modernization, population growth, urbanization, and changing consumption behaviors.

In response, there is growing momentum toward the development and adoption of cleaner, renewable energy technologies. This transition is no longer a choice but a necessity to be able to reduce carbon emissions and align national policies with the principles of sustainable development. As Moreover, advancing environmentally responsible technologies is central to building a more climate-resilient and sustainable global future (Sajid et al., 2024).

Adopting green technologies represents a paradigm change which integrates economic success with environmental stewardship and attract substantial interest from academics and increasingly being integrated into conventional business practices via specialized frameworks across various nations. This transition fundamentally reshapes economic and social paradigms: economies move from carbon-intensive industries to sustainable, innovation-driven models, production processes become circular and resource-efficient, and societal values increasingly prioritize long-term environmental well-being (Suki et al., 2022). Green technologies are mainly characterized as molding the world, facilitating economic advancement while maintaining environmental accountability (Zhou et al., 2015). By dissociating development from carbon-intensive practices these innovations directly contribute to several SDGs specifically SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production) and SDG 13 Climate Action (Anzolin & Lebdioui, 2021). Adopting renewable energy and energy-efficient technologies directly supports SDG 7 by expanding access to clean power and improving energy efficiency in developing regions (Estevão, and Lopes, 2024). Green infrastructure and low-emission transport contribute to SDG 11 by reducing pollution and enhancing urban sustainability (Patel et al., 2024). Likewise, cleaner production methods and recycling technologies promote SDG 12 through improved resource efficiency, while widespread deployment of emissions-reducing innovations is crucial for SDG 13 (Wang et al., 2025).

The development and implementation of climate change adaptation and mitigation technologies is also highlighted in international assessments carried out by international organizations such as the United Nations Environment Program (UNESCAP, 2020). Such evaluations are being considered as essential to the response to the rapidly escalating problem of climate change. A socioeconomic potential for fostering sustainable development on a worldwide scale is presented by the transition to environmentally friendly technology, which is not only a necessity for the environment but also a necessity for the economy. To accomplish the objectives of global sustainability, it is essential to identify the barriers which are inhibiting the adoption of environmentally friendly technologies and to strategically overcome them. The transition toward environmentally responsible innovation is typically hampered by structural and behavioral limits that influence investment, policy, and societal action (Maghyereh et al., 2025). These restrictions, in addition to the technical and financial factors, are a significant barrier. There are two primary categories of such barriers: psychological and functional. Functional constraints include factors like poor infrastructure, inconsistent regulations, inadequate finance schemes, and limited technology. These elements determine an economy's structural capacity to implement green transformations. On the other hand, psychological barriers are related to society attitudes, beliefs, and incentives that affect how responsive institutions are, how consumers act, and how committed politicians are. These indicators imply that the success of global green technologies deployment depends on both physical assets and governance structures, as well as a social and cultural readiness to accept sustainable change (Nketiah et al., 2024). Acknowledging and tackling these different aspects leads to a more thorough comprehension of the motives behind the global green transition's frequent inability to meet set sustainability objectives, and underscores the necessity of combined policy, education, and innovation initiatives for sustainable development.

Across developing economies, energy transitions proceed under tighter fiscal space, higher capital costs, and uneven institutional capacity. Governments are pursuing mixed pathways that pair rapid scale-up of renewables with interim reliability measures such as grid reinforcement and flexible generation, while catalyzing industrial decarbonization through standards, concessional finance, and public private partnerships (Olaniyi et al., 2025). Anchor firms and state-owned utilities often act as early movers, de-risking technologies and crowding in private investment, yet diffusion is frequently slowed by tariff design, currency risk, technology access, and skills gaps. These realities underscore a central implementation challenge: translating national ambition into bankable projects and routine practice in settings where functional readiness infrastructure, regulation, finance, and technology and motivational readiness incentives, norms, and institutional responsiveness vary widely. The maturity of green technology adoption is closely tied to the presence of digital ecosystems and platform-based innovation, which enhance the scalability and systemic integration of green solutions (Sassanelli et al., 2023). Recognizing this heterogeneity, we adopt a comparative lens on developing economies to identify which barriers most constrain adoption, and which interventions yield the greatest marginal gains under real-world constraints.

The transition to green technologies still faces many significant obstacles, especially in developing nations regardless of the ongoing global initiatives (Hernández Soto, 2024). Financial limitations, technological disparities, institutional deficiencies, and socio-cultural aversion usually hinder the widespread adoption and successful execution of green technologies; by recognizing these obstacles and identifying appropriate solutions, their implementation can promote an inclusive efficient and prompt green transformation. The purpose of this study is to assess green technology barriers and recommend practical solutions.

The study is guided by the research question: Which barriers most critically impede Green Technology Adoption (GTA) in a developing country, and what integrated strategies can effectively overcome these barriers? In addressing this question, we make two key contributions. First, we develop an integrated GTA strategic framework and analyzed seven major categories and twenty-six sub-barriers by Fuzzy Analytic Hierarchy Process (FAHP) was applied to rank the main and sub barriers and, then used the Fuzzy VIekriterijumsko KOmpromisno Rangiranje (FVIKOR) methods. This hybrid approach leverages FAHP to derive rigorous weights for each barrier category and FVIKOR to rank potential solutions, thereby combining the strengths of hierarchical weighting and compromise ranking in one decision-making system. This integration offers more robust and balanced insights. Second, through an empirical application, this study provides actionable policy recommendations and a prioritized roadmap that can inform stakeholders in other developing economies. These contributions advance the literature on GTA by bridging methodological gaps and delivering practical, context-sensitive findings

The study is organized as follows. Section 2 presents the comprehensive literature review of main barriers and sub-barriers of GTA. The FAHP and FVIKOR construction steps detailed in section 3. The findings and analysis are explained in section 4. Section 5 outlines the discussion and policy implications whereas, the conclusion along with limitations and future directions are presented in the last section of paper.

## 2. Literature review

The growing challenges of climate change, environmental degradation, and resource scarcity have placed green technologies at the center of global sustainability discussions. These technologies are often described as green innovation, eco-innovation, or environmental innovation referring to products, processes, and systems designed to reduce environmental harm while supporting economic and social progress. Although the importance of these concepts is widely recognized, their definitions remain somewhat inconsistent in academic and policy literature, leading to different interpretations and areas of emphasis among scholars and institutions (Omisore, 2018; Wang and Azam, 2024). In this study green technology is defined as any technology or innovation designed to mitigate environmental impacts and promote sustainability such as renewable energy systems, pollution control, resource-efficient processes. This definition aligns with recent literature and encompasses concepts sometimes labeled as eco-innovation or green innovation, which we treat equivalently in scope (Oduro et al., 2022)

Green technologies can be understood as a broad range of technical solutions such as renewable energy systems, energy-efficient infrastructure, clean production methods, and pollution-control technologies that directly contribute to the global environmental objectives. At the same time, they represent forms of innovation that go beyond technology itself, extending to organizational practices, public policy design, and even individual behavior. Because of this overlap, many scholars describe the terms green innovation, eco-innovation, and green technology as closely connected sometimes even used interchangeably within the literature (Faucheux & Nicolaï, 2011; Jian Wang et al., 2025).

Building upon this conceptual framework, recent research has demonstrated that corporate actors are increasingly promoting the adoption and development of green technologies by employing targeted green innovation strategies. Scholars are increasingly emphasizing that the eventual direction of corporate sustainability management will require the establishment of sustainable development practices, carbon emission reduction, and green transformation (R. Zhao et al., 2025). In this regard, corporate green innovation plays a key role in improving the environmental performance of firms. This form of innovation involves not only the development of cleaner technologies but also a notable progress in information systems, digital platforms, and e-commerce activities that help companies adapt to growing global competition. These elements highlight the strategic importance of embedding green innovation within core business operations, allowing sustainability to function both as an environmental necessity and as a potential source of long-term competitive advantage (Le et al., 2024). Particularly, green technologies have the potential to revolutionize the energy sector by lowering energy demand, improving efficiency, and promoting the development of cost-effective renewable projects. Policymakers worldwide are recognizing the critical role of green technologies in promoting the adoption of renewable energy and optimizing resource use and are implementing forward-thinking strategies to incorporate environmentally sustainable innovations into the energy sector (Behera et al., 2024).

The ongoing shift toward green technologies is not without challenges, as traditional industries often resist to transformation, particularly when new innovations begin to gain economic relevance. In addition, variations in the availability of natural resources can negatively influence investments in renewable energy, sometimes even more strongly than general economic conditions. Despite these barriers, the expansion of clean energy continues to be supported by steady technological progress, favorable market dynamics, and improvements in energy efficiency. Although volatility in the financial markets appears to have a limited direct impact, the adoption of renewable energy has been strongly encouraged by advancements in ecological innovation (Han et al., 2025). The relationship between economic development, foreign direct investment (FDI), and green technology remain intricate and context-dependent (Hernández Soto, 2024). While it may occasionally impede the adoption of renewable energy in the short term, it can also contribute to the long-term reduction of carbon emissions and energy consumption. Environmental and economic benefits are further reinforced by policy mechanisms, such as revenue-neutral taxation that concentrates on fossil fuel-based energy generation. All together, these dynamics emphasize the essential role of integrated innovation and policy in facilitating sustainable energy transitions in developing nations (Radtke, 2025).

Moreover, it is important to note that the critical role of Small and Medium-sized Enterprises (SMEs) in advancing green technologies within developing economies. SMEs account for the majority of businesses and thus have substantial cumulative environmental impact, yet they face unique barriers to green innovation. Recent studies indicate that SMEs often struggle with limited financial resources and technical expertise, as well as inadequate institutional support, which hinder their ability to implement sustainable technologies (Yacobet al., 2019).

Further green technologies not only support a shift toward low-carbon energy systems but also optimize the use of sustainable resources (Lv et al., 2024). The focal point of green innovation is the development and implementation of technologies that minimize the environmental impact at every stage, from production to use; these advancements are intended to not only mitigate damage but also to actively monitor and resolve it at the source. The structured use of design rules within product-service systems facilitates coordinated knowledge and lifecycle integration principles that directly support green technology adoption by enabling more sustainable design and operational practices across business units (Sassanelli et al., 2018).

Green technologies play a vital role in advancing sustainability by improving energy efficiency, cutting emissions, and enabling better management of environmental impacts. However, many of these goals remain difficult to achieve through traditional, non-green technologies alone. For this reason, accelerating progress in green innovation has become essential to make sustainable development genuinely attainable and to move closer to a model of growth that is both economically viable and environmentally responsible (Islam, 2025).

Recent research highlights several major barriers that make it difficult to adopt green technologies on a large scale. Prior studies highlight five major challenges in advancing the green transition. First, real transformation requires radical innovation rather than small, incremental improvements (Nabi et al., 2023). Second, uncertainty in markets remains high, as many sectors still operate under a business-as-usual mindset, which makes investment in green technologies both risky and unpredictable (Roper & Tapinos, 2016). Third, it is not easy for governments to design policies that are consistent, long-term, and effective in promoting green innovation (H. Wang et al., 2022). Fourth, the transition also raises questions of social fairness, since the costs and benefits of environmental actions are not equally distributed across different groups (Ternes et al., 2024). Lastly, environmental risks are global by nature, which means that no single country or company can address them alone (Benzaken et al., 2024). Together, these interconnected challenges suggest that moving toward a green economy will require not only new technologies but also deeper structural and institutional changes. Recent systematic reviews further confirm that financial constraints, technological limitations, policy uncertainty, and weak institutional support remain among the main barriers to GTA globally and highlighted the importance of culturally sensitive approaches, enhanced community engagement, and access to financing and technical expertise to overcome similar obstacles (Al-Emran & Griffy-Brown, 2023; Zheng et al., 2024). The detailed summary of GTA barriers and sub-barriers is presented in table 1. The description of each GTA barrier is presented in supplementary material (see table A2).

**Table 1: Summary of green technology barriers and sub-barriers**

| Main Barrier | Code | Sub-Barriers | Code | Source |
|---|---|---|---|---|
| Financial Barriers | **FB** | Lack of Access to Financial Resources | **FB 1** | (Solangi et al., 2021), (Sardianou & Kostakis, 2020), (Mirza et al., 2024) |
| | | High-Cost Premium | **FB 2** | |
| | | Unattractive Returns on Investment (ROI) | **FB 3** | |
| | | Unavailability of government subsidies | **FB 4** | |
| | | High Operational and Maintenance Costs | **FB 5** | |
| Regulatory Barriers | **RB** | Unclear regulations | **RB1** | (Painuly & Wohlgemuth, 2020), (D. Wang et al., 2023) |
| | | Lack of government support/incentives | **RB2** | |
| | | Ineffective enforcement of environmental laws | **RB3** | |
| | | Complex and Rigid Legislation | **RB4** | |
| Technological Barriers | **TB** | Lack of local expertise and R&D | **TB 1** | (Oryani et al., 2021), (Jafarizadeh et al., 2024), (Akusta et al., 2025) |
| | | Obsolete infrastructure | **TB 2** | |
| | | Limited access to green technologies | **TB 3** | |
| Market Barriers | **MB** | Low demand for sustainable products | **MB 1** | (Du et al., 2025), (Bang-Ning et al., 2025), (Barbieri et al., 2025) |
| | | Limited awareness of green technologies | **MB 2** | |
| | | Market resistance to change | **MB 3** | |
| | | Unequal Distribution of Benefits | **MB 4** | |
| Institutional Barriers | **IB** | Bureaucratic inefficiency | **IB 1** | (Jiang et al., 2021), (Yang et al., 2022), (Healey et al., 2017) |
| | | Poor coordination | **IB 2** | |
| | | Limited institutional capacity | **IB 3** | |
| | | Political Instability | **IB 4** | |
| Environmental Barriers | **EB** | Natural resource dependency | **EB 1** | (Tantawat et al., 2023), (Gao et al., 2024), (P. Guo et al., 2024) |
| | | Climate challenges | **EB 2** | |
| | | Limited natural resource availability | **EB 3** | |

| | | | | |
|---|---|---|---|---|
| Social Barriers | **SB** | Public resistance to change<br>Low stakeholder engagement<br>Social inequalities | **SB 1**<br>**SB 2**<br>**SB 3** | (Jang et al., 2024), (de Soysa, 2025), (H. Guo et al., 2024) |

This study developed an integrated  framework represents a holistic, multi-dimensional model for GTA for developing economies (see figure 1). It positions GTA as the central outcome, driven by the integration of several readiness dimensions that address the spectrum of barriers typically impeding sustainability innovations in these regions. Specifically, the framework integrates functional readiness encompassing technical competence, infrastructure, and operational capability, motivational readiness the organizational commitment and drive to adopt green innovations. Compatibility the fit of new technology with existing processes and values, and synergy across business units cross-departmental collaboration and knowledge sharing. These internal dimensions are conceptually supported by an integration layer that binds them into a cohesive strategy, and the entire system is encircled by external environmental and stakeholder monitoring factors that continually inform and influence the adoption process. This integrated design is a novel theoretical contribution, directly responding to calls in the literature for more systemic approaches prior studies have noted that green transitions involve multiple factors, and it is not enough to analyze only from one perspective or through one factor (Haaja and Harikkala-Laihinen, 2025). By unifying technical, organizational, and contextual elements, the framework systematically tackles key barriers financial, regulatory, technological, institutional, environmental, and social that have been widely documented in developing economies. In contrast to fragmented models, this comprehensive framework offers a central guiding theory for understanding and overcoming the complex, interrelated obstacles to green technology uptake in less developed settings. Beyond core readiness, the framework introduces compatibility and synergy ccross business units as key dimensions that ensure the green technology can be embedded effectively within the organization. Compatibility denotes the degree to which a new green technology aligns with the firm's existing processes, values, and needs. High compatibility smooths the adoption process, as innovations perceived to be consistent with current practices face less resistance (Xia et al., 2019). In the context of sustainable technology, compatibility is crucial because many green practices are additions to or modifications of – a company's established operations. A technology that fits well with local circumstances and organizational culture helps overcome social and behavioral barriers such as user resistance or misalignment with norms. Meanwhile, synergy across business units emphasizes breaking organizational silos so that different departments or units work collaboratively in the adoption effort. Developing economies often struggle with siloed implementation of new technologies, which can lead to fragmented outcomes and lost opportunities for scale (Sethi et al., 2024). The framework's inclusion of cross-unit synergy addresses this by promoting internal collaboration and knowledge sharing. Literature on green innovation management has highlighted that cross-functional integration within the firm is a critical enabler for sustainability-oriented innovations, as it facilitates the flow of environmental knowledge and coordinated action across various divisions (Ul-Durar et al., 2023; Sassanelli et al., 2021). When R&D,

operations, marketing, and other units are jointly engaged, firms can leverage diverse expertise and ensure that the green technology is compatible across the entire enterprise.

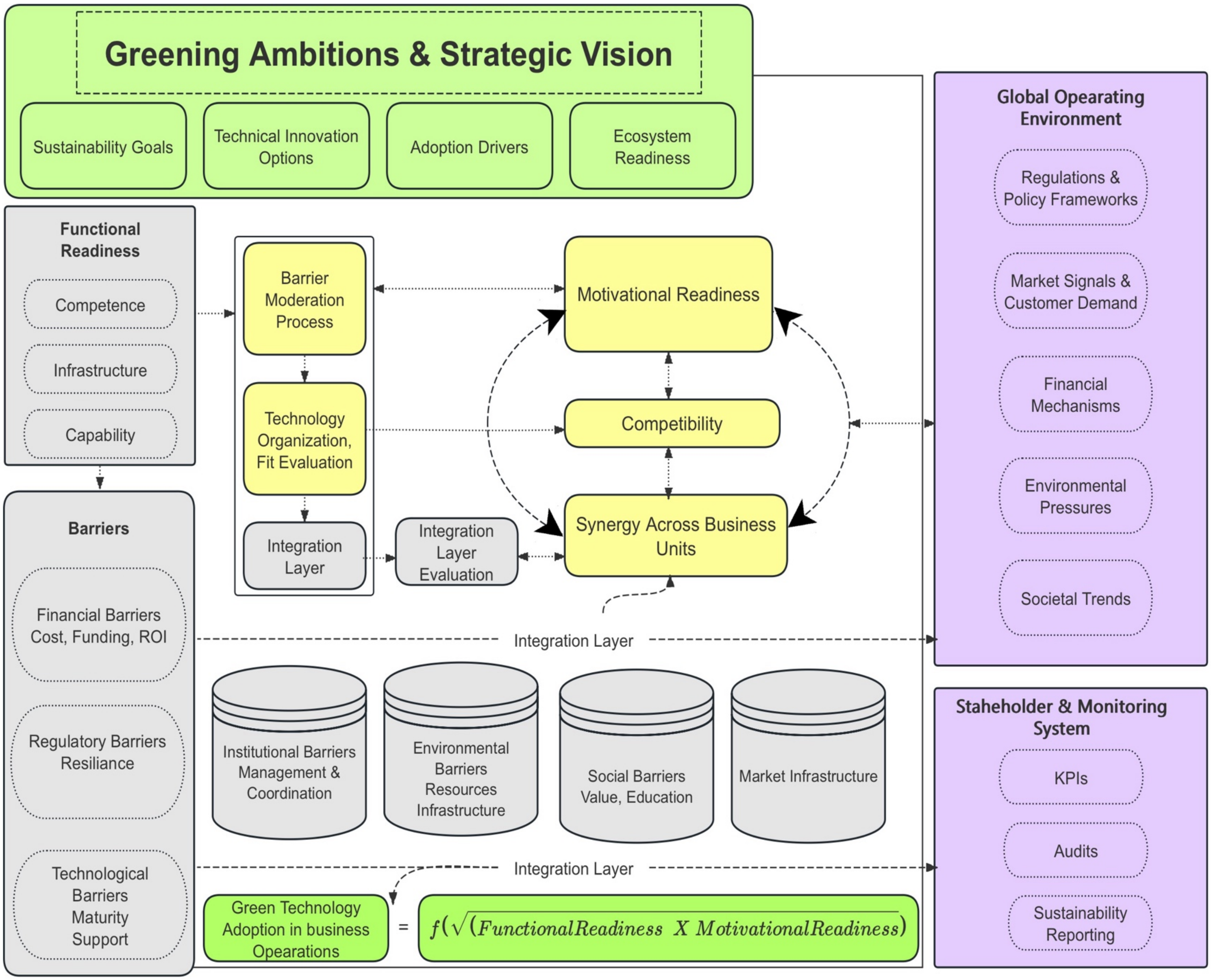



***Figure 1:*** An integreated green technology adoption barriers framework

This integrated approach mitigates barriers related to organizational structure and culture. Moreover, it reduces internal resistance to change by fostering a shared vision. The compatibility and synergy dimensions of the framework ensure that once a firm is functionally and motivationally ready, the innovation is organizationally feasible and supported throughout the business. This integrated attention to internal fit and cooperation is part of the framework's unique contribution, as it systematically engineers an environment where green innovations can thrive rather than flounder due to internal frictions. The proposed integrated framework offers a systemic, novel approach: it develops internal capacity-building and motivation with organizational alignment and external vigilance. In doing so, it provides a theoretical foundation for overcoming the multifaceted barriers to GTA in developing economies, emphasizing that true progress requires a synchronized effort across all levels of the firm and its environment. Further, most existing models of GTA either focus on identifying and ranking barriers or on evaluating solutions, but seldom both together. Our proposed integrated framework extends these models by unifying the two stages: it first quantifies barrier importance under uncertainty via fuzzy AHP and then directly feeds those insights into a fuzzy VIKOR analysis to rank solutions. This dual-stage integration challenges the traditional siloed approach and provides a more holistic tool for decision-makers, capturing the interplay between barrier severity and solution efficacy within one model.

## 3. Research method

The GTA barriers were chosen in light of developing economic structure, governmental regulations, and the necessity of implementing green technologies to promote sustainable development. This study identified twenty-six sub-barriers under seven main categories of GTA barriers. We adopted this categorization framework based on recurring themes in the literature. Thus, the basis of our barrier classification is a combination of literature-derived taxonomy and expert validation, lending credibility to the structure of our analysis. To our knowledge, no universally accepted guideline specifies how many experts are required for this type of analysis. Prior studies have employed different panel sizes to ensure robust results. For instance, Akusta et al., (2025) engaged seven experts to assess barriers to renewable energy for Turkey's sustainable energy planning, whereas Abdullah et al., (2022) used a five-member panel within an FAHP framework to identify strategic solutions to mitigate barriers for sustainable manufacturing. Guided by this precedent and balancing diversity with feasibility, we convened eight experts from academia and industry for the present study. Details of the expert panel are provided in the supplementary materials (Table A1).

The experts were selected based on explicit criteria to ensure high relevance and credibility. Each expert had a minimum of 10 years of professional experience in fields related to sustainable technology and environmental policy. The panel was balanced between academia and industry: two members are university researchers specializing in green innovation and policy, and six are senior industry practitioners and government officials involved in green technology projects. All experts possess advanced knowledge of the specific barrier categories addressed in this study. These selection criteria and diverse expert profiles strengthen the validity of the input and align with recommended practices for expert-based MCDM studies.

### 3.1 Fuzzy Delphi Method

Hsu et al. (2010) presented the fuzzy Delphi approach, which has since emerged as an established technique in decision-making research for the screening and structuring of evaluation criteria. The fuzzy variant of the Delphi procedure provides a more efficient method for consolidating expert opinions by accommodating the fundamental inconsistency of linguistic judgements and eliminating the need for multiple survey rounds. Conventional Delphi exercises often require several iterations before the responses converge, which can be time-consuming and may still result in weak consensus or response exhaustion among experts. The fuzzy Delphi method typically achieves a stable collective judgement in one iteration by representing experts' opinions as fuzzy numbers and mathematically aggregating them.

In fuzzy Delphi, the level of consensus among experts is expressed via a membership function. Prior studies have utilized various fuzzy number shapes, including triangular, trapezoidal, and Gaussian, to characterize this membership. Following this stream, the present study employs triangular fuzzy numbers (TFNs) to represent experts' assessments and to construct the membership degree function. The aggregated TFNs are subsequently combined through the geometric mean to identify the convergence point of the expert group. This study employs a three-phase procedure:

Phase 1: Aggregating individual fuzzy judgements

Let the significance assigned to the $i$th component (where $k$ = 1, 2, 3, ..., $m$) by the $j$th expert (where $j$ = 1, 2, 3, ..., $n$) be represented as $w_{kj}$ = ($akj$, $bkj$, $ckj$). Subsequently, the fuzzy weight of the $i$th element ($k$ = 1,2,3, ..., $m$) is denoted as $w_k$ = ($ak$, $bk$, $ck$), where the components $ak$, $bk$, and $ck$ are calculated as follows

$$a_k = Min\{a_{kj}\} = b_j = \frac{1}{n} = \sum_{k=1}^{n} b_{kj}, \;\; c_k = Max\{c_{kj}\} \tag{1}$$

Phase 2: Defuzzification of fuzzy weights

During the second phase, the transformation of each fuzzy weight into an actual weight $S_k$ by utilizing the center-of-gravity method:

$$S_k = \frac{\sum a_k, b_k, c_k}{3} \tag{2}$$

Phase 3: Selection of the definitive criteria set

In the final step, the criteria for selecting GTA are established by comparing the weight of each barrier with the threshold $\tilde{a}$. The average of the weights assigned to all GTA criteria represents the threshold value $a$. If the weight value of GTA criteria is greater than or equal to $\tilde{a}$, then the criteria are selected. Otherwise, it will be rejected. In adopting this strategy, decision-makers' support for the FAHP technique was utilized to calculate the weights of the primary and sub-attributes of GTA using a pairwise comparison matrix.

### 3.2 FAHP method

The FAHP has been utilized to achieve optimal outcomes for complex decision-making processes, due to its enhanced accuracy relative to traditional models. (Kumar et al., 2023). The FAHP is a term that refers to fuzzy set theory and advanced adjusted AHP, in which each membership component is represented by a membership function. Furthermore, each aspect of incorporation is analyzed in greater detail, categorized into levels that span from 0 to 1. Inability to participate is represented by a value of 0, whereas complete participation within the set is indicated by a value of 1. The aspect's degree of membership is quantified by any value that lies within these two extremities, indicating that it is partly incorporated into the set. The numbers that are fuzzy are essential as the basis for linguistic function membership to address uncertainties encountered in the valuation phase. TFNs are utilized to represent these linguistic values within the framework of the FAHP.

FAHP is recognized for their durable and robust attributes and are frequently employed in a variety of fields. The applications cover a variety of tasks, including the determination of the significance of social aspects in business sustainability (Arslan et al., 2023), the evaluation of the potential for groundwater in semiarid regions (Chen et al., 2025), the determination of green tourism sustainability (Li et al., 2024).

The FAHP framework consists of six stages for prioritising GTA barriers.

**Stage 1:** In this phase, the hierarchical framework of the issue is established.

**Stage 2:** Following the establishment of the hierarchical issue scheme, one of the most critical phases in the FAHP technique is to create a significance scale for relative importance comparisons. This rating mechanism, which spans from 1 to 9, employs TFNs to assist specialists in selecting investments in green technology based on numerical values. There exist five TFNs: $\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, and $\tilde{9}$. Table 2 and figure 2 contains the listed TFNs. TFNs that efficiently gather and evaluate expert opinions mitigate uncertainty and confusion during the evaluation process. In order to facilitate a comprehensive assessment and understanding of the factors influencing decision-making.

**Table 2. Linguistic variables of fuzzy numbers**

| Scale | Linguistic characteristic | TFNs value |
|---|---|---|
| 1 | Equal Important | (1,1,3) |
| 2 | Moderate Important | (1,3,5) |
| 3 | Strong Important | (3,5,7) |
| 4 | Very strong Important | (5,7,9) |
| 5 | Extreme Important | (7,9,11) |

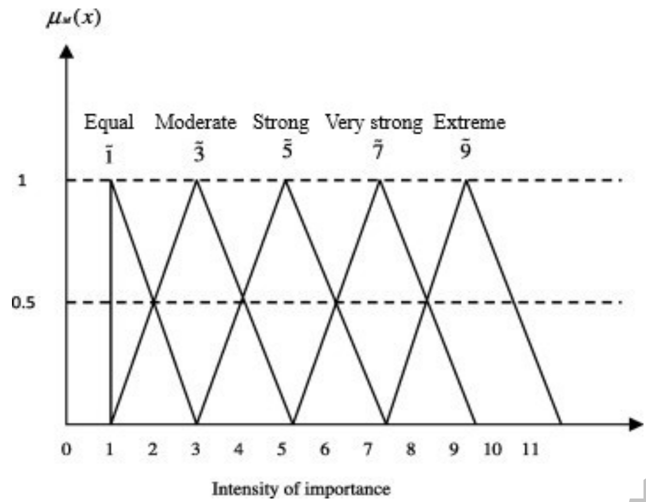



***Figure 2:*** The fuzzy membership function pertaining to linguistic variables

**Stage 3:** To prioritize investments in GTA, the approach seeks to develop a fuzzy comparative matrix. Specialists employed TFNs to perform relative importance comparisons for this assessment. The arithmetic mean of the experts contributions was employed to construct a fuzzy analysis matrix, referred to as matrix Z, which integrated these assessments. Equation 3 highlights the preceding approach by converting the collection of expert inputs into a comprehensive fuzzy evaluation tool. which allows for more logical decision-making in terms of green technology's significance hierarchy.

$$Z = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & \dots & 1 \end{bmatrix} \tag{3}$$

where $\tilde{a}_{ij} = 1$ if $i = j$ and where $\tilde{a}_{ij} = (\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9})$ or where $(\tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1},)$. If i is not equal to j. The inverse value for the scores is derived by inverting the Z matrix comparison to compute the score for each pair. Let $\tilde{Z}_{ij}$ denote the value of matrix Z that represents the relations between components i and j.

$\tilde{Z}_{ij} = \frac{1}{\tilde{z}_{ij}}$.

**Stage 4:** This stage focusses on developing a detailed comparison matrix through the α-cut methodology to improve the accuracy of expert decision-making inputs. The α-cut method, introduced by Adamo in 1980, enables the management of fuzzy numbers by defining regions within the values that align with the α value. The α-cut is used to include only those fuzzy membership values above a certain threshold α, effectively focusing on the most plausible values and improving decision robustness. The optimism index (μ) represents the decision-maker's optimism level in aggregating fuzzy numbers. In this study, we set $\mu = 0.5$, reflecting a moderate level of optimism. This value was chosen to balance optimistic and pessimistic scenarios, consistent with common practice in fuzzy decision analysis, and was tested to ensure results were not overly sensitive to this parameter. Setting the value at $\alpha=0.5$ and applying it to TFN results in an interval of a 0.5=(2,3,4), as demonstrated in figure 3.

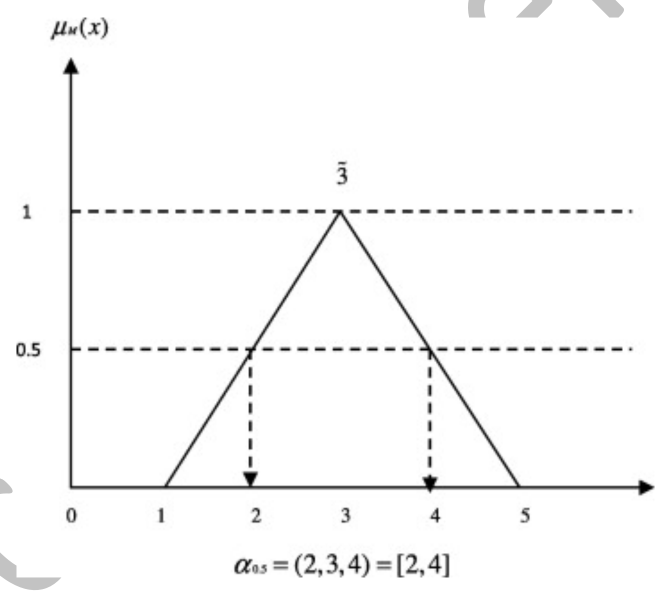



***Figure 3:*** TFN based α-cut operation (Wang et al., 2023)

The constant value in numbers of an is adjusted simply based on the projection level necessary to meet the requirements of the Z matrix, taking into account the optimism index μ obtained from the fuzzy comparison matrix. A comparison matrix for the α-cut can be constructed as follows.

$$\tilde{Z}^{\alpha} = \begin{bmatrix} 1 & \tilde{b}_{12}^{\alpha} & \ldots & \ldots & \tilde{b}_{1n}^{\alpha} \\ \mathrm{b}_{21}^{\alpha} & 1 & \ldots & \ldots & \tilde{b}_{2n}^{\alpha} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \tilde{b}_{n1}^{\alpha} & \tilde{b}_{n2}^{\alpha} & \ldots & \ldots & 1 \end{bmatrix} \tag{4}$$

The μ denotes the degree of satisfaction or trust among stakeholders and functions as an efficiency metric within the selection matrix. This index measures decision-makers' faith in their decisions, with a higher score of μ indicating increased satisfaction or confidence in the decision made. A linear concentric relationship is integrated through the procedure for calculating μ. This method quantifies the consensus or preference levels among decision-makers regarding specific alternatives within the decision-making framework, indicating their confidence and optimism in the assessment.

$$\tilde{b}_{ij}^{\alpha} = \mu b_{iju}^{\alpha} + (1-\mu) b_{iju}^{\alpha} \text{ where } 0 < \mu \leqslant 1 \tag{5}$$

By adding μ to Equation (5), the fuzzy similarity matrix with α-cut becomes the sharp comparison matrix Z. The new matrix z is shown below:

$$Z = \begin{bmatrix} 1 & b_{12} & \ldots & \ldots & a_{1n} \\ b_{21} & 1 & \ldots & \ldots & \mathrm{b} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ b_{n1} & \mathrm{b} & \ldots & \ldots & 1 \end{bmatrix} \tag{6}$$

**Stage 5:** Evaluating the consistency of results

In order to validate the specialist's assessment, the coherence of each matrix and the overall homogeneity of the hierarchical structure were examined using a consistency ratio (CR). Consequently, the constant sharp comparison matrix Z is converted into a consistent fuzzy comparison matrix, $\tilde{Z}$.

The following equation determines the matrix with the largest eigenvalue, which is given by equation (7).

$$X_v = \lambda_{\max} v \tag{7}$$

where $v$ indicates the main eigenvector value of the matrix.

The data obtained from the expert method's assessment is then verified by applying the CR for an approximate importance comparison. Equation 8 displays the CR assessment formula.

$$CR = \frac{CI}{RI} \tag{8}$$

$$CI = \frac{\lambda_{\max} - k}{k-1} \tag{9}$$

CI denotes the Consistem Index, while RI, as shown in table 3, indicates the Random Index.The size of the underlying matrix is also denoted by the letter k.

**Table 3:** Random Index

| ***k*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| ***RI*** | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 |

If the relative importance comparison matrix's CR value is less than 0.10, the matrix is considered acceptable; if not, the experts' procedure must be repeated until the outcomes are more apparent.

**Stage 6:** Determine the weights assigned to the criteria

Normalizing a portion or all of matrix Z's sections and rows in order to determine the weights related to green technologies is the last step in the FAHP development process.

### 3.3 Fuzzy VIKOR method

Opricovic first proposed the VIKOR technique in 1980 (Opricovic & Tzeng, 2004). This strategy can assist decision-makers in reaching a final conclusion by calculating the weights of possibilities and ranking them to identify compromise solutions of a decision-problem with incompatible or conflicting factors. A compromise is an agreement reached via reciprocal concessions, and in this case, the compromise solution is a workable option that is the closest to the ideal. The F-VIKOR levels are shown below:

**Level 1.** Performance-based fuzzy matrix development and the weight vector is as follows $\tilde{D} =$

$$\begin{array}{c} \\ O_1 \\ \vdots \\ O_n \\ \\ \end{array} \begin{bmatrix} C_1 & C_2 & \cdots & C_n \\ \tilde{p}_{11} & \tilde{p}_{12} & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & \tilde{p}_{22} & \cdots & \tilde{p}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{p}_{m1} & \tilde{p}_{m2} & \cdots & \tilde{p}_{mn} \end{bmatrix} \tag{10}$$

$\tilde{W} = (w_1, w_2, w_3), \sum_{j=1}^{n} w_j = 1$

where $O_i$ indicates the alternative $i$, i.e., i = (1,2,3, … , m); $C_j$ represents the indicators $j$, i.e., j = (1,2,3, … , n); $\tilde{p}_{ij}$ represents the performance of alternatives by fuzzy rating $O_i$ with respect to indicators $C_j$; and $\widetilde{W}_j$ represent the fuzzy weight for each indicator. Thus, TFN can be written as $\tilde{p}_{ij} = (x_{ij}, y_{ij}, z_{ij})$.

**Level 2.** Calculation of all benefit criteria values $\tilde{p}_i^+ = (x_i^+, y_i^+, z_i^+)$ and the values of cost criteria $\tilde{p}_i^- = (x_i^-, y_i^-, z_i^-)$. The set of benefit criteria is indicated as $l^b$ whereas, $l^c$ represent the set of cost criteria is followed as.

$$\tilde{p}_i^+ = max_j\ \tilde{p}_{ij}, \tilde{p}_i^- = min_j\ \tilde{p}_{ij} \quad \text{for} \quad i \in l^b$$
$$\tilde{p}_i^+ = min_j\ \tilde{p}_{ij}, \tilde{p}_i^- = max_j\ \tilde{p}_{ij} \quad \text{for} \quad i \in l^c. \tag{11}$$

**Level 3.** Determine the values of normalized fuzzy decision matrix $\widetilde{D}_{ij}$:

$$\widetilde{D}_{ij} = \frac{\tilde{p}_i^+ (-) \tilde{p}_{ij}}{z_i^+ - l_i^-} \quad \text{for} \quad i \in l^b$$

$$\widetilde{D}_{ij} = \frac{\tilde{p}_{ij} (-) \tilde{p}_i^+}{z_i^- - l_i^+} \quad \text{for} \quad i \in l^c. \tag{12}$$

**Level 4.** Calculate the values $\tilde{S}_j = (\tilde{S}_j^x, \tilde{S}_j^y, \tilde{S}_j^z)$ and $\tilde{R}_j = (\tilde{R}_j^x, \tilde{R}_j^y, \tilde{R}_j^z)$:

$$\tilde{S}_j = \sum_{i=1}^{n} \widetilde{W}_i (\times)\ \widetilde{D}_{ij} \tag{13}$$

$$\tilde{R}_j = max_i\ \widetilde{W}_i (\times)\ \widetilde{D}_{ij} \tag{14}$$

**Level 5.** Calculate the values $\tilde{Q}_j = (\tilde{Q}_j^x, \tilde{Q}_j^y, \tilde{Q}_j^z)$:

$$\tilde{Q}_j = v \frac{\tilde{S}_j (-) \tilde{S}^+}{S^{-z} - S^{+x}} (+) (1 - v) \frac{\tilde{R}_j (-) \tilde{R}^+}{R^{-z} - R^{+x}} \tag{15}$$

here $\tilde{S}^+ = min_j\ \tilde{S}_j$; $S^{-z} = max_j S_j^z$; $\tilde{R}^+ = min_j \tilde{R}_j$; $R^{-z} = max_j R_j^x$

Additional, $v$ is shown as a group strategy weight for most criteria $\tilde{S}_j$; whereas, $(1 - v)$ is the individual weight of $\tilde{R}_j$.

**Level 6 & 7.** Perform defuzzification on the values $\tilde{S}_j$,$\tilde{R}_j$ and $\tilde{Q}_j$ values, respectively. The alternatives are prioritized in descending order based on the crisp values of S, R, and Q. The outcomes are three prioritization results$\{O\}_S$,$\{O\}_R$ and $\{O\}_Q$, respectively.

**Level 8.** To meet two subsequent conditions, propose a solution to the alternative $O^{(1)}$ which represents the optimal solution of the measure $Q$:

**Condition 1:** Required benefit Ben must be greater than or equal $\geq DQ$

Where $ben = \frac{[Q(O^{(2)}) - Q(O^{(1)})]}{[Q(O^{(m)}) - Q(O^{(1)})]}$ is the benefit rate of alternative $O^{(1)}$ is prioritized over the alternative with the second-ranked $O^{(2)}$ in $\{O\}_Q$ and the threshold $DQ = \frac{1}{(m-1)}$

**Condition 2:** Stability of decision-making: Option O(1) ought to be regarded as the best option according to S or Q values. This should meet at least one of the CI and C2 requirements. A set of comprising solutions is proposed in the event that both conditions are not met, and they can be described as follows:

**Condition satisfied $C_1$:** Alternative $O^{(1)}$ and $O^{(2)}$ are applicable only if $C_1$ is not satisfied, or: only ($C_2$) is not satisfied, or:

**Condition satisfied $C_2$:** Alternative$O^{(1)}$,$O^{(2)}$,…, $O^{(M)}$ if ($C_1$) is not satisfied; $O^{(m)}$ is defined by the following relation:

$\frac{[Q(O^{(M)}) - Q(O^{(1)})]}{[Q(O^{(m)}) - Q(O^{(1)})]} < DQ$ determine the optimal value of $M$. The alternatives are located in proximity to one another. The schematic methodological framework of GTA barriers ins presented in figure 4.

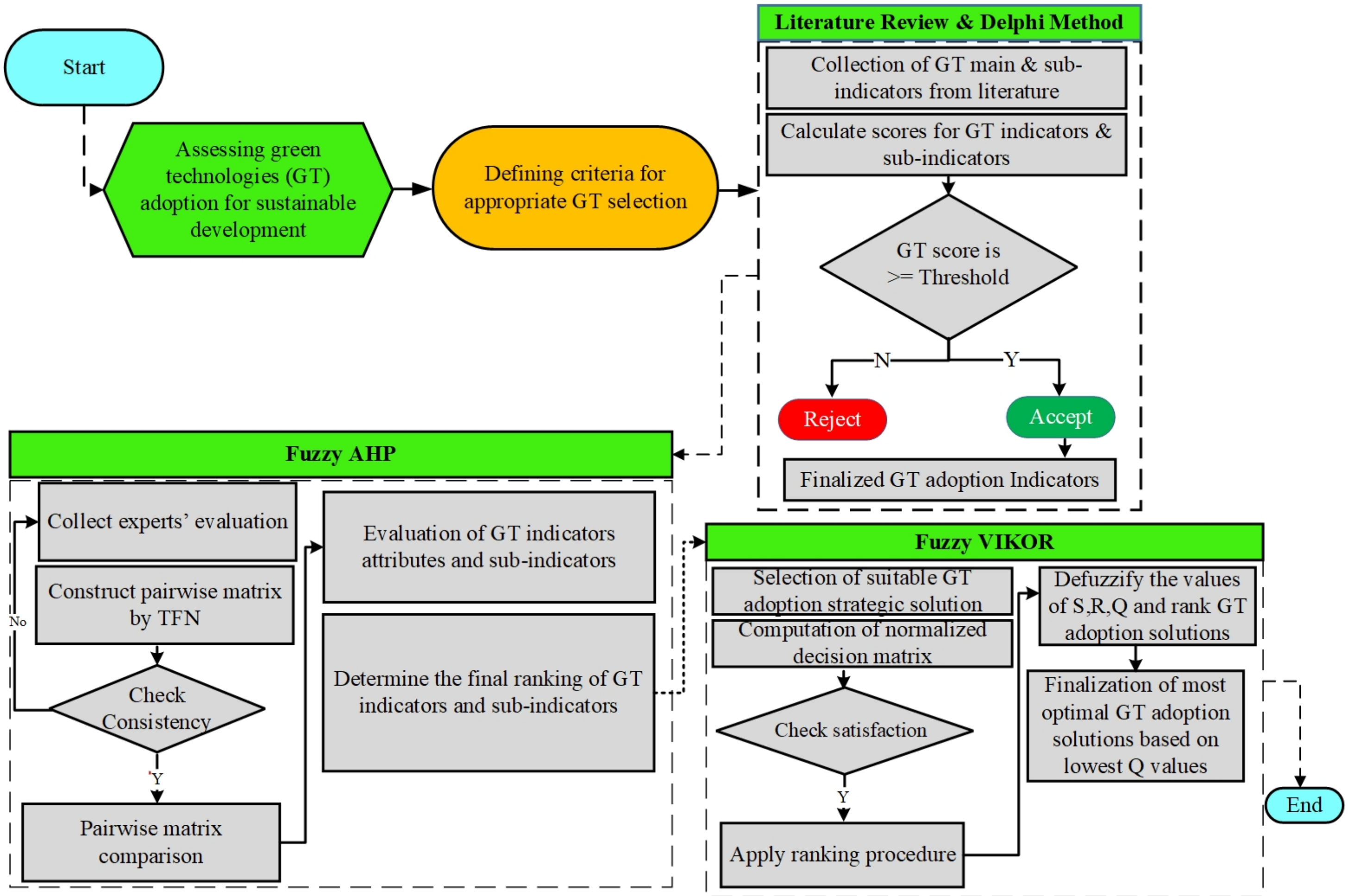



***Figure 4:*** Integrated Fuzzy AHP and Fuzzy VIKOR decision support framework

## 4. Results and Discussion

The findings of the paper are organized into three sections. First section represents the inclusion /exclusion criteria of GTA barriers based on Fuzzy Delphi method. The second section determines the most significant GTA barriers and sub-barriers, the FAHP is initially used. The subsequent approach, the Fuzzy VIKOR, provides a structured strategy to conquer these barriers by evaluating and ranking strategic alternatives is presented in third section. The findings offer an in-depth understanding of the main barriers and the best approaches to support a long-term shift to green technologies. The details of GTA barriers and sub-barriers are presented in figure 5.

## 4.1 Fuzzy Delphi results

The fuzzy Delphi analysis determined a cut-off value of 5.125 based on the mean score of the GTA barriers. Barriers with scores at or above this threshold were retained, whereas those scoring below were excluded from further consideration. Table 4 summarizes that eleven GTA barriers met the requirement, while a limited set of GTA barriers namely administrative burden barriers, expertise barriers and insufficient cost benefit/ barriers failed to meet the threshold and were consequently excluded. Their exclusion does not indicate that these factors are unimportant in broader discussions on adoption of green technology; instead, it signifies that they fall outside the specific evaluative focus of this study. Experts consulted in this research opted to exclude it, contending that inadequate coordination among institutions would exert a uniform, system-wide influence on all GTA in developing countries, rendering it conceptually inappropriate to estimate its proportional impact on individual technologies.

**Table 4: Fuzzy Delphi results to finalize GTA barriers**

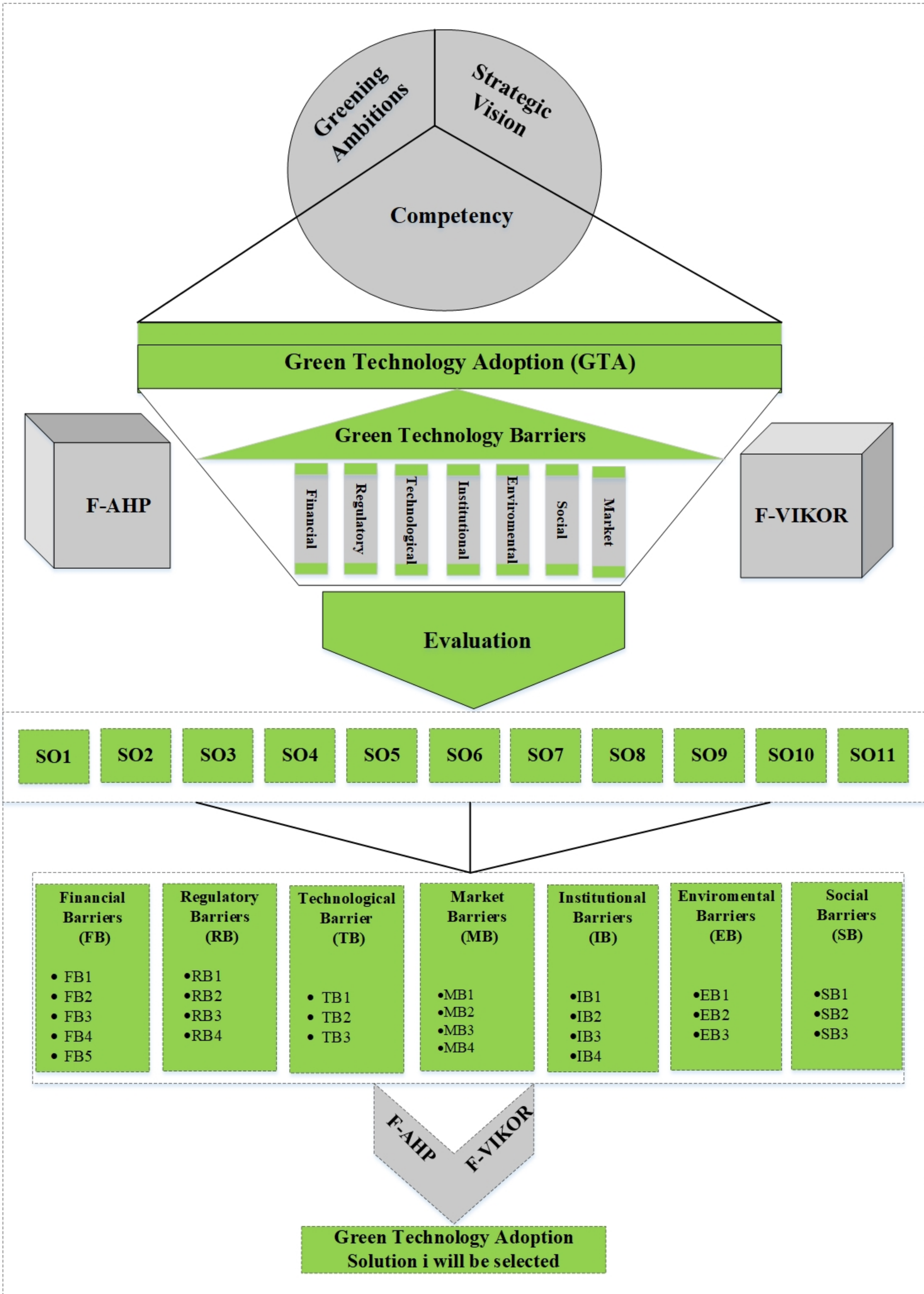
| GTA Barriers | a | b | c | Fuzzy Delphi Scores | Selected √/ Rejected × | Barrier code |
|---|---|---|---|---|---|---|
| Financial Barriers | 3 | 6.8 | 9.9 | 6.57 | √ | FB |
| Regulatory Barriers | 3 | 6.7 | 9.8 | 6.54 | √ | RB |
| Technological Barriers | 3 | 6.2 | 9.3 | 5.83 | √ | TB |
| Market Barriers | 3 | 6.0 | 9.5 | 6.17 | √ | MB |
| Institutional Barriers | 3 | 7.6 | 9.8 | 6.80 | √ | IB |
| Environmental Barriers | 3 | 6.5 | 9.4 | 6.77 | √ | EB |
| Social Barriers | 3 | 5.9 | 9.7 | 6.21 | √ | SB |
| Administrative Burden Barriers | 2 | 3.8 | 5.5 | 3.77 | × | AB |
| Expertise Barriers | 2 | 4.1 | 5.4 | 3.83 | × | EB |
| Insufficient Cost Benefit/ Barriers | 2 | 4.3 | 5.3 | 3.87 | × | CB |

## 4.2 Fuzzy AHP Methods results

In the first phase of this study, FAHP method was applied using a relative importance matrix as the starting point. This matrix was built through the geometric average algorithm, which made it possible to calculate each expert's rating separately. Through this process seven main barriers were identified, and each of them included three to five sub-barriers. Together, these levels formed a clear structure for examining the key obstacles to GTA. The sub-barriers helped to refine the evaluation by breaking each main category into more specific issues that allowed for a deeper and more systematic analysis. This hierarchical approach improved the accuracy of the results and provided a broader understanding of the factors that limit sustainable technology development. The FAHP analysis was carried out in two main steps. First, the weights of the seven primary criteria related to GTA barriers were determined and integrated into the AHP framework. In the second step, the weights for the sub-criteria were calculated to offer a more detailed view. The final ranking of the main criteria for GTA barriers is presented in figure 6. The fuzzy pairwise matrix of main green technologies adoption barriers is presented in supplementary material (see Table A3)

#### *4.2.1 The ranking of main GTA Barriers*

Figure 6 presents the weights of each primary criterion derived through the FAHP method. Financial Barriers (FB) emerge as the most critical challenge among the seven identified barriers carrying the highest weight of 31.20%, underscoring the fundamental role of financial constraints in hindering the transition to sustainable technologies. Technological Barriers (TB) rank second, with a weight of 24.50% followed by Regulatory Barriers (RB) in the third position at 17.50%. Institutional Barriers (IB) rank fourth at 11.55%, followed by Market Barriers (MB) at 7.53%, Environmental Barriers (EB) at 5.40%, and Social Barriers (SB) at 2.22%.



Greening Ambitions
Strategic Vision
Competency
Green Technology Adoption (GTA)
Green Technology Barriers
Financial
Regulatory
Technological
Institutional
Environmental
Social
Market
F-AHP
F-VIKOR
Evaluation
SO1
SO2
SO3
SO4
SO5
SO6
SO7
SO8
SO9
SO10
SO11
Financial Barriers (FB)
FB1
FB2
FB3
FB4
FB5
Regulatory Barriers (RB)
RB1
RB2
RB3
RB4
Technological Barrier (TB)
TB1
TB2
TB3
Market Barriers (MB)
MB1
MB2
MB3
MB4
Institutional Barriers (IB)
IB1
IB2
IB3
IB4
Enviromental Barriers (EB)
EB1
EB2
EB3
Social Barriers (SB)
SB1
SB2
SB3
F-AHP
F-VIKOR
Green Technology Adoption Solution i will be selected

***Figure 5:*** The strategic framework of GTA barriers and sub-barriers

The implementation of green technology in developing economies is being slowed down by financial hurdles, which make up 31.20% of the total weight. One of the primary obstacles is the restricted availability of credit and investment capital, which makes it challenging for entrepreneurs and enterprises to fund sustainable projects. Approximately 84% of developing economies climate and green technology entrepreneurs rely on self-financing in the early phases of their businesses (Soumonni & Ojah, 2022). This circumstance demonstrates the acute lack of outside finance and the pressing need for more robust financial systems to assist the nation's green transition (The world bank, 2023). The limited availability of financing continues to discourage many potential investors from engaging in green innovation. Technological challenges appear as the second major obstacle to adopting green technologies largely because access to advanced tools and systems remains restricted in several sectors. In agriculture and other key industries many actors still depend on conventional methods, and the use of modern, climate-smart technologies is progressing only slowly. Despite ongoing efforts to enhance irrigation efficiency through drip irrigation systems the widespread implementation of such innovations remains constrained. This limitation impedes optimal water resource management and reduces agricultural productivity highlighting the urgent need for broader technological dissemination and support (The world bank, 2023).

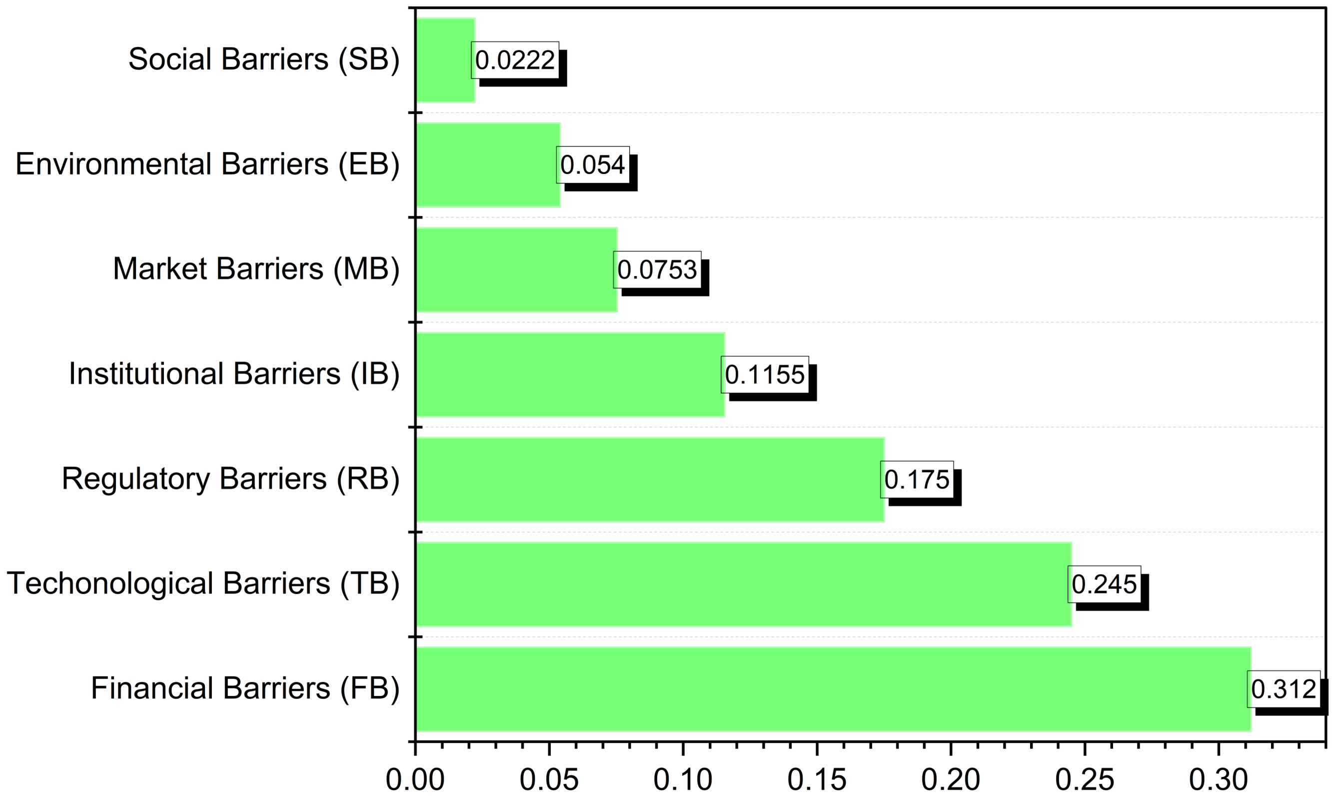



***Figure 6:*** Ranking of main GTA barriers

#### *4.2.2 Financial Sub Barriers*

Figure 7 presents the ranking of financial barriers' sub-criteria as follows: FB1 > FB4 > FB3 > FB2 > FB5. The FB1 refers to the lack of access to financial resources with a weight of (32.15%) followed by the Unavailability of Government Subsidies with a weight of (25.83%). This finding echoes a commonly recognized issue in the literature, where restricted access to funding is consistently emphasized as a primary barrier to deploying green technologies, especially among developing nations where there is still restricted access to long-term, affordable funding. According to IRENA, (2023), concessional financing comprised only 1% of all renewable energy financing in 2020, restricting businesses' capacity to undertake the high-capital projects required for a sustainable energy transition, particularly in developing nations. Our analysis found a continuing gap in financial accessibility despite the existence of financing tools, supporting the notion that FB1 and FB4 are the main barriers to the adoption of green technologies. UNDP, (2023) pointed out that public funds are frequently inadequate and poorly allocated, particularly for distributed or small-scale projects, even though it is crucial for early-stage green investments. Green technology implementation is slowed down by the absence of steady, predictable government assistance, which discourages private sector involvement and increases overall investment risk. Developing economies may be able to overcome this obstacle by strengthening current green finance structures, rendering them more accessible to all sectors through better regulatory clarity, and boosting risk-mitigation strategies to attract private investment.

Unattractive returns on investment (FB3) and High-cost premium (FB4) are ranked third and fourth with a respective score of (20.12%) and (14.97%). Subsequently, High operational and maintenance costs (FB5) is the least impactful sub-criteria among all with a weight of (6.9%).

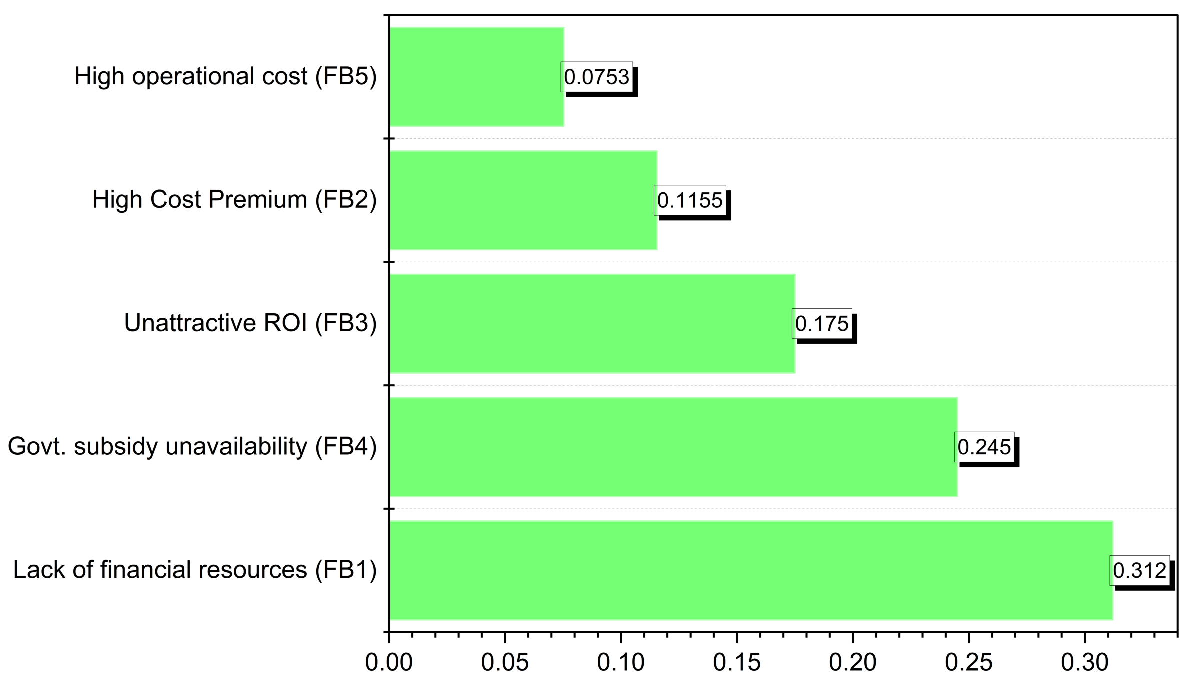



***Figure 7:*** Ranking of the financial sub-barriers

#### *4.2.3 Technological Sub-Barriers*

The sub-criterias of technological barriers are presented in figure 8 and ranked as follows: TB2>TB3>TB1, the most impactful sub-barrier is Obsolete Infrastructure with a weight of (41.25%). These findings align with global patterns of energy investment in developing economies. Despite increased global urgency and the relative economic viability of green energy sources, clean energy spending in developing nations, especially in Africa and parts of Asia, is still at 2015 levels (L. Wang et al., 2025).

Research on the development of green banking products in Pakistan has identified challenges including inadequate technological expertise, limited awareness of green financial innovations, difficulties in pinpointing target markets, and insufficient access to funding mechanisms designed for green initiatives (Khan et al., 2024). A qualitative study on green banking in India identified numerous obstacles associated with the adoption of green technology, unwillingness to embrace new digital and environmental technologies, insufficient awareness of green tools and services, along with elevated short-term implementation costs and technical constraints (Sharma & Choubey, 2022). These insights highlight the crucial need for technology development, strategic investment in green technologies, and the development of human resources to facilitate a quicker green transition.

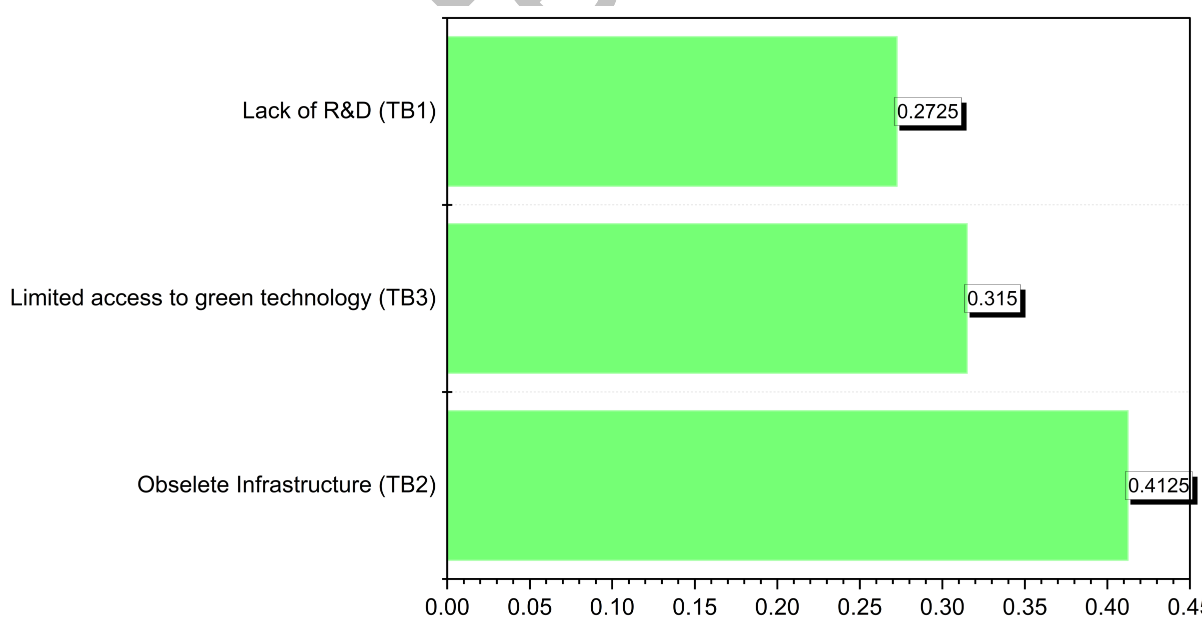


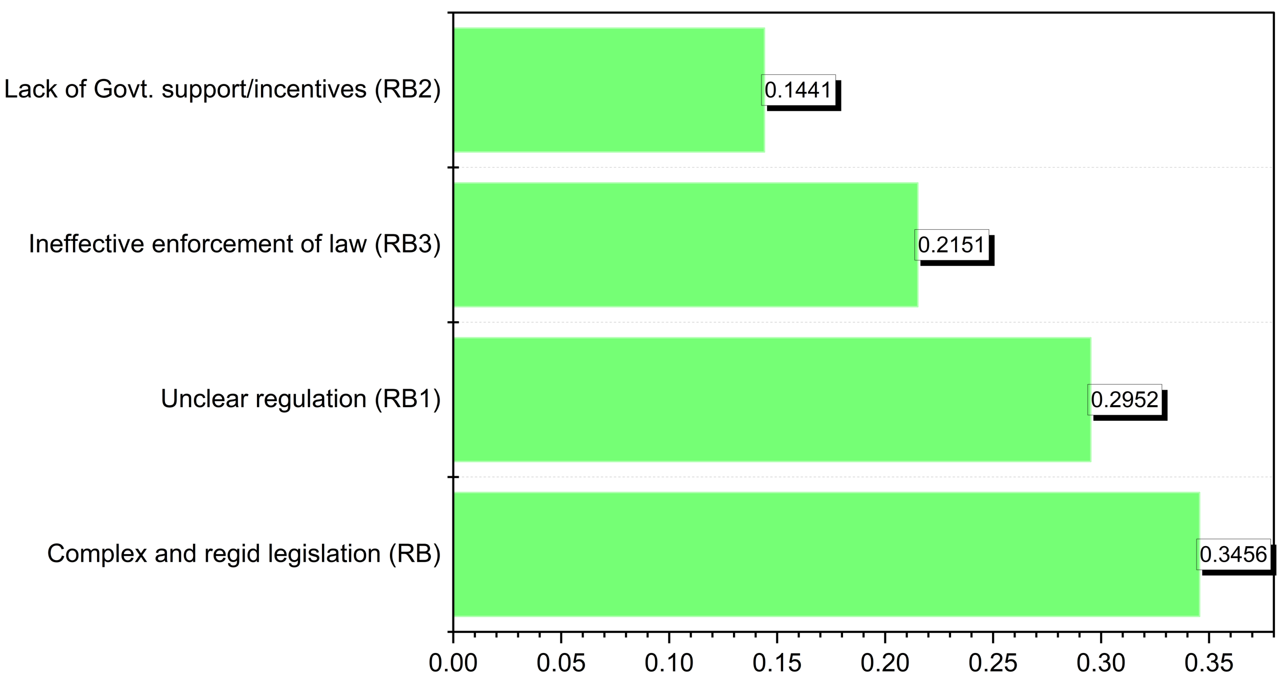

***Figure 8:*** Ranking of the technological sub-barriers

### 4.2.4 Regulatory Sub-Barriers

The four criterions of regulatory barriers are presented in figure 9 and ranked as follows : RB4>RB1>RB3>RB2. The two most impactful sub barriers are Conmplex and rigid legislation (RB4) with a weight of (34,56%) and Unclear regulations (RB1) with a weight of (29,52%). MENA economies, such as Morocco, experience delicate administrative processes and obsolete legal structures that lack adaptability. These inflexible frameworks obstruct private sector involvement in green energy, notwithstanding the region's abundant solar and wind resources. It additionally emphasizes that reforms in energy price and regulation are essential for facilitating investment and sustainably expanding renewable energy (Liu et al., 2023). Ambiguous and contradictory governmental objectives and regulatory structures are primary impediments to the progress of green technology implementation. Moreover, insufficient inter-agency coordination, ambiguous licensing procedures, and the lack of persistent legal assurances impede investor trust and operational planning (Owojori & Erasmus, 2025).

Ineffective enforcement of environmental laws (RB3) and lack of government support/incentives (RB2) are ranked third and fourth with a weight of (21,51%) and (14,41%) respectively. Regulatory





measures are crucial in the green energy ecosystem, for they protect financial stability by reducing market imbalances and promoting enhanced openness, uniformity, and predictability in investment implementation. Nauman et al. (2024) assert that stable and consistent rules are essential for attracting long-term capital, particularly in emerging nations where green technologies contend with substantially.

***Figure 9:*** Ranking of the regulatory sub-barriers

### *4.2.5 Institutional Sub-Barriers*

Poor coordination (IB2) has ranked as the most critical sub-barrier within the Institutional Barriers affecting the development of green technologies with the highest weight value of (34.25%) (see figure 10). This issue is particularly evident in the overlapping responsibilities between national bodies and regional authorities, which often leads to project delays and inefficient implementation of green strategies. To streamline planning, funding, and deployment processes for green technologies effective coordination among these entities is primordial. The remaining sub-barriers are prioritized as follows: Bureaucratic inefficiency (IB1) ranks as the second most significant barrier with a weight of (29,58%), indicating that complicated administrative procedures and long-lasting approval processes persist in preventing both domestic and foreign investment (Zhang & Li, 2022)

Limited institutional capacity (IB3) ranked the third position within the category obtaining weight of (26.04%), indicating a deficiency in technical understanding and insufficient human resources within essential energy-related organizations. Ultimately, political instability (IB4) is positioned fourth, possessing the minimal weight of (10.13%). Investor attitude is significantly influenced by domestic and global political and economic developments. The geopolitical tensions and economic instability in the MENA area highly affect the returns and volatility of green technologies (Ma & Najam, 2024). This sensitivity underscores the necessity of preserving a stable legislative framework and executing proactive risk management techniques to protect investor trust and guarantee the continued expansion of green technologies investment in the country.

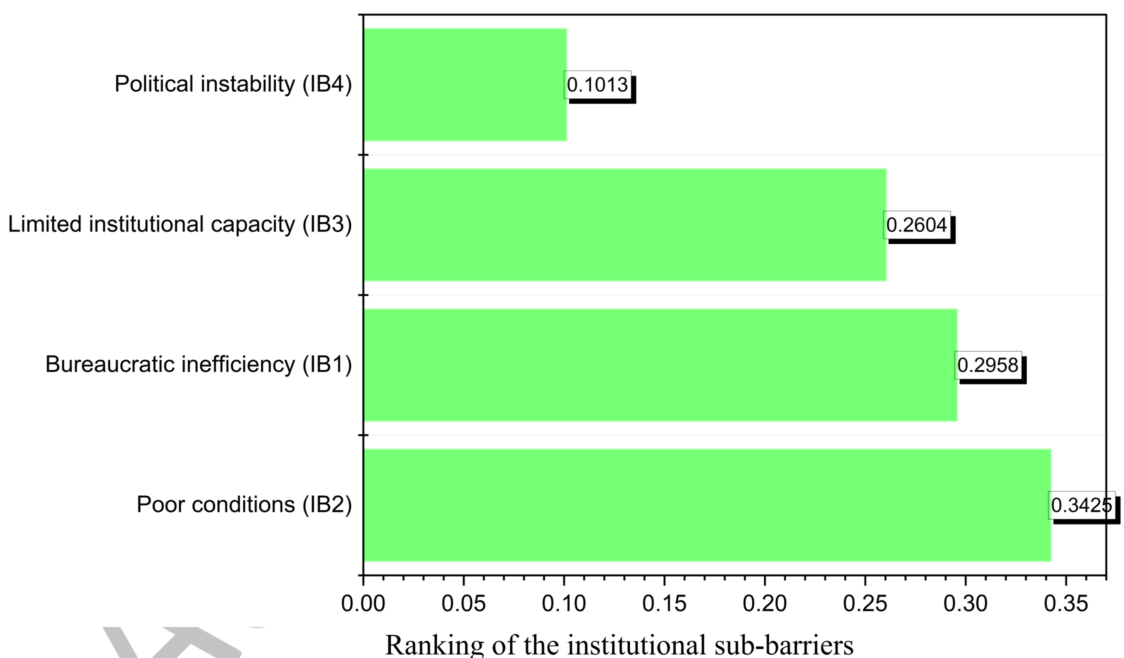



***Figure 10:***

### *4.2.6 Market Sub-Barriers*

Market barriers sub-criterias are ranked as follows: MB2>MB1>MB4>MB3. As represented in figure 11. Limited Awareness of Green Technologies (MB2) recorded the most significant score of (33%) within its category. These results are in line with (Zhao et al., 2024), who stress the importance of public education on the monetary and environmental advantages of green technologies as a means to overcome the current information gap and break into the market. The following sub barrier is the low demand for sustainable products (MB1) received the weight value (29.50%). Whereas, unequal distribution of benefits (MB4) comes in row on the third position within the market barriers category with a weight of (22%); this sub barrier highlights systemic equity issues; wherein small firms may regard themselves as marginalized from the actual or perceived advantages of the green transition. Lastly, market resistance to change (MB3) is the lowest ranked of the four with a weight of (15.50%%) indicating that, although cultural stagnation and a preference for traditional practices are still factors, they are not the primary roadblocks that hinder progress. Collectively, these market-related results emphasize the crucial importance of consumer-oriented incentives, inclusive policy formulation, and public awareness campaigns to expedite the widespread use of green technologies in developing countries.



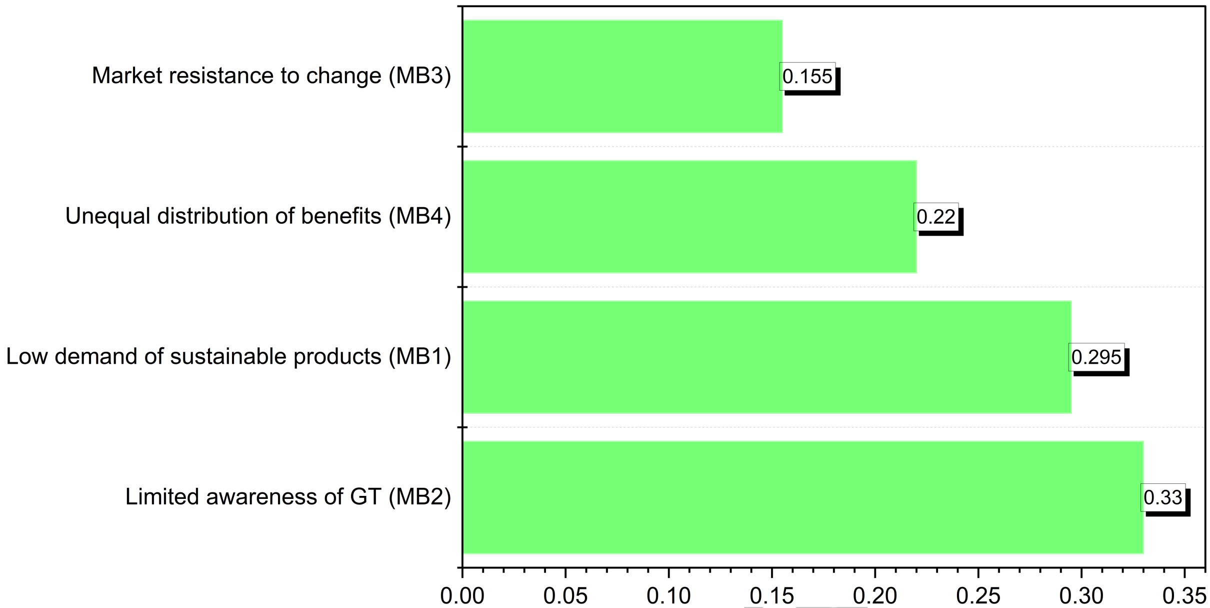



**Figure 11**: Ranking of the market sub-barriers

#### *4.2.7 Environmental sub- barriers*

Among the environmental barriers (EB), climate challenges (EB2) have been recognized as the most significant sub-barrier to the advancement of green technologies, possessing the greatest weight value of (38.19%). Developing countries such Morocco and Egypt are most environmental vulnerable the region due to harsh weather phenomena, including droughts, desertification, and erratic precipitation patterns, considerably affects the viability and dependability of green technology initiatives (Ikram, 2025). Subsequently, natural resource dependency (EB1) is ranked second with a weight value of (34.00%). Finally, limited natural resource availability (EB3) is ranked third, with a weight value of (27.81%) is presented in figure 12.

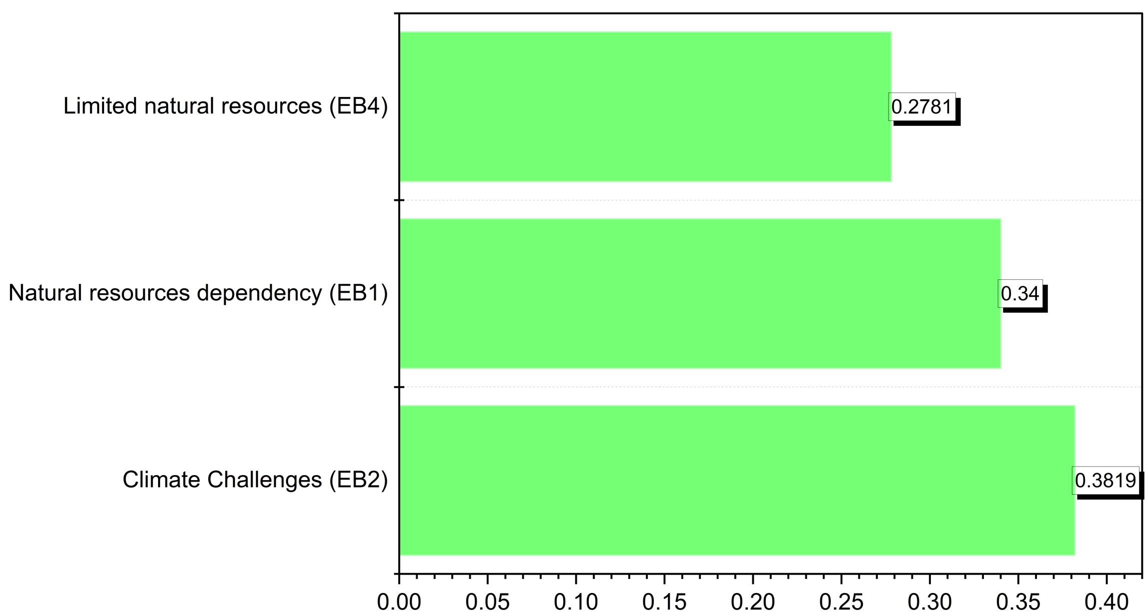



***Figure 12:*** Ranking of the environmental sub-barriers

#### 4.2.8 Social sub-Barriers

Social Inequalities (SB3) have ranked as the most important sub-barrier within the social barriers (SB) category, obtained the highest weight value of (40.62%), is presented in figure 13. Whereas, low stakeholder engagement (SB2) is identified as the second most significant obstacle, assigned a weight value of (35.10%). Numerous renewable energy initiatives in developing economies have encountered obstacles due to insufficient engagement of local groups, commercial sector participants, and civil society organizations during the design and execution phases (Brito Cedeno & Wei, 2024). Moreover, public resistance to change (SB1) is ultimately rated third, assigned a weight value of (24.78%). switching to renewable energy frequently necessitates major shifts in consumption behaviors, land execution, and societal norms.

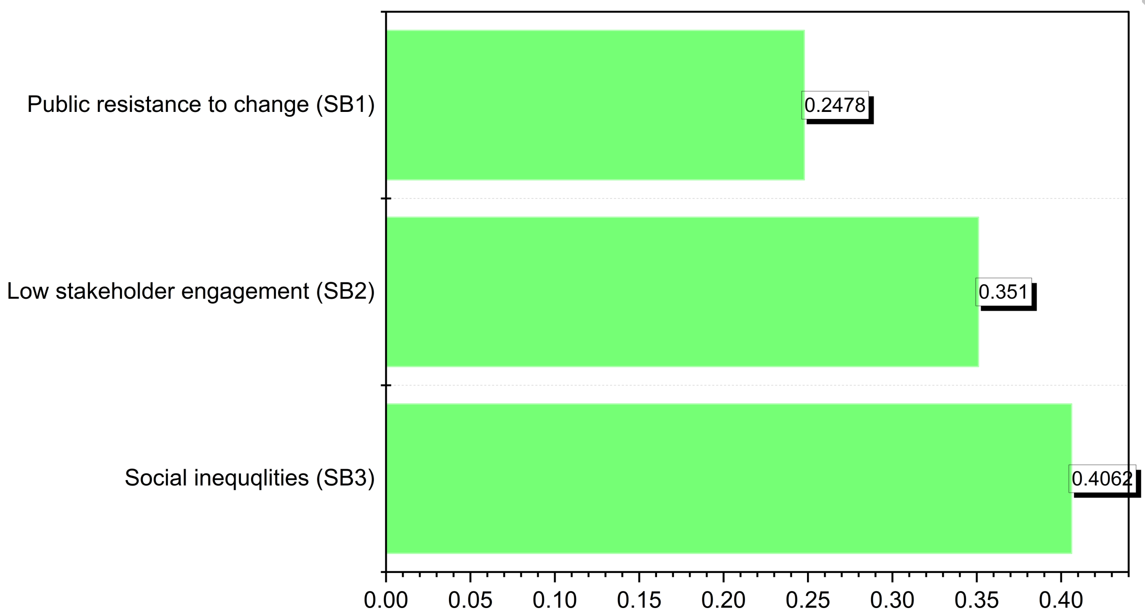



***Figure 13:*** Ranking of the social sub-barriers

### 4.2.9 Overall GTA Sub barriers results

The final ranking of sub-criteria, as illustrated in Figure 14, is established by multiplying the global weights of the sub-criteria by the weight of each respective category. The overall ranking of GTA barriers classification is determined by the final weights assigned to all sub-criteria. The attributes of sub-criteria for classifying green technologies in developing economies are presented as follows: EB1, IB3, EB2, SB1, IB2, EB3, IB4, IB1, FB1, RB2, SB2, FB4, RB3, MB4, FB5, MB1, TB1, RB1, MB2, SB3, FB2, RB4, TB2, MB3, TB3, FB3. In this study's classification of GTA barriers, Natural resource dependency (EB1) is the sub-criteria within the environmental category that received the highest weight score of 0.0734, followed by Limited institutional capacity (IB3) with a weight of 0.0722. Climate challenges (EB2) and public resistance to change (SB1) occupy the third and fourth positions, respectively, with weight scores of 0.0691 and 0.0668, as shown in Table 5. The final three sub-barriers assessed for the classification of GTA in developing economies are market resistance to change (MB3) 0.0126, limited access to green technologies (TB3) 0.0104, and unattractive returns on investment (FB3) 0.0075, respectively. The fuzzy pairwise matrix of GTA sub-barriers is presented in supplementary material (see table A4-A10).

**Table 5: Final ranking of GTA barriers**

| Main Barriers | Main Barrier Weights | Sub-Barriers codes | Consistency Ratio (CR) | Global Weight | Local weight |
|---|---|---|---|---|---|
| Financial Barriers | 0.3120 | FB1 | 0.0335 | 0.0481 | 0.0250 |
| | | FB2 | | 0.0175 | 0.0241 |
| | | FB3 | | 0.0075 | 0.0266 |
| | | FB4 | | 0.0388 | 0.0415 |
| | | FB5 | | 0.0323 | 0.0555 |
| Regulatory Barriers | 0.1750 | RB1 | 0.0370 | 0.0275 | 0.0389 |
| | | RB2 | | 0.0472 | 0.0197 |
| | | RB3 | | 0.0376 | 0.0162 |
| | | RB4 | | 0.0160 | 0.0231 |
| Technological Barriers | 0.2450 | TB1 | 0.0431 | 0.0305 | 0.0549 |
| | | TB2 | | 0.0156 | 0.0528 |
| | | TB3 | | 0.0104 | 0.0511 |
| Market Barriers | 0.0753 | MB1 | 0.0444 | 0.0316 | 0.0324 |
| | | MB2 | | 0.0261 | 0.0637 |
| | | MB3 | | 0.0126 | 0.0299 |
| | | MB4 | | 0.0361 | 0.0113 |
| Institutional Barriers | 0.1155 | IB1 | 0.0179 | 0.0485 | 0.0393 |
| | | IB2 | | 0.0603 | 0.0631 |
| | | IB3 | | 0.0722 | 0.0363 |
| | | IB4 | | 0.0517 | 0.0194 |
| Environmental Barriers | 0.0540 | EB1 | 0.0172 | 0.0734 | 0.0573 |
| | | EB2 | | 0.0691 | 0.0330 |
| | | EB3 | | 0.0600 | 0.0651 |
| Social Barriers | 0.0222 | SB1 | 0.0862 | 0.0668 | 0.0125 |
| | | SB2 | | 0.0449 | 0.0649 |
| | | SB3 | | 0.0181 | 0.0425 |

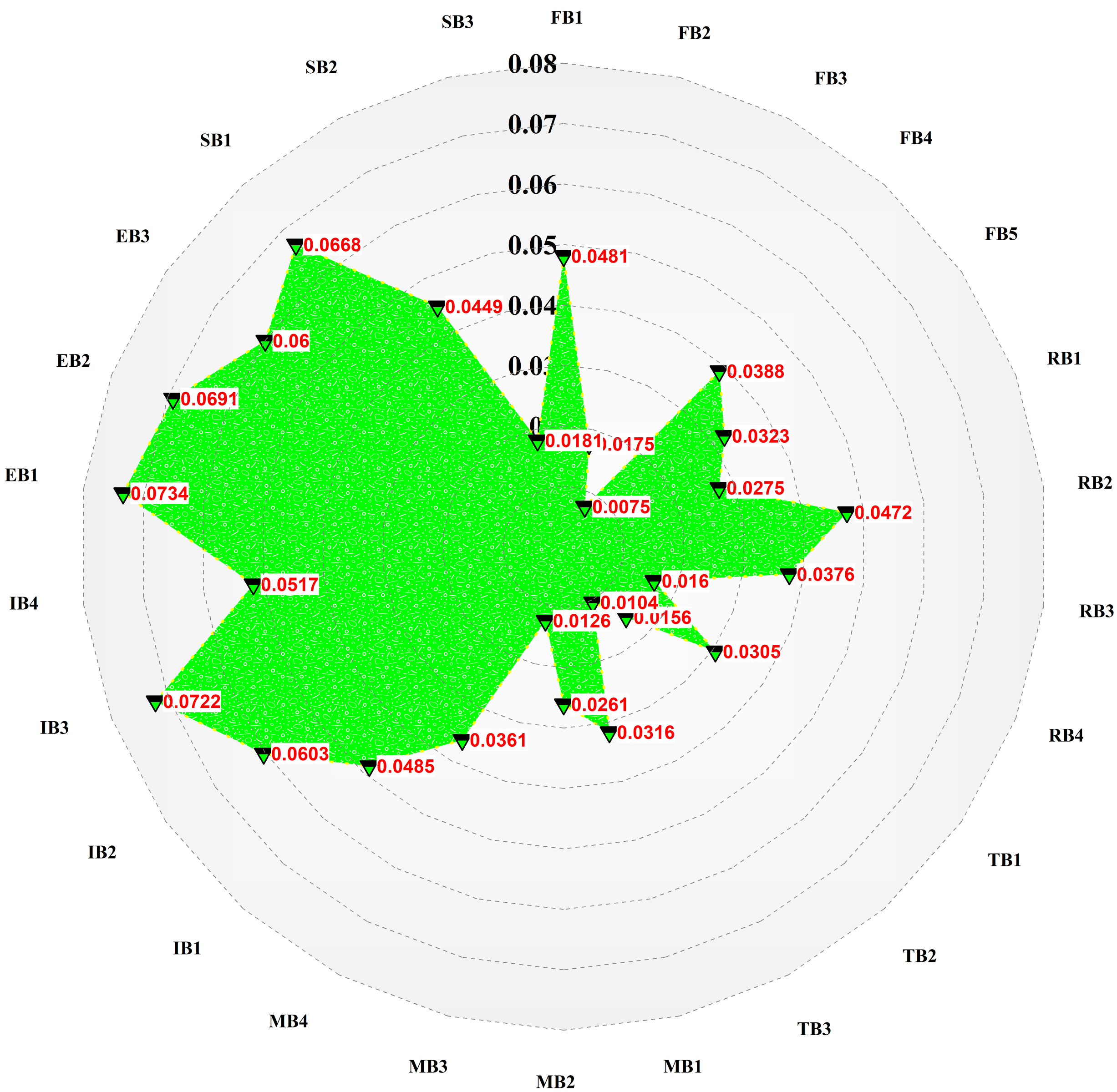



***Figure 14 :*** Overall ranking of GTA sub-barriers

## 4.3 Fuzzy VIKOR results

To ascertain which solutions are optimally situated to mitigate the barriers to GTA, the FVIKOR method helped assess alternatives through three principal dimensions: overall group utility $S_i$, individual regret $R_i$, and a compromise ranking index $Q_i$. Among these, $Q_i$ is the most pivotal, as it merges both the collective advantage and the worst-case performance and assists in prioritizing the most favorable policy alternatives, as shown in table 6. Moreover, the Fuzzy VIKOR matrix is presented in supplementary material (see table A11).

Each solution was assigned a weight Q value where lower weight suggests enhanced overall performance and greater balance across different evaluation criteria. The most favorable solution is Resilience programs for green tech jobs, deemed（SO7) with the lowest score of 21.46% (see figure 15). This result proves that the most balanced and effective strategy for facilitating the adoption of green technology is to invest in workforce training and growth. As such, investments provide professionals with the necessary skills for the emergence of green sectors and promote a seamless transition to a green economy. Its first ranking makes it a highly practical and inclusive solution for overcoming green technology barriers. The second crucial solution is banks consolidating digital tools for green investments, with a weight of 24.46%. SO6 endorses the use of contemporary financial instruments to optimize investment flows toward green projects, enhancing the accessibility and efficiency of funding, especially for SMEs and startups. The third crucial solution is platform connecting vendors and financial institutions (SO4), with a Q value of 29.72% (see table 7). SO4 stresses enhancing collaboration between green technology innovators and the financial institutions. In most developing countries, several green technology ventures encounter barriers not necessarily due to insufficient finance but due to inadequate connections between the supply and financing system. A digital or an institutional specialized platform can facilitate the connection between technology innovators, service providers, banks, investors, and funding programs. Its high ranking shows its potential to unlock funding and accelerate the adoption of green technologies across the country. Solutions Simplifying and modernizing regulatory processes (SO2) and Coordinated efforts between key institutions (SO10) appear to also have a primordial impact, ranking fourth and fifth, with a score of 35.32% and 39.61%, respectively (see figure 16). These are crucial for guaranteeing that Morocco's institutional environment facilitates green development. Minimizing bureaucratic obstacles and enhancing collaboration among ministries, and governmental agencies may expedite project approvals and prevent policy fragmentation.

**Table 6: S, R, and Q values of GTA strategic solutions**

| Code | Strategic solutions | $S_i$ | $R_i$ | $Q_i$ |
|---|---|---|---|---|
| **SO7** | Resilience programs for green tech jobs | 0.2329 | 0.2267 | 0.2146 |
| **SO6** | Banks consolidating digital tools for green investments | 0.5366 | 0.2949 | 0.2446 |
| **SO4** | Platform connecting vendors and financial institutions | 0.8843 | 0.4797 | 0.2972 |
| **SO2** | Simplifying and modernizing regulatory processes | 0.8999 | 0.8532 | 0.3532 |
| **SO10** | Coordinated efforts between key institutions | 0.2248 | 0.763 | 0.3961 |
| **SO3** | Demand-side incentives (rebates, tax credits) | 0.1565 | 0.4961 | 0.47 |
| **SO9** | Feed-in Tariffs (FiTs) with long-term contracts | 0.4282 | 0.3064 | 0.4815 |
| **SO8** | Transparent governance and green public procurement | 0.804 | 0.5099 | 0.5088 |
| **SO5** | Dedicated green technology R&D funds | 0.728 | 0.5658 | 0.5657 |
| **SO11** | Capital subsidies to reduce initial costs | 0.1521 | 0.7909 | 0.7657 |
| **SO1** | Green industrial policies for targeted support | 0.774 | 0.7918 | 0.8239 |

Strategies with significant Qi values, such as Capital subsidies to reduce initial costs (SO11) and Green industrial policies for targeted support (SO1), although crucial, are deemed less immediately efficient according to the current judgment.

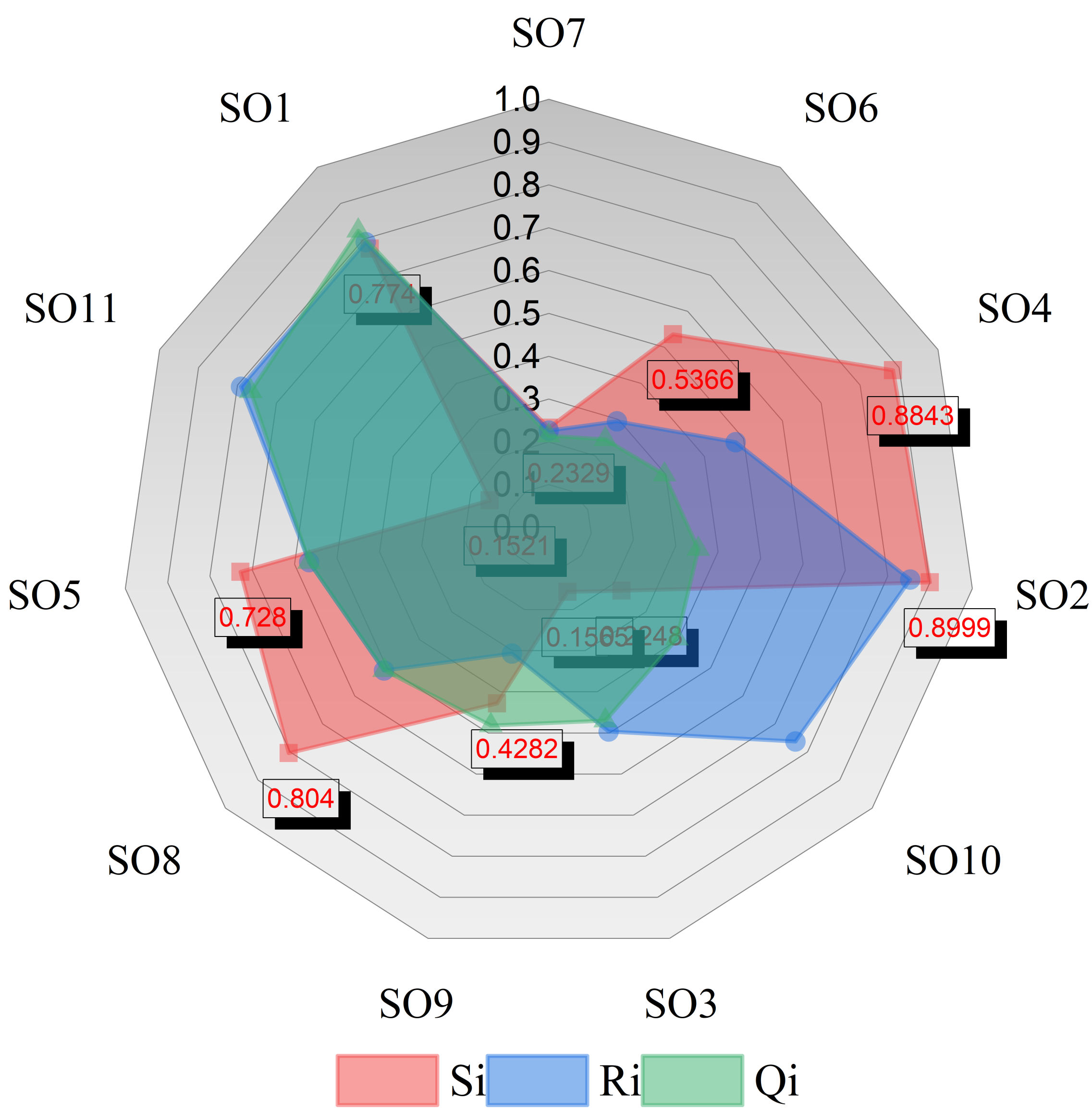



***Figure 15:*** GTA Strategic alternative results based on $S_i$, $R_i$, and $Q_i$

The FVIKOR approach prioritizes strategies for converting intricate green technology barriers into implementable paths, guiding stakeholders to focus on the most impactful and feasible solutions. his systematic method guarantees that resources and efforts are allocated to solutions with the highest potential for enduring impact, meeting both green growth objectives and economic requirements.

**Table 7. Prioritization of green technology policies according to lowest Q values**

| Code | Policies | $Q_i$ | Rank |
|---|---|---|---|
| **SO1** | Green industrial policies for targeted support | 0.8239 | 11 |
| **SO2** | Simplifying and modernizing regulatory processes | 0.3532 | 4 |
| **SO3** | Demand-side incentives (rebates, tax credits) | 0.470 | 6 |
| **SO4** | Platform connecting vendors and financial institutions | 0.2972 | 3 |
| **SO5** | Dedicated green technology R&D funds | 0.5657 | 9 |
| **SO6** | Banks consolidating digital tools for green investments | 0.2446 | 2 |
| **SO7** | Reskilling programs for green tech jobs | 0.2146 | 1 |
| **SO8** | Transparent governance and green public procurement | 0.5088 | 8 |
| **SO9** | Feed-in Tariffs (FiTs) with long-term contracts | 0.4815 | 7 |
| **SO10** | Coordinated efforts between key institutions | 0.3961 | 5 |
| **SO11** | Capital subsidies to reduce initial costs | 0.7657 | 10 |

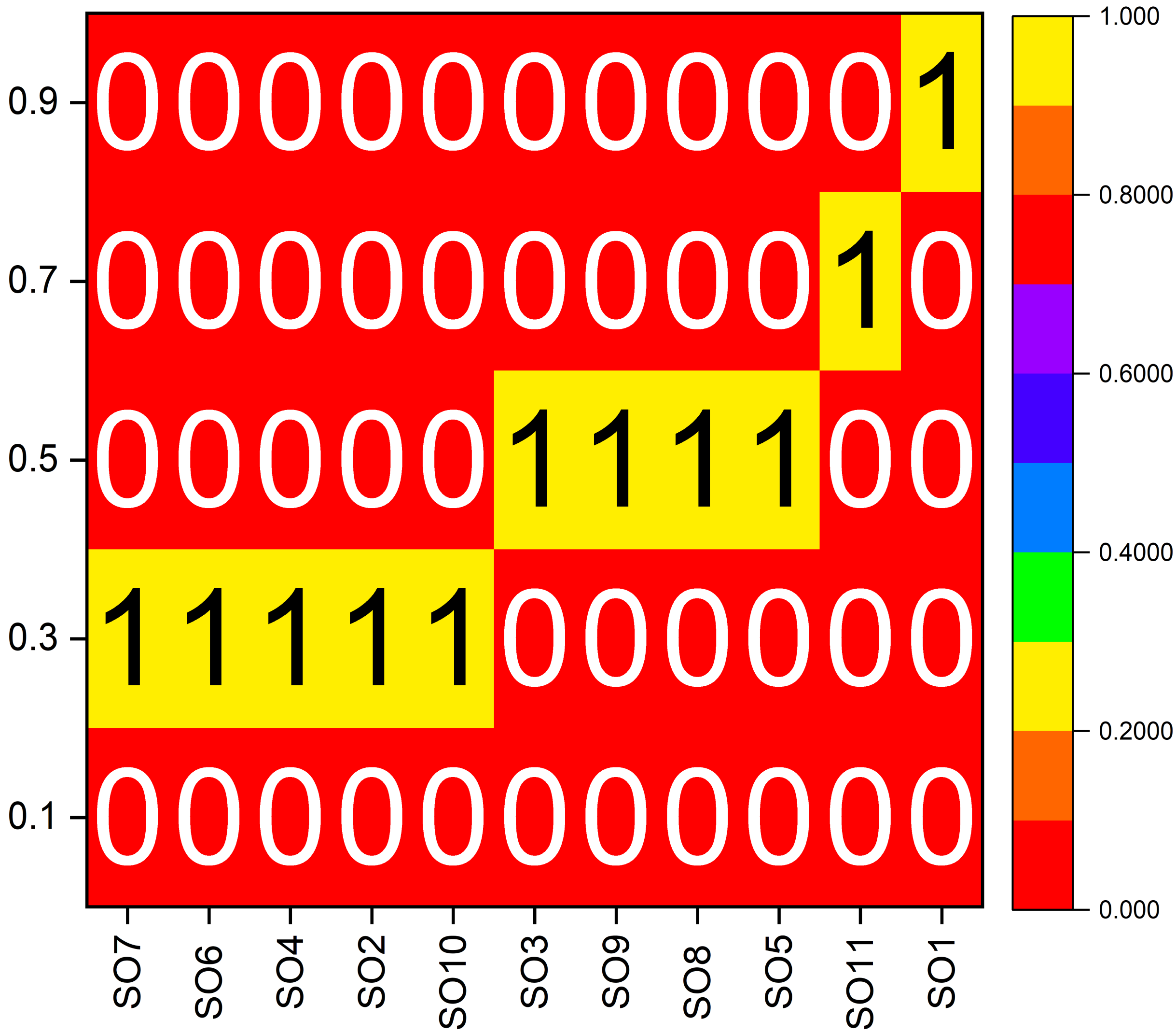



***Figure 16***: Lowest $Q_i$-based prioritization of solutions to GTA barriers

This study's findings, along with a thorough evaluation of recent advances in developing economies green technology sector, offer essential insights into the primary and secondary obstacles to GTA. The Fuzzy AHP results unequivocally indicate that financial barriers (FB), technology barriers (TB), and regulatory barriers (RB) are the most substantial impediments, corroborating prior literature. This conversation primarily highlights the importance of our study in academia, examining its practical consequences for policymakers, industry stakeholders, and the general public. The highest-ranked solutions; reskilling programs for green tech jobs (SO7) and Banks consolidating digital tools for green investments (S06) indicate that solutions targeting institutional and financial barriers are perceived as most urgent. Moreover, the highest-ranked strategy, resilience programs for green tech jobs (SO7), tackles the critical skills deficit. Experts prioritized this because a well-trained workforce is fundamental to implementing new technologies and sustaining green initiatives, thereby amplifying the impact of subsequent investments (OECD, 2023). Moreover, the integration of sustainability into educational and urban systems through structured knowledge management not only enhances environmental awareness but also accelerates behavioral shifts critical to the long-term adoption of green technologies (Basilico et al., 2025). In contrast, while direct capital subsidies (SO11) are valuable for lowering financial hurdles, they were viewed as slightly less foundational funding without human capital and institutional capacity may not yield lasting progress. This synergistic rationale explains why capacity-building strategies outrank purely financial interventions in our results. Each top-ranked solution thus addresses a leverage point in the system of barriers, which, if strengthened, produces broad positive effects on adoption of green technology.

This finding aligns with broader international experiences where human capital development and financial innovation are recognized as crucial enablers for green transitions (Abbas & Najam, 2025). The identification of financial barriers as a primary limitation aligns with the issues of Morocco's green revolution highlighted in recent reports in which the accessibility of affordable finance for renewable energy and green infrastructure persists as a constraint despite the nation's ambitious and optimistic renewable energy objectives. The economic structures such as energy communities can serve as pivotal enablers of green technology diffusion by addressing local investment barriers and aligning stakeholder incentives, especially in resource-constrained settings (Basilico et al., 2025). Sub-barriers such as lack of access to financial resources (FB1) and unavailability of government subsidies (FB4) scored high in their respective category indicating systemic limitations in financial markets and an urgent need for more substantial state-supported incentives.

The focus on streamlining and modernizing regulatory processes (SO2) underscores the regulatory challenges identified in both the present study and previous scholarly works (Tian & Pang, 2023). In this setting, legislative reforms are essential rather than merely supplementary, serving as the foundation for all subsequent policy activities. Moreover, the barrier hierarchy observed here is broadly reflective of challenges in many developing economies. The recent studies have identified financial constraints and regulatory gaps as top barriers to green initiatives in countries such as India and Malaysia (Wasan et al., 2021; Majekodunmi et al., 2023). This suggests that Morocco's experience is not isolated limited access to capital, insufficient technology infrastructure, and policy enforcement issues are common impediments across emerging economies. Therefore, the strategic solutions prioritized in our study dedicated green financing mechanisms, strengthening regulatory frameworks, and capacity-building programs which are applicable to other developing nations facing similar sustainable development constraints. By generalizing our findings, this study provides a roadmap that policymakers in various developing country contexts can adapt to accelerate GTA.

## 5. Conclusion and policy Implications

This study intended to investigate the barriers impeding the adoption of green technologies in Morocco and to offer pragmatic solutions that would expedite the nation's transition to sustainability. Using a hybrid decision-making framework that included the Fuzzy VIKOR approach and the Fuzzy Analytic Hierarchy Process (FAHP), the study offered a methodical evaluation of the most significant challenges and the most effective strategies to overcome them. The findings of this research offer valuable insights for policymakers, financial institutions, industry stakeholders, and researchers concerned with advancing green transitions in emerging markets.

According to the FAHP assessment, the most substantial hurdle to green technology adoption in Morocco is financial restrictions, which account for 31.2% of the aggregate. The most pressing sub-barriers in this category were a lack of access to financial resources and the absence of government subsidies, indicating structural flaws in Morocco's financial ecosystem. Technological barriers, which ranked second at 24.5%, were mostly related with outdated infrastructure and limited access to modern technology, both of which slowed the dissemination of advances across sectors such as energy and agriculture. Regulatory barriers, ranked at 17.5%, were deemed as substantial, owing to complicated and restrictive legislation and opaque regulatory frameworks that create uncertainty for investors. The remaining institutional, market, environmental, and social barriers while less dominant in relative weight, continue to impede Morocco's green transformation in terms of efficiency and inclusiveness.

The Fuzzy VIKOR methodology offered further clarity on the most efficacious techniques for overcoming these obstacles. The findings indicated that reskilling initiatives for green technology employment (SO7) provide a notably advantageous option, underscoring the significance of human capital advancement in enabling a green transition. Workforce training is essential for equipping Morocco to meet the requirements of emerging green sectors and ensuring that technological adoption is not impeded by skill deficiencies. The second-ranked option is the consolidation of digital instruments for green investments by banks (SO6), highlighting the significance of financial innovation. Improving banks' capacity to evaluate, administer, and allocate capital for green initiatives can significantly reduce financing deficits, particularly for small and medium-sized enterprises. The third-ranked option, platforms that link green technology suppliers with financial institutions (SO4), emphasizes the necessity for enhanced collaboration between innovators and bankers to align funding options more accurately with technological supply and demand. Additional criteria, like the simplification of regulatory processes (SO2) and the enhancement of institutional coordination (SO10), received high scores, underscoring the significance of creating a conducive institutional and policy framework.

The results of this research indicate that Morocco's strategy for expediting the adoption of green technology involves tackling the interactions among finance, technology, and legislation. A limited emphasis on infrastructure or subsidies will not suffice. Instead, a holistic approach is crucial, combining financial innovation, workforce development, and regulatory reform with wider institutional cooperation. When combined with regulatory modernization and institutional cooperation, these policies provide a viable road to a low-carbon economy. Morocco can achieve its sustainability goals while simultaneously creating excellent jobs, attracting international investment, and positioning itself as a regional leader of green innovation and resilience.

### 5.1 Research Implications

This study enhances the conceptual discourse on green technology uptake by integrating actual data from Morocco with established frameworks on systemic innovation and transition management. The Fuzzy AHP method offered a systematic approach to identify, quantify, and prioritize the primary obstacles to adoption, particularly in emerging economies. The approach enhances comprehension of the interactions among financial, technological, and regulatory systems that either facilitate or impede sustainable transitions. It underscores the significance of connecting innovation systems to the reality of local governance and market settings, providing a solid foundation for comparison with nations experiencing analogous socio-economic circumstances. This study enhances theoretical understanding of how institutional capability and economic maturity affect global green transition dynamics by analyzing Morocco in the context of developing economies.

The study outcomes have a crucial managerial policy implications for Morocco's efforts to enhance green technologies and overcome its barriers. These findings underscore the pressing necessity for specialized financial instruments such as green bonds, concessional loans, and public-private partnership frameworks to address the financing deficit for practitioners and policymakers. Technology managers should focus on innovation that happens in their own country by putting money into research and development and training programs for workers. This will make them less reliant on solutions that come from other countries. To get more private sector involvement, regulatory bodies need to make bureaucratic processes easier and policies more open. To make sure that green technology projects are good for the environment and for everyone, it will be important to improve collaboration between different sectors and community involvement measures. The suggested alternatives give us a way to build a stronger and more resilient energy infrastructure while also reducing the negative effects of global warming.

A thorough and coordinated plan is needed to successfully get over the barriers to using green technology in Morocco. This should include making the rules easier to follow and more encouraging of private investment as well as upgrading infrastructure to make it easier for green technologies to be used. A critical element of this strategy involves implementing reskilling programs for green technology jobs to build a workforce capable of supporting emerging industries. Financial reforms are equally crucial; on one hand banks must consolidate digital tools to enhance access to green investments and on the other hand platforms connecting vendors with financial institutions should be established to facilitate better market integration. Regulatory processes must be simplified and modernized to reduce bureaucratic hurdles and attract private sector participation. Additionally, coordinated efforts among key institutions are needed to harmonize policies, investments, and innovation initiatives. Raising public awareness about environmental protection and sustainability practices is necessary to drive cultural change and foster societal acceptance. Finally, by actively involving local communities and stakeholders in decision-making processes, Morocco can enhance trust, ensure project relevance, and build a participatory framework for sustainable development. These measures will not only address immediate barriers but also lay the foundation for a resilient, inclusive, and thriving green economy.

This study demonstrates the efficacy of integrating fuzzy multi-criteria methods in sustainability research. It provides a template for how to systematically link barrier analysis with solution ranking, contributing to the literature on decision-support frameworks for sustainable development. The application of integrated FAHP–FVIKOR hybrid approach can adopt to other complex decision problems, suggesting a versatile tool for interdisciplinary studies. By highlighting these implications, this study addressed an immediate case of developing economies and also informs broader policy strategies and methodological approaches in the field of GTA.

Despite the effectiveness of the methodology, this study has certain limitations. This study focused on a Moroccan context with an expert panel of eight, which adequate for our methodology, may limit the generalizability of the findings. Future research should address these limitations through expanded and comparative analyses. Moreover a longitudinal study could track how the significance of these barriers evolves over time as new policies and technologies emerge, providing insights into the dynamics of GTA. Similarly, applying our integrated FAHP–FVIKOR framework in other developing economies such as comparative analysis between different regions would test the robustness and universality of the barrier rankings and solution effectiveness in different cultural and economic settings. Additionally, future work might involve a larger expert pool or a Delphi-based approach to refine the weightings and consensus on barriers. By pursuing these directions, subsequent research can build on our findings, address current limitations, and ultimately enhance the strategies for overcoming GTA barriers worldwide.

**References**


Abbas, J., & Najam, H. (2025). Role of environmental decentralization, green human capital, and digital finance in firm green technological innovation for a sustainable society. *Environment, Development and Sustainability*, *27*(8), 19763–19777. https://doi.org/10.1007/s10668-024-04783-3

Abdullah, A., Saraswat, S., & Talib, F. (2022). Barriers and Strategies to Sustainable Manufacturing Implementation in Smes: A Hybrid Fuzzy Ahp-Topsis Framework. *SSRN Electronic Journal*, *2*, 100012. https://doi.org/10.2139/ssrn.4193856

Akusta, E., Ari, A., & Cergibozan, R. (2025). Barriers to renewable energy investments in Turkiye: A fuzzy AHP approach. *Renewable Energy*, *240*, 122161. https://doi.org/10.1016/j.renene.2024.122161

Al-Emran, M., & Griffy-Brown, C. (2023). The role of technology adoption in sustainable development: Overview, opportunities, challenges, and future research agendas. *Technology in Society*, *73*, 102240. https://doi.org/10.1016/j.techsoc.2023.102240

Anzolin, G., & Lebdioui, A. (2021). Three Dimensions of Green Industrial Policy in the Context of Climate Change and Sustainable Development. *European Journal of Development Research*, *33*(2), 371–405. https://doi.org/10.1057/s41287-021-00365-5

Arslan, O., Kececi, T., Solmaz, M. S., & Usluer, H. B. (2023). A social sustainability model for maritime labour force based on card sorting, fuzzy AHP & QFD method. *Research in Transportation Business and Management*, *49*, 101018. https://doi.org/10.1016/j.rtbm.2023.101018

Bang-Ning, H., Jitanugoon, S., & Puntha, P. (2025). AI-Powered Sustainable Tourism: Unlocking Circular Economies and Overcoming Resistance to Change. *Business Strategy and the Environment*, *34*(5), 5781–5802. https://doi.org/10.1002/bse.4276

Barbieri, N., Consoli, D., Marin, G., & Perruchas, F. (2025). Green technology and income inequality: an empirical analysis of US metro areas. *Regional Studies*, *59*(1), 2171378. https://doi.org/10.1080/00343404.2023.2171378

Basilico, P., Biancardi, A., D'Adamo, I., & Gastaldi, M. (2025). Energy communities toward sustainable development: the role of economic factors in a social analysis. *Sustainable Development*. https://doi.org/10.1002/sd.3417

Basilico, P., D'Adamo, I., Del Giudice, M., Di Santo, F., Gastaldi, M., Passarelli, F., & Uricchio, A. F. (2025). Sustainable Schools and Knowledge Management: Driving Urban and Social Transitions for Sustainable Development. *Sustainable Development*. https://doi.org/10.1002/sd.70215

Behera, P., Behera, B., & Sethi, N. (2024). Assessing the impact of fiscal decentralization, green finance and green technology innovation on renewable energy use in European Union countries: What is the moderating role of political risk? *Renewable Energy*, *229*, 120715. https://doi.org/10.1016/j.renene.2024.120715

Belaïd, F., Al-Sarihi, A., & Al-Mestneer, R. (2023). Balancing climate mitigation and energy security goals amid converging global energy crises: The role of green investments. *Renewable Energy*, *205*, 534–542. https://doi.org/10.1016/j.renene.2023.01.083

Benzaken, D., Adam, J. P., Virdin, J., & Voyer, M. (2024). From concept to practice: Financing sustainable blue economy in lessons learnt from the Seychelles experience. *Marine Policy*, *163*, 106072. https://doi.org/10.1016/j.marpol.2024.106072

Brito Cedeno, R. C., & Wei, J. (2024). Investigating factors to promote energy: Socio-political barriers to renewable energy sector in India. *Electricity Journal*, *37*(2), 107366. https://doi.org/10.1016/j.tej.2024.107366

Chen, M., Zhang, S., Liu, S., Li, M., Zhang, T., Wu, T., & Bu, X. (2025). Mapping the groundwater potential zones in mountainous areas of Southern China using GIS, AHP, and fuzzy AHP. *Scientific Reports*, *15*(1), 17159. https://doi.org/10.1038/s41598-025-01837-y

de Soysa, I. (2025). Green with envy? The effects of inequality and equity within and across social groups on greenhouse gas emissions, 1990–2020. *World Development*, *188*, 106885. https://doi.org/10.1016/j.worlddev.2024.106885

Du, P., Liu, T., Chen, T., Jiang, M., Zhu, H., Shang, Y., Goh, H. H., Zhao, H., Huang, C., Kong, F., Kurniawan, T. A., Goh, K. C., Du, Y., & Zhang, D. (2025). Enhancing green mobility through vehicle-to-grid technology: potential, technological barriers, and policy implications. *Energy and Environmental Science*, *18*(10), 4496–4520. https://doi.org/10.1039/d5ee00116a

Estevão, J., & Lopes, J. D. (2024). SDG7 and renewable energy consumption: The influence of energy sources. *Technological Forecasting and Social Change*, *198*, 123004. https://doi.org/10.1016/j.techfore.2023.123004

Faucheux, S., & Nicolaï, I. (2011). IT for green and green IT: A proposed typology of eco-innovation. *Ecological Economics*, *70*(11), 2020–2027. https://doi.org/10.1016/j.ecolecon.2011.05.019

Gao, P., Li, Z., & Shi, R. (2024). Impact of natural resource dependence on green technology development: Role of digital governance in mitigating resource-curse using big data. *Resources Policy*, *92*, 105023. https://doi.org/10.1016/j.resourpol.2024.105023

Guo, H., Dong, M., Tsinopoulos, C., & Xu, M. (2024). The influential capacity of carbon neutrality environmental orientation in modulating stakeholder engagement toward green manufacturing. *Corporate Social Responsibility and Environmental Management*, *31*(1), 292–310. https://doi.org/10.1002/csr.2570

Guo, P., He, Y., Scrimgeour, F., Shao, S., & Yu, Y. (2024). The impact of natural resource dependency on green economic growth: A business environment perspective. *Technological Forecasting and Social Change*, *208*, 123680. https://doi.org/10.1016/j.techfore.2024.123680

Haaja, E., & Harikkala-Laihinen, R. (2025). Emotions in sustainability advancement: Multiactor experiences of the ongoing green transition. *Journal of Cleaner Production*, *486*, 144532. https://doi.org/10.1016/j.jclepro.2024.144532

Han, S., Peng, D., Guo, Y., Aslam, M. U., & Xu, R. (2025). Harnessing technological innovation and renewable energy and their impact on environmental pollution in G-20 countries. *Scientific Reports*, *15*(1), 2236. https://doi.org/10.1038/s41598-025-85182-0

Healey, P., Cars, G., Madanipour, A., & De Magalhães, C. (2017). Transforming governance, institutionalist analysis and institutional capacity. In *Urban Governance, Institutional Capacity and Social Milieux* (pp. 6–28). Routledge. https://doi.org/10.4324/9781315202877

Hernández Soto, G. (2024). The role of foreign direct investment and green technologies in facilitating the transition toward green economies in Latin America. *Energy*, *288*, 129933. https://doi.org/10.1016/j.energy.2023.129933

IEA. (2023). *Energy Efficiency 2023*. https://www.iea.org/reports/energy-efficiency-2023

Ikram, M. (2025). Assessing Food Security and Environmental Sustainability in North Africa: A Composite Indicator Approach Using Data Envelopment Analysis. *Sustainability (Switzerland)*, *17*(13), 6017. https://doi.org/10.3390/su17136017

Ikram, M., Ferasso, M., Sroufe, R., & Zhang, Q. (2021). Assessing green technology indicators for cleaner production and sustainable investments in a developing country context. *Journal of Cleaner Production*, *322*, 129090. https://doi.org/10.1016/j.jclepro.2021.129090

IRENA. (2023). *World energy transitions outlook 2023. Abu Dhabi: IRENA.* The Energy Transition Is Off-Track.

Islam, H. (2025). Nexus of economic, social, and environmental factors on sustainable development goals: The moderating role of technological advancement and green innovation. *Innovation and Green Development*, *4*(1), 100183. https://doi.org/10.1016/j.igd.2024.100183

Jafarizadeh, H., Yamini, E., Zolfaghari, S. M., Esmaeilion, F., Assad, M. E. H., & Soltani, M. (2024). Navigating challenges in large-scale renewable energy storage: Barriers, solutions, and innovations. *Energy Reports*, *12*, 2179–2192. https://doi.org/10.1016/j.egyr.2024.08.019

Jang, H. W., Yoo, J. J. E., & Cho, M. (2024). Resistance to blockchain adoption in the foodservice industry: moderating roles of public pressures and climate change awareness. *International Journal of Contemporary Hospitality Management*, *36*(5), 1467–1489. https://doi.org/10.1108/IJCHM-09-2022-1127

Jiang, T., Ji, P., Shi, Y., Ye, Z., & Jin, Q. (2021). Efficiency assessment of green technology innovation of renewable energy enterprises in China: a dynamic data envelopment analysis considering undesirable output. *Clean Technologies and Environmental Policy*, *23*(5), 1509–1519. https://doi.org/10.1007/s10098-021-02044-9

Khan, I. U., Hameed, Z., Khan, S. U., & Khan, M. A. (2024). Green banking practices, bank reputation, and environmental awareness: evidence from Islamic banks in a developing economy. *Environment, Development and Sustainability*, *26*(6), 16073–16093. https://doi.org/10.1007/s10668-023-03288-9

Kumar, P., Brar, P. S., Singh, D., & Bhamu, J. (2023). Fuzzy AHP approach for barriers to implement LSS in the context of Industry 4.0. *International Journal of Productivity and Performance Management*, *72*(9), 2559–2583. https://doi.org/10.1108/IJPPM-12-2021-0715

Le, T. T., Tran, P. Q., Lam, N. P., Tra, M. N. Le, & Uyen, P. H. P. (2024). Corporate social responsibility, green innovation, environment strategy and corporate sustainable development. *Operations Management Research*, *17*(1), 114–134. https://doi.org/10.1007/s12063-023-00411-x

Li, Y., Liu, Y., & Solangi, Y. A. (2024). Analysis of factors and strategies for the implementation of sustainable tourism in a green economic structure in China. *Journal of Cleaner Production*, *434*, 140011. https://doi.org/10.1016/j.jclepro.2023.140011

Liu, W., Shen, Y., & Razzaq, A. (2023). How renewable energy investment, environmental regulations, and financial development derive renewable energy transition: Evidence from G7 countries. *Renewable Energy*, *206*, 1188–1197. https://doi.org/10.1016/j.renene.2023.02.017

Lv, Z., Chen, L., Ali, S. A., Muda, I., Alromaihi, A., & Boltayev, J. Y. (2024). Financial technologies, green technologies and natural resource nexus with sustainable development goals: Evidence from resource abundant economies using MMQR estimation. *Resources Policy*, *89*, 104649. https://doi.org/10.1016/j.resourpol.2024.104649

Ma, X., & Najam, H. (2024). Achieving environmental sustainability goals through capitalizing on renewable energy channels: Role of green finance, resources productivity and geopolitical situation in the MENA region. *Geological Journal*, *59*(6), 1828–1840. https://doi.org/10.1002/gj.4972

Maghyereh, A., Boulanouar, Z., & Essid, L. (2025). The dynamics of green innovation and environmental policy stringency in energy transition investments. *Journal of Cleaner Production*, *487*, 144649. https://doi.org/10.1016/j.jclepro.2024.144649

Majekodunmi, T. B., Shaari, M. S., Abidin, N. Z., & Ridzuan, A. R. (2023). Green technology, exports, and CO2 emissions in Malaysia. *Heliyon*, *9*(8). https://doi.org/10.1016/j.heliyon.2023.e18625

Miao, Y., Ather Bukhari, A. A., Bukhari, W. A. A., Ahmad, S., & Hayat, N. (2025). Why fossil fuels stifle green economic growth? An environmental management perspective in assessing the spatial spillover impact of energy consumption in South Asia. *Journal of Environmental Management*, *373*, 123471. https://doi.org/10.1016/j.jenvman.2024.123471

Mirza, Z. T., Anderson, T., Seadon, J., & Brent, A. (2024). A thematic analysis of the factors that influence the development of a renewable energy policy. *Renewable Energy Focus* , *49*, 100562. https://doi.org/10.1016/j.ref.2024.100562

Nabi, M. N., Zhiqiang, L., & Akter, M. (2023). Transformational leadership and radical innovation for sustainability: mediating role of knowledge management capability and moderating role of competitive intensity. *Innovation and Management Review*, *20*(3), 298–310. https://doi.org/10.1108/INMR-05-2021-0075

Nauman, M., Naheed, R., & Khan, J. (2024). Navigating sustainable horizons: exploring the dynamics of financial stability, green growth, renewable energy, technological innovation, financial inclusion, and soft infrastructure in shaping sustainable development. *Environmental Science and Pollution Research*, *31*(20), 29939–29956. https://doi.org/10.1007/s11356-024-33202-3

Nketiah, E., Song, H., Adjei, M., Obuobi, B., & Adu-Gyamfi, G. (2024). Assessing the influence of research and development, environmental policies, and green technology on ecological footprint for achieving environmental sustainability. *Renewable and Sustainable Energy Reviews*, *199*, 114508. https://doi.org/10.1016/j.rser.2024.114508

Oduro, S., Maccario, G., & De Nisco, A. (2022). Green innovation: a multidomain systematic review. *European Journal of Innovation Management*, *25*(2), 567-591. https://doi.org/10.1108/EJIM-10-2020-0425

OECD. (2023). Skills for a Resilient Green and Digital Transition. https://www.oecd.org/en/publications/oecd-skills-outlook-2023_27452f29-en.html#page1[Retrieved date November 22, 2025]

Olaniyi, C. O., Al-Faryan, M. A. S., & Ogbaro, E. O. (2025). Do institutional quality and its threshold matter in the sensitivity of the renewable energy transition to financial development? New empirical perspectives. *International Journal of Finance and Economics*, *30*(1), 5–43. https://doi.org/10.1002/ijfe.2900

Omisore, A. G. (2018). Attaining Sustainable Development Goals in sub-Saharan Africa; The need to address environmental challenges. *Environmental Development*, *25*, 138–145. https://doi.org/10.1016/j.envdev.2017.09.002

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, *156*(2), 445–455. https://doi.org/10.1016/S0377-2217(03)00020-1

Oryani, B., Koo, Y., Rezania, S., & Shafiee, A. (2021). Barriers to renewable energy technologies penetration: Perspective in Iran. *Renewable Energy*, *174*, 971–983. https://doi.org/10.1016/j.renene.2021.04.052

Owojori, O. M., & Erasmus, L. J. (2025). Public–private partnerships as catalysts for green infrastructure: a three-pronged analysis of economic, environmental, and institutional factors. *Frontiers in Sustainable Cities*, *7*, 1591278. https://doi.org/10.3389/frsc.2025.1591278

Painuly, J. P., & Wohlgemuth, N. (2020). Renewable energy technologies: barriers and policy implications. In *Renewable-Energy-Driven Future: Technologies, Modelling, Applications, Sustainability and Policies* (pp. 539–562). Elsevier. https://doi.org/10.1016/B978-0-12-820539-6.00018-2

Patel, U. R., Ghaffarianhoseini, A., Ghaffarianhoseini, A., & Burgess, A. (2024). Digital Twin Technology for sustainable urban development: A review of its potential impact on SDG 11 in New Zealand. *Cities*, *155*, 105484. https://doi.org/10.1016/j.cities.2024.105484

Radtke, J. (2025). Understanding the Complexity of Governing Energy Transitions: Introducing an Integrated Approach of Policy and Transition Perspectives. *Environmental Policy and Governance*, *35*(4), 595–614. https://doi.org/10.1002/eet.2158

Roper, S., & Tapinos, E. (2016). Taking risks in the face of uncertainty: An exploratory analysis of green innovation. *Technological Forecasting and Social Change*, *112*, 357–363. https://doi.org/10.1016/j.techfore.2016.07.037

Sajid, M. J., Zhang, Y., & Janjua, L. R. (2024). Breaking barriers: Assessing technology transfer for climate-resilient development. *Environmental Technology and Innovation*, *33*, 103471. https://doi.org/10.1016/j.eti.2023.103471

Sardianou, E., & Kostakis, I. (2020). Perceived barriers to invest in renewable energy sources in the Cretan hotel industry. *International Journal of Sustainable Energy*, *39*(3), 240–249. https://doi.org/10.1080/14786451.2019.1673393

Sassanelli, C., Pezzotta, G., Pirola, F., Sala, R., Margarito, A., Lazoi, M., ... & Terzi, S. (2018). Using design rules to guide the PSS design in an engineering platform based on the product service lifecycle management paradigm. *International Journal of Product Lifecycle Management*, *11*(2), 91-115. https://doi.org/10.1504/IJPLM.2018.092826

Sassanelli, C., Da Costa Fernandes, S., Rozenfeld, H., Mascarenhas, J., & Terzi, S. (2021). Enhancing knowledge management in the PSS detailed design: a case study in a food and bakery machinery company. *Concurrent Engineering*, *29*(4), 295-308. https://doi.org/10.1177/1063293X21991

Sassanelli, C., Arriga, T., Zanin, S., D'Adamo, I., & Terzi, S. (2022). Industry 4.0 driven result-oriented PSS: An assessment in the energy management. *International Journal of Energy Economics and Policy*, 12(4), 186-203. https://doi.org/10.32479/ijeep.13313

Sethi, L., Behera, B., & Sethi, N. (2024). Do green finance, green technology innovation, and institutional quality help achieve environmental sustainability? Evidence from the developing economies. *Sustainable Development*, *32*(3), 2709–2723. https://doi.org/10.1002/sd.2811

Sharma, M., & Choubey, A. (2022). Green banking initiatives: a qualitative study on Indian banking sector. *Environment, Development and Sustainability*, *24*(1), 293–319. https://doi.org/10.1007/s10668-021-

01426-9

Hsu, Y. L., Lee, C. H., & Kreng, V. B. (2010). The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection. *Expert systems with Applications*, *37*(1), 419-425.https://doi.org/10.1016/j.eswa.2009.05.068

Solangi, Y. A., Longsheng, C., & Shah, S. A. A. (2021). Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach. *Renewable Energy*, *173*, 209–222. https://doi.org/10.1016/j.renene.2021.03.141

Soumonni, O., & Ojah, K. (2022). Innovative and mission-oriented financing of renewable energy in Sub-Saharan Africa: A review and conceptual framework. *Wiley Interdisciplinary Reviews: Energy and Environment*, *11*(1), e416. https://doi.org/10.1002/wene.416

Suki, N. M., Suki, N. M., Afshan, S., Sharif, A., & Meo, M. S. (2022). The paradigms of technological innovation and renewables as a panacea for sustainable development: a pathway of going green. *Renewable energy*, *181*, 1431-1439. https://doi.org/10.1016/j.renene.2021.09.121

Tantawat, W., Phdungsilp, A., & Vorarat, S. (2023). Energy Return on Energy and Carbon Investment of Wind Energy Farms in Thailand. *GMSARN International Journal*, *17*(4), 396–405.

Ternes, V., Marsden, G., & Harrison, G. (2024). A just transition or just a transition? The understanding and relevance of fairness in planning for a decarbonised transport system. *Energy Research and Social Science*, *113*, 103549. https://doi.org/10.1016/j.erss.2024.103549

The world bank. (2023). Challenges of Green Finance. In *International Finance Corporation* (Issue November). https://documents1.worldbank.org/curated/en/099717411212328052/pdf/IDU0d3c2f00d0351404d7c08cc40cd0b621a7d59.pdf

Tian, Y., & Pang, J. (2023). What causes dynamic change of green technology progress: Convergence analysis based on industrial restructuring and environmental regulation. *Structural Change and Economic Dynamics*, *66*, 189–199. https://doi.org/10.1016/j.strueco.2023.05.002

Ul-Durar, S., Awan, U., Varma, A., Memon, S., & Mention, A. L. (2023). Integrating knowledge management and orientation dynamics for organization transition from eco-innovation to circular economy. *Journal of Knowledge Management*, *27*(8), 2217–2248. https://doi.org/10.1108/JKM-05-2022-0424

UNDP. (2023). Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate investment and planning on climate adaptation leaves world exposed. In *Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate investment and planning on climate adaptation leaves world exposed*. https://doi.org/10.59117/20.500.11822/43796

UNESCAP. (2020). *Climate Action Reserve - Climate Action Reserve : Climate Action Reserve*. The World Is in a Climate Emergency. Unless Greenhouse Gas Emissions Fall Dramatically, Warming Could Pass 2.9°C This Century. https://www.climateactionreserve.org/

Wang, D., Li, J., & Liu, Y. (2023). Evaluating barriers and strategies to green energy innovations for sustainable development: developing resilient energy systems. *Frontiers in Energy Research*, *11*, 1201692. https://doi.org/10.3389/fenrg.2023.1201692

Wang, H., Qi, S., Zhou, C., Zhou, J., & Huang, X. (2022). Green credit policy, government behavior and green innovation quality of enterprises. *Journal of Cleaner Production*, *331*, 129834. https://doi.org/10.1016/j.jclepro.2021.129834

Wang, Jian, Osei, A., & Agyemang, A. O. (2025). Leveraging Green Innovation and Eco-Technology for Sustainable Competitive Advantage: Firm-Level Productivity Analysis in China and the United States. *Business Strategy and the Environment*, *34*(6), 7389–7411. https://doi.org/10.1002/bse.4360

Wang, Jiannan, & Azam, W. (2024). Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. *Geoscience Frontiers*, *15*(2), 101757. https://doi.org/10.1016/j.gsf.2023.101757

Wang, L., Pal, S., Mahalik, M. K., & Gozgor, G. (2025). Empowering sustainable development in emerging economies: The role of renewable energy and domestic investment. *Energy Economics*, *148*, 108631. https://doi.org/10.1016/j.eneco.2025.108631

Wang, Q., Li, Y., Pata, U. K., & Li, R. (2025). Artificial intelligence and global carbon inequality: Addressing the challenges and opportunities for SDG 10, SDG 12, and SDG 13. *Geoscience Frontiers*, *16*(4), 102072. https://doi.org/10.1016/j.gsf.2025.102072

Wang, Y. J., Lyu, H. M., & Shen, S. L. (2023). Rapid determination of fuzzy number in FAHP and assessment risk in coal mine roof fall. *Geomatics, Natural Hazards and Risk*, *14*(1), 2184670. https://doi.org/10.1080/19475705.2023.2184670

Wasan, P., Kumar, A., & Luthra, S. (2021). Green finance barriers and solution strategies for emerging economies: The case of India. *IEEE Transactions on Engineering Management*, *71*, 414-425. 10.1109/TEM.2021.3123185

Xia, D., Zhang, M., Yu, Q., & Tu, Y. (2019). Developing a framework to identify barriers of Green technology adoption for enterprises. *Resources, Conservation and Recycling*, *143*, 99–110. https://doi.org/10.1016/j.resconrec.2018.12.022

Yacob, P., Wong, L. S., & Khor, S. C. (2019). An empirical investigation of green initiatives and environmental sustainability for manufacturing SMEs. *Journal of Manufacturing Technology Management*, *30*(1), 2-25. https://doi.org/10.1108/JMTM-08-2017-0153

Yang, H. C., Cai, Y. F., & Zhang, M. Y. (2022). Political risk and green technology improvement: New insights from global evidence. *Innovation and Green Development*, *1*(1), 100004. https://doi.org/10.1016/j.igd.2022.100004

Zhang, W., & Li, G. (2022). Environmental decentralization, environmental protection investment, and green technology innovation. *Environmental Science and Pollution Research*, *29*(9), 12740–12755. https://doi.org/10.1007/s11356-020-09849-z

Zhao, R., Hu, C., Du, C., Wang, C., & Sun, L. (2025). Synergistic effect assessment of pollution and carbon reduction and pathway of green transformation at regional level in China. *Journal of Cleaner Production*, *495*, 145013. https://doi.org/10.1016/j.jclepro.2025.145013

Zhao, S., Teng, L., & Ji, J. (2024). Impact of environmental regulations on eco-innovation: the moderating role of top managers' environmental awareness and commitment. *Journal of Environmental Planning and Management*, *67*(10), 2229–2256. https://doi.org/10.1080/09640568.2023.2184331

Zhao, X., Gao, Y., Hou, Y., Albasher, G., & Bu, F. (2024). Addressing the resource curse: Empirical analysis of greenhouse gas mitigation strategies for sustainable development. *Resources Policy*, *88*, 104454. https://doi.org/10.1016/j.resourpol.2023.104454

Zheng, Z., Shafique, M., Luo, X., & Wang, S. (2024). A systematic review towards integrative energy management of smart grids and urban energy systems. *Renewable and Sustainable Energy Reviews*, *189*, 114023. https://doi.org/10.1016/j.rser.2023.114023

Zhou, Y., Xu, G., Minshall, T., & Liu, P. (2015). How do Public Demonstration Projects Promote Green-Manufacturing Technologies? A Case Study from China. *Sustainable Development*, *23*(4), 217–231. https://doi.org/10.1002/sd.1589

**Assessing barriers to the adoption of green technologies in developing countries by using an integrated decision-making systems**

**Table A1: List of experts**

| No | Position | Gender | Age | Company/Institution |
|---|---|---|---|---|
| 1 | Manager | Male | 24 | Gi3: Green Innov Industry Investment |
| 2 | Professor | Female | 58 | Mohammed VI Polytechnic University |
| 3 | General Manager | Female | 23 | Kohinoor Maple Leaf Group |
| 4 | Director | Female | 47 | Ministry of Energy Transition and Development |
| 5 | Deputy Director | Male | 38 | Ministry of Climate Change and Environmental Coordination |
| 6 | R&D Manager | Male | 26 | OCP Group |
| 7 | Green Technology Expert | Male | 53 | Bureau Veritas Consumer Products Services |
| 8 | Professor | Female | 54 | Shenzhen Technology University |



**Table A2: Green technology adoption survey**

Thank you for participating in our comprehensive survey designed to gather expert insights on Green Technology Adoption (GTA) barriers and potential solutions. Your input is invaluable as we seek to identify the various challenges that hinder sustainable development and green innovation. Please provide thoughtful responses based on your expertise and experience. The information you provide will help shape important discussions and decisions in the field of sustainable development.

**Section 1. Survey Questionnaire**

**Demographic Information**

Gender: …………………………………………………………………………..………………

Age: ……………………………………………………………………………………...….…

Experience in Current Position: …………………………………………………….………

Academic Background…………...…………………………………………………………………

Current Professional Status: ………………………………………………………………………

Company type: ……………………………………………………………………………………...

**Section 2: Main Barriers and Sub-Barriers of green technologies ranking**

The main barriers and sub-barriers of green technology of this research are listed below.

| Criteria | Sub-criteria | Description |
|---|---|---|
| Financial Barriers (FB) | Lack of Access to Financial Resources (FB1) | Firms face difficulties in securing affordable financing for green investments due to perceived risks, limited collateral, and the absence of specialized green credit facilities. Financial institutions often lack assessment frameworks for environmental projects, reducing access to capital. |
| | High-Cost Premium (FB2) | The initial investment required for eco-technologies is significantly higher than that for conventional systems. These upfront costs discourage firms from adopting sustainable technologies, particularly in developing economies where liquidity constraints are common. |
| | Unattractive Returns on Investment (FB3) | The long payback period of green technologies and uncertain market benefits make such investments financially unattractive to many businesses. Decision-makers often prioritize short-term profitability over long-term environmental gains. |
| | Unavailability of government subsidies (FB4) | Limited or poorly structured subsidy schemes weaken firms' motivation to shift toward cleaner production. The absence of tax incentives, low-interest loans, or grants further reduces the financial feasibility of green transitions. |
| | High Operational and Maintenance Costs (FB5) | Even after adoption, green technologies often involve expensive maintenance, skilled labor requirements, and imported spare parts, increasing long-term operational costs for organizations. |
| Regulatory Barriers (RB) | Unclear regulations (RB1) | Ambiguous or outdated environmental policies create uncertainty for investors and firms. A lack of clarity in compliance standards and performance benchmarks discourages technology adoption. |
| | Lack of government support/incentives (RB2) | Weak policy support, minimal fiscal incentives, and fragmented green strategies fail to stimulate market confidence. Governments often prioritize short-term industrial growth over long-term sustainability objectives. |

| | | |
|---|---|---|
| | Ineffective enforcement of environmental laws (RB3) | Even when environmental laws exist, enforcement mechanisms are often weak. Corruption, insufficient monitoring, and lenient penalties reduce compliance and disincentivize firms from transitioning to green technologies. |
| | Complex and Rigid Legislation (RB4) | Overly bureaucratic or inconsistent regulations delay project approvals and increase transaction costs. This complexity creates a hostile environment for technological innovation and sustainability investment. |
| Technological Barriers (TB) | Lack of local expertise and R&D (TB1) | The shortage of skilled professionals, limited research infrastructure, and weak university-industry collaboration hinder innovation and adaptation of green technologies to local conditions. |
| | Obsolete infrastructure (TB2) | Many firms operate with outdated machinery and limit digital capacity, making integration of advanced green systems technically challenging and economically unviable. |
| | Limited access to green technologies (TB3) | Developing countries face import restrictions, high tariffs, and intellectual property constraints that restrict access to modern low-carbon technologies, slowing the diffusion of innovation. |
| Market Barriers (MB) | Low demand for sustainable products (MB1) | Consumer awareness and willingness to pay for eco-friendly goods remain low, leading to insufficient market pull and discouraging firms from producing sustainable alternatives. |
| | Limited awareness of green technologies (MB2) | Lack of information dissemination and weak communication between producers and consumers contribute to the slow diffusion of sustainable technologies. Many firms are unaware of potential efficiency gains. |
| | Market resistance to change (MB3) | Existing supply chains and market actors often resist new sustainable models due to habit, risk aversion, and fear of disrupting established relationships and profit structures. |
| | Unequal Distribution of Benefits (MB4) | The benefits of green transformation are not evenly shared among stakeholders. Small firms, suppliers, and local communities often bear the costs, while large corporations capture most of the gains. |
| Institutional Barriers (IB) | Bureaucratic inefficiency (IB1) | Lengthy administrative procedures, redundant paperwork, and lack of digital governance systems create bottlenecks in implementing green initiatives. |

| | | |
|---|---|---|
| | Poor coordination (IB2) | Fragmented responsibilities across ministries, agencies, and sectors lead to overlapping or conflicting mandates that hinder coherent sustainability policies. |
| | Limited institutional capacity (IB3) | Institutions often lack the technical, managerial, and human resource capacity to design, implement, and monitor effective green programs. |
| | Political Instability (IB4) | Frequent political changes and weak governance reduce investor confidence and disrupt long-term sustainability planning. |
| Environmental Barriers (EB) | Natural resource dependency (EB1) | Economies dependent on extractive industries or resource-intensive sectors face structural challenges in adopting green technologies that could reduce output or employment. |
| | Climate challenges (EB2) | Harsh climatic conditions, such as droughts or floods, can damage renewable energy infrastructure and hinder the consistent performance of green technologies. |
| | Limited natural resource availability (EB3) | The scarcity of essential raw materials, such as rare earth elements, limits the scalability of certain green technologies and increases dependency on imports. |
| Social Barriers (SB) | Public resistance to change (SB1) | Societal attachment to traditional practices, low environmental literacy, and skepticism toward new technologies slow the diffusion of sustainable behaviors. |
| | Low stakeholder engagement (SB2) | Insufficient involvement of communities, NGOs, and civil society in policy design reduces local ownership and acceptance of green initiatives. |
| | Social inequalities (SB3) | Economic disparities and unequal access to education and resources prevent marginalized groups from participating in and benefiting from the green transition. |

**<u>Section-3: Answering Instruction</u>**

**Instruction 1:** For each pair of main barriers, please rate the importance of one barrier relative to the other using a scale from 1 to 5, where 1 means that both barriers are equally important, and higher ratings indicate a preference for one barrier being more important than the other. Please specify your preference clearly.

**Scale of importance 1 to 5 for barriers and sub-barriers**

| Code | Linguistic Variable | Triangular fuzzy Numbers |
|---|---|---|
| 1 | Equal Important | (1,1,3) |
| 2 | Moderate Important | (1,3,5) |
| 3 | Strong Important | (3,5,7) |

| | | |
|---|---|---|
| 4 | Very strong Important | (5,7,9) |
| 5 | Extreme Important | (7,9,11) |

**Instruction No. 2:**

You need to consider relative importance of barrier's and score any one barrier in the respective blank space (either left or right) in the questionnaire. Here are a few examples to help you complete this questionnaire.

**Example:** Please rate the importance of one barrier Financial Barriers (FB) to another barrier, Regulatory Barriers (RB). In this case, you have to employ your judgment to enter a score (1-5) in any blank space according to the previous description.

For instance, if you believe Financial Barriers (FB) is extreme important than Regulatory Barriers (RB), you must enter the score in the empty spot on the left.

| Main indicator | Score 1-5 | | Main indicator |
|---|---|---|---|
| Financial Barriers (FB) | 5 | | Regulatory Barriers (RB) |

Accordingly, you consider the SOC indicator as being extremely important in comparison to the ENV indicator.

<u>**Part A: Main Barriers**</u>

A questionnaire survey concerning the green technology adoption barriers to Morocco's toward sustainable development.

Please rate the importance of the main barrier against each barrier using a scale from 1 to 5.

| **Main Barrier** | **Score (1–5)** | | **Main Barrier** |
|---|---|---|---|
| Financial Barriers (FB) | | | Regulatory Barriers (RB) |
| Financial Barriers (FB) | | | Technological Barriers (TB) |
| Financial Barriers (FB) | | | Market Barriers (MB) |
| Financial Barriers (FB) | | | Institutional Barriers (IB) |
| Financial Barriers (FB) | | | Environmental Barriers (EB) |
| Financial Barriers (FB) | | | Social Barriers (SB) |
| Regulatory Barriers (RB) | | | Technological Barriers (TB) |
| Regulatory Barriers (RB) | | | Market Barriers (MB) |
| Regulatory Barriers (RB) | | | Institutional Barriers (IB) |
| Regulatory Barriers (RB) | | | Environmental Barriers (EB) |
| Regulatory Barriers (RB) | | | Social Barriers (SB) |
| Technological Barriers (TB) | | | Market Barriers (MB) |

| | | | |
|---|---|---|---|
| Technological Barriers (TB) | | | Institutional Barriers (IB) |
| Technological Barriers (TB) | | | Environmental Barriers (EB) |
| Technological Barriers (TB) | | | Social Barriers (SB) |
| Market Barriers (MB) | | | Institutional Barriers (IB) |
| Market Barriers (MB) | | | Environmental Barriers (EB) |
| Market Barriers (MB) | | | Social Barriers (SB) |
| Institutional Barriers (IB) | | | Environmental Barriers (EB) |
| Institutional Barriers (IB) | | | Social Barriers (SB) |
| Environmental Barriers (EB) | | | Social Barriers (SB) |

**<u>Part B: Sub-Barriers</u>**

Instructions: For each pair of green technologies sub-barriers, please rate the importance of one sub-barriers relative to the other using a scale from 1 to 5, where 1 means that both barriers are equally important, and higher ratings indicate a preference for one barrier being more important than the other. Please specify your preference clearly.

**Determining Sub-barriers for the green technology adoption in Morocco.**

**1.** Please rate the importance of sub-barriers (FB1–FB5) against each sub-barriers (FB1–FB5) relating to Financial Barriers (FB) using a scale from 1 to 5.

| Sub-Barriers (Financial) | Score (1–5) | | Sub-Barriers (Financial) |
|---|---|---|---|
| Lack of Access to Financial Resources (FB1) | | | High-Cost Premium (FB2) |
| Lack of Access to Financial Resources (FB1) | | | Unattractive Returns on Investment (FB3) |
| Lack of Access to Financial Resources (FB1) | | | Unavailability of government subsidies (FB4) |
| Lack of Access to Financial Resources (FB1) | | | High Operational and Maintenance Costs (FB5) |
| High-Cost Premium (FB2) | | | Unattractive Returns on Investment (FB3) |
| High-Cost Premium (FB2) | | | Unavailability of government subsidies (FB4) |
| High-Cost Premium (FB2) | | | High Operational and Maintenance Costs (FB5) |
| Unattractive Returns on Investment (FB3) | | | Unavailability of government subsidies (FB4) |
| Unattractive Returns on Investment (FB3) | | | High Operational and Maintenance Costs (FB5) |
| Unavailability of government subsidies (FB4) | | | High Operational and Maintenance Costs (FB5) |

**2.** Please rate the importance of sub-barriers (RB1–RB4) against each sub-barriers (RB1–RB4) relating to Regulatory Barriers (RB) using a scale from 1 to 5.

| Sub-Barriers (Regulatory) | Score (1–5) | | Sub-Barriers (Regulatory) |
|---|---|---|---|
| Unclear regulations (RB1) | | | Lack of government support/incentives (RB2) |
| Unclear regulations (RB1) | | | Ineffective enforcement of environmental laws (RB3) |
| Unclear regulations (RB1) | | | Complex and Rigid Legislation (RB4) |
| Lack of government support/incentives (RB2) | | | Ineffective enforcement of environmental laws (RB3) |
| Lack of government support/incentives (RB2) | | | Complex and Rigid Legislation (RB4) |
| Ineffective enforcement of environmental laws (RB3) | | | Complex and Rigid Legislation (RB4) |

**3.** Please rate the importance of sub-barriers (TB1–TB3) against each sub-barriers (TB1–TB3) relating to Technological Barriers (TB) using a scale from 1 to 5.

| Sub-Barriers (Technological) | Score (1–5) | | Sub-Barriers (Technological) |
|---|---|---|---|
| Lack of local expertise and R&D (TB1) | | | Obsolete infrastructure (TB2) |
| Lack of local expertise and R&D (TB1) | | | Limited access to green technologies (TB3) |
| Obsolete infrastructure (TB2) | | | Limited access to green technologies (TB3) |

**4.** Please rate the importance of sub-barriers (MB1–MB4) against each sub-barriers (MB1–MB4) relating to Market Barriers (MB) using a scale from 1 to 5.

| Sub-Barriers (Market) | Score (1–5) | | Sub-Barriers (Market) |
|---|---|---|---|
| Low demand for sustainable products (MB1) | | | Limited awareness of green technologies (MB2) |
| Low demand for sustainable products (MB1) | | | Market resistance to change (MB3) |
| Low demand for sustainable products (MB1) | | | Unequal Distribution of Benefits (MB4) |
| Limited awareness of green technologies (MB2) | | | Market resistance to change (MB3) |
| Limited awareness of green technologies | | | Unequal Distribution of Benefits (MB4) |

| | | | |
|---|---|---|---|
| (MB2) | | | |
| Market resistance to change (MB3) | | | Unequal Distribution of Benefits (MB4) |

**5.** Please rate the importance of sub-barriers (IB1–IB4) against each sub-barriers (IB1–IB4) relating to Institutional Barriers (MB) using a scale from 1 to 5.

| **Sub-Barriers (Institutional)** | **Score (1–5)** | | **Sub-Barriers (Institutional)** |
|---|---|---|---|
| Bureaucratic inefficiency (IB1) | | | Poor coordination (IB2) |
| Bureaucratic inefficiency (IB1) | | | Limited institutional capacity (IB3) |
| Bureaucratic inefficiency (IB1) | | | Political Instability (IB4) |
| Poor coordination (IB2) | | | Limited institutional capacity (IB3) |
| Poor coordination (IB2) | | | Political Instability (IB4) |
| Limited institutional capacity (IB3) | | | Political Instability (IB4) |

**6.** Please rate the importance of sub-barriers (EB1–EB3) against each sub-barriers (EB1–EB3) relating to Environmental Barriers (EB) using a scale from 1 to 5.

| **Sub-Barriers (Environmental)** | **Score (1–5)** | | **Sub-Barriers (Environmental)** |
|---|---|---|---|
| Natural resource dependency (EB1) | | | Climate challenges (EB2) |
| Natural resource dependency (EB1) | | | Limited natural resource availability (EB3) |
| Climate challenges (EB2) | | | Limited natural resource availability (EB3) |

**6.** Please rate the importance of sub-barriers (SB1–SB3) against each sub-barriers (SB1–SB3) relating to Social Barriers (SB) using a scale from 1 to 5.

| **Sub-Barriers (Social)** | **Score (1–5)** | | **Sub-Barriers (Social)** |
|---|---|---|---|
| Public resistance to change (SB1) | | | Low stakeholder engagement (SB2) |
| Public resistance to change (SB1) | | | Social inequalities (SB3) |
| Low stakeholder engagement (SB2) | | | Social inequalities (SB3) |

## Part C: Green Technologies Strategies towards Sustainable Development in Morocco

**Section C:** Please rate the importance of various solution strategies with respect to all sub-barriers using a scale from 1 to 5.

**Scale of importance for green technology adoption strategies**

| Code | Linguistic Variable | Triangular fuzzy Numbers |
|---|---|---|
| 1 | Equal Important | (1,1,3) |
| 2 | Moderate Important | (1,3,5) |
| 3 | Strong Important | (3,5,7) |
| 4 | Very strong Important | (5,7,9) |
| 5 | Extreme Important | (7,9,11) |

**Green technologies adoption strategic towards sustainable development**

| Strategies | Code | Description |
|---|---|---|
| Green Industrial Policies | **SO1** | Green industrial policies can help Morocco overcome barriers to green technology adoption by providing targeted support in finance, skills, infrastructure, and regulatory frameworks to accelerate its transition to a low-carbon economy. |
| Regulatory Modernization | **SO2** | Simplifying and modernizing regulatory processes can make it easier for new green tech companies to enter the market and bring innovative solutions forward. |
| Demand-side Incentives | **SO3** | Implementing demand-side incentives, such as rebates and tax credits, to increase consumer and business adoption of green technologies can drive to a sustainable market shift in Morocco. |
| Green Finance Platforms | **SO4** | Implementing a platform that connects green technology vendors with financial institutions, standardizing assessments, and raising awareness can help overcome financing barriers and promote the adoption of green technologies in Morocco's capital market. |
| R&D Funds for Green Technology | **SO5** | Establishing dedicated green technology R&D funds in Morocco can drive the development of locally relevant green technologies to address the country's specific environmental needs. |

| | | |
|---|---|---|
| Digital Banking Tools for Green Investments | **SO6** | Banks can play a key role by consolidating digital tools to assess and track green investments in order to promote the adoption of green technologies in the country. |
| Reskilling and Workforce Development | **SO7** | Implementing a reskilling program to upskill workers for green technology jobs and fostering partnerships between organizations can help Morocco build a skilled workforce for the growing green sector and promote the adoption of green technologies. |
| Transparent Governance | **SO8** | Establishing transparent and predictable governance in Morocco's clean energy sectors, protecting intellectual property rights, simplifying permitting processes, and implementing fair green public procurement can reduce political and regulatory risks, accelerating green technology adoption. |
| Feed-in Tariffs (FiTs) | **SO9** | Implementing Feed-in Tariffs (FiTs) with long-term contracts and guaranteed pricing can reduce financial risks and incentivize investment in green technologies, accelerating their adoption in Morocco. |
| Institutional Coordination | **SO10** | Establishing coordinated efforts between Morocco's key institutions, such as MASEN, ONHYM, and IRESEN, to align their research, development, and deployment strategies can help overcome green technology barriers by enhancing innovation, sharing resources, and reducing inefficiencies in the adoption of green technologies. |
| Capital Subsidies | **SO11** | Offering capital subsidies to reduce initial costs for green technology projects can make it easier for businesses and investors to adopt green technologies in Morocco. |

**Instructions:** You need to consider the relative importance of green technology adoption strategic solution based on each sub-barrier. Below is an example of filling out this Matrix Style Table.

**Example:** Please rate the importance of green technologies adoption strategies *(SO)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5).*

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO1)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO1* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO2)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB1 | FB2 | FB3 | FB4 | FB5 | RB1 | RB2 | RB3 | RB4 | TB1 | TB2 | TB3 | MB1 | MB2 | MB3 | MB4 | IB1 | IB2 | IB3 | IB4 | EB1 | EB2 | EB3 | SB1 | SB2 | SB3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO2* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO3)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB1 | FB2 | FB3 | FB4 | FB5 | RB1 | RB2 | RB3 | RB4 | TB1 | TB2 | TB3 | MB1 | MB2 | MB3 | MB4 | IB1 | IB2 | IB3 | IB4 | EB1 | EB2 | EB3 | SB1 | SB2 | SB3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 3* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO4)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 4* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO5)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 5* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO6)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 6* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO7)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 7* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO8)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 8* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO9)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 9* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO10)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 10* | | | | | | | | | | | | | | | | | | | | | | | | | | |

Please rate the importance of green technologies adoption strategies *(SO11)* based on each Sub-Barriers (FB1-SB3). In this case you are required to consider your judgment and put down *importance/score (1–5)*.

| | FB 1 | FB 2 | FB 3 | FB 4 | FB 5 | RB 1 | RB 2 | R B3 | R B4 | TB 1 | TB 2 | TB 3 | M B1 | M B2 | MB 3 | MB 4 | IB 1 | IB 2 | IB 3 | IB 4 | EB 1 | EB 2 | EB 3 | SB 1 | SB 2 | SB 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SO 11* | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table A3. The fuzzy pairwise matrix of main green technologies adoption barriers**

| Barriers | FB | RB | TB | MB | IB | EB | SB |
|---|---|---|---|---|---|---|---|
| **FB** | 1,1,1 | 0.478,0.472,0.547 | 1.185,1.57,1.923 | 0.809,1.015,1.32 | 0.661,0.864,1.171 | 3.232,3.521,3.992 | 3.238,3.672,3.886 |
| **RB** | 1.647,2.046,2.402 | 1,1,1 | 1.4,1.814,2.263 | 0.893,1.069,1.303 | 1.059,1.312,1.518 | 2.809,3.055,3.418 | 2.85,3.285,3.409 |
| **TB** | 0.467,0.675,0.95 | 0.392,0.487,0.685 | 1,1,1 | 0.394,0.576,0.711 | 0.445,0.471,0.684 | 0.592,0.927,1.418 | 1.547,1.749,1.908 |
| **MB** | 0.852,1.039,1.236 | 0.772,1.02,1.099 | 1.28,1.721,2.376 | 1,1,1 | 0.716,1.032,1.364 | 0.331,0.638,0.989 | 3.339,3.733,3.916 |
| **IB** | 0.858,1.132,1.394 | 0.587,0.771,0.975 | 1.679,2.161,2.624 | 0.799,0.965,1.295 | 1,1,1 | 0.524,0.751,0.997 | 0.886,1.122,1.233 |
| **EB** | 0.509,0.739,1.041 | 0.754,1.086,1.194 | 1.192,1.499,1.684 | 0.427,0.814,1.222 | 0.362,0.567,1.001 | 1,1,1 | 2.25,2.501,2.873 |
| **SB** | 2.671,3.017,3.408 | 1.915,2.275,2.412 | 0.306,0.563,0.891 | 1.112,1.514,1.648 | 3.081,3.551,3.783 | 2.907,3.213,3.415 | 1,1,1 |

**Table A4. The fuzzy pairwise matrix of sub-barriers concerning financial barriers (FB)**

| Sub-Barriers | FB1 | FB2 | FB3 | FB4 | FB5 |
|---|---|---|---|---|---|
| **FB1** | 1,1,1 | 0.522,0.786,0.927 | 0.573,0.758,0.909 | 0.623,0.721,0.779 | 0.316,0.432,0.657 |
| **FB2** | 1.099,1.237,1.625 | 1,1,1 | 0.646,0.748,1.102 | 0.942,1.004,1.254 | 0.449,0.665,1.066 |
| **FB3** | 1.153,1.283,1.71 | 0.878,1.219,1.7 | 1,1,1 | 0.547,0.642,0.864 | 2.976,3.143,3.45 |

| | | | | | |
|---|---|---|---|---|---|
| **FB4** | 1.203,1.505,1.725 | 0.737,0.911,1.055 | 1.085,1.364,1.778 | 1,1,1 | 3.259,3.512,3.742 |
| **FB5** | 0.899,1.013,1.417 | 1.984,2.129,2.49 | 1.1,1.252,1.384 | 0.669,0.945,1.246 | 1,1,1 |

**Table A5. The fuzzy pairwise matrix of sub-barriers concerning regulatory barriers (TB)**

| Sub-Barriers | RB1 | RB2 | RB3 | RB4 |
|---|---|---|---|---|
| **RB1** | 1,1,1 | 1.153,1.372,1.763 | 0.764,0.94,1.286 | 0.886,1.103,1.427 |
| **RB2** | 0.535,0.695,0.895 | 1,1,1 | 1.031,1.17,1.448 | 0.912,1.128,1.379 |
| **RB3** | 0.799,1.002,1.353 | 0.591,0.783,1.035 | 1,1,1 | 1.142,1.478,1.932 |
| **RB4** | 1.238,1.517,1.904 | 0.744,0.956,1.208 | 1.026,1.281,1.624 | 1,1,1 |

**Table A6. The fuzzy pairwise matrix of sub-barriers concerning technological barriers (TB)**

| Sub-Barriers | TB1 | TB2 | TB3 |
|---|---|---|---|
| **TB1** | 1,1,1 | 1.107,1.36,1.872 | 0.733,0.926,1.292 |
| **TB2** | 0.62,0.693,0.92 | 1,1,1 | 1.012,1.211,1.554 |
| **TB3** | 0.802,1.025,1.411 | 0.738,0.909,1.051 | 1,1,1 |

**Table A7. The fuzzy pairwise matrix of sub-barriers concerning Market barriers (MB)**

| Sub-Barriers | MB1 | MB2 | MB3 | MB4 |
|---|---|---|---|---|
| **MB1** | 1,1,1 | 0.3,0.399,0.54 | 0.341,0.554,0.639 | 0.539,0.589,0.64 |
| **MB2** | 2.006,2.635,3.327 | 1,1,1 | 0.77,0.775,0.895 | 0.808,1.09,1.2 |
| **MB3** | 1.651,1.865,2.545 | 1.083,1.245,1.309 | 1,1,1 | 1.177,1.315,1.537 |
| **MB4** | 1.652,1.869,2.047 | 0.817,0.906,1.121 | 0.567,0.674,0.767 | 1,1,1 |

**Table A8. The fuzzy pairwise matrix of sub-barriers concerning Institutional barriers (IB)**

| Sub-Barriers | IB1 | IB2 | IB3 | IB4 |
|---|---|---|---|---|
| IB1 | 1,1,1 | 0.847,1.003,1.169 | 0.663,0.818,0.97 | 0.67,0.824,1.008 |
| IB2 | 0.9,1.1,1.256 | 1,1,1 | 1.324,1.644,1.808 | 1.871,2.371,2.756 |
| IB3 | 1.071,1.209,1.473 | 0.615,0.571,0.845 | 1,1,1 | 1.368,1.94,2.344 |
| IB4 | 1.052,1.249,1.611 | 0.369,0.474,0.523 | 0.351,0.456,0.715 | 1,1,1 |

**Table A9. The fuzzy pairwise matrix of sub-barriers concerning Environmental barriers (EB)**

| Sub-Barriers | EB1 | EB2 | EB3 |
|---|---|---|---|
| EB1 | 1,1,1 | 0.498,0.451,0.629 | 0.468,0.643,0.722 |
| EB2 | 1.616,2.128,2.328 | 1,1,1 | 0.728,0.724,0.968 |
| EB3 | 1.449,1.621,2.059 | 1.016,1.319,1.491 | 1,1,1 |

**Table A10. The fuzzy pairwise matrix of sub-barriers concerning Social (SB)**

| Sub-Barriers | SB1 | SB2 | SB3 |
|---|---|---|---|
| SB1 | 1,1,1 | 0.432,0.426,0.599 | 0.529,0.637,0.891 |
| SB2 | 1.701,1.989,2.299 | 1,1,1 | 0.784,1.158,1.473 |
| SB3 | 1.363,1.66,2.082 | 1.133,1.344,1.563 | 0.782,0.843,1.111 |

**Table A11. Fuzzy VIKOR Matrix**

| | SO1 | SO2 | SO3 | SO4 | SO5 | SO6 | SO7 | SO8 | SO9 | SO10 | SO11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **FB1** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **FB2** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **FB3** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **FB4** | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 3.4, 5.2, 7.0 |
| **FB5** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **RB1** | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 3.4, 5.2, 7.0 |
| **RB2** | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 7.6, 9.2, 10.0 |
| **RB3** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **RB4** | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 1.2, 3.4, 5.0 |
| **TB1** | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 3.4, 5.2, 7.0 |
| **TB2** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **TB3** | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 7.6, 9.2, 10.0 |
| **MB1** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **MB2** | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 7.6, 9.2, 10.0 |
| **MB3** | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 3.4, 5.2, 7.0 |
| **MB4** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **IB1** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **IB2** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **IB3** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **IB4** | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 3.4, 5.2, 7.0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **EB1** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **EB2** | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.2, 3.4, 5.0 | 1.2, 3.4, 5.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 7.6, 9.2, 10.0 |
| **EB3** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **SB1** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **SB2** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |
| **SB3** | 1.2, 3.4, 5.0 | 3.4, 5.2, 7.0 | 5.8, 7.6, 9.1 | 7.6, 9.2, 10.0 | 1.0, 1.2, 3.0 | 1.0, 1.2, 3.0 | 7.6, 9.2, 10.0 | 5.8, 7.6, 9.1 | 3.4, 5.2, 7.0 | 1.2, 3.4, 5.0 | 5.8, 7.6, 9.1 |