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Landscape Scenario Archetypes for Desertification-Prone Oases: A Resilience Framework for the Drâa Valley

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Abstract

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Oasis regions in southern Morocco face intensifying desertification, water scarcity, and socio-economic pressures that erode long-term resilience. This paper examines how landscape scenario design can inform future-oriented strategies for the Drâa Valley. Integrating STEEP trend analysis, landscape assessment, and two rounds of participatory survey. The study identifies key drivers and community preferences and constructs four plausible socio-ecological scenarios, Oasis Minimisation, Oasis Emancipation, Rural Abandonment, and Rural Refuge, translating each into spatial design principles for the Drâa Valley's desertification-prone oases. Its principal contribution is a landscape scenario building-block framework that establishes an operational link between identified drivers and spatial interventions, moving scenarios from narrative to implementable design. Findings indicate that combining traditional oasisification practices with contemporary landscape strategies can strengthen ecological functioning, water management, and adaptive capacity. The results suggest that landscape scenario archetypes offer an effective means of exploring alternative futures and informing decisions in desertification-prone regions.

Keywords: Landscape Scenario Archetypes ; Desertification; Oasis Resilience; STEEP Drivers; Participatory Planning

1. Introduction

Desertification represents one of the most pressing environmental challenges facing arid and semi-arid regions globally, with profound implications for ecosystem services, agricultural productivity, and human livelihoods (Barbero-Sierra et al., 2015). The United Nations Convention to Combat Desertification defines desertification as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, 2017). Morocco, particularly its southern regions, faces acute desertification threats driven by water scarcity, soil salinization, sand encroachment, and socio-economic transformations that collectively undermine the resilience of traditional oasis systems (Karmaoui, 2015).

The Drâa Valley in southern Morocco exemplifies these challenges. As one of Morocco's most important oasis territories, the valley has sustained human settlement for centuries through sophisticated traditional water management systems, multi-layered agricultural practices, and vernacular architecture adapted to extreme aridity (Lightfoot, 1996; Baglioni et al., 2016). However, contemporary pressures - including climate change, groundwater depletion, rural-urban migration, and evolving governance structures - have destabilized these time-tested systems, raising urgent questions about the region's environmental and social future (Berger et al., 2021; Johannsen et al., 2016).

Despite growing recognition of desertification as a multidimensional phenomenon requiring holistic responses, research on oasis resilience has largely focused on technical interventions in water management or agricultural productivity, with limited attention to scenario-based design approaches that could guide long-term strategic planning (Karmaoui & Moumane, 2016). Existing studies have documented the environmental degradation of Moroccan oases (Lamqadem et al., 2017; Ait Lamqadem et al., 2018), analyzed socio-economic transformations (de Haas, 2003; Sobczak, 2008), and examined traditional knowledge systems (Laureano, 2012), yet few have systematically explored alternative futures through integrated landscape scenarios that link environmental drivers with spatial design.

This research addresses this gap by developing landscape scenario archetypes as a framework for exploring plausible futures for the Drâa Valley and informing resilience-oriented design strategies. Building on scenario planning methodologies from landscape ecology and futures studies (Hunt et al., 2012; Börjeson et al., 2006), this study constructs scenarios that represent distinct socio-ecological trajectories shaped by governance structures and social values. The research explicitly positions scenarios not as predictions but as exploratory tools that mediate between uncertainty and design action, enabling stakeholders to envision alternative pathways and their spatial implications (Dockerty et al., 2006).

The objectives of this research are threefold: first, to identify and analyze the key STEEP drivers shaping desertification processes in the Drâa Valley; second, to develop four landscape scenario archetypes representing alternative futures for the region; and third, to translate these scenarios into spatial design principles for the Drâa Valley's desertification-prone oases, demonstrated through M'hamid as a representative site. The research asks: How can landscape scenario archetypes inform resilience strategies for desertification-prone oases? What spatial interventions emerge from contrasting governance and social paradigms? And how do traditional oasisification practices relate to contemporary landscape strategies in scenario-based planning?

Unlike conventional scenario-based approaches that remain at the level of narrative exploration, this research introduces a landscape scenario building block framework that establishes a direct and operational link between identified drivers and spatial design interventions. This enables scenarios to function not only as exploratory tools but as implementable design mechanisms within landscape planning processes.

2. Theoretical Background and Key Concepts

2.1 Desertification and Oasis Systems

Desertification is a complex and multi-dimensional process that affects both natural systems and human settlements, particularly in arid and semi-arid regions. In oasis environments, this process is intensified due to the fragile balance between limited water resources, agricultural productivity, and socio-economic stability (Mahmoud et al., 2009). Traditionally, oasis systems have functioned as highly adaptive landscapes, structured around a symbiotic relationship between human activity and natural resources. The typical oasis model is characterised by a multi-layered agricultural system, where date palms form the upper protective layer, followed by fruit trees and ground crops. This configuration creates a controlled microclimate that maximises productivity while minimising water loss (Oberlack et al., 2019). However, increasing pressures such as water scarcity, soil salinisation, and climate variability have disrupted this balance, leading to declining ecological performance and increased vulnerability to desertification. These processes are further intensified by socio-economic transformations, including migration, shifts in land use, and changes in local management systems (Boschetti et al., 2016; Hunt et al., 2012). The structure and functioning of oasis systems are illustrated in Figure 1.

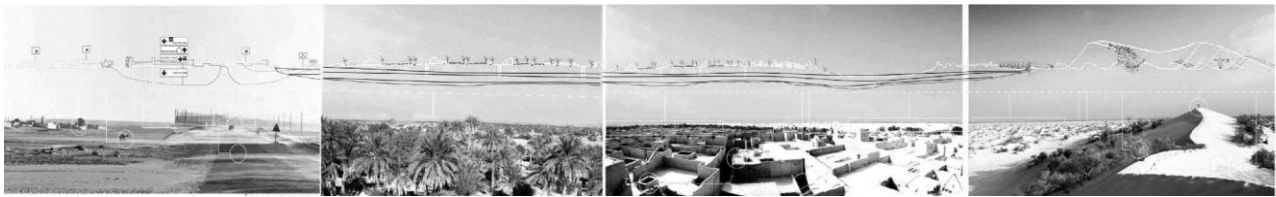


Figure 1. Cross-section of oasis system illustrating vegetation stratification, water management, and microclimatic regulation.

2.2 Scenario Planning and Landscape Approaches

Scenario planning has been widely used as a tool to explore uncertain futures, particularly in contexts where long-term environmental and socio-economic changes are difficult to predict. Unlike predictive models, scenario approaches allow for the exploration of multiple plausible futures, providing a framework for understanding the potential consequences of different development pathways (Baker et al., 2004; Mahmoud et al., 2009). Within landscape architecture, scenario-based approaches enable the integration of spatial, ecological, and social dimensions into a coherent structure. They support the interpretation of complex systems and facilitate communication between different stakeholders involved in planning processes. However, while scenario planning is effective in generating future narratives, its application in spatial design often remains limited, with a lack of clear mechanisms for translating scenarios into actionable interventions.

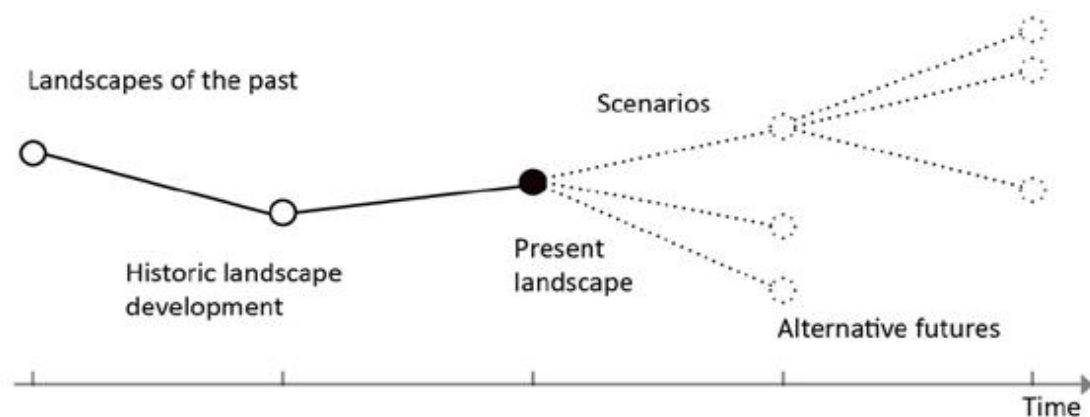


Figure 2. Scenario framework illustrating alternative futures and archetypal trajectories (based on Hunt et al., 2012).

2.3 Scenario Archetypes and STEEP Drivers

In order to construct meaningful future scenarios, it is necessary to identify and organise the driving forces that influence system dynamics. Scenario archetypes provide a structured approach to this process, allowing for the classification of trends and the development of comparable future conditions (Boschetti et al., 2016). The number of scenarios typically ranges between three and six, with four scenarios being the most commonly adopted configuration in scenario planning studies (Hunt et al., 2012). This structure enables the representation of contrasting yet plausible futures within a clearly defined framework.

The identification of key drivers is supported through the use of analytical tools such as the impact–uncertainty matrix, which ranks drivers according to their level of influence and degree of uncertainty (Maack, 2001). This process allows for the selection of the most critical variables that shape future outcomes. To ensure a comprehensive understanding of the system, the STEEP framework (Social, Technological, Economic, Environmental, Political) is employed to categorise and analyse the drivers influencing desertification processes. This approach enables the integration of multiple dimensions of change and supports the development of holistic and context-specific scenarios (Maack, 2001; Hunt et al., 2012). Furthermore, the use of archetype-based scenarios has been applied in various environmental contexts to explain large-scale transformations and their impacts on local systems (Oberlack et al., 2019). This reinforces the relevance of scenario archetypes as a methodological tool for addressing complex socio-ecological challenges.

2.4 From Scenario Narratives to Spatial Design

To construct plausible scenarios, it is necessary to define a set of variables that reflect the identified drivers and their interactions (Mahmoud et al., 2009). However, a key limitation in existing scenario-based approaches lies in the gap between conceptual scenario development and practical spatial implementation. While scenarios effectively describe potential futures, they often remain abstract and lack direct applicability within design processes. This limitation is particularly evident in landscape architecture, where the translation of narratives into spatial strategies is essential for implementation.

This research addresses this gap by introducing the concept of landscape scenario building blocks, which function as an intermediate layer between scenario narratives and spatial design. These building blocks represent specific landscape interventions derived from STEEP drivers and scenario conditions, enabling the operationalisation of scenarios within the design process. By structuring scenarios into spatially explicit components, this approach facilitates the evaluation and comparison of alternative interventions, supporting decision-making in complex and uncertain environments.

3. Study Area: The Drâa Valley

3.1 Regional Context: Drâa Valley

The Drâa Valley is one of the most significant oasis systems in southern Morocco, extending along a linear corridor structured by the Drâa River. The region is characterised by an arid to hyper-arid climate, with low annual precipitation, high evapotranspiration rates, and strong seasonal variability. These environmental conditions make the valley highly dependent on controlled water management systems for sustaining agricultural production and human settlements.

Historically, the valley has functioned as a continuous oasis network, where settlements are closely linked to irrigation systems and agricultural land. The spatial organisation of the valley reflects this dependency, with palm groves, cultivated fields, and compact settlements forming an integrated socio-ecological system. However, over recent decades, this system has been increasingly affected by reduced water availability, irregular rainfall patterns, and upstream water regulation, leading to a decline in agricultural productivity and increased land degradation.

3.2 M'hamid Oasis: A Representative Lower-Valley Site

M'hamid oasis, at the southern edge of the Drâa Valley, is taken here as a representative case of the lower valley's desertification-prone oases for detailed spatial demonstration; it marks the transition between the cultivated landscape and the Sahara Desert. Due to its geographical position, the area is particularly exposed to desertification processes, including sand dune encroachment, soil degradation, and water scarcity.

The oasis has historically relied on traditional irrigation systems and agricultural practices to sustain local livelihoods. However, the reduction in water flow and the deterioration of irrigation infrastructure have significantly weakened these systems. As a result, agricultural land has progressively declined, and the ecological balance of the oasis has been disrupted.

In addition to environmental challenges, M'hamid is affected by socio-economic pressures, including population decline, migration, and limited economic opportunities. These factors contribute to the abandonment of agricultural land and the deterioration of the built environment, further accelerating desertification processes (Dominguez Martínez et al., 2017).

3.3 Key Challenges and System Dynamics

The challenges faced by the oases of the Drâa Valley are the result of interconnected environmental and socio-economic processes. Water scarcity remains the most critical factor, influencing agricultural productivity, settlement viability, and ecosystem stability. The reduction of water resources is linked to both climatic variability and upstream water management, highlighting the multi-scalar nature of the problem. At the same time, land degradation is intensified by soil salinisation, overexploitation of resources, and the expansion of desert conditions. These environmental pressures are closely linked to social and economic dynamics, including changes in land use, shifts in livelihood strategies, and reduced community engagement in traditional management systems.

The interaction of these factors reflects the complexity of desertification as a socio-ecological process, where environmental degradation cannot be separated from governance structures, economic conditions, and social behaviour.

This complexity reinforces the need for integrated approaches that consider multiple dimensions of change, as addressed through the STEEP framework applied in this research.



Figure 3. Threats and concerns map of the lower Drâa Valley illustrating sand encroachment, water scarcity, and environmental pressures.

4. Methodological Framework

This research adopted a structured, four-phase mixed-methods framework that integrates descriptive analysis, scenario development, and participatory inquiry within a single coherent methodology. The methodological framework consisted of four phases: (1) literature review and STEEP driver analysis; (2) landscape assessment and cultural landscape documentation; (3) scenario prototype development through iterative refinement; and (4) participatory validation through two survey rounds. This approach aligns with established scenario planning protocols while incorporating spatial design translation specific to landscape architecture (Dockerty et al., 2006; Albert, 2011). The overall research process is summarised in Figure 4.

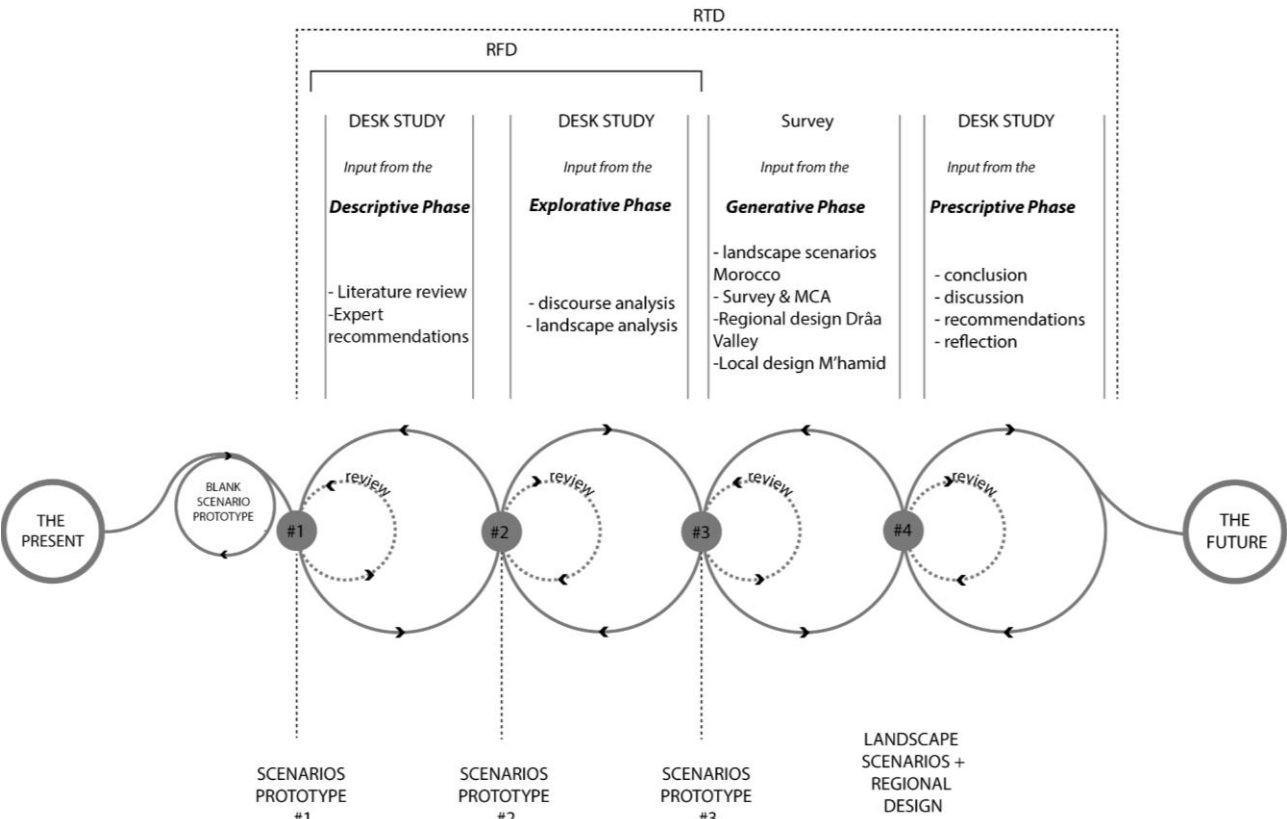


Figure 4. The methodological framework illustrates four iterative phases (descriptive, exploratory, generative, and prescriptive), including evaluation loops for scenario refinement.

4.1 STEEP Driver Analysis

Following Hunt et al. (2012), desertification drivers were systematically categorized across five domains: Social (demographic patterns, education, cultural values, migration), Technological (irrigation methods, agricultural mechanization, infrastructure), Economic (market forces, poverty, tourism), Environmental (water availability, soil degradation, biodiversity loss, climate variability), and Political (governance structures, legislation, resource management policies). Driver identification drew from peer-reviewed literature, governmental reports, and field observations conducted in M'hamid oasis between 2020 and 2022.

Each driver was assessed for importance (impact magnitude on landscape change) and uncertainty (predictability of future state) through a structured evaluation informed by expert interviews with local agricultural extension officers, NGO representatives, and municipal authorities. Drivers exhibiting high importance and high uncertainty were prioritized as scenario-defining axes, following established scenario construction protocols (Börjeson et al., 2006). This systematic categorization addresses reviewer concerns regarding driver weighting methodology by providing transparent criteria for driver prioritization and scenario axis selection. The prioritisation of key drivers is conducted using an impact–uncertainty matrix (Figure 5). Drivers were assessed using a qualitative ranking approach (low, medium, high) based on triangulation between literature review, expert input, and field observations, ensuring consistency in the identification of high-impact and high-uncertainty variables.

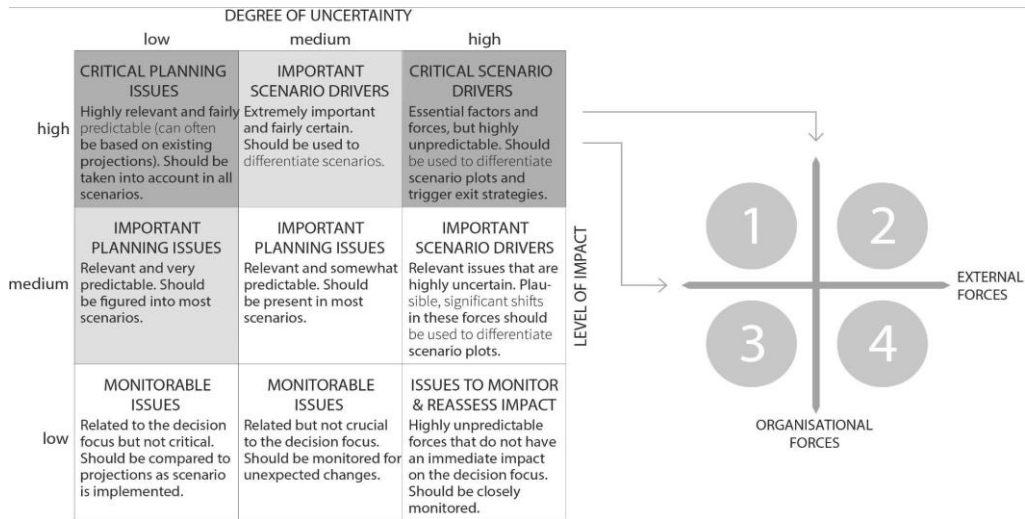


Figure 5. Impact–uncertainty matrix used to prioritise STEEP drivers based on their level of influence and uncertainty (adapted from Maack, 2001).

4.2 Scenario Development Process

Scenario construction followed a three-stage iterative process. In Prototype 1, preliminary scenarios were drafted based on STEEP analysis and existing desertification literature. Prototype 2 refined these scenarios by incorporating critical uncertainties around governance mode (top-down versus bottom-up) and social values (reactive individualism versus proactive solidarity), creating a two-dimensional scenario space. Prototype 3 validated internal consistency through cross-checking scenario narratives against identified drivers and ensuring that scenario combinations represented genuinely distinct futures rather than variations on similar themes.

The four final scenarios - Oasis Minimisation, Oasis Emancipation, Rural Abandonment, and Rural Refuge - were developed as archetypes rather than precise forecasts. This archetypal approach, widely recognized in scenario literature, enables pattern recognition across case studies while acknowledging local specificity (Hunt et al., 2012; Eisenack, 2012).

4.3 Landscape Building Blocks and Spatial Translation

To translate abstract scenarios into spatial design frameworks, landscape building blocks were identified as discrete spatial elements responding to specific STEEP drivers. Examples include mixed-cropping systems (responding to environmental and social drivers for biodiversity and self-sufficiency), solar energy parks (responding to technological and economic drivers), and rural revitalization programs (responding to political and social drivers for population retention). Each building block was mapped to its driving forces and then recombined within scenario contexts to generate scenario-specific spatial configurations for the Drâa Valley's oases, demonstrated through the representative site of M'hamid.

4.4 Participatory Survey

Two rounds of participatory surveys were conducted to validate scenarios and assess community preferences. The first survey (n=20) presented scenario narratives and visual representations to Drâa Valley residents, including farmers (n=6), tourism operators (n=8), construction professionals (n=2), and government employees (n=4). Respondents evaluated scenario plausibility, identified preferred futures, and suggested modifications. Survey participants were recruited through local NGOs, municipal offices, and existing community networks. However, female participation remained limited (n=2), reflecting broader gender marginalization in public discourse within the study region.

4.5 Validation and Consistency

To ensure consistency between scenarios and their corresponding spatial strategies, the research employs an iterative evaluation process across all phases of development. Scenario prototypes are continuously refined through the integration of literature findings, landscape analysis, and participatory feedback. Validation is achieved through:

- cross-referencing identified drivers with existing literature
- comparing scenario outcomes against survey responses
- evaluating building blocks through multi-criteria assessment

This approach ensures that the developed scenarios remain coherent, context-specific, and grounded in both empirical data and stakeholder perspectives. The survey combined structured questions with open-ended responses, allowing both quantitative comparison of preferences and qualitative insights into local perceptions. Responses were analysed through frequency comparison and thematic interpretation.

5. Results

5.1 STEEP Driver Characterization

Analysis identified 47 distinct drivers distributed across STEEP categories. Environmental drivers dominated in both numbers (n=14) and assessed impact, with water scarcity, sand encroachment, and soil salinization identified as critical threats. Social drivers (n=12) centered on demographic shifts, particularly youth out-migration and declining agricultural succession. Economic drivers (n=9) reflected tension between traditional subsistence agriculture and emerging tourism-based economies. Technological drivers (n=7) encompassed both traditional systems (khettara, seguia) and modern interventions (motorized wells, greenhouse agriculture). Political drivers (n=5) highlighted governance gaps in water allocation, land-use planning, and environmental regulation enforcement.

Table 1. Classification of desertification drivers based on STEEP categories and their impacts on the landscape system.

Driver category (STEEP)	Key drivers and indicators
Desertification drivers by STEEP category	
Socio-cultural	Age, family, household and ethnic structures; regional and national migration patterns; spatial distribution of population; wealth distribution, including regional and national poverty rates.
Technological	Farming methods, water management and mechanical structures to fight sand encroachment; level of technology in key industries; emerging technologies; capacity to manufacture technology for export.
Economical	Change in size, type and ownership of firms; formal and informal labour-force structure by region; employment rate; changes in economies of scale and structure of key industries; style of tourism; consumer spending patterns (urban/rural, national/regional); international demand for key exports; distribution and efficiency of rural and urban markets; impact of the informal sector; sources of competition (national, regional, international).
Environmental	Energy prices and availability (likelihood and impact of an oil shock); raw materials (rate of depletion, ease of access); sustainability (strategic use of resources); regional distribution of natural resources.

Political	Change in governmental development strategy and policy (privatisation); changes in legislation (regulation, creation of an enabling environment); changes in the structure and responsibility of ministries; changes in rules governing the formation and functioning of parties; stability of government and likelihood of change; governmental environmental action.
Associated concerns for the oasis landscape system	
Water scarcity	Weak mobilisation of surface waters; population growth; oasis communities no longer isolated; urban sprawl; tourism development; agricultural expansion and intensification; extension onto rangelands; low level of awareness; non-application of, or insufficient respect for, the laws in force.
Biodiversity degradation	Population growth creating additional needs for food and medicine; expansion of residential and infrastructural building at the expense of natural areas; absence of ex-situ conservation programmes and gene banks; irrational water management; changing consumption patterns; change in land use; market forces; locust invasion; tourism development.
Sand encroachment	Unsuitable means and techniques to fight sand encroachment; excessive livestock; agricultural expansion; anarchic construction that eliminates natural barriers.
Oasis lifestyle	Accentuation of poverty; ignorance and illiteracy; exclusion and marginalisation; new needs created by necessity or the pursuit of luxury and well-being; market forces; lack of communication and transport.

Four cross-cutting issues emerged as highest priority: water deficit (affecting 89% of agricultural households), sand dune advancement (threatening 12 of 28 settlements), biodiversity degradation (73% decline in palm grove density since 1984), and deteriorating living conditions (45% poverty rate, 68% youth unemployment). These issues exhibit complex interdependencies: water scarcity drives agricultural abandonment, which reduces vegetation cover, which accelerates sand encroachment, which further degrades soil and water resources.

5.2 Scenario Archetypes

Four distinct landscape scenarios emerged from the iterative development process, positioned along axes of governance structure (top-down to bottom-up) and social values (reactive individualism to proactive solidarity). Each scenario represents a coherent socio-ecological trajectory with specific implications for desertification processes, landscape configuration, and community well-being. The four scenarios are positioned within a structured scenario space, as illustrated in Figure 6.

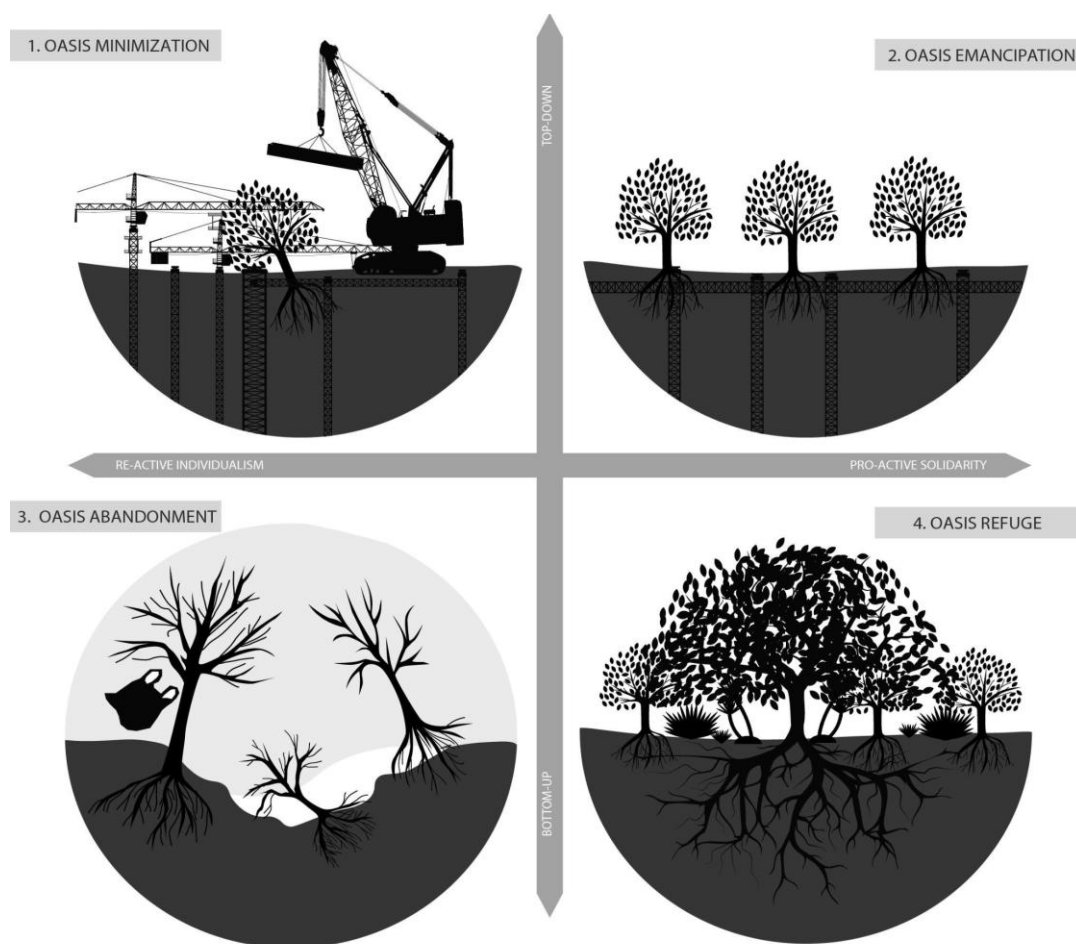


Figure 6. Scenario space illustrating four landscape archetypes structured along governance and social value axes.

5.2.1 Scenario 1: Oasis Minimisation

This scenario depicts strong state intervention combined with market-driven individualism. Large-scale agricultural corporations operate precision-farmed monocultures using sensor networks and automated irrigation. Settlement concentrates in planned urban zones with controlled access and protective infrastructure against sand encroachment. Traditional oasis areas are abandoned or repurposed for industrial agriculture and solar energy generation. Water resources are managed through centralized infrastructure connecting to national grids. Desertification accelerates in unmanaged areas as vegetation removal and soil compaction from industrial operations trigger erosion and gullying. Social outcomes include high migration rates, loss of traditional knowledge, economic polarization between corporate employees and displaced farmers, and dissolution of community-based resource management institutions.

5.2.2 Scenario 2: Oasis Emancipation

This scenario features coordinated state-led environmental restoration combined with collective social values. Comprehensive reforestation programs stabilize dunes using native species. Urban areas implement green infrastructure and mandate earthen construction. Agricultural systems transition to certified organic and regenerative practices supported by technical extension services. Water management integrates modern wastewater treatment with restored traditional systems. Eco-tourism and agri-tourism generate economic value while preserving cultural heritage. Environmental sensors monitor ecosystem health, with data informing adaptive management. Desertification is slowed or stabilized through systematic intervention, though urban expansion continues creating localized land-use pressures. Social outcomes include reduced out-migration, revitalized rural settlements, improved environmental quality, but potential loss of local autonomy to bureaucratic structures.

5.2.3 Scenario 3: Rural Abandonment

This scenario portrays governance failure coupled with fragmented individualistic responses. Weak or absent state presence creates regulatory vacuums filled by informal practices. Illegal well drilling proliferates as households prioritize immediate survival over collective resource management. Agricultural land is progressively abandoned as youth migrate and elderly farmers cannot sustain labor-intensive traditional systems. Sand dunes advance unchecked, engulfing settlements and palm groves. Urban areas fragment into disconnected enclaves with inadequate infrastructure. Water pollution from untreated sewage contaminates remaining aquifers. Desertification accelerates dramatically through compound degradation: vegetation loss, soil erosion, groundwater depletion, and biodiversity collapse. Social outcomes include extreme poverty, educational collapse, health crises from waterborne disease, gender-based violence, ethnic conflict over dwindling resources.

5.2.4 Scenario 4: Rural Refuge

This scenario envisions bottom-up community organization guided by solidarity values. Self-organizing cooperatives manage water, agriculture, and land stewardship through revitalized traditional institutions. Mixed agroforestry systems combine date palms with vegetables, medicinal plants, and nitrogen-fixing species. Scattered reforestation efforts by community groups protect settlements from encroaching dunes. Households generate energy through small-scale solar installations. Eco-tourism operates on community-controlled terms emphasizing cultural exchange over profit maximization. Improved rural connectivity through enhanced roads and digital communication enables market access while maintaining settlement character. Desertification is locally managed through nature-based solutions and traditional ecological knowledge, though coordination challenges limit landscape-scale effectiveness. Social outcomes include strong community cohesion, preservation of cultural practices, environmental stewardship, but potential vulnerability to external economic shocks.

5.3 Spatial Design Principles by Scenario

Translation of the scenarios into spatial configurations — demonstrated for the representative oasis of M'hamid in the lower Drâa Valley — revealed distinctive landscape patterns. In Oasis Minimisation, urban expansion occurs on desert margins with defensive perimeters, large-scale solar parks occupy abandoned palm groves, and precision agriculture operates in consolidated parcels. In Oasis Emancipation, urban growth is contained by green belts, reforestation creates continuous corridors, wastewater treatment enables grey-water reuse, and revitalized ksour serve as cultural tourism nodes. In Rural Abandonment, urban fragmentation creates disconnected patches, abandoned farmland converts to wilderness with advancing sand. In Rural Refuge, scattered community forests protect settlements, mixed agriculture maintains palm grove structure, and community-managed commons provide shared spaces. The translation of STEEP drivers into spatial elements is represented through landscape scenario building blocks (Figure 7). The integration of these elements into spatial strategies is illustrated in Figure 8.

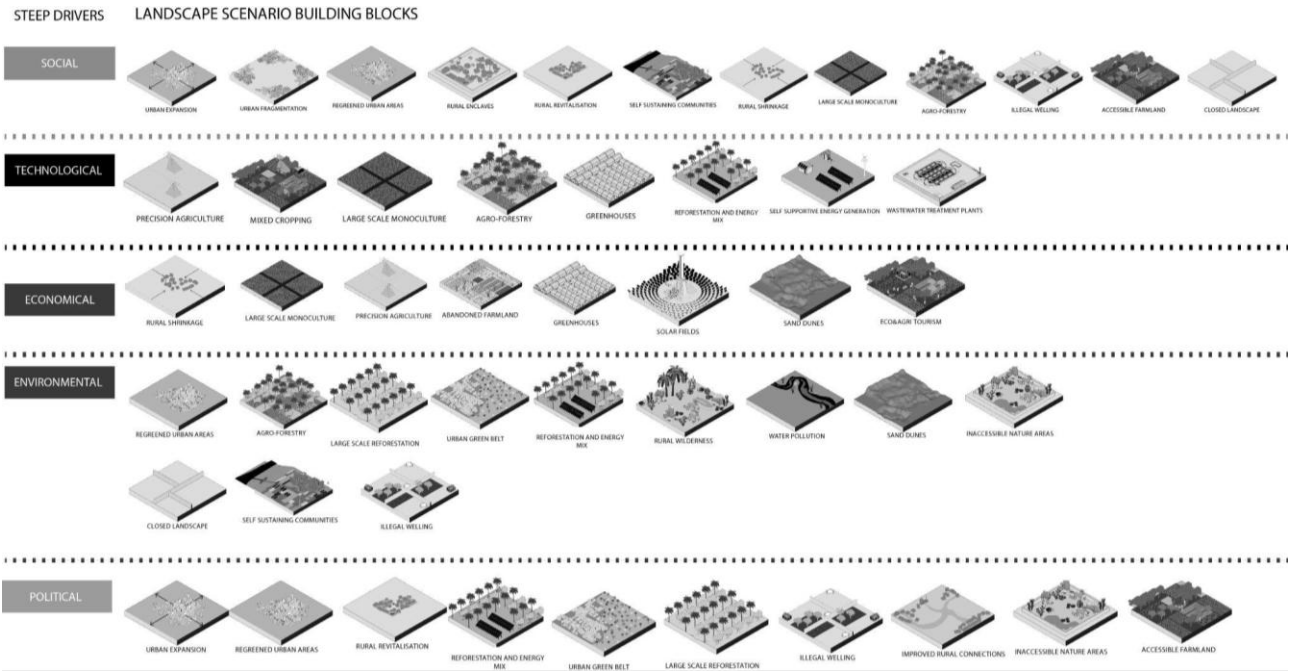


Figure 7. Landscape scenario building blocks derived from STEEP drivers and their relationships within the landscape system.

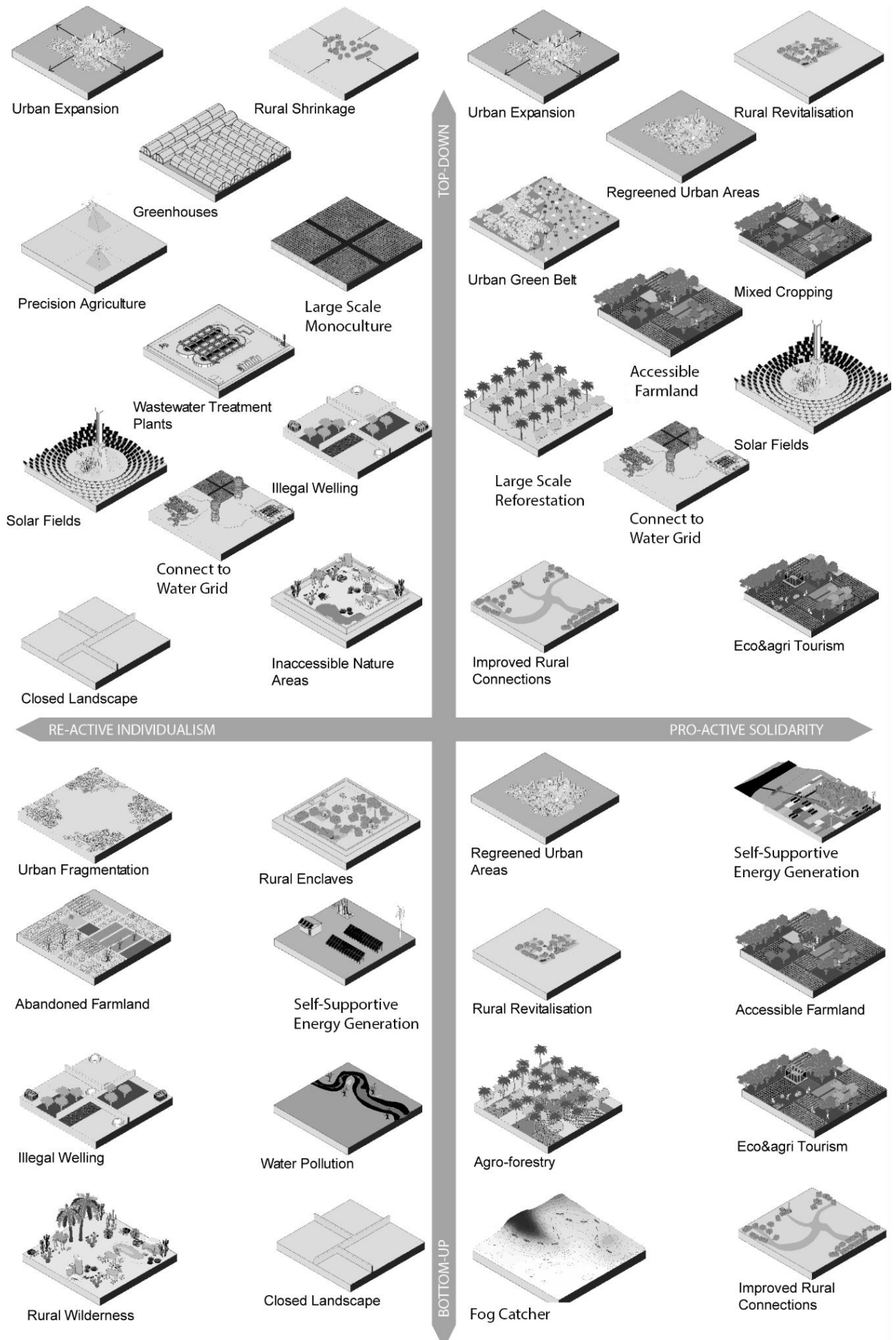


Figure 8. Spatial configuration of landscape scenario building blocks within the four scenario frameworks, demonstrated for M'hamid as a representative oasis.

5.4 Evaluation of Landscape Interventions

The landscape scenario building blocks are evaluated through a multi-criteria assessment framework, based on five dimensions:

- social acceptance
- political feasibility
- economic viability
- environmental impact
- technological feasibility

This evaluation process allows for the comparison of different interventions across scenarios, supporting the identification of the most desirable and feasible strategies. The results indicate that interventions combining ecological restoration with socio-economic benefits, such as agroforestry systems, water harvesting techniques, and eco-tourism, demonstrate higher levels of acceptance and feasibility across multiple criteria. The conducted evaluation was a comparative qualitative scoring approach, enabling the identification of interventions that perform consistently across multiple criteria rather than optimising a single dimension.

5.5 Synthesis into Spatial Strategy

The final stage of the results integrates the selected building blocks into a coherent spatial strategy for the Drâa Valley's oases, demonstrated through M'hamid as a representative site. The strategy aims to:

- reduce desertification through ecological restoration
- improve water availability and management
- rehabilitate degraded land through alternative agricultural practices
- strengthen socio-economic resilience through diversified activities

This synthesis reflects the transition from scenario exploration to design implementation, where selected interventions are combined to form a context-specific and adaptive landscape strategy.

6. Discussion

6.1 Theoretical Contributions to Resilience and Scenario Planning

This research advances theoretical understanding of landscape scenarios as mediators between uncertainty and design action in complex socio-ecological systems. The study extends scenario methodology by explicitly linking archetypal narratives to spatial design through the landscape building block framework, addressing a persistent challenge in translating exploratory scenarios into actionable design guidance.

The research positions landscape scenario archetypes within resilience theory and socio-ecological systems thinking, specifically engaging debates around adaptive versus transformative responses to environmental change. Scenarios 2 and 4 emphasize adaptive resilience - maintaining system function through responsive management. Scenario 1 represents transformative change toward an industrialized system. Scenario 3 depicts system collapse from failed adaptation.

6.2 Linking Scenarios to Resilience Outcomes

This research hypothesizes that scenarios emphasizing traditional knowledge integration, participatory governance, and nature-based solutions (Scenarios 2 and 4) enhance oasis resilience more effectively than technology-substitution or laissez-faire approaches. This hypothesis derives from resilience theory principles: diversity supports adaptive capacity, modularity prevents cascading failure, and social capital enables collective action.

Survey participants with direct experience overwhelmingly favored scenarios preserving mixed agriculture, community-based resource management, and cultural continuity. Historical analysis demonstrates that traditional oasis systems sustained populations for centuries by balancing resource extraction with regeneration. Contemporary case studies from other arid regions show that combining traditional practices with modern ecological engineering yields superior outcomes to purely technical interventions (Li et al., 2015). However, these scenarios may face limitations under conditions of weak institutional support or external economic pressures, highlighting the importance of governance capacity and long-term policy continuity in sustaining resilience-oriented strategies.

6.3 Methodological Validation and Limitations

The participatory survey process provides internal validation of scenario plausibility. However, limitations warrant acknowledgment. First, the sample size (n=20) and composition (predominantly male, tourism-sector-biased) limit generalizability. Systematic exclusion of women's perspectives represents a critical gap. Second, while STEEP analysis provides systematic driver categorization, assessments incorporate expert judgment alongside quantitative data. Third, scenarios represent synchronic cross-sections rather than dynamic temporal progressions.

Findings hold direct implications for regional development planning. First, governance mode profoundly shapes landscape outcomes. Effective policy likely requires hybrid governance balancing state capacity with community participation. Second, nature-based solutions integrating traditional knowledge offer cost-effective resilience strategies. Third, scenarios highlight the inadequacy of single-sector interventions. Addressing desertification requires integrated approaches simultaneously tackling water, agriculture, energy, infrastructure, and social equity.

7. Conclusions

Addressing the three objectives set out at the outset, identifying the STEEP drivers of desertification, developing landscape scenario archetypes, and translating them into spatial design principles, this research demonstrates that landscape scenario archetypes provide an effective framework for exploring alternative futures in desertification-prone oases and for converting exploratory narratives into spatial design. Four distinct scenarios, Oasis Minimisation, Oasis

Emancipation, Rural Abandonment, and Rural Refuge, emerged from systematic analysis of STEEP drivers and participatory validation, representing coherent socio-ecological trajectories shaped by governance structures and social values. Consistent with the study's hypothesis, scenarios emphasising traditional-knowledge integration, participatory governance, and nature-based solutions (Scenarios 2 and 4) were found to support oasis resilience more effectively than technology-substitution or laissez-faire trajectories.

The research makes three original contributions. First, it extends scenario methodology by developing the landscape building block framework as an explicit mechanism for translating scenarios into spatial design. Second, it positions scenarios within resilience theory, exploring how different governance-society paradigms enable adaptive versus transformative change. Third, it demonstrates the value of integrating traditional ecological knowledge with contemporary landscape strategies.

Findings indicate that combining traditional oasisification practices - mixed agriculture, community-based water management, earthen construction - with nature-based solutions and appropriate technologies can enhance ecological functioning, improve resource efficiency, and strengthen social adaptive capacity. Survey results showing strong preference for scenarios emphasizing these elements suggest alignment between community values and sustainability principles.

Future research directions include: (1) developing quantitative models to simulate scenario trajectories; (2) expanding participatory engagement to systematically include marginalized voices, particularly women; (3) conducting cross-case scenario development in other North African oases; and (4) implementing pilot interventions informed by preferred scenarios to assess practical feasibility. By advancing scenario-based planning for dryland regions, this research contributes methodological and substantive insights toward sustainable development in environmentally challenged yet culturally rich landscapes.

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Conflicts of Interest

The authors report no conflicts of interest.

Data Availability Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Institutional Review Board Statement

The survey was anonymous and voluntary, posed minimal risk, and collected no personally identifying information; informed consent was obtained from all participants, who could withdraw at any time. The research was conducted in accordance with the ethical research standards of Politecnico di Milano, and ethical oversight was provided through the doctoral supervision and examination process. As such, separate institutional review board approval was not required.

CRedit Author Statement

Salwa Abdalla Alhejazi: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing - original draft. Carlotta Maria Serena Fontana: Supervision, Writing - review and editing, Project administration. All authors have read and approved the final manuscript.

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