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Resilient and sustainable green technology strategies: A study of Morocco's path toward sustainable development

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A B S T R A C T

This study proposes a strategic framework to develop resilient green technology strategies for sustainable development in Morocco. The fuzzy Delphi method was applied to finalize and categorize the indicators. Twenty-three indicators were identified and grouped into five categories. Furthermore, the fuzzy analytical hierarchical process was used to compute and rank the green technology indicators. The findings indicate that the environmental capital foundation and output efficiency rank the highest among the major categories, with the regulatory measure subindicator being the most important among the twenty-three subindicators. Finally, this study assessed resilient green technology strategies to promote economic and environmental sustainability in Morocco.

1. Introduction

In an era where environmental concerns and social responsibilities are reshaping global economies, sustainable investment has emerged as an essential strategy, fostering innovation in green technology and influencing decision-making among academics and policymakers. The debate around sustainable development has become more important in light of escalating worldwide environmental problems, including global warming, woodland loss, and water pollution. The relationship between environmental protection and corporate strategy is often seen as a trade-off between achieving green objectives and maximizing economic gains, despite the priority placed on sustainability by many organizations. There is an urgent need for integrated strategies that balance sustainable development with economic growth, as both governments and corporations face the challenge of navigating the fine line between embracing environmentally friendly practices and pursuing [1,2].

The United Nations advocated green growth in 2005 as the most effective strategy for sustainable development. According to the Organization for Economic Cooperation and Development (OECD), green growth is an innovative plan for promoting development and economic growth in a nation without harm to the environment or the individuals residing there [3].

The adverse effects of human activity on the global environment have increased the need for sustainable development [4]. In 2015, the Millennium Development Goals (MDGs) expired, and the vacancy was replaced by the Sustainable Development Goals (SDGs) of the post-2015 agenda. With 17 goals that span a wide range of human endeavors throughout the three sustainable development dimensions (financial, social, and environmental), the SDGs also substantially broaden the range of action. These objectives are known as the five Ps of the new agenda people, planet, prosperity, peace, and partnership and are intended to be a plan of action for all nations [5].

Green technologies play a crucial role in achieving the sustainable goals set by the United Nations (UN). The International Energy Agency (IEA) argues that power-efficient infrastructure, green transportation, and renewable energy systems may considerably reduce emissions of greenhouse gases, which are essential for tackling global warming [6]. Green energy innovations also serve as key factors for environmental, social, and economic growth, which are consequently crucial for sustainable development. Morocco's 2030 National Sustainable Development Strategy is currently in operation. The objective of this strategy is to guide Morocco through a progressive shift toward a green economy while considering environmental issues and working to ensure unity in society, human development, and a sustained increase in fiscal competitiveness [7].

As the country is working to address its environmental concerns and reach lofty sustainability targets, the significance of green technologies is becoming more widely recognized. During the Paris-based COP 21, Morocco pledged to strike a legally enforceable and optimistic agreement. With respect to this, Morocco's government released a

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comprehensive plan to greatly increase energy efficiency and improve the proportion of renewable energy in the country's energy mix. With the goal of reaching 52 % of installed power capacity from renewables by 2030, the Moroccan Ministry of Energy, Mines, and Environment, along with the Moroccan Agency for Sustainable Energy [8], have emphasized the nation's commitment to developing green energy systems. By encouraging the growth of the green hydrogen industry, Morocco solidified its status as an energy hub and played a significant role in the worldwide energy revolution. The Kingdom is one of the nations with the greatest likelihood of producing green hydrogen, and by 2030, it could provide over 4 % of global needs. This enables the country to boost its economy and create more job opportunities.

Morocco has made efforts to improve its overall SDG performance, but despite these efforts, its ranking decreased from 69th to 84th, with a score of 68.98, as presented in Fig. 1. While this score is higher than the regional average for MENA, it still falls short of the global SDG score of 70.9 in 2023. In North Africa, Morocco ranks third, behind Tunisia (64th) and Algeria (63rd). Nonetheless, the country remains committed to promoting its global standing and advancing key SDGs, including well-being, renewable energy, economic growth, and public health [9, 10].

One notable illustration of the country's commitment to green technologies is its leadership in renewable energies throughout the Noor Solar Power project located in Ouarzazate Province. Under the direction of the Moroccan Agency for Sustainable Energy (MASEN), the achievement of the Noor Solar Power Project underlines the importance of reducing the footprint and developing an all-encompassing plan to promote sustainable investment. Morocco is currently recognized as one of the pioneers in the worldwide energy transition, particularly in Africa, owing to a number of initiatives to produce power from renewable resources and lessen the impact of industrial global warming [11].

In a similar vein, it aims to support initiatives using green technologies to increase competitiveness, taking into consideration that biodiversity offers a competitive edge and that sustainable development and economic growth are both achievable [12]. Morocco is also recognized among the highest ranked countries in the field of environmental development. In most categories, such as energy consumption, greenhouse gas emissions, and climate policy, the country maintains its top ranking [9]. Accurate forecasting tools play a crucial role in the effective deployment of green technologies, especially in energy markets experiencing rapid changes. With the growing integration of renewable energy sources and technologies like smart grids, it becomes increasingly important to anticipate and manage fluctuations in energy demand and supply. This helps ensure the smooth adoption of green technologies

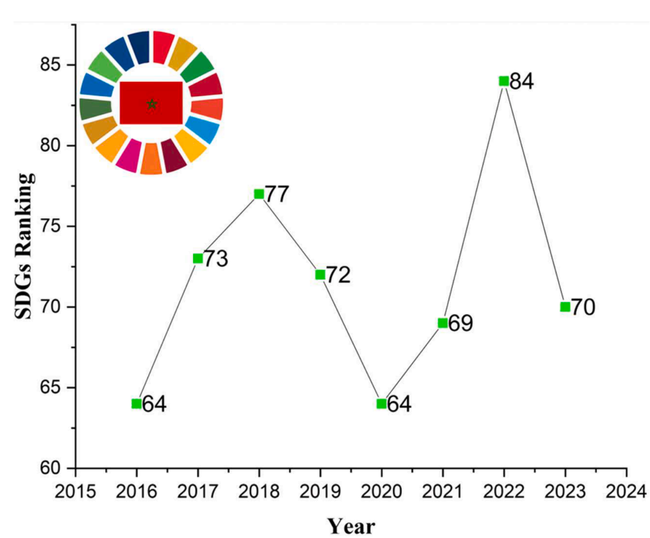

Fig. 1. Morocco SDG rankings from 2016—2023 (Author composition).

while maintaining stability in energy systems [13].

The emerging field of sustainable and responsible investment (SRI) focuses on the integration of environmental, social, and governance (ESG) factors into investment decisions. It seeks to increase financial market accountability to address societal and environmental problems. The previous two decades have seen a rise in the acceptance of sustainable investing, as evidenced by the expansion of mutual funds and indexes that prioritize ESG standards [14].

Like many nations, Morocco has to focus further on developing green technologies to boost its economy and reduce costs. This entails continuous work to improve the performance of solar and wind technology. The lack of financing is another challenge that the country encounters, as it relies on international funding and partnerships, making it economically dependent on other countries and foreign organizations [15]. However, as a consequence of the government's proactive policies and activities, Morocco has achieved remarkable progress in coordinating economic development with sustainability.

To reduce environmental effects and produce environmentally friendly items, firms may implement cleaner manufacturing practices through procedures and activities that support sustainable development [16]. Concurrently, corporations must simultaneously transition to green technology that promotes sustainable development, which benefits stakeholders in the social, environmental, and financial spheres. Hence, businesses should prioritize different aspects of sustainability as important facilitators of technology investments.

In line with this vision, the OCP Group launched a USD 12 billion Green Investment Program for 2023–2027 to improve its mining and fertilizer production capacity while prioritizing sustainability. This ambitious program, which emphasizes the rise of clean energies and creative solutions, is in line with Morocco's energy transition policy and His Majesty King Mohammed VI's vision. By attempting to power its industrial operations entirely with green energy from wind, solar, hydroelectric, and cogeneration sources by 2027, the OCP Group reinforced its commitment to achieving carbon neutrality by 2040.

Despite the country's commitment to moving toward green technology, it remains in the transitional stage, and there is nevertheless a lack of clear classification for these technologies, especially in the energy sector. Despite Morocco's efforts to transition toward green technology, the prior studies reveal a persistent gap in the classification and understanding of these technologies. Most existing studies focus broadly on green technology adoption but fail to address the specific criteria necessary for its effective classification and implementation within the local context. Additionally, the alignment of these technologies with international standards for sustainable growth is often overlooked, leaving policymakers and investors without clear guidance on how to integrate global sustainability practices into Morocco's development strategies. This gap hampers effective decision-making and the formulation of policies that could foster the country's green transition. Moreover, this gap raises an obstacle for policymakers and investors seeking to align their strategies with global standards for sustainable growth. To develop appropriate policies, direct investment decisions, and monitor Morocco's growth in its green technology journey, this gap must be addressed. Therefore, the purpose of this research is to develop a thorough framework for the development and implementation of green technology strategies that draw on sustainable investments and cleaner production and accelerate Morocco's shift to a more environmentally friendly economy. The study uses the TOWS-fuzzy analytical hierarchy process (AHP), which allows the shaping of complex problems to address the decision-making problem. The fuzzy AHP is suitable for this study because it may consider the criteria and subcriteria for the assessment and development of green innovations in Morocco. Bridging a switch to innovative green energy is crucial for minimizing climate change while ensuring Earth's longevity. Furthermore, this research enables Morocco to address the investments in green technology needed to establish a brighter future on the basis of sustainable development principles.

This study develops a multidimensional green technology that focuses on the relationships among cleaner production, sustainable investment, and sustainable development, emphasizing the pivotal role of the SDGs in driving these relationships, as presented in Fig. 2. Green technology acts as a crucial element, linking Cleaner Production, Sustainable Investment, and Sustainable Development, all within Morocco's national sustainability agenda. However, CP is essential for driving technological innovation and green processes, contributing to environmental sustainability through green integration. This process supports the development and adoption of green technology, which is critical for Morocco, as the country seeks to reduce its environmental footprint and promote sustainable industrial practices. Sustainable investment in Morocco is depicted as both a provider of resources and a beneficiary of green technology. By enhancing living standards and profitability, such investments are instrumental in fulfilling SDG targets, particularly in areas such as clean energy, water management, and sustainable agriculture. Sustainable horticulture, especially in areas with difficult climates, is essential for both economic resilience and protecting the environment [17]. Implementing green technologies and innovative farming methods is key to improving efficiency and minimizing losses after harvest. These practices are critical for advancing sustainability and ensuring long-term growth in sectors that rely heavily on natural resources. The strategic advancement and SDG performance depicted in the model illustrate how the SDGs accelerate the development and application of green technology in Morocco, aligning with the nation's Vision 2030 for sustainable development. Moreover, the relationship between green technology and sustainable development is underscored by the SDGs, which guide the fulfillment of Morocco's sustainability goals. By integrating SDG targets into the nation's green technology strategy, Morocco can ensure that technological innovations contribute to broader sustainable outcomes, including economic growth, social equity, and environmental protection. This model highlights the reciprocal and dynamic relationships among these components, with the SDGs serving as catalysts for aligning and advancing each element toward achieving Morocco's global sustainability commitments.

This study is organized as follows. The literature review is presented in section 2. The Fuzzy Delphi and Fuzzy AHP methods are described in section 3. The findings and analysis are explained in section 4. The discussion and implications are presented in section 5, and the conclusion is presented in the last section of the paper.

2. Literature review

The Technology Acceptance Model (TAM) is one of the most impactful frameworks for predicting and explaining technology adoption, and it has been extended over the years to suit various contexts, including green technologies [18]. At its core, TAM posits that perceived usefulness and perceived ease of use are the primary drivers of an individual's intention to adopt a technology, which subsequently influences their actual usage [19]. As environmental concerns grow, the relevance of TAM in the adoption of green technologies has become more prominent, as these factors can strongly impact the adoption of innovations aimed at sustainability, such as renewable energy systems or eco-friendly production methods.

Moreover, TAM integrate additional constructs like perceived risk, trust, innovation culture, and competitive pressure, which are crucial in the context of green technology adoption [20]. For instance, green technologies often face challenges related to perceived risk and high costs, which can delay adoption despite their environmental benefits. Incorporating these factors enhances TAM's predictive power, particularly in understanding how organizations adopt green innovations like AI-driven energy management or eco-efficient supply chain processes [21,22]. Understanding how green technologies can enhance both sustainability and operational efficiency is key to promoting their broader acceptance and integration [23]. Reducing waste and using nontoxic and hazardous substances are the two means by which green innovation can be achieved [24,25]. Additionally, proactively investing in innovative green technologies has been proven to increase organizational

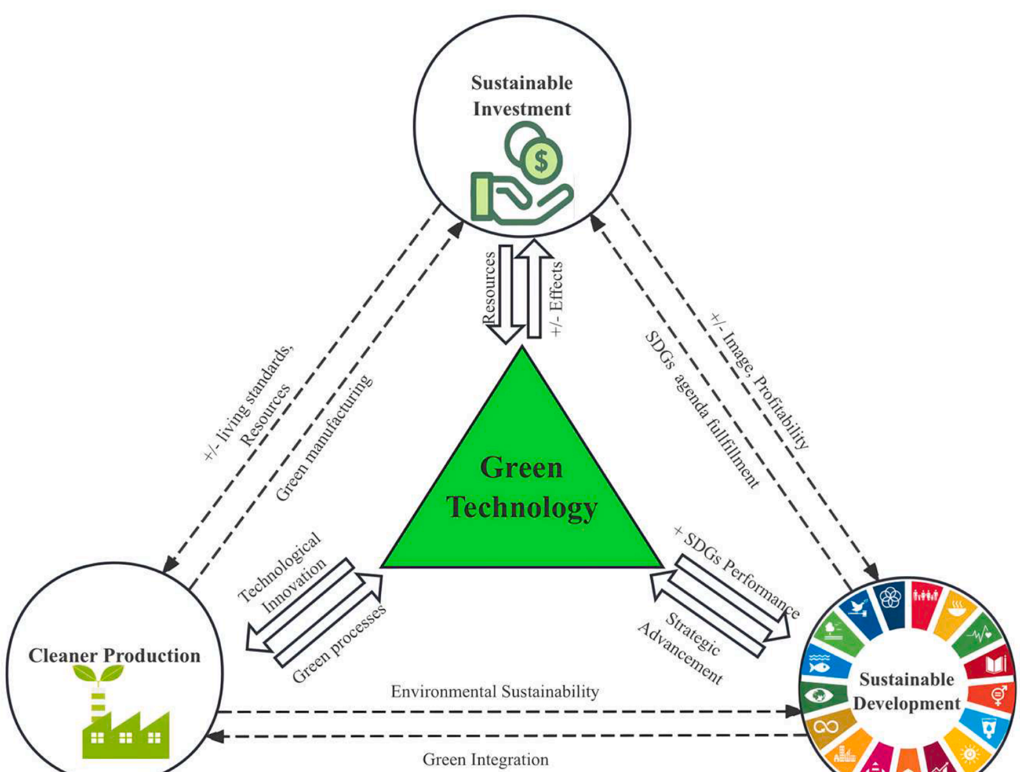

Fig. 2. Green technology framework for cleaner production and sustainable investment (Author composition).

productivity [26]. By building environmental competencies, these proactive approaches also assist corporations in mitigating environmental hazards. However, corporations can strategically minimize potential expenses with the aid of green innovation, which boosts economic performance and promotes sustainability [27].

Green technology is a broadened, interdisciplinary concept that is constantly changing yet lacks a single, universally recognized definition. The lack of a unified classification or set of standards frequently makes it more difficult to determine what exactly qualifies as green technology [28].

Green innovation aims to create and implement green technologies that minimize harm to the environment during manufacturing, implementation, and consumption of goods. These innovations may track, oversee, and mitigate environmental damage at their source. Green technology innovation may assist in reducing emissions, saving energy, properly managing adverse environmental effects, and ultimately enhancing sustainability. This is difficult to execute with current nongreen technology; therefore, only through speeding up green innovation advances might we provide practical assurances for the implementation of green advancement and thus genuinely achieve green growth [29].

According to Hottenrott et al. [30], the deployment of green technologies is the application of innovations intended to lower carbon emissions. This can involve more comprehensive greenhouse gas (GHG) mitigation strategies as well as a reduced use of fossil fuels. Furthermore, this category includes green inventions that emphasize energy and resource conservation. Green hydrogen, a carbon-neutral fuel, has the capacity to significantly reduce greenhouse gas emissions and is essential in combating climate change. As a key component of green technology strategies, its production through renewable sources like wind and solar can accelerate the shift to sustainable energy systems [1,31]. For Morocco, integrating green hydrogen can enhance its existing renewable energy initiatives and support the country's sustainability goals.

As synthesized from the perspective of the OECD (Organization for Economic Co-operation and Development), World Bank green growth is the aim of economic growth and development, but guaranteeing it does not adversely affect ecosystems or renewable resource sustainability [32]. This involves limiting or lessening the impact on the ecosystem by improving productivity, developing new technologies, and implementing regulations that support the sustainable utilization of resources. To accomplish this, it is necessary to encourage innovation and investment, which will sustain steady expansion and open new business opportunities [33]. Innovative green technology is essential for encouraging sustainable investment since it reduces greenhouse gas emissions, increases resource utilization, and fosters eco-innovation.

The implementation of green technologies is crucial for reducing the ecological impact since it promotes cleaner production processes and enhances national and international sustainability objectives. Green technology provides a path to sustainable growth and development while maintaining socioeconomic footprints, as countries work to accomplish sustainable development goals (SDGs), notably those related to climate action and resource conservation [34].

Renewable energy sources, including solar, wind, hydropower, and geothermal energy, have the capacity to meet a substantial portion of global energy needs with no adverse effects on the environment. Adopting green technologies, such as renewable energy and sustainable production methods, is essential for driving long-term environmental and economic sustainability. These technologies help minimize resource depletion and environmental impact, contributing to a more sustainable future [35]. Green energy innovation is crucial for sustainable growth given that it makes it possible to transition from fossil fuels to clean and renewable energy sources. However, there are many obstacles facing green energy innovation, such as a lack of public support and financial, policy, and technical limitations [36]. Despite these challenges, innovation in green energy has much potential to promote economic growth and provide new job opportunities. The utilization of green energy can also ensure the long-term survival of the planet and lessen the effects of global warming.

Although becoming increasingly popular, the concept of "green growth" has suffered from a lack of a clear conceptual framework, which has led to numerous studies aimed at defining it. Notably, the OECD defined green growth in 2009 as a strategy for promoting growth and development in the economy while simultaneously tackling global warming, reducing biodiversity loss, minimizing environmental harm, and guaranteeing sustainable resource use [37]. This specific definition led to the development of a measurement framework with various green growth indicators. Within this framework, this study applies five specific criteria: (1) the Environmental Capital Foundation, (2) regulatory measures, (3) economic performance, (4) living standards, and (5) output efficiency. This dissertation employs these subject areas in the Moroccan context to investigate how green technology techniques might be included in the national economic strategy to promote sustainable investment. The living standards component of green growth monitors how people's social well-being is affected by the resources taken out for economic expansion.

Living standards are an important element, especially when welfare and well-being are considered. This criterion offers a comprehensive picture of a population's quality of life since it includes subcriteria such as exposure to environmental risks, the sufficiency of sewage and waste treatment, the availability of clean drinking water, and the effects of environmental conditions on health. These subcriteria emphasize the direct connection between environmental quality and the health of individuals and communities, highlighting the need for technology that protects populations from environmental hazards while simultaneously meeting basic human requirements [38].

Antonietti and Marzucchi [39] provide strong evidence for the positive influence of greener tangible investment strategies on business efficiency and export performance, thereby contradicting the conventional wisdom that the environment and economic aims are incompatible. Their outcomes imply that investing in environmentally friendly technologies not only boosts the efficiency of an organization but also allows it to enter more tightly regulated overseas markets. This investigation is especially significant since it emphasizes the synergistic potential of sustainability and a strong economy. By illustrating how green technology investment strategies may contribute to a "win−win" situation, improving both the environment and corporate performance, this research reinforces the premise that sustainable investment in green technologies may serve as a vital driver of economic expansion and worldwide rivalry.

Furthermore, Shen et al. [40] explored the impact of green investment, economic growth, and financial growth on environmental pollution in the G-7 economies. found that green investments substantially decrease pollution by improving energy conservation, promoting advances in technology, and improving manufacturing processes. This is consistent with Antonietti and Marzucchi's [39] results, which show that green investments have a positive influence on corporate efficiency and export outcomes. In the G-7 setting, both positive and negative shocks in green investment have been demonstrated to have a substantial relationship with environmental pollution, illustrating the complex dynamics of investment affecting the quality of the environment. These findings indicate that increasing green investment expenditures is a critical strategy for decreasing environmental pollution, backed by the favorable influence of green investments in reducing carbon dioxide (CO2) emissions in G-7 nations over both short and long horizons.

Technological innovation is critical for lowering greenhouse gas emissions and creating sustainable growth strategies. A study of OECD nations revealed that technical advances significantly reduce greenhouse gas emissions through R&D investment and education while also moderating the influence of growing economies on emissions [41].

While sustainable investing examines a wide range of ESG factors, green finance explicitly stipulates the financial instruments required to promote environmentally conscious activities. As evidenced by Nepal et al. [42], green financing has had a substantial effect on the renewable energy industry by supporting the switch to clean sources of energy and increasing the effectiveness of energy use. Furthermore, such transformation improves the durability of the renewable energy system, making it a vital component of sustainable growth.

Perry [43] reported that Morocco should take additional mitigation measures to minimize the amount of carbon in the energy sector to meet its climate change (NDC) commitments and make further efforts to promote an effective transition to a sustainable economy. Moreover, it must invest further in renewable energy and improve its energy performance to ensure a reliable energy supply and sustainable growth.

To address the adverse effects of global warming, governments use measures such as subsidies, direct regulation, and environmental taxes. While critics believe that rigorous environmental rules may inhibit private investment and restrict economic expansion, studies show that environmental taxes may improve the environment, economic performance, and use of resources, supporting green growth [44].

According to Chen et al. [45] and Asadi et al. [46], governments that have firm commitments to sustainability are increasingly regarded as better positioned to capitalize on investment in green technology, which is vital for increasing energy efficiency, preventing pollution, and recycling waste. The contemporary environmental background emphasizes the urgent need for these technologies, which require increased business dedication to accomplish sustainable development objectives. Investment in green technologies arises as a tactical approach to achieve these goals while enabling a pathway not only for adherence but also for supporting sustainable development and economic growth [41]. Green technology strategies play a vital role in addressing both environmental challenges and improving human well-being. Artificial Intelligence (AI) based Indoor Environmental Quality (IEQ) systems significantly influence behavioral changes, leading to enhanced health and productivity. For instance, AI-technology-driven improvements in IEQ have been shown to boost productivity, with notable positive impacts on both the psychological and physical health [47].

Sustainable rules play an important role in encouraging businesses to invest in green technology, which is a critical method for addressing diverse issues related to the environment. These restrictions frequently act as catalysts, urging enterprises to comply with the wider sustainable growth goals established by authorities. Governments provide favorable conditions for such investments by creating regulations, providing financial support, and carrying out detailed legislation [48].

Taxation of energy and other commodities is critical in stimulating the implementation of green innovations, acting as an effective tool for supporting investments in green technologies [49]. This fiscal method encourages enterprises to embrace eco-friendly activities by increasing the cost of unsustainable resources, ultimately moving businesses toward greener decisions.

3. Research framework and methods

A systematic approach was employed to carry out this research. First, an extensive literature review of relevant studies was conducted to identify green technology indicators. The Delphi method was subsequently used to finalize and categorize the green technology indicators within the context of Morocco. Finally, the FAHP was applied to assign weights to the indicators and rank them according to their importance.

There is currently no established benchmark for determining the appropriate number of experts to be involved in this study. Earlier research, data analysis was performed by various numbers of experts to obtain appropriate findings. For example, Solangi et al. (2021) hired 10 specialists to analyze data to identify obstacles to renewable energy to develop a sustainable energy plan. Kansara et al. [50] employed the expertise of eight professionals to assess supplier evaluation using FAHP, a method particularly suitable for managing uncertainty and disruptions, such as those caused by events like COVID-19, to ensure reliable vendor supplies. Further, Wang et al. (2019) employed the FAHP with the assistance of five experts to determine Pakistan's important sources of renewable energy with the goal of promoting equitable development. Fifteen relevant experts were involved in the Delphi and FAHP processes. The group consisted of five university professors, four senior research fellows, two board members from Morocco's Ministry of Energy Transition and Sustainable Development, and four investors.

3.1. Fuzzy delphi method

The fuzzy Delphi approach proposed by Hsu et al. [51] is often used to classify criteria in the area of decision analysis. The key benefit of fuzzy Delphi lies in the fact that it is deeper than the standard Delphi method in gathering expert feedback. Furthermore, by constantly asking experts to modify their input to settle on a potential consensus, the traditional Delphi approach is complex and continuously experiences low convergence, which leads to errors in expert consensus and increases the length of time consumed [52]. On the other hand, specialists can reach consensus after a single phase of research when the fuzzy Delphi technique is implemented. The function for membership is used by the fuzzy delphi technique to describe the thoughts of the specialists. To describe the level of fuzzy membership, previous studies have employed Gaussian fuzzy numbers, trapezoidal fuzzy numbers, and triangular fuzzy numbers (TFNs). This study opted for the use of TFNs in the construction of the membership degree function. Triangular fuzzy numbers (TFNs) were therefore used in this study to create the membership degree function. To be more exact, TFNs were used to convert assessments that were deemed biased into figures that accurately represented the level of the membership function. By using this method, expert perspectives are represented more accurately, and the decision-making process is strengthened. To determine the point of convergence that reflects the consensus of the specialists, the geometric average is used to resolve the TFNs. The structure of the fuzzy Delphi method procedure is as follows:

Phase 1: Consider that the significance given to the ith component ($i = 1,2,3\ldots, m$) by the jth expert ($j = 1,2,3\ldots, n$) is denoted by $wij = (aij, bij,cij)$. The fuzzy weight of the ith element ($i = 1,2,3\ldots, m$) is then indicated as $wi = (ai, bi, ci)$, where the ai, bi, and ci components are computed as follows:

$$a_i = Min\{a_{ij}\} = b_j = \frac{1}{n} = \sum_{i=1}^{n} b_{ij},\ c_i = Max\{c_{ij}\} \tag{1}$$

Phase 2: This step entails converting fuzzy weights into accurate weights Si via the center-of-gravity method. It can be expressed as follows:

$$S_i = \frac{\sum a_i, b_i, c_i}{3} \tag{2}$$

Phase 3: The last stage of our process analyzes each criterion's value to an initial threshold, represented by the character $\widetilde{a}$, to choose the criteria for green technology. This cutoff point is determined by taking the average of all the weights given to the various criteria. A criterion is selected if its value is above or equivalent to $\widetilde{a}$; otherwise, it is eliminated from further consideration. The fuzzy analytic hierarchy process (FAHP) is used in this approach to determine the relative weights of the primary and secondary sustainability factors for businesses. Decision-makers assist with the procedure by employing relative importance matrices to guarantee a thorough and organized assessment.

3.2. FAHP

The analytical hierarchical process (AHP), which is extensively employed in multiple fields of science, is acknowledged as a particularly flexible multicriteria decision-making (MCDM) technique for managing intricate decision-making situations. For an alternative set of possibilities, the AHP foundation uses a ratio scale to determine the decision maker's participation. This strategy is currently applied in a variety of industries and is among the best-suited multicriteria decision-making (MCDM) strategies for resolving complicated challenges in decision-making [53].

To maximize results in the decision-making process, this technique measures the instinctive input of leaders and evaluates coherence. To increase its efficacy, the analytic hierarchy process (AHP) may be used with a number of techniques, including envelopment analysis of data, fuzzy set theory, gray system theory, and linear programming. Although the AHP excels at capturing decision-makers' perspectives, it has some drawbacks because human assessment may be biased in certain ways. These constraints involve the inability to handle expert input that is erratic or disproportionate, difficulties interpreting the opinions of a variety of specialists and unclear system connections, decreased reliability of the results, and a propensity for decision-makers to base their decisions subjectively.

Hence, the use of fuzzy set theory improved the AHP method. The FAHP is frequently used to deliver the most effective responses for complex decisions since it is more precise than conventional models are. [54]. Fuzzy set theory and advanced adjusted AHP are referred to as the FAHP, where each membership component is represented by a membership function. Moreover, each inclusion element is further broken down into levels of inclusion, which vary from 0 to 1. Complete inclusion in the set is indicated by a degree of 1, whereas absenteeism is indicated by a degree of 0. Partially included in the set is marked by any degree that falls within these two extremities; it quantifies the element's degree of membership. To address ambiguities in the estimation stage, fuzzy numbers must be used as the basis for the linguistic membership functions. Consequently, in the fuzzy analytic hierarchy process (FAHP), these linguistic values are represented by triangular fuzzy numbers (TFNs).

FAHPs are commonly used in many different disciplines and are well known for their strong characteristics. The applications encompass a range of tasks, such as determining the importance of social aspects associated with business sustainability [55], assessing the prospects for groundwater in semiarid regions [56], selecting novel methods for production [57], assessing the requirements for fog cloud computing platforms (Ogundoyin and Kamil, 2020), deciding on green tourism sustainability [58], locating optimal sites for the development of hybrid renewable energy systems [59], recognizing risk variables that promote the spread of COVID-19 [60], and choosing suitable aircraft types [61].

To prioritize green technology in Morocco, the FAHP framework comprises six phases:

Stage 1: In this step, the hierarchical structure of the problem is designed.

Stage 2: One of the most important steps in the FAHP method is creating an importance scale for relative importance comparisons after the hierarchical problem architecture has been established. This ranking system, which ranges from 1 to 9, uses triangular fuzzy numbers (TFNs) to help professionals select investments in Morocco's green technology on the basis of their numerical values. There are five TFNs: $\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, and $\tilde{9}$. These TFNs are outlined in Table 1. By efficiently capturing and quantifying expert opinions, such TFNs reduce ambiguity and uncertainty throughout the review process. To further assist in the methodical assessment and elucidation of the criteria for decision-making, Fig. 3 also shows the fuzzy inclusion functions implemented for the main and subcriteria.

Table 1
Triangular fuzzy number criteria with linguistic variables.

Linguistics variable	Triangular fuzzy Numbers	Fuzzy Value	AHP Scale Equivalent
Extreme preference	(7,9,11)	$\tilde{9}$	9
Very strong preference	(5,7, 9)	$\tilde{7}$	7
Strong preference	(3,5,7)	$\tilde{5}$	5
Moderate preference	(1,3,5)	$\tilde{3}$	3
Equal preference	(1,1,3)	$\tilde{1}$	1

Stage 3: To prioritize green technology investments in Morocco, the method entails creating a fuzzy comparative matrix. Triangular fuzzy numbers (TFNs) were used by specialists to conduct relative importance comparisons for this assessment. The arithmetic mean of the specialist contributions was used to create a fuzzy comparison matrix, or matrix Z, which synthesized these comparisons. Eq. (3) summarizes the above process by formalizing the collection of inputs from experts into a thorough fuzzy assessment instrument. This facilitates methodical decision-making concerning the order of importance for green technology.

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

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 $i \neq j$. The reciprocal of the scores is obtained by reversing the Z matrix comparison to calculate each pair's score. Suppose that if $\tilde{Z}_{ij}$ is the value of matrix Z representing the connections of components i and j, then $\tilde{Z}_{ij} = \frac{1}{\tilde{z}_{ij}}$.

Stage 4: The next step focuses on building a clear comparison matrix with the α-cut approach to improve the accuracy of specialist decision-making contributions. The α-cut approach was first introduced by Adamo in 1980 and makes managing fuzzy numbers easier by identifying areas within the values that match the α value. Setting the value at α=0.5 and applying it to the TFN results in an interval of $a_{0.5} = (2,3,4)$, as presented in Fig. 4.

The numerical value of a is fixed and modified according to the estimation level required to satisfy the Z matrix criteria by taking into account the optimism index μ on the basis of the fuzzy comparison matrix. One can construct the following α-cut comparison matrix.

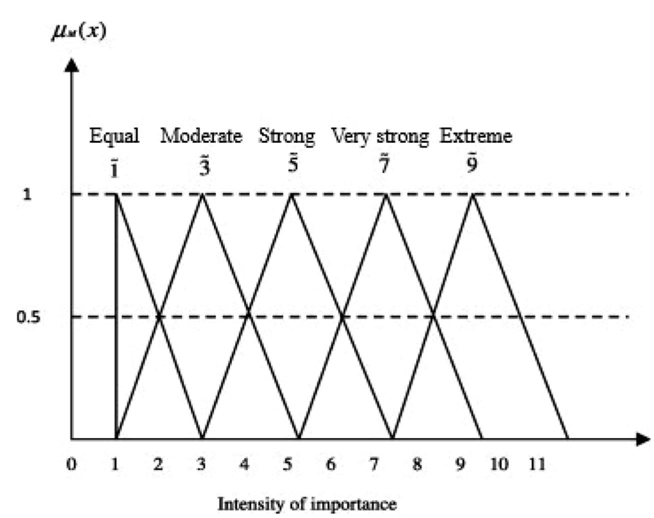

Fig. 3. Fuzzy membership function for linguistic variables.

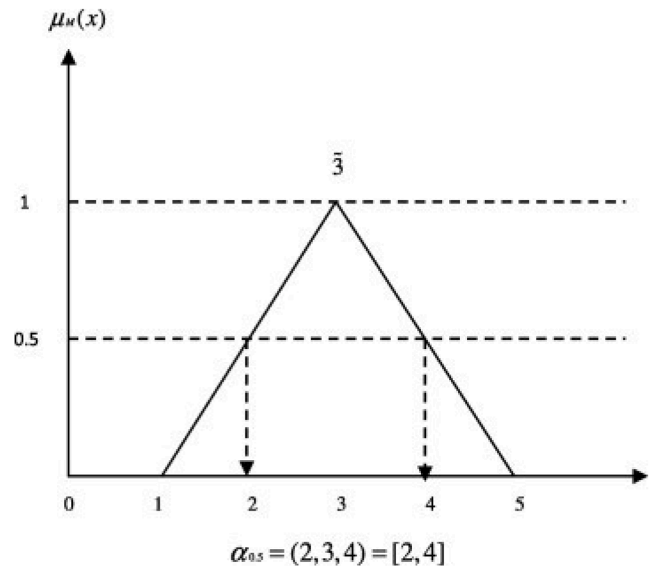

Fig. 4. α-cut operation on a TFN (shah et al., 2019).

$$\tilde{Z}^{\alpha} = \begin{bmatrix} 1 & \tilde{b}_{12}^{\alpha} & \dots & \dots & \tilde{b}_{1n}^{\alpha} \\ b_{21}^{\alpha} & 1 & \dots & \dots & \tilde{b}_{2n}^{\alpha} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{b}_{n1}^{\alpha} & \tilde{b}_{n2}^{\alpha} & \dots & \dots & 1 \end{bmatrix} \quad (4)$$

The character μ denotes the degree of satisfaction or trust among decision-makers and is used as an index of optimization within the selection matrix. Decision-makers' level of trust in their choices is gauged by this index, where a greater score of μ denotes a greater degree of contentment or conviction in the choice made. A linear convex conjunction is integrated into the approach used to calculate μ; this idea was first proposed by Lee et al. in 1999. This methodology efficiently measures the degree of agreement or inclination that decision-makers hold for particular options inside the framework for decision-making, capturing their trust in and optimism for the evaluation.

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

The inclusion of μ in Eq. (5) transforms the fuzzy similarity matrix with α-cut to the sharp comparison matrix Z. The following is an illustration of the new form of matrix z:

$$Z = \begin{bmatrix} 1 & b_{12} & \dots & \dots & a_{1n} \\ b_{21} & 1 & \dots & \dots & b \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ b_{n1} & b & \dots & \dots & 1 \end{bmatrix} \quad (6)$$

Stage 5: Evaluating the consistency

A consistency ratio (CR) was used to examine each matrix's coherence as well as the general uniformity of the hierarchical structure with the goal of validating the specialist's evaluation. As a result, Z ̃, a consistent fuzzy comparison matrix, is created from the continuous sharp comparison matrix Z.

Eq. (7) has the greatest eigenvalue of the matrix determined by the subsequent equation.

$$X_v = \ \lambda_{\max} v \quad (7)$$

where v indicates the main eigenvector value of the matrix.

The CR is subsequently applied for relative importance comparison to confirm the input that was acquired via the judgment of the specialist technique. The calculation formula of the CR is shown in Eq. (8).

$$CR = \frac{CI}{RI} \quad (8)$$

$$CI = \frac{\lambda_{\max} - k}{k-1} \quad (9)$$

CI represents the Consistem Index, and RI, depicted in Table 2, represents the Random Index. Additionally, the term k refers to the size of the matrix involved.

Any matrix that has a CR value of <0.10 is considered to be in the acceptability range; if nonetheless, the experts' procedure must be repeated in the relative importance comparison matrix until the outcomes improve.

Stage 6: Calculation of the weights for the criteria

The final phase of the FAHP development process is to normalize some or all of the columns and rows of matrix Z to estimate the weights associated with green technologies.

The TWOS-AHP has been used to determine the order of strategic initiatives, ensuring that each plan is in line with both internal resources and external market dynamics. TOWS evaluation is an advanced combination of analytical methods intended to improve decision-making and assist in the establishment of accurate strategies [62]. The methodological framework of green technology via TWOS-FAHP is presented in Fig. 5.

4. Results

An extensive literature review was conducted to identify and shortlist green technology indicators relevant to the Moroccan context. The search involved keywords such as "Sustainable investment and cleaner production indicators in Morocco," "environmental issues in Morocco," and "green growth challenges in Pakistan." The primary search engines used included Google Scholar, Science Direct, and Google. Using the Delphi method, twenty-three green technology indicators were finalized for Morocco. These indicators were grouped into five major categories: environmental capital foundation, regulatory measures, economic performance, living standards, and output efficiency. Within these categories, five subindicators were identified under an environmental capital foundation, five under regulatory measures, four under economic performance, four under living standards, and five under output efficiency. The classification of these indicators is presented in Table 3.

4.1. Fuzzy Delphi

The minimum acceptable score for fuzzy Delphi scores is determined via the average of the green technology criteria, which is 5. The green technology criteria that earned a rating of five or above (Score ≥5) are retained, while the remaining criteria are eliminated. Table 4 contains the environmental capital foundation, regulatory measures, economic performance, living standards, and output efficiency, which are the five accepted main criteria with values above five (score ≥5). This suggests that experts concur that these criteria are significant and pertinent for addressing in this research. There is sufficient agreement on this point to say that these criteria should be examined. Additionally, four main criteria were rejected on the basis of the fuzzy Delphi scores, for which a value of less than five was obtained (score ≤ 5). Resource utilization, transportation, nepotism and agriculture/forestry. This rejection only means that these criteria are not important enough to be included in this specific study. Their lower ratings in this Delphi procedure do not mean

Table 2
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

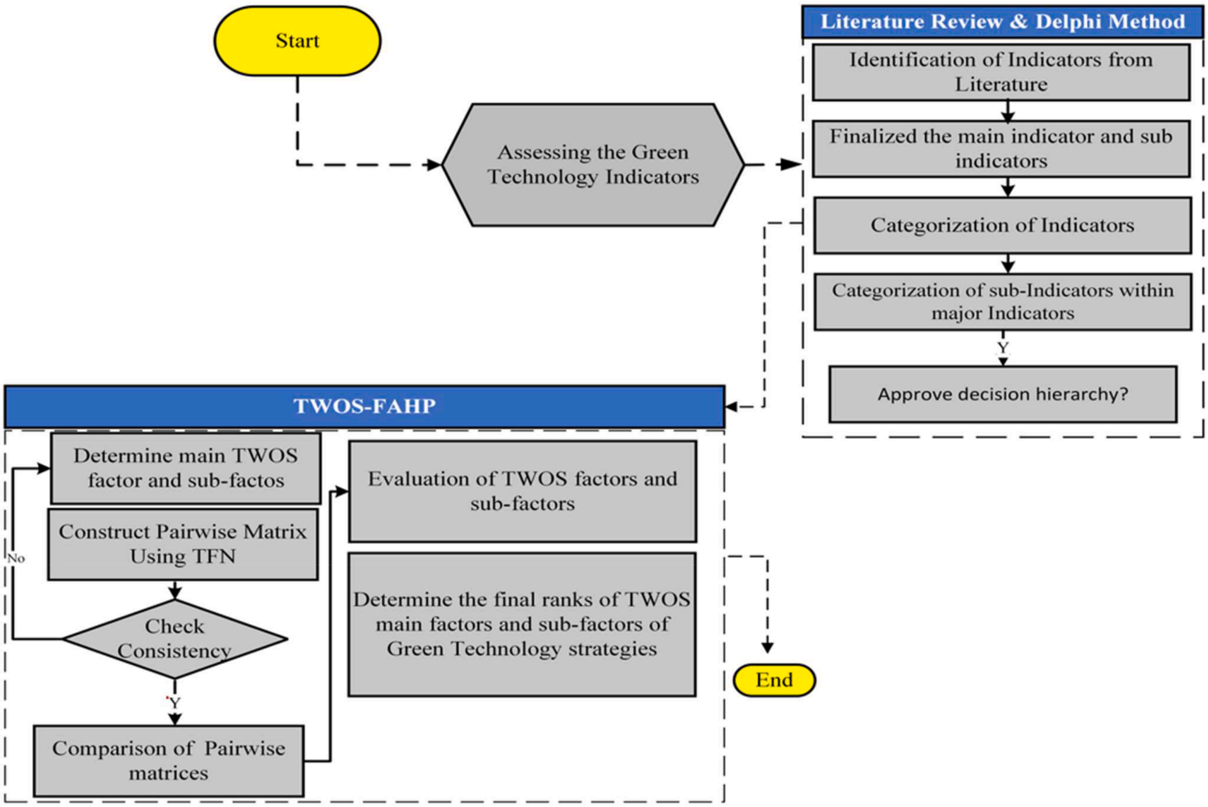

Fig. 5. Methodological framework for green technology via TWOS-FAHP (Author composition).

that they are not significant in aggregate; rather, they imply that they failed to meet the threshold in this context. The five accepted criteria constitute the primary emphasis of this study. These criteria, which exhibit a significant consensus among the experts, are regarded as robust and crucial for the analysis. Furthermore, the inclusion of these five key areas provides a comprehensive framework for evaluating sustainable investment and green technology strategies, ensuring that the most impactful factors are addressed. This focused approach helps streamline the research and target the areas with the greatest potential for driving sustainability initiatives forward in Morocco.

4.2. FAHP main criteria

Using a relative importance matrix as the basis, the FAHP approach was applied in the following step of the study. This matrix was generated by adopting the geometric average algorithm to determine each expert's rating separately. As mentioned before, five main criteria were selected on the basis of the experts' perspectives. Each criterion has between four or five subcriteria, which are crucial for enhancing and improving the analysis since they dissect each primary criterion into deeper subcriteria.

The FAHP itself contains two sections. The weights of the five most important primary criteria for green technologies are determined and included in the AHP approach. The calculation of subcriteria weights is covered in the second section of the FAHP. The rankings of the main criteria of Green Technologies are presented in Table 5.

Fig. 6 visually organizes the different components related to the concept of green technology into five main criteria: the Environmental Capital Foundation, regulatory measures, economic performance, living standards, and output efficiency. In addition, there are 23 subcriteria

Table 5 shows the weights of each main criterion calculated via the FAHP technique. The Environmental Capital Foundation was ranked 1st with the highest weight (27.26 %) out of the five primary criteria, making it the most impactful. Output efficiency was ranked second with a weight of 25.52 %, followed by regulatory measures with a weight of 18.15 %, living standards with a weight of 15.78 %, and economic performance with a weight of 13.29 %. The fact that the Environmental Capital Foundation is the most crucial criterion can be justified by serious environmental issues such as drought, water scarcity, and declining biodiversity that Morocco is currently facing. This emphasis highlights the crucial role of ecological sustainability in Morocco's strategic plan for green technology growth. Morocco's financial objectives are further supported by giving the Environmental Capital Foundation the highest priority, especially in the renewable energy sector.

The second highest score of output efficiency emphasizes the significance of evaluating the efficiency with which resources are transformed into outputs, indicating an emphasis on increasing productivity and decreasing waste in both economic and environmental endeavors. Morocco's efforts to improve output efficiency are paying off, as reflected by a gradual rise in green growth efficiency in recent years [32]. These initiatives most likely target increasing energy efficiency, process innovation, and technological adoption—all important elements that support sustainable development and efficient production of goods and services while lowering harmful emissions. The expert's critical evaluation method was used to evaluate each of the 23 green technology subcriteria, as indicated by the relative importance matrix.

4.3. FAHP subcriteria

4.3.1. Environmental capital foundation

Fig. 6(a) presents the ranking of the environmental capital foundation subcriteria as follows: ECF5 > ECF4 > ECF3 > ECF2 > ECF1. ECF5, which represents air and climate quality, has a weight of 33.33 %, followed by wildlife conservation, with a weight of 27.67 %. According to the Ministry Delegate, which is responsible for the environment, the costs of ecological damage in Morocco amount to 4 % of GDP, whereas

Table 3
Decision subcriteria of green technologies.

Main Criteria	Main criteria Code	Sub-Criteria	Subcriteria code
Environmental Capital Foundation	**ECF**	Land quality Forest coverage Water quality & availability Wildlife conservation Air & Climate quality	**ECF-1** **ECF-2** **ECF-3** **ECF-4** **ECF −5**
Regulatory Measures	**RM**	Advancing Innovation: R&D and patents International Financial Flows Environmental management policies Environmental Taxes& Transfers Compliance Rates	**RM-1** **RM-2** **RM-3** **RM-4** **RM-5**
Economic Performance	**ECP**	Social equity in green access Economic growth from green sector Investment in sustainable infrastructure Access to green financing	**SEF-1** **SEF-2** **SEF-3** **SEF-4**
Living Standards	**LS**	Exposure to Environmental Hazards Adequacy of sewage and waste treatment Accessibility to clean drinking water Health impacts due to environmental factors	**LS-1** **LS-2** **LS-3** **LS-4**
Output Efficiency	**OE**	CO2 emissions Renewable energy share in total energy production Efficiency of resource use in production Economic output adjusted for environmental factors Rate of recycling and material recovery	**OE-1** **OE-2** **OE-3** **OE-4** **OE-5**

Table 4
Results of fuzzy Delphi.

Indicators	A	b	c	Fuzzy Delphi Scores	Selected √/Rejected×	Indicator code
Environmental Capital Foundation	3	5.74	10	6.65	√	ECF
Resource Utilization	3	2.72	10	2.38	×	R ES
Regulatory Measures	0	6.81	5	5.99	√	RM
Transportation	3	5.07	7	3.57	×	T RP
Economic Performance	3	8.58	10	6.17	√	ECP
Living Standards	3	8.12	10	7.40	√	LS
Nepotism	0	2.10	5	2.67	×	N OP
Output Efficiency	3	5.88	10	6.44	√	OE
Agriculture/ Forestry	3	7.70	10	3.60	×	A GF

the costs of air quality degradation are approximately 1.03 % of GDP. Morocco prioritized the issue of air pollution to address this condition, although it is not an industrialized nation. In this context, the national sustainability plan and wellness should prioritize the battle against the deterioration of air quality [63]. The air quality in Morocco tends to exceed the WHO yearly limit by 1.8 times, indicating that there is potential for improvement. Figs. (7a–7e) Classify the subcriteria for green

Table 5
Ranking of the main criteria of Green Technologies.

Main Criteria	Code	Weight	Rank
Environmental Capital Foundation	ECF	0.2726	1st
Regulatory Measures	RM	0.1815	3rd
Economic Performance	ECP	0.1329	5th
Living Standards	LS	0.1578	4th
Output Efficiency	OE	0.2552	2nd

technology.

Owing to the photochemical processes promoted by its sunny climate, Marrakech has a complex pollution profile with high levels of NO2, PM10, and ozone (O3), especially during spring and summer. Towns such as Casablanca and Khouribga have high NO2 levels because of their outdated car fleets [64].

By implementing cutting-edge technologies and enacting stronger emission regulations, Morocco may be able to lower its air quality and comply with global environmental requirements.

Morocco has been identified as the second-richest nation in the Mediterranean Region behind Turkey in terms of biodiversity. With a wide variety of ecosystems, habitats, and species, it has high biological richness [65]. To sustain healthy ecosystems, preserve the ecological balance, and increase biodiversity, wildlife is vital. The importance of safeguarding animal habitats, maintaining species variety, and providing healthy natural resources for subsequent generations is reflected in the designation of protecting wildlife (ECF4) as a second major subcriterion. Water quality & availability. ECF3 and forest coverage (ECF2) are ranked third and fourth, with scores of 20 % and 13.33 %, respectively. Alternatively, land quality (ECF2) is the least impactful subcriterion, with a weight of (6.67 %).

4.3.2. Regulatory measures

The subcriteria of the regulatory measures criterion are shown in Fig. 7(b) and are ranked as follows: RM4>RM2 >RM5>RM1>RM3>. The three most influential subcriteria are Environmental Taxes & Transfers (RM4), which obtained a weight of 32.12 %; International Financial Flows (RM2), with a weight of 26.06 %; and Compliance Rates, with a weight of 20 %. According to the World Bank report, Morocco is exploring carbon pricing schemes and has achieved considerable strides in environmental fiscal changes, notably in fuel taxation after subsidies were removed. To maintain the polluter-pays concept, the country has banned plastic bags and instituted waste management costs (World Bank, 2023).

Major indicators, including investment, consumption, and production development, are efficiently controlled by taxation tools [66]. Morocco seeks to encourage these sectors to adopt more environmentally friendly practices while maintaining stability and economic expansion through carefully modifying their tax regulations.

Morocco has been collecting a sizable number of financial inflows, comprising both governmental and private funds, according to the latest OECD data. These grants are used to support a range of national development initiatives that improve the country's economic and social structures. An increasing amount of foreign capital entering Morocco is moving toward funding vital areas that are essential to sustainable development, such as research and development (R&D), the generation of renewable energy, and the implementation of clean energy systems, including hybrid technology [9]. According to the financial stability report, to handle international trade in a way that promotes Morocco's sustainable development priorities, such as lowering carbon emissions and improving energy efficiency, strict regulatory procedures are controlled by organizations such as Bank Al-Maghrib.

Compliance Rates (RM5) and Advancing Innovation: R&D and patents (RM1) are ranked third and fourth, with scores of 20.00 % and 13.94 %, respectively. In contrast, environmental management policies (RM1) are the least influencing subcriteria within the regulatory

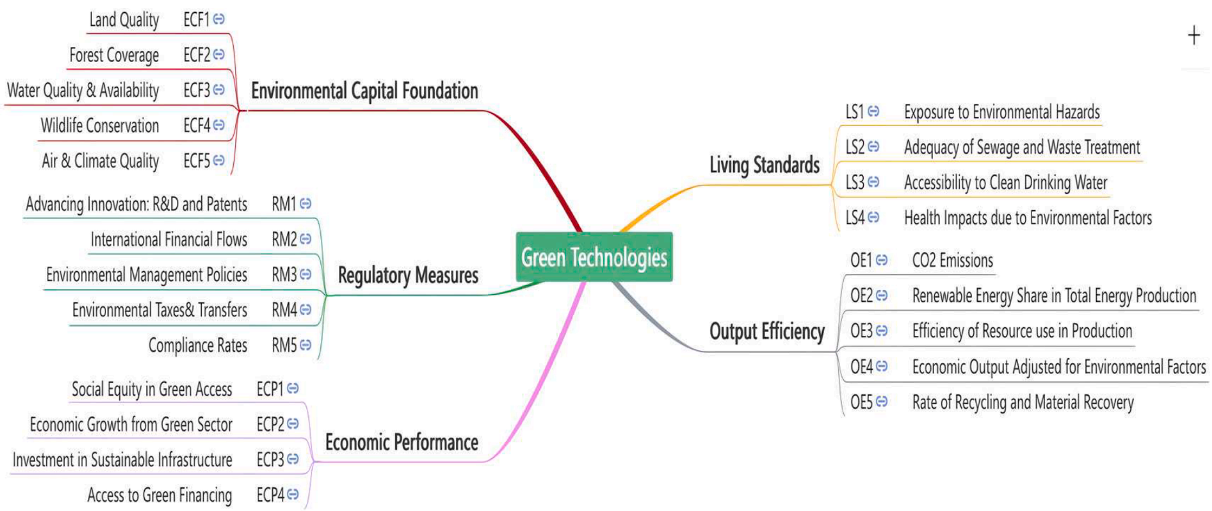

Fig. 6. The structure of the green technology criteria and subcriteria (Author composition).

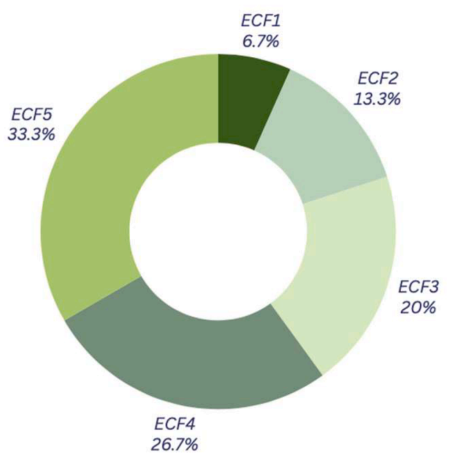

Fig. 7(a). : Ranking of the Environmental Capital Foundation Subcriteria.

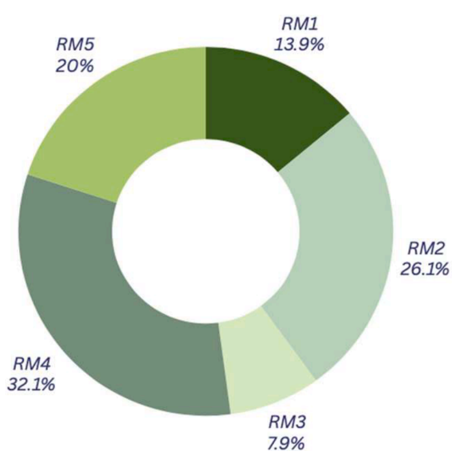

Fig. 7(b). : Ranking of Regulatory Measures Subcriteria.

measures category, with a weight of 7.88 %. Hence, regulatory measures are crucial components, as they uphold financial security by averting market biases and augmenting reliability and openness in the execution of investments.

4.3.3. Economic performance

Under the economic performance criterion category, the following ranking sequence of subcriteria is obtained: ECP4>ECP3>ECP2>ECP1. as shown in Fig. 7(c). Access to green financing (ECP4) was the most significant and influential subcriterion within the category, with a score of 43.25 %. According to the World Bank, green financing is essential for developing green technological innovation, boosting economic growth, and improving energy security. The acquisition of significant green funding and investment in initiatives that promote sustainability is key to this strategy. Financing significant advances in renewable energy industries such as hydroelectric, solar, and wind power requires such financing methods [67]. The subcriterion that obtained the highest weight (31.08 %) within the category was investment in sustainable infrastructure (ECP3). The fact that this subcriterion is given priority shows that infrastructure is strategically recognized as a crucial component of sustainable economic growth and plays a crucial role in Morocco's larger economic strategy, which aims to achieve resilience and sustainability over the long run.

Barrios-Crespo et al. (2021) argued that funding environmental policy, ecological restoration, and green infrastructure would be extremely profitable. In particular, the results point to a high rate of return on investment, with advantages of up to 100 euros for every euro invested in these projects. This not only validates but also strongly encourages greater financial investment in sustainable practices and regulations.

According to the World Bank, Morocco's funding for climate action is

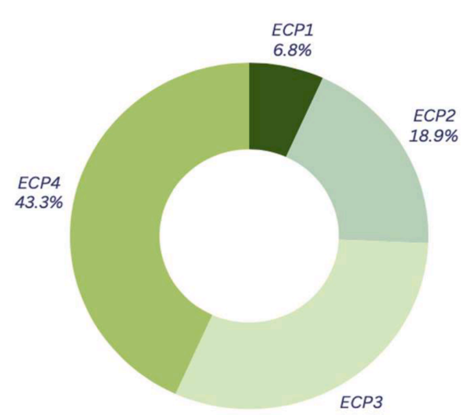

Fig. 7(c). : Ranking of Economic Performance Subcriteria.

anticipated to have a significant positive impact, including the creation of jobs and the kingdom's status as a center for green industry, both of which are consistent with the country's larger development objectives. Furthermore, the European Bank for Reconstruction and Development (EBRD) has additionally made substantial investments in green bonds to fund environmentally friendly infrastructure initiatives, such as Morocco's high-speed train line, which is anticipated to improve sustainable transportation and lower carbon emissions. Two hundred million MAD (or €19.2 million equivalent) is invested in green bonds by EBRD.

Economic growth from the green sector (ECP2) ranks third in the economic performance category, with a score of 18.92 %. In contrast, the least influencing subcriterion within the category is economic inclusivity in green access (ECP1), with a score of 6.75 %. Morocco is moving toward an era where environmental sustainability and economic development complement one another, proving that it is possible to successfully combine sustainability goals with economic performance.

4.3.4. Living standards

Under the living standard category, the outcome in Fig. 7(d) presents the subcriteria in the following sequence of significance: LS4>LS1> LS2 >LS3. Health impacts due to environmental factors (LS4) obtained the highest score (42.39 %) within the category, which underscores the important linkage between environmental quality and public health. The strong link between environmental sustainability and public health is demonstrated by the fact that addressing these ecological problems can significantly improve public health outcomes, lower costs associated with healthcare and enhance the general standard of life. Exposure to environmental hazards (LS1) and the adequacy of sewage and waste treatment (LS2) ranked second and third, with weights of 30.80 % and 19.20 %, respectively. As mentioned before, Morocco has had to address issues such as managing waste, shortages of water, and air pollution, all of which have had an impact on the health of the population. For example, excessive levels of air pollution in towns such as Casablanca contributed to pulmonary and cardiovascular disorders among individuals. Therefore, Morocco must address these negative health effects via environmentally sound measures. Stricter rules on emissions from manufacturing, greater investment in renewable energy to mitigate air pollution, improved air quality evaluation, and clean water delivery systems are a few examples of sustainable measures. According to the experts' feedback, accessibility to clean drinking water (LS3) is the least important subcriterion in this category, as it has a score of 7.61 %.

Proper decentralization is essential for improving sustainable development in Morocco, especially in underprivileged areas. Morocco may empower the local population to create and carry out policies that directly address their unique environmental and developmental challenges by increasing their autonomy (Ibourk et al., 2021). By improving the ability of local authorities and communities to handle public affairs successfully, this approach increased the standard of living for all Moroccan people and led to a more equitable allocation of resources.

4.3.5. Output efficiency

Under the output efficiency category, the results presented in Fig. 7 (e) enabled the identification of the following ranking sequence: OE1>OE2>OE3>OE5>OE4. CO2 emissions (OE1) are presented as the most influencing subcriterion within the category, with a rate of 30.38 %. In environmental economics, the link between economic development and CO2 emissions is a complicated and frequently debated subject. According to the Environmental Kuznets Curve (EKC) theory, there is a U-shaped inverse correlation between economic development and environmental damage. Specifically, CO2 emissions initially increase as economies develop but then decrease gradually after a particular level of income per capita is achieved [68]. Morocco may achieve its green aims, promote energy conservation, and decrease its carbon footprint by emphasizing lowering CO2 emissions. The experts' emphasis on CO2 emissions demonstrates how Morocco is successfully prioritizing sustainable practices and green technologies that help minimize greenhouse gas emissions.

The second highly rated subcriterion in this category is the renewable energy share in total energy production (OE2), which yields a weight of 25.19 %. Over the past 20 years, there has been a shift toward renewable energy (RE), which has highlighted its vital role in the global sustainability of the environment and economic growth. Renewable energy is a means of boosting economic independence and lowering carbon emissions for developing nations, where power imports can represent a substantial financial burden [69]. Following these two major subcriteria, the efficiency of resource use in production (OE3) ranks third within the output efficiency category, with a weight of 20.00 %. In contrast, the least influencing subcriteria within the category are the rate of recycling and material recovery (OE5), with a weighted score of 14.81 %, and the economic output adjusted for environmental factors (OE4), with a weight of 9.62 %.

4.4. Final ranking

The ultimate ranking of the subcriteria is established by multiplying the subcriteria of the global weights by the weight for every corresponding category, as illustrated in Table 6 and Fig. 8.

With respect to the classification of the subcriteria of this study, the subcriteria are ranked as follows:

$$RM5 > LS2 > ECF3 > OE1 > ECP2 > ECF4 > ECF1 > ECP1 > OE4 > RM4 > LS1 > RM2 > OE5 > ECF2 > LS4 > ECP3 > ECF5 > OE3 > LS3 > RM3 > ECP4 > OE2 > RM1$$

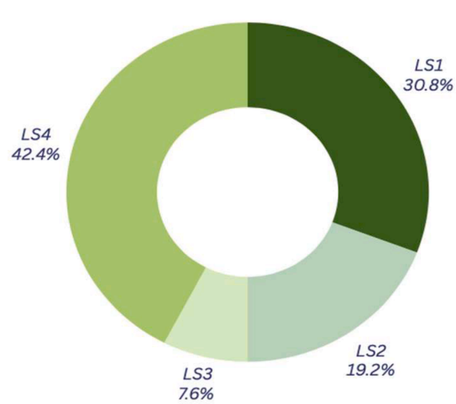

Fig. 7(d). : Ranking of standard living subcriteria.

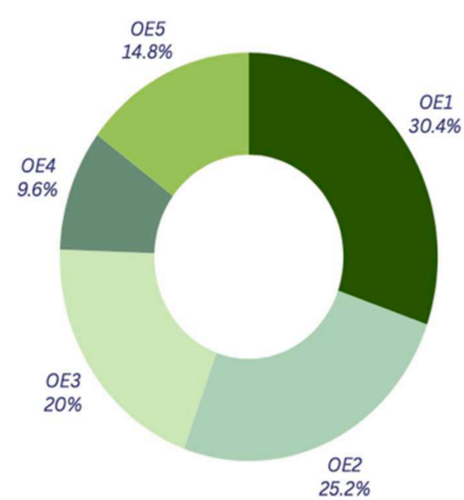

Fig. 7(e). : Ranking of Output Efficiency Subcriteria.

Table 6
Final weights of green technology.

Main Criteria	Main Criteria Weights	Sub-Sub Criteria codes	Consistency Ratio (CR)	Global Weight	Local weight
Environmental Capital Foundation	0.2726	ECF1	0.1743	0.0668	0.0590
		ECF2		0.0411	0.0370
		ECF3		0.0743	0.0654
		ECF4		0.0697	0.0614
		ECF5		0.0281	0.0259
Regulatory Measures	0.1815	RM1	0.1791	0.0103	0.0147
		RM2		0.0320	0.0401
		RM3		0.0167	0.0222
		RM4		0.0422	0.0521
		RM5		0.0590	0.0814
Economic Performance	0.1329	ECP1	0.2671	0.0225	0.0551
		ECP2		0.0256	0.0620
		ECP3		0.0095	0.0264
		ECP4		0.0069	0.0207
Living Standards	0.1578	LS1	0.0114	0.0844	0.0492
		LS2		0.1271	0.0735
		LS3		0.0430	0.0256
		LS4		0.0503	0.0297
Output Efficiency	0.2552	OE1	0.3681	0.0610	0.0623
		OE2		0.0152	0.0171
		OE3		0.0241	0.0259
		OE4		0.0521	0.0534
		OE5		0.0381	0.0397

The TWOS evaluation and fuzzy approach provided a strategic analysis of opportunities by assigning numerical weights to each plan, which were then ranked by their relative importance, as shown in Table 7. The top strategy, labeled ST2, is to develop stringent environmental taxes and transfers to ensure air and climate quality, with the highest score of 8.82 %. Strategies SO3, WO3, and SO2 follow closely, ranking second, third, and fourth, with scores of 7.32 %, 7.29 %, and 7.08 %, respectively.

ST2, the highest-ranked strategy, is vital for leveraging Morocco's strengths to mitigate environmental risk. The implementation of stricter environmental taxes and transfers is aimed at reducing greenhouse gas emissions and other pollutants, thus preserving air and climate quality. This strategy not only ensures compliance with regulatory standards but also promotes financial accountability and environmental stewardship, which are essential for sustainable development. Fig. 9 presents the SO, WO, ST and WT strategies of green technology for cleaner production and sustainable investment in the context of Morocco.

The high ranking of SO3 highlights its potential to drive Morocco's

Table 7
Final weights of the TWOS strategies.

TWOS Strategies	Strategy Criteria	Consistency Ratio	Overall Weight	Ranking
Strength-Opportunity Strategies (SO)	SO1	0.18286	0.0463	15th
	SO2		0.0708	4th
	SO3		0.0732	2nd
	SO4		0.0590	11th
Strength-Threat Strategies (ST)	ST1	0.17806	0.0699	5th
	ST2		0.0882	1st
	ST3		0.0683	6th
	ST4		0.0512	14th
Weakness-Opportunity Strategies (WO)	WO1	0.26334	0.0528	13th
	WO2		0.0639	7th
	WO3		0.0729	3rd
	WO4		0.0450	16th
Weakness-Threat Strategies (WT)	WT1	0.00764	0.0624	8th
	WT2		0.0593	10th
	WT3		0.0550	12th
	WT4		0.0618	9th

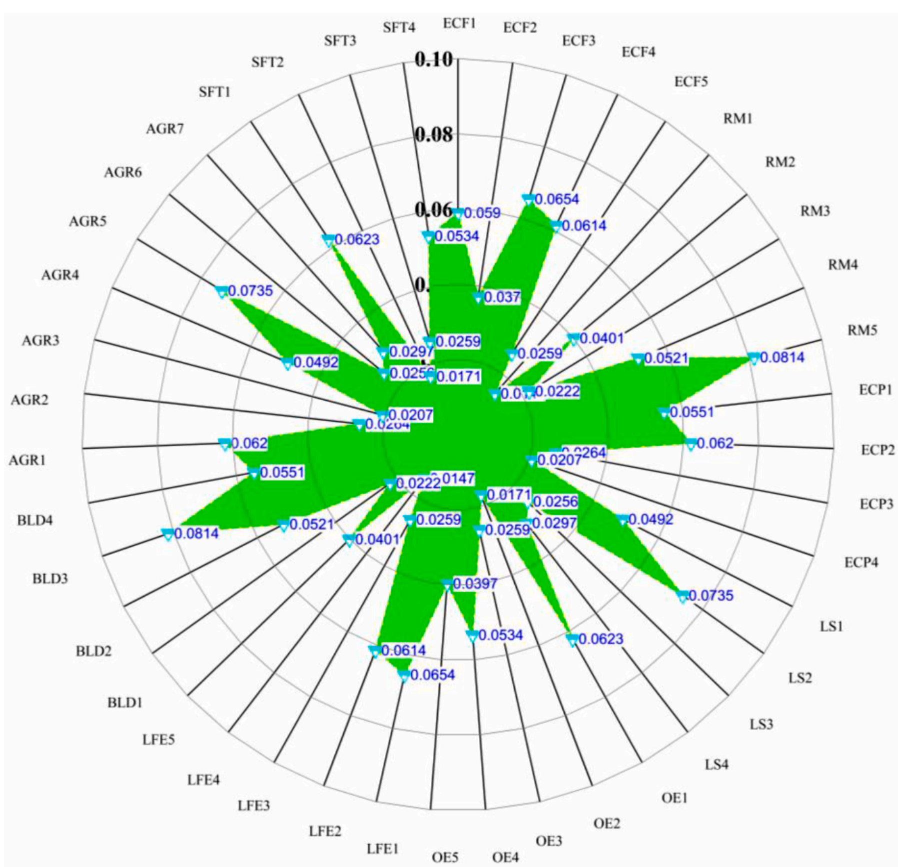

Fig. 8. Overall ranking of the green technology criteria TWOS Strategies Analysis (Author composition).

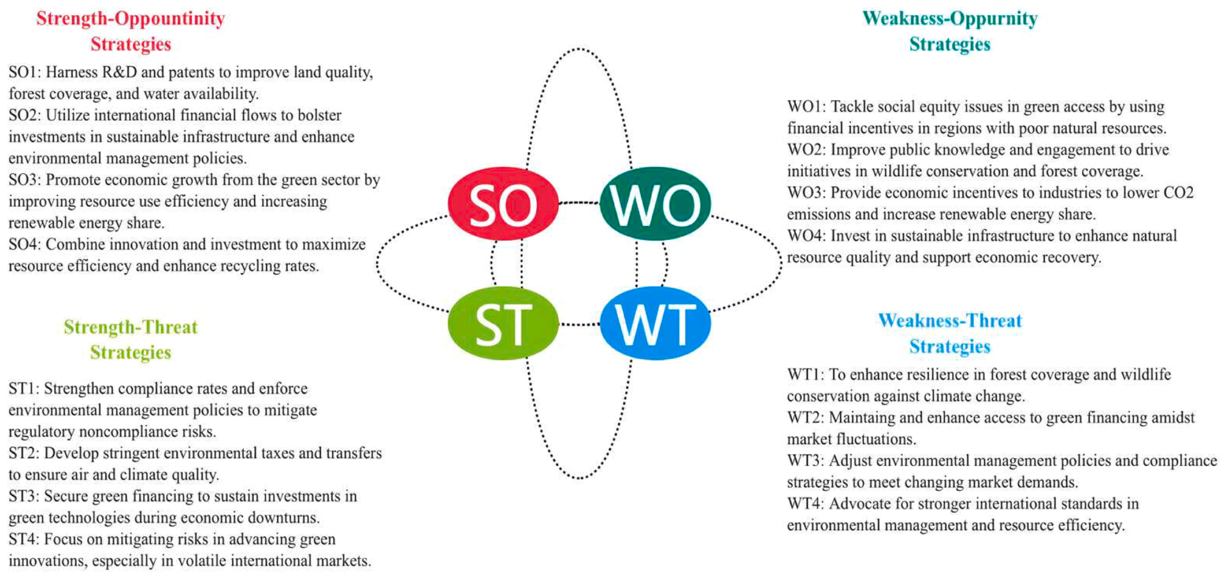

Fig. 9. Resilient green technology strategies for sustainable development (Author composition).

economic growth through green industry. This strategy supports environmental goals by increasing the share of renewable energy and improving resource efficiency, thereby reducing reliance on imported fossil fuels, creating local jobs in green sectors, and fostering financial sustainability.

WO3, the third most critical strategy, focuses on encouraging the adoption of greener innovations within industries through financial incentives, turning disadvantages into competitive advantages. This plan directly contributes to national and international sustainability goals by reducing greenhouse gas emissions and increasing the share of renewable energy while also attracting sustainable investment.

Finally, SO2, ranked fourth, aims to capitalize on viable opportunities by strategically leveraging Morocco's strengths and global financial flows. Strengthening environmental management regulations and investing in green technology are crucial for transitioning to a green economy and achieving future sustainability targets. These ratings effectively transform complex strategic assessments into actionable goals, guiding stakeholders toward the most beneficial and impactful strategies for achieving green growth and environmental sustainability in Morocco. This systematic approach to prioritization ensures that strategic efforts align with the most urgent needs and potential outcomes, fostering a stronger and more resilient economic landscape.

5. Discussion and policy implications

Our investigation identified important strategic targets necessary for supporting sustainable investment and cleaner production in the region, which translates with Morocco's wider ecological and economic goals. This discussion highlights the relevance of our research to the scholarly landscape, as it examines its practical implications for policymakers, industry stakeholders, and the general public. Environmental taxes and transfers are efficient instruments for shaping corporate behavior and investment decisions. Governments can discourage ecologically adverse activities and shift investment toward greener options by levying fees on emissions or the use of resources. A greenhouse gas tax, for example, motivates firms to cut emissions or move to sources of clean energy to mitigate the tax's financial impact. Environmental taxes, which serve as crucial instruments for governments to preserve the environment and conserve resources, provide many benefits. In the near future, they effectively limit polluters' emissions and promote the sensible use of ecologically friendly industrial materials [70]. In the long run, they promote technological advancement, resulting in higher manufacturing productivity and market competitiveness [71].

Investments in clean energy sources enable fulfilling national energy requirements in an environmentally conscious way, as it promotes Morocco as a regional leader in green technology, perhaps leading to new opportunities. This may give rise to more foreign investment, technological transfers, and alliances, benefiting the regional green tech economy. The involvement of the government in fostering these industries through supportive laws, focused R&D funding, and the creation of platforms for innovation is critical to achieving these objectives. The integration of technologies in sustainable practices such as utilizing clean energy and optimizing processes technologies, is essential for improving the efficiency of supply chains and supporting environmental sustainability [72,35].

Furthermore, financial incentives are essential for minimizing obstacles to embracing green technologies. Incentives such as tax exemptions, reduced tariffs on renewable energy supplies, and funding for green technology R&D might render it economically viable for enterprises to invest in improvements and upgrades that lower the ecological impact.

Various studies endorse the idea of providing economic incentives along with regulatory frameworks to increase the implementation of green technologies and minimize greenhouse gas emissions [73]. Saqib et al. [74] emphasized the effectiveness of financial incentives in driving innovation and the adoption of cleaner technologies. Financial incentives are important, as they reduce the financial hurdles that businesses may encounter while they transition to green technologies or activities. For example, green energy incentives can lower the initial investment rates of solar or wind power structures, rendering these technologies more affordable and fiscally viable for enterprises. In a similar vein, tax breaks or exemptions for goods that satisfy specific sustainability standards may motivate corporations to develop and use environmentally friendly manufacturing procedures. Moreover, combining these financial instruments with environmental economic strategies that focus on structural modifications, such as establishing sustainability standards and eco-labels, guarantees that the transition to green technologies is financially driven yet culturally embedded. This comprehensive approach not only encourages immediate reductions in CO_2 emissions via rewarded initiatives but also encourages a wider shift in society toward environmental sustainability, which is critical for the foreseeable feasibility of such sustainable development objectives. These strategies demonstrate the complicated strategy required to shift sectors efficiently to lower greenhouse gas emissions and increase reliance on sources of clean energy, complementing Morocco's dedication to sustainable growth and environmental stewardship.

5.1. Managerial implications

The study outcomes have important managerial policy implications for Morocco's efforts to enhance green technologies and sustainable investment. Fiscal incentives may foster private investment in green technologies. The government can create and enforce policies that promote green innovation and ensure fair competition for green projects. Uniform laws and rules reduce investment ambiguity and promote green innovation. The recommended options provide a pathway for building a more durable and resilient energy system while preventing the damaging impacts of global warming. By encouraging environmentally friendly investment, a country could greatly decrease its carbon footprint, helping drive a global move toward renewable energy sources. This proactive plan not only targets local sustainability objectives but also connects with global initiatives to prevent environmental deterioration, emphasizing the importance of strategic investments in ensuring long-term ecological and climatic stability. For successful implementation of the recommended green technology alternatives in Morocco, a holistic approach that combines supportive regulatory structures, the involvement of stakeholders, and infrastructure improvements is needed. Reforms to regulations and monetary incentives, such as environmental taxes, subsidies, and grants, are critical to boosting corporate and public acceptance of green technologies. Adopting green technologies could lead to significant social benefits, including job creation in renewable energy sectors, which can reduce unemployment and improve livelihoods. Additionally, increasing public awareness of sustainability and environmental protection can foster a culture of eco-friendly practices. By engaging local communities and stakeholders, Morocco can build a more resilient society that actively participates in the transition to a green economy, thus ensuring long-term social cohesion and sustainable development.

Furthermore, ongoing monitoring and evaluation should be carried out to evaluate performance and adjust methods when necessary, guaranteeing that the initiatives remain viable and in line with Morocco's sustainable development goals.

5.2. Theoretical implications

The theoretical contribution of our research includes fostering the implementation of green technologies. Our results illustrate the alignment of green technology investments with green growth and a sustainable economy. The idea of investing in green technologies not only reduces environmental harm but also boosts the economy, reflecting the win–win situation commonly raised in sustainable growth debates mentioned in the literature. Moreover, this research contributes to the discipline of investment theories by concretely proving that investing in green technologies has a significant influence on the Moroccan economy. Our findings are strongly linked to theoretical frameworks underlying the spread and acceptance of new technologies.

According to the assessment, the deployment of supportive legislation and strategic government measures, such as green taxes and financial incentives, may significantly enable the widespread use of green technologies among corporations. This finding aligns with innovation theory, which argues that positive governmental action plans and financial incentives play a key role in stimulating the adoption of innovations and new environmentally friendly technologies.

6. Conclusion

This research aimed to develop a green technology strategic framework for sustainable investment and cleaner production in Morocco by utilizing an integrated TWOS-fuzzy AHP method. The study identified and selected green technology indicators relevant to sustainable investment and cleaner production in Morocco from the literature, which were then refined with expert input via the fuzzy Delphi method. The twenty-three green technology indicators were categorized into five primary groups: environmental capital foundation, regulatory measures, economic performance, living standards, and output efficiency. The weights of these indicators were determined via the fuzzy AHP approach. The results indicate that the Environmental Capital Foundation and Output Efficiency exert the most significant influence among the five categories. Notably, the most impactful subcriteria include compliance rates (RM5), the adequacy of sewage and waste treatment (LS2), and water quality and availability (ECF3), with weights of 8.14 %, 7.35 %, and 6.54 %, respectively. This study represents the first attempt to assess green technology indicators for sustainable investment from a Moroccan perspective.

This study makes valuable contributions by employing TWOS analysis to prioritize and implement sustainable investment strategies. The TWOS framework was utilized to assess the threats, weaknesses, opportunities, and strengths within Morocco's sustainable investment landscape thoroughly. As a result, three key strategic priorities were identified: implementing stringent environmental taxes and transfers to safeguard air and climate quality (ST2), driving economic growth in the green sector by enhancing resource efficiency and increasing the share of renewable energy (SO3), and offering economic incentives to industries to reduce CO2 emissions and expand the use of renewable energy (WO3).

The first strategy focuses on ensuring air and climate quality through robust legislation and regulations. By enforcing strict environmental taxes and facilitating transfers, Morocco can encourage businesses to adopt cleaner, more environmentally friendly practices, thereby reducing waste and greenhouse gas emissions. The second strategy involves optimizing resource use and increasing the proportion of renewable energy within the national energy mix. By emphasizing the green sector, Morocco can minimize its environmental impact while leveraging the economic potential of green technologies and businesses. The third strategy highlights the importance of providing financial incentives to companies to lower CO2 emissions and increase the adoption of clean energy sources. These incentives could take various forms, such as funding, tax breaks, and grants, all aimed at motivating businesses to invest in green technologies and transition to sustainable practices.

To successfully implement green technology strategies in Morocco, a comprehensive approach involving policy reforms, stakeholder collaboration, and infrastructure upgrades is essential. Clear regulatory frameworks, along with incentives like subsidies and tax breaks, can drive industries to adopt more sustainable practices. Encouraging partnerships between the public and private sectors will further enhance resource efficiency and promote technological innovation. Regular assessments of these initiatives will help Morocco remain on course to meet its sustainability and economic objectives.

This study has several limitations that could be addressed in future investigations. The analysis was limited to Morocco; thus, its recommendations may not apply to other regions. This study covers a limited set of green technology indicators in context of Morocco. The future research could cover a wide range of green technology indicators in different sectors to perform a more comprehensive examination of green technology strategies. The recommended green technology initiatives are based on expert perspectives, which may not adequately reflect the needs and concerns of all interested stakeholders. This constraint underlines the possibility of a divergence between the suggested approaches and the broader concerns of stakeholders, which might influence the practicality and adoption of the offered strategies across diverse sectors and groups. Future studies might bridge this gap by embracing a wider spectrum of expert inputs to guarantee that the strategies proposed are inclusive and relevant to the needs of the community. While these limits are accepted, it is critical to note the significant benefits gained from investigations such as these, as well as the countless potential for future study.

CRediT authorship contribution statement

Muhammad Ikram: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Jinane Es Sadki:** Writing – original draft, Visualization, Validation, Investigation, Data curation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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