www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2026, 76(1), pp. 19–36

Original scientific paper

UDC: 712.2:551.583(65)
https://doi.org/10.2298/IJGI250512023B

Received: May 12, 2025
Reviewed: September 8, 2025
Accepted: November 15, 2025

ENHANCING SUSTAINABLE LANDSCAPING IN ALGERIA: A STRATEGIC APPROACH TO CLIMATE ADAPTATION

Hocine Sami Belmahdi[1]*

[1]University of Batna 1, Institute of Architecture and Urbanism, Laboratory: Architecture, Urbanism and Transport: Habitat, Landscape and Urban Mobility (LAUTr), Batna, Algeria;
e-mail: hocine.belmahdi@univ-batna.dz

Abstract: This paper investigates landscape sustainability in Algeria and provides strategic recommendations to enhance resilience. The research followed a three-step process. First, a systematic review of global literature on sustainable landscapes identified the best practices suitable for local adaptation. Second, landscape sustainability in Algeria was assessed through scenario analysis using Representative Concentration Pathways (RCP 4.5 and RCP 8.5), accounting for population growth, carbon emissions, and climate change. The third and key step was the development of an original City Information Modeling (CIM) framework that integrates environmental, social, and economic factors to guide sustainable landscape design. CIM was further evaluated through a SWOT analysis, demonstrating its potential as a comprehensive tool for resilient, adaptive landscape planning. This study emphasizes that CIM provides practical guidance for policymakers and planners as well as theoretical support for future research. By enabling forecasting of climate impacts, evaluating actionable strategies, and optimizing resource use, CIM promotes long-term sustainability and transforms concepts of landscape sustainability into context-sensitive, adaptive solutions across Algeria's diverse landscapes.

Keywords: landscape sustainability; scenario analysis; climate change; City Information Modeling; Algeria

1. Introduction

Landscape research responds to the impacts of land and resource use that have disturbed the natural balance. Scholars from different disciplines seek to explore sustainable technologies that combine human development with environmental conservation. This interdisciplinary collaboration aims to design landscapes that improve quality of life and support biodiversity.

Landscape sustainability literally means the continued capacity of the landscape to supply critical and sustainable ecosystem services, conditional upon its unique features and functions that play an important role in human communities' well-being (Wu, 2021). The field of sustainable landscapes is undergoing a significant transformation, driven by the integration of innovative technological solutions that are facilitating the restoration of ecosystems. Recent research in landscape architecture is increasingly focused on landscape performance and ecosystem services, which are essential to support human and non-human species in urban

*Corresponding author, e-mail: hocine.belmahdi@univ-batna.dz

environments (Corkery & Bishop, 2022). The design and management of landscaping in cities are better realized via tools like parametric modeling in terms of standards that enhance efficiency in design and spatial management (Xue & Zhao, 2023). Tools like SketchUp support these processes through 3D modeling and visualization capabilities, while Geographic Information System (GIS), particularly functions related to spatial visualization and data management, enhance them by providing real-time connectivity and efficient handling of spatial information (Yi, 2023). Furthermore, accurate 3D models can be produced to facilitate visualization and planning using Computer Aided Design (CAD) and Building information modeling (BIM) technologies. Integrating BIM and GIS data is increasingly recognized as a valuable and comprehensive tool for landscape design and infrastructure projects. This development is of particular significance in the field of Land Information Modeling (LIM) (Borkowski & Wyszomirski, 2021).

The integration of diverse fields, including genetics for plant adaptation, landscape architecture and engineering, has resulted in innovative and sustainable solutions in the design of built environments. A notable illustration of this integration is the application of interactive genetic algorithms in landscape design, which facilitates the optimization of spatial arrangements in gardens, thereby enhancing both their aesthetic appeal and their ecological functionality (Chen & Wen, 2022).

There has been a notable change in the landscape on account of deep sociological and ecological changes: population growth, greater demand for resources, shifting land uses, changing climatic conditions, and increased pollution. The phenomenon of climate change has exerted a profound influence on terrestrial landscapes, both naturally occurring and modified by human activities, on a global scale. Research has demonstrated that changes in land use and land cover have a pivotal role in influencing local and regional climates. In their systematic review, Cao et al. (2020) analyzed mid-scale modeling studies to assess these impacts and found that urbanization and agricultural development contribute to changing temperature and precipitation patterns. In regions such as the Mediterranean, climate change poses a threat to cultural landscapes and heritage. To this end, multi-source remote sensing data were utilized in a study focusing on the listed sites of Cos and Cévennes in France. Study results revealed rising temperatures, deforestation, and deteriorating landscape stability (Zhu et al., 2025).

As in many other countries, Algeria is also facing adverse effects from these changes, which threaten the sustainability of its ecosystems. Among the challenges confronting Algeria are mounting pressure on agricultural areas, urban sprawl, and the unsustainable exploitation of natural resources. The sustainability of Algeria's urban and natural landscapes is increasingly impacted by climate change, with studies demonstrating that shifts in climate patterns impact land use and population growth in urban areas. For instance, an analytical study of Bounoua et al. (2023) examining five major provinces in Algeria demonstrated that the relationship between land use and population growth is nonlinear, thus highlighting the challenges facing sustainable urban planning.

The concept of sustainability is inherently linked to a multitude of intricate ecological challenges including desertification, water scarcity, and land cover degradation. This underscores the imperative for the preservation and further development of landscapes toward sustainability. Algeria's rapid urbanization worsened by environmental pressures on cities, calls for innovative and sustainable design strategies that integrate landscapes into cities. The challenge lies in the following: How to best predict the future impact of the design decisions, especially given the complexity that characterizes urban systems? Hence, this paper addresses the following research questions: What are possible future scenarios in relation to urban landscape sustainability in cities and in the natural environment, and what are the appropriate means to implement them? On another front, how can integrated design methodologies be developed based on predictive modeling for the sustainability of landscapes in general, in both natural and urban settings so that they incorporate environmental dynamics and help improve the sustainability of cities and quality of life in the long term?

2. Data and research methodology

2.1. Study area

Algeria, situated in North Africa, is the largest country in both Africa and the Mediterranean basin, covering 2,381,741 km² with a population estimated at 43.9 million in January 2020 (Office National des Statistiques, 2020; Figure 1).

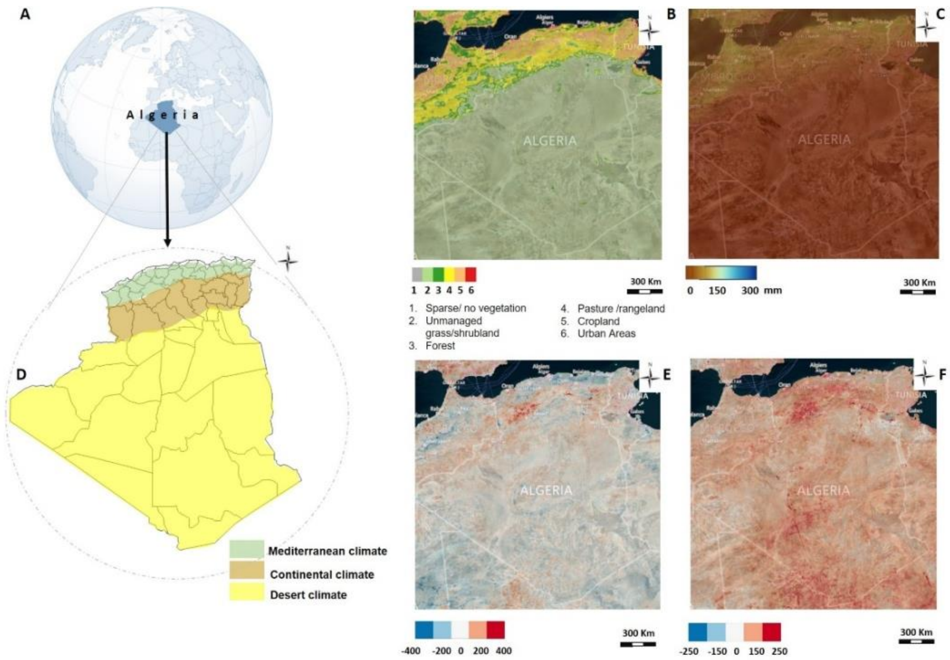

Figure 1. Location of Algeria (A); Land Dynamics Assessment – Global dataset of annual land use/cover change (2000–2021) (B); Monthly precipitation (mm) – multisource average based on SM2RAIN-ASCAT (2007–2021) (C); Climate (D); MOD11A2 long-term land surface temperature trend (daytime) (2000–2020) (E); MOD11A2 long-term land surface temperature trend (nighttime) (2000–2020) (F).
Note. Panel A and D: Adapted from *Countries of the World* by Natural Earth, n.d. (https://www.naturalearthdata.com). In the public domain. Accessed January 2025. Panel B: Adopted from *Land dynamics assessment – Global dataset of annual land use/cover change* by OpenLandMap, n.d. (https://openlandmap.org). In the public domain. Panel C: Adopted from *Global long-term mean monthly precipitation (SM2RAIN-CCI)* by OpenLandMap, n.d. (https://openlandmap.org). In the public domain. Panel D: Adopted from *Land surface temperature daytime trend (MOD11A2)* by OpenLandMap, n.d. (https://openlandmap.org). In the public domain. Panel E and F: Adopted from *Land surface temperature nighttime trend (MOD11A2)* by OpenLandMap, n.d. (https://openlandmap.org). In the public domain.

Its vast territory encompasses coastal areas, mountain ranges, high plateaus, and the Sahara Desert, generating significant climatic variability (Figures 1B, 1C, 1D, 1E, and 1F). According to the Köppen–Geiger classification, northern Algeria has a Mediterranean climate (Csa/Csb), characterized by hot, dry summers and mild, wet winters, which supports agricultural activities. Inland plateau regions exhibit a continental climate, with pronounced seasonal contrasts, including cold winters and hot summers. In the south, the Sahara is dominated by an arid desert climate (BWh/BWk), marked by extreme heat, recurrent drought, and minimal precipitation (Beck et al., 2018).

2.2. Materials and method

This study aims to evaluate the current state of landscape sustainability in Algeria and to establish guiding principles for a predictive modeling approach that supports more sustainable practices. Figure 2 illustrates the methodological framework, structured into three interrelated steps:

- Step 1: systematic literature review. A structured search was conducted in Scopus, Web of Science, and Google Scholar using keywords such as "landscape sustainability", "sustainable landscape design", "climate adaptation", and "urban resilience". Studies were included if they addressed strategies for sustainable landscapes, climate adaptation, or ecological resilience. Relevant works were then classified by approaches and tools to identify best practices appropriate to the Algerian context;
- Step 2: scenario analysis in Algeria. Landscape sustainability was evaluated under Representative Concentration Pathways (RCP 4.5 and 8.5), as defined by the Intergovernmental Panel on Climate Change (IPCC; 2021):
  - – RCP 4.5 was selected as a stabilization pathway, useful for moderate policy scenarios (Climate-Scenarios Canada, 2020; Thomson et al., 2011); and
  - – RCP 8.5 was chosen as a high-emission pathway, useful for exploring worst-case risks (Hausfather, 2019; United Nations Framework Convention on Climate Change, 2011).

The variables considered included population change, carbon emissions, and climate impacts. Data were obtained from OpenLandMap, Data Commons, and the World Bank, and were supplemented by national ecological and climate reports. This phase identified the risks and opportunities associated with sustainable landscapes in changing conditions.

- Step 3: developing City Information Modeling (CIM) framework. The third phase introduces a conceptual workflow for CIM as a theoretical framework for integrating environmental, social, and economic dimensions of sustainable landscape design. Although not yet applied to Algerian case studies, it provides a structured pathway for future applications.

The proposed CIM was evaluated through a SWOT analysis in order to identify potential organizational, technological, and environmental issues affecting its implementation in Algeria. SWOT provides a structured approach to assess internal strengths and weaknesses as well as external opportunities and threats, helping planners recognize challenges and opportunities and support informed decision-making for sustainable implementation (Mupfumira et al., 2024). This method allows for a balanced evaluation of the CIM framework, ensuring that both internal and external factors are considered before application.

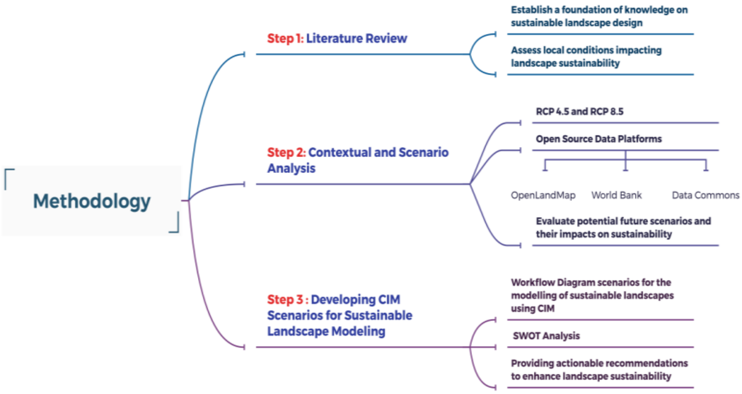

Figure 2. Research Methodological Framework.

3. Results and discussion

3.1. Sustainable landscape approaches

This chapter presents the first stage of the study, which includes a systematic review of the literature on sustainable landscape approaches. The review focuses on key aspects such as climate-responsive landscape design, biodiversity conservation and ecological restoration, green infrastructure and urban resilience, sustainable materials and construction techniques, smart landscapes and data-driven planning, urban morphology and landscape, and predictive landscape modeling.

The concept of landscape is of paramount importance across a wide range of disciplines, including the social, geographical, and biological sciences (Lenzholzer & Brown, 2013), as well as in spatial and landscape planning practices. This is because it represents a variety of origins and interpretations with extensive, wide-ranging implications. The present undertaking to achieve sustainable landscapes is precipitating the integration of pioneering concepts, landscape ecological principles (Wu, 2021), and avant-garde technological solutions. Landscape ecology provides valuable insights into spatial patterns, ecological processes, and connectivity, which are essential for designing resilient and sustainable landscapes. This approach offers a unique opportunity to rejuvenate our natural environment, enhance ecological functions, and concurrently cultivate human development in harmony with ecosystems. In this section, a discourse is initiated, and an examination is conducted of the salient issues that emerge from the array of approaches to landscape sustainability, drawing on theoretical, ecological, and practical perspectives.

3.1.1. Climate-responsive landscape design

Cities are becoming increasingly vulnerable to environmental challenges due to rapid urban growth and climate change, which can reduce quality of life and intensify the urban heat island effect (Kycheryavj et al., 2018). In Algeria, urbanization has noticeably increased local temperatures compared with rural surroundings. In cities such as Annaba, the difference can reach around 6.9 °C, reflecting how reduced vegetation and dense infrastructure intensify local heat. This pattern highlights the growing urban heat island effect and its implications for public health and environmental management across the country (Sayad et al., 2024). Strategic landscape architecture offers a vital tool to mitigate these effects. Successful examples, such as Medellín's green corridors (2016), demonstrate how well-designed urban vegetation can reduce local temperatures and enhance well-being. Effective interventions require careful planning and a solid understanding of urban temperature dynamics (Lenzholzer & Brown, 2013). As climate threats grow, landscapes must be designed using science-driven principles (Brown & Corry, 2011). Sustainable, evidence-based practices enable landscape architects to create resilient and adaptive urban environments.

Recent research in contemporary landscape architecture emphasizes dynamic responses to climate challenges, integrating climate data, predictive modeling, and GIS technology. These tools allow innovative and responsive designs, helping communities proactively address climate change while supporting sustainable ecosystems despite future uncertainties.

3.1.2. Biodiversity conservation and ecological restoration

Recently, ecology has made remarkable progress in highlighting the role of biodiversity in maintaining ecological balance, with the development of modern models for biodiversity conservation and ecosystem restoration within the framework of landscape and regional management (Margules & Pressey, 2000). Sustainable biodiversity conservation involves comprehensive planning that includes land allocation for production or urban use, with a focus on enhancing natural processes and reintroducing native species to ensure ecosystem sustainability and enhance its ability to withstand various environmental pressures.

In Algeria, semi-desert and desert ecosystems face particular challenges, especially in oases, where invasive species can threaten the local ecological balance and affect biodiversity. A recent study on the Djelfa region indicates that the degradation of steppes and deserts is the result of intertwined climatic, social, and economic factors, which increases the importance of implementing ecological restoration strategies to ensure the sustainability of these systems and protect their natural resources (Liiv et al., 2025). Added to this is the rapid urban expansion, which leads to the loss of traditional agricultural land and a reduction in natural habitats, making the adoption of effective environmental restoration strategies essential to preserve biodiversity and ensure the continuity of the ecological functions of oases and their surrounding areas.

3.1.3. Green infrastructure and urban resilience

As modern landscape research advances, the concept of green infrastructure has gained particular attention in urban areas. Green infrastructure encompasses the intentional integration of natural systems including parks, green spaces, wetlands, green roofs, and urban forests into urban areas to address a variety of environmental challenges while providing multiple co-benefits. Urban resilience is a relatively new idea born from the need to tackle the problems presented by environmental, social, and economic change (Olazabal et al., 2012). Moreover, urban resilience is seen as the ability of a city to withstand shocks, bounce back quickly from disruption and adapt to shifting circumstances while retaining its essential functions, structures, and identity. It also has environmental, social, and economic dimensions, and effective implementation of green infrastructure therefore has a significant role in urban resilience approaches.

A matrix summarizing the proposal is presented in Table 1, showing the relationships between green infrastructure and urban resilience/landscape. Landscape provides the overall framework encompassing natural and human-made elements, creating habitats for biodiversity, supporting healthy environments, mitigating disaster risks, and enhancing air and water quality. Green infrastructure contributes to ecologically sustainable development by integrating natural and semi-natural elements into urban areas, improving biodiversity, air quality, and disaster resilience, thereby directly supporting urban adaptability. While these interventions offer multiple benefits, their implementation may face practical limitations, including high installation and maintenance costs, water demand conflicts in arid regions. In Algeria's mostly arid and semi-arid regions, high costs and competing water demands challenge the implementation of green infrastructure. Addressing these obstacles is essential for sustainable and context-appropriate urban planning, while such infrastructure can also help mitigate water scarcity and enhance urban resilience: permeable pavements facilitate groundwater recharge, while green roofs and drought-resistant landscaping reduce storm water runoff and water demand. Utilizing locally adapted vegetation further enhances water efficiency while maintaining urban resilience. Built areas represent the constructed environment, shaping cities' physical form, reflecting cultural identity, and providing spaces that foster community cohesion. Urban resilience is defined as the capacity of cities to adapt to environmental and social uncertainties. It enables effective emergency response, risk mitigation, enhancement of quality of life, and the promotion of a sustainable and livable urban ecosystem (Vasilevska & Slavković, 2024).

Table 1. Green infrastructure and urban resilience/landscape relationship matrix

Elements	Landscapes	Green infrastructure	Built areas	Urban resilience
Landscapes	Includes rivers, lakes, and forests*	Conserve biodiversity and provide healthy environments	Provides natural spaces that support wildlife	Protects against disasters and preserves the ecosystem
Green infrastru-cture	Improves local climate and supports biodiversity	Ensures healthy environments and supports biodiversity*	Boosts aesthetics and provides green spaces for socializing	Enhances resilience to crises and mitigates risks
Built Areas	Provides natural spaces that support wildlife	Enhances appearance and boosts comfort	Includes buildings and streets reflecting cultural identity*	Contributes to improving the quality of life
Urban resilience	Supports biodiversity and improves air quality	Promoting adaptation to environmental and social challenges	Improving the city's response to crises and reducing risks	Includes the ability to respond to crises and adapt to changes*

Note. The fields with an asterisk indicate similar element intersections, while others indicate different ones.

3.1.4. Sustainable materials and construction techniques

The use of sustainable construction materials and practices is crucial for the development of urban environments, which form the foundation for improving urban life. Techniques that enhance specific aspects of the urban fabric while simultaneously reducing resource depletion are collectively considered sustainable. The construction of urban features involves carefully selecting numerous components based on their environmental friendliness and economic viability. Today, researchers are increasingly exploring eco-friendly materials and construction methods to create more sustainable landscapes. The use of recyclable and biodegradable materials, alongside environmentally responsible construction techniques, is driving a shift in how landscapes are designed and built. These approaches not only help to reduce environmental impact but also support the creation of effective and sustainable urban landscapes.

3.1.5. Smart landscapes and data-driven planning

Recent advancements in intelligent technologies and the Internet of Things (IoT) have transformed landscape planning and management. These technologies enable professionals to design efficient, durable, and user-centered outdoor spaces that respond effectively to both users and the environment. Smart landscapes integrate digital technologies, IoT devices, and data into their design, operation, and management. IoT applications allow monitoring of environmental conditions, user behavior, and resource usage, supporting data-driven decisions and more efficient management (Ye, 2025).

The main goals of smart landscapes are to improve user experience, optimize resource use, and ensure effective operational outcomes. These objectives are closely linked to global environmental challenges, as biodiversity is declining worldwide, with 75% of terrestrial and 66% of marine environments impacted by human activities, highlighting the need for urgent conservation measures (United Nations, 2019). Smart street systems are built on four key pillars: intelligent infrastructure, services, protection and maintenance, and management and evaluation (Li et al., 2021). Recent case studies in arid regions, such as Morocco's Solar City initiative (2021) and the UAE's Nasim Al-Jarf project in Abu Dhabi (2020–2022), demonstrate the practical benefits of these approaches. Algeria can benchmark these experiences to guide its sustainable urban landscape initiatives.

3.1.6. Urban morphology and landscape

Urban landscape research has its origins in the contributions of the Anglo-European school of urban geography and landscape ecology, a branch of human geography, which focused on the interaction between the built environment and urban nature and influenced the formation of concepts of urban planning and sustainable design. The school blended environmental and planning principles, leading to the development of new approaches to analyzing and planning green spaces in cities, emphasizing the importance of balancing urban development with the preservation of the natural environment. This theoretical foundation was further elaborated by the seminal works of Michael Robert Günter Conzen, who pioneered the formal analysis of cities, with a particular focus on the evolution of urban layouts and the urban fabric.

Urban landscapes exploration has gained increasing importance in recent years, driving innovative approaches in urban morphology. This research focuses on analyzing the elements that constitute urban landscapes, aiming to define and delimit them, following previous studies (Conzen, 1960) and the redefinition of key elements by Belmahdi and Djemili (2022). Understanding urban form components, including street networks, buildings, green spaces, and resource management, helps analyze city structure, influencing traffic, accessibility, public spaces, and energy efficiency. Proper organization of these elements contributes to sustainable and resilient cities. Connecting urban morphology theories to Algeria's context can help address specific city challenges, particularly irregular street patterns, crowded neighborhoods, and limited public spaces. Applying Conzen's approach, for instance, can guide the design and organization of Algerian urban areas, integrating traditional urban forms with contemporary planning needs and linking theoretical insights to practical solutions.

3.1.7. Predictive landscape modeling

Predictive modeling is another critical aspect of modern landscape research. Technological advances greatly facilitated the seamless integration of dynamic systems models, spatial analysis, GIS, and ecological processes, broadening the scope of urban modeling to encompass disciplines like biology and ecology. Urban models are anticipated to continue to be influenced by theories like ecological energetics, fuzzy logic, fractal geometry, and neural networks (Berling-Wolff & Wu, 2004). Designers and planners can simulate how a landscape will respond to different climate scenarios with sophisticated computer models. These models take into account the entire climate system by considering factors such as changes in temperature, changes in water availability, and changes in ecosystem dynamics to help designers anticipate how climate change will ultimately impact the landscape and its ecosystems.

The integration of GIS in landscape architecture has been notably sluggish, with limited use mostly focused on basic mapmaking and data access tasks (Nijhuis, 2016). Currently, GIS offers landscape architects a highly effective tool for precisely and efficiently mapping climate parameters, such as areas prone to flooding, heat islands, and fragile ecosystems. This spatial awareness is vital for orienting landscape architects to areas in need of special attention and climate-based intervention in resilient landscape design. Landscape architects propose adaptive solutions that address site-specific challenges, and these are based on climate data analysis, predictive modeling. The integration of CIM with GIS facilitates the delivery of more accurate and comprehensive visualizations of urban environments, thereby enhancing designers' capacity to make data-driven, sustainable decisions.

3.2. Algeria's landscape sustainability

This section, constituting the second stage of the study, examines landscape sustainability in Algeria within the broader context of climate-change adaptation. It analyzes two key scenarios of population growth and carbon emissions and explores their impacts on urbanization, land use, and environmental pressures, providing a strategic foundation for enhancing sustainable landscaping practices.

3.2.1. Scenarios of population growth and carbon emissions

Algeria experienced major demographic and environmental changes between 1960 and 2020. Figure 3 shows the impact of urbanization (World Bank, 2025) and CO_2 emissions (Data Commons, 2025) on the country's landscape.

Figures 3A and 3B demonstrate a substantial increase in the population size of urban areas from under five million in 1960 to over 40 million by 2020. In comparison, the population size of rural areas remained at approximately 10 million. This transition indicates that increasing rates of urbanization and migration from rural to urban areas have led to a sprawling of urbanization, with a consequent loss of agricultural and natural lands (World Bank, 2025). With this urban expansion came rapid land-use changes, with reductions of areas of natural vegetation and large portions of the land inundated by urban sprawl. This spelled trouble for biodiversity and increasing vulnerability to desertification in the hinterlands (United Nations Environment Program [UNEP], 2021). Per capita CO_2 emissions have thus risen from about 2 t in 1990 to about 4 t in 2015–2016, with some decrease in 2020 owing to the effects of the corona pandemic on industrial activity, as shown in Figure 1B and Figures 3C and 3D. This rise is an outcome of heavy dependence on fossil fuels to meet the demands of urban and industrial growth. In addition, an increase in the transport and electricity networks leads to increased energy consumption, which causes increased pollution (International Energy Agency, 2023). This has further put mounting pressure on natural resources and threatened the ecosystem, especially in urban and semi-urban areas. To cope with these effects, there is a need for setting up development policies which can curb unregulated urban expansion, promote renewable energy sources, and conserve biodiversity ensuring the sustainability of resources under environmental pressures (UNEP, 2021).

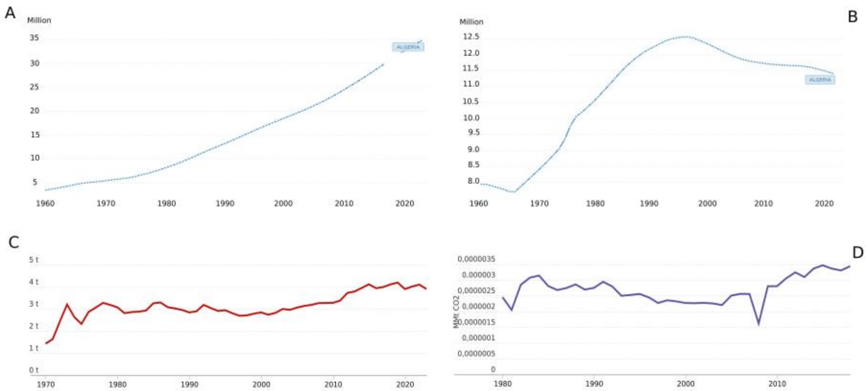

Figure 3. Urban population (A); Rural population (B); Carbon dioxide emissions (CO_2) Annual (C); CO_2 emissions per capita (2023) (D) in Algeria.

Note. Panel A: Adopted from *Urban population data* by World Bank, n.d. (https://data.worldbank.org). In the public domain. Panel B: Adopted from *Rural population data* by World Bank, n.d. (https://data.worldbank.org). In the public domain. Panel C: Adopted from *CO_2 Emissions, Annual data* by Data Commons, n.d. (https://datacommons.org). In the public domain. Panel D: Adopted from *CO_2 Emissions per capita (2023) data* by Data Commons, n.d. (https://datacommons.org). In the public domain.

The following details provide a numerical summary of the trends shown in Figure 3:

- urban population: less than 5 million in 1960, rising to over 35 million by 2020 (~7-fold increase), driving higher CO_2 emissions;
- rural population: declined in 1960–1967, peaking around 1999, then falling below 11 million after 2020, reflecting urbanization shifts;
- annual CO_2 emissions: 1.2 t in 1970, increasing to ~4.2 t after 2010, following urban growth patterns; and
- per capita CO_2 emissions: ~1.5 t in the early 1980s, rising to ~2.5 t by mid-1980s, stable until ~2007, dropping to ~2.2 t in 2008–2009, then increasing to ~3.0 t after 2010, reflecting industrialization and policy changes.

3.2.2. Scenarios of climate change and emissions: effects on landscapes

Algeria, a climatically diverse region, faces serious challenges from climate change. Projected maximum temperature changes under two greenhouse gas emission scenarios, RCP 4.5 and RCP 8.5 (Data Commons, 2025), indicate substantial impacts on the country's landscape and environment (Figure 4).

The RCP 4.5 scenario is defined as follows: This is considered to be a medium impact scenario based on a moderate reduction in greenhouse gas emissions in the coming decades due to climate change mitigation policies (IPCC, 2023). In the above scenario, an increase in extreme temperatures between 0 °C and 8 °C is predicted for Algeria in 2100. This moderate increase may lead to limited degradation of very fragile ecosystems, such as those found in steppe and semi-arid areas, and the risk of desertification would be lower as some areas would still have vegetation support (Figure 1B and Figure 4A). However, the expectation of maintaining the productivity of agricultural land in the northern regions will depend on the implementation of effective water management policies and the improvement of agricultural practices (Food and Agriculture Organization of the United Nations [FAO], 2021). This scenario gives the following outlook for Algeria in 2100:

- some degradation in sensitive ecosystems such as steppes and semi-arid areas;
- a lowered desertification risk as compared with a most severe scenario, whereby some areas would still support vegetation; and
- depending on the implementation of effective water management strategies and the adjustment of agricultural practices, this scenario presents a potential maintenance of the productivity of agricultural land, particularly in the northern regions.

The RCP 8.5 scenario represents a future with extreme changes and great impacts, driven by high emissions trends into their prolonged increase without proper mitigation measures. Climate projections in this scenario show excessive variability and very high maximum temperatures of over 10 °C. The impacts of this scenario will be severe and will include (Figure 1B and Figure 4B):

- an increase in desertification and faster land degradation, particularly in the south and central regions, leading to much less land across which to practice agriculture;
- a significant deterioration in vegetation cover and biodiversity where local plant and animal species are unable to cope with extreme climatic conditions;
- worsening of the water crisis due to rising evaporation rates and depleted renewable water supplies, negatively affecting agriculture and water supply (FAO, 2021); and
- a rise in the northern fire risk, as the droughts and high temperatures provide the conditions under which such fires flourish (IPCC, 2023).

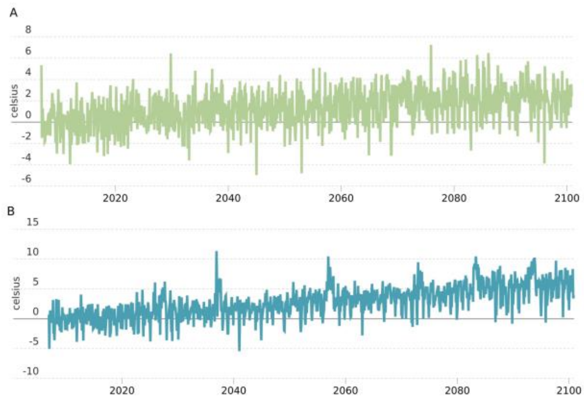

Figure 4. Projected max temperature change in Algeria by 2100: Under RCP 4.5 (A); RCP 8.5 (B).
Note. Panel A: Adopted from *RCP 4.5 data* by Data Commons, n.d. (https://datacommons.org).
Panel B: Adopted from *RCP 8.5 data* by Data Commons, n.d. (https://datacommons.org).

The following details provide a numerical summary of the trends shown in Figure 4:

- RCP 4.5 (A): Gradual increase in maximum temperatures, stabilizing around +4 °C by 2100; and

- RCP 8.5 (B): More rapid and variable increase, reaching up to +10 °C by 2100, indicating a high-emission scenario’s stronger impact.

The overall impacts will vary greatly throughout the landscape in many cases affecting environmental components both directly and indirectly. Desert areas will become drier, thus encouraging the spreading of sand and the incidence of sandstorms. Oases depending on scarce water will be threatened by extinction since aquifers are being depleted. Coastal plains, which are, in fact, among the most important agricultural regions, are bound to experience reduced productivity on account of heat waves and droughts. It is necessary for planners and stakeholders to recognize and adopt such strategies in order to avert the impacts outlined above. To achieve this, several measures can be implemented, including: integrated management of water resources through the use of modern technologies such as water reuse and seawater desalination; drought-resistant agriculture through the development of varieties that can withstand drought and heat; and policies of reforestation and anti-desertification to preserve forests and ecosystems.

3.3. Toward modeling Algeria’s landscapes via CIM

This section represents the third stage of the research, focusing on the practical application of CIM in Algeria to enhance urban data management and support sustainable urban planning. CIM was chosen for Algeria due to its capacity to enhance urban data management and promote sustainable urban planning, thereby improving the quality of the urban landscape. By providing an integrated digital framework combining geographic, social, and environmental information, CIM enables informed decision-making tailored to Algeria’s unique context. For example, research suggests that integrated planning models based on CIM can promote resource sustainability, support sectoral development, and reduce pollution. This strengthens urban governance and planning outcomes (Yu et al., 2025).

3.3.1. Core methodology for CIM implementation

CIM is defined as the digital representation of the physical and functional aspects of a city or urban environment, integrating BIM and GIS to establish a Geographic Building Information Modeling (GeoBIM) environment. The management and display of urban data is facilitated in such an environment (Cureton & Hartley, 2023). The prevailing paradigm of design is evolving toward a perspective that considers it as an enduring and unchangeable entity, capable of addressing the present population's needs while ensuring the future viability of resources for subsequent generations. Thus, the aim is to create designs that enhance human well-being while protecting the environment and advancing holistic sustainable development.

The overall framework of the methodology (Figure 5) is comprised of digital data, intelligent analysis, and sustainable planning that aim to balance the needs of urban growth and natural ecosystem protection. The methodology is built on the most recent science and emerging practices in sustainable urban planning to provide a holistic framework for urban and natural modeling within different contexts to encourage sustainability and resource efficiency. The methodology utilizes multiple interdependent phases, beginning with the collection and analysis of data through remote sensing, 3D scanning, and GIS, which provides an understanding of the relationships between the built and natural environment and the anticipated environmental and cultural challenges. The second phase of the methodology is the digital modeling phase that develops a three-dimensional model that integrates aspects of nature and urbanism to enable the simulation of urban planning scenarios and environmental impacts, and forecasting variables such as climate change, resource consumption, and carbon emissions.

The planning and design process includes balanced strategies that integrate green infrastructure, improved water management systems, and the use of sustainable building materials, improving the efficiency and sustainability of cities. The environmental simulation and assessment phase uses artificial intelligence and computer modeling to assess the impacts of urbanization before it happens, creating an evidence-based process of decision-making and avoiding negative environmental issues. The methodology also relies on smart monitoring and management in real-time IoT, smart sensors, which can enable the constant monitoring of pollution, air quality, traffic, and energy and water consumption, providing the means to enhance urban performance and adapt efficiently. The continuous evaluation and update phase analyzes data to assess progress and adjust strategies in response to social and environmental changes, contributing to the city's long-term sustainable and balanced development.

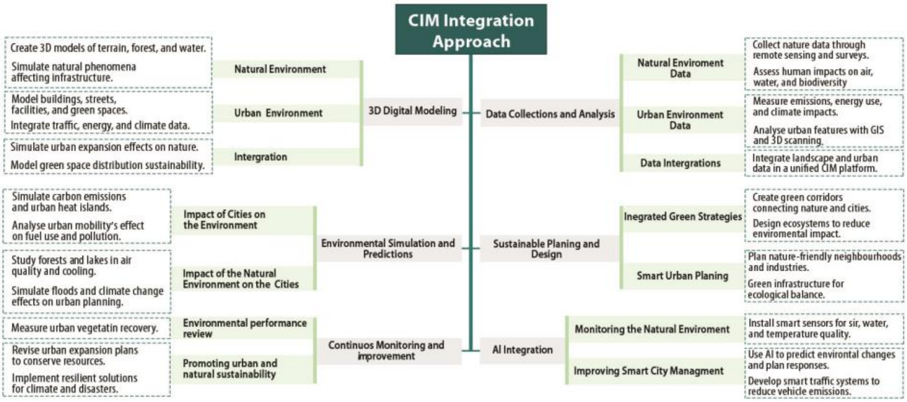

Figure 5. A General Core methodology for CIM implementation.

Despite the potential benefits of green infrastructure and climate-responsive design, Algeria faces several challenges in their implementation. For example, green roofs can help reduce urban heat islands, but they require significant water, which may conflict with the country's arid climate. Other challenges include high costs, maintenance requirements to ensure successful and sustainable adoption. Table 2 summarizes the CIM framework in Figure 5, showing the tools, data sources, key metrics, and AI applications for each component. It highlights how the framework can be applied in practice.

Table 2. Tools, Data, Metrics, and AI Applications in the CIM Framework

Component	Tools / Platforms	Data Sources	Metrics / Indicators	AI Application
Natural and Urban Environment Data	GIS software, Remote Sensing platforms, 3D scanners	Satellite imagery, field surveys, air & water sensors	Air/water quality, biodiversity, energy usage	Data analysis and integration
Sustainable Planning & Design	Urban planning software, CAD, GIS	Land use maps, ecological surveys	Ecosystem services, environmental impact	Optimize green space distribution

Table 2. Tools, Data, Metrics, and AI Applications in the CIM Framework (*continued*)

Component	Tools / Platforms	Data Sources	Metrics / Indicators	AI Application
3D Digital Modelling	3D modelling software (Blender, CityEngine), GIS	Terrain, forests, urban infrastructure, traffic, climate	Terrain elevation, building density, green space coverage	Simulate urban expansion and natural phenomena
Continuous Monitoring and Improvement	Monitoring platforms, dashboards, GIS	Vegetation recovery, pollution, urban expansion	Vegetation recovery, noise/heat/pollution, resilience indices	AI-assisted evaluation and scenario planning
Environmental Simulation and Predictions	Simulation software (ENVI-met, MATLAB), climate models	Climate, mobility, natural resource data	Carbon emissions, heat island intensity, flood risk	Predictive modelling of urban and natural impacts
AI Integration	AI frameworks (Python, TensorFlow, PyTorch), IoT sensors	Environmental, traffic, energy sensors	Air/water/temperature, traffic flow, energy use	Machine learning for prediction and decision support

3.3.2. Proposal of CIM model to promote sustainable landscapes

The CIM model for sustainable landscape modeling in Algeria proposes an integrated approach that balances urban development and environmental protection (Figure 6). This is achieved by involving all stakeholders to ensure transparency and promote community acceptance. This approach involves government agencies, urban planners, environmental experts, and civil society, helping to develop policies in line with local needs and environmental and economic challenges. The first stage involves collating data using methods such as remote sensing, 3D scanning, and GIS. The data include sustainable landscape design, green infrastructure, urban resilience, and sustainable building materials.

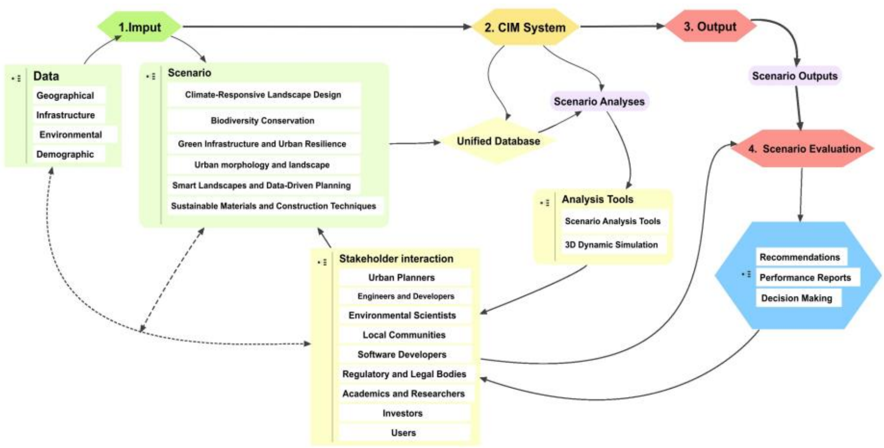

Figure 6. CIM workflow for sustainable landscape modeling in Algeria.

The CIM system is applied for storage and analysis of the data by using various scenarios to examine the effects of urban choices on the environment and resources. This enables predicting climate change and carbon emissions. The planning process utilizes integrated methods that optimize water systems, enhance green infrastructure, and utilize AI and computer modeling in analyzing scenarios prior to the implementation to ensure an evidence-based decision-making process. The IoT technologies allow real-time persona monitoring of the city through smart sensors analyzing air quality, pollution, traffic, and energy and water use, enabling quick adaptation to the changes. The process culminates in a continuous evaluation and update phase, where data is analyzed to revise strategies according to environmental and social changes, ensuring sustainable and balanced urban development in the long term. This model relies on the latest technologies and practices to ensure a more efficient and sustainable urban environment for future generations.

In Table 3, the aim is to evaluate the proposal for CIM in the sustainable design of the landscape in Algeria, together with the SWOT method.

Table 3. SWOT Analysis of landscape modeling using CIM

Strengths	Weaknesses
Enhanced efficiency in the collection and analysis of precise data regarding customer behavior and requirements. Attainment of personalization in design and services with customer preferences, thereby increasing customer satisfaction. Augmentation of customer engagement. Achievement of sustainability and making sustainable decisions. Predict future needs.	High implementation and maintenance costs. Complex data integration from multiple sources may reduce system accuracy. Big data analysis is challenging and may lead to suboptimal decisions. Technical failures can compromise the accuracy and effectiveness of CIM systems.
Opportunities	**Threats**
Enhances efficiency and service personalization. Promotes innovation and continuous improvement. CIM facilitates the continuous enhancement of processes based on available data, thereby enhancing efficiency.	Companies may encounter challenges in complying with data protection laws. Sudden changes in customer behavior may render previous data inaccurate or useless. The presence of competitors utilizing advanced CIM technologies may pose a threat to companies unable to keep pace with these technological advancements.

Despite the potential benefits of CIM and smart technologies, Algeria faces several challenges in their widespread implementation. Key obstacles include high costs, digital divides among the population, and the need for specialized technical expertise, as well as concerns about data privacy in the IoT. Additionally, advanced technological solutions must be balanced with local knowledge and practices to ensure sustainable implementation, highlighting the importance of considering limitations and trade-offs before adopting new strategies.

4. Conclusion

Algeria's pursuit of sustainable landscapes demands urgent, science-based action. The RCP analysis conducted in this study highlights stark divergences between possible futures: under the high-emission RCP 8.5 pathway, Algiers could face temperature increases approaching 10 °C by 2100, with the potential displacement of millions from vulnerable coastal floodplains. Meanwhile, the southern oases remain underdeveloped despite having access to groundwater, which restricts their agricultural potential. Declining productivity in the north poses a risk to food security. By contrast, the mitigation scenario of RCP 4.5 suggests that stabilization of these pressures remains possible if timely interventions are pursued.

The proposed CIM framework provides a practical and integrated response to these challenges. By embedding predictive modeling and evidence-based tools into land-use planning, CIM provides context-sensitive solutions. For example, GIS layers simulating urban heat islands in the capital can inform the strategic placement of green corridors, species-distribution modeling can guide the selection of drought-resistant plants for urban parks, and land-use zoning can redirect urban sprawl away from wetlands toward underused brownfield sites. Such applications illustrate how CIM can move from theoretical promise to tangible actions.

Nonetheless, implementation is constrained by persistent barriers. Fragmented climate data, and limited technical expertise hinder the effective application of CIM nationwide. These challenges highlight the need for incremental, place-based testing. Pilot projects in metropolitan cities such as Oran or Constantine could demonstrate scalability, blending modern GIS-based analysis with traditional water-harvesting practices to foster resilience while ensuring cultural relevance.

The policy implications are clear. Municipal governments must embed CIM approaches into city masterplans, while national authorities need to strengthen cross-sectoral collaboration across water, agriculture, and urban development. International partners such as the United Nations Development Program could further support this transition by funding pilot projects, facilitating capacity building, and deploying IoT-based drought monitoring systems to enhance adaptive capacity.

This research demonstrates the use of climate-informed modeling in assisting the sustainable management of landscapes in Algeria. The climate-informed modeling framework links climate data to planning decisions, and it not only aids in making science-based arbitrary yet practical decisions but these tools have validity in the realm of science and practice. Ultimately, this framework is much more informed than educational, and it also provides detailed methods of intervention planners can use to enact positive change to landscapes and communities. The model is not without limitations. It has not been tested in real conditions, and data reliant on second-hand data may miss more specific environmental and societal differences at local scales. Future studies should examine the example of CIM planning model application in various cities in Algeria with community involvement and documented medium to long-term follow-up. This work will both improve the academic framework and test whether it fosters adaptation support for sustainable and resilient landscapes where it would matter the most in practice.

Ultimately, Algeria's landscapes face a critical crossroads, requiring solutions that blend innovation, local knowledge, and sustainable planning to protect regions from climate and demographic pressures.

References

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data*, *5*, Article 180214. https://doi.org/10.1038/sdata.2018.214

Belmahdi, H. S., & Djemili, A. (2022). Urban landscape structure anatomy: Structure patterns and typology identification in the space-time of Setif City, Algeria. *Frontiers of Architectural Research, 11*(3), 421–439. https://doi.org/10.1016/j.foar.2021.12.004

Berling-Wolff, S., & Wu, J. (2004). Modeling urban landscape dynamics: A review. *Ecological Research*, *19*(1), 119–129. https://doi.org/10.1111/j.1440-1703.2003.00611.x

Borkowski, A. S., & Wyszomirski, M. (2021). Landscape Information Modelling: an important aspect of BIM modelling, examples of cubature, infrastructure, and planning projects. *Geomatics, Landmanagement and Landscape*, *1*, 7–22. https://doi.org/10.15576/GLL/2021.1.7

Bounoua, L., Bachir, N., Souidi, H., Bahi, H., Lagmiri, S., Khebiza, M. Y., Nigro, J., & Thome, K. (2023). Sustainable Development in Algeria's Urban Areas: Population Growth and Land Consumption. *Urban Science*, *7*(1), Article 29. https://doi.org/10.3390/urbansci7010029

Brown, R. D., & Corry, R. C. (2011). Evidence-based landscape architecture: The maturing of a profession. *Landscape and Urban Planning*, *100*(4), 327–329. https://doi.org/10.1016/j.landurbplan.2011.01.017

Cao, Q., Liu, Y., Georgescu, M., & Wu, J. (2020). Impacts of landscape changes on local and regional climate: A systematic review. *Landscape Ecology*, *35*, 1269–1290. https://doi.org/10.1007/s10980-020-01015-7

Chen, M., & Wen, R. (2022). Optimal Design of Garden Landscape Space Environment Based on Interactive Genetic Algorithm. In R. K. Nayak, M. K. Pradhan, A. Mandal, & J. P. Davim (Eds.), *Recent Advances in Materials and Manufacturing Technology*. *Lecture Notes in Mechanical Engineering* (pp. 419–427). Springer. https://doi.org/10.1007/978-981-99-2921-4_39

Climate-Scenarios Canada. (2020). *Representative Concentration Pathways (RCPs) overview*. Government of Canada. https://climate-scenarios.canada.ca/?page=scen-rcp&utm

Conzen, M. R. G. (1960). Alnwick, Northumberland: a study in town-plan analysis. *Transactions and Papers (Institute of British Geographers)*, *27*, iii–122. https://doi.org/10.2307/621094

Corkery, L., & Bishop, K. (2022). Landscape Architecture: Playing a Vital Role in a Time of Climate Crisis, Global Urbanization and Social Upheaval. In K. Bishop & L. Corkery (Eds.), *Routledge Handbook of Urban Landscape Research* (pp. 1–7). Routledge. https://doi.org/10.4324/9781003109563

Cureton, P., & Hartley, E. (2023). City information models (CIMs) as precursors for urban digital twins (UDTs): a case study of Lancaster. *Frontiers in Built Environment*, *9*, Article 1048510. https://doi.org/10.3389/fbuil.2023.1048510

Data Commons. (n.d.). *Data & information for communities* [Data Set]. https://datacommons.org

Food and Agriculture Organization of the United Nations. (2021). *Water management and agricultural adaptation in North Africa*. https://openknowledge.fao.org/server/api/core/bitstreams/0d2e5602-2234-44bb-a539-5323ecbddfc2/content

Hausfather, Z. (2019, August 21). *Explainer: The high-emissions "RCP8.5" global warming scenario*. CarbonBrief. https://www.carbonbrief.org/explainer-the-high-emissions-rcp8-5-global-warming-scenario

Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. https://www.ipcc.ch/report/ar6/wg1/

Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report*. https://www.ipcc.ch/report/ar6/syr/

International Energy Agency. (2023). *World Energy Outlook 2023*. https://www.iea.org/reports/world-energy-outlook-2023

Ivanenko, V., Klimova, I., & Morozov, V. (2024). SWOT analysis: Navigating sustainability amid uncertainty. *Economics. Management. Innovations*, *1*(34), 153–168. https://doi.org/10.35433/ISSN2410-3748-2024-1(34)-10

Kycheryavyj, V. P., Popovych, V., & Kycheryavyj, V. S. (2018). The climate of a large city and ecocline ordination of its vegetation cover. *Journal of the Geographical Institute "Jovan Cvijić" SASA, 68*(2), 177–193. https://doi.org/10.2298/IJGI1802177K

Lenzholzer, S., & Brown, R. D. (2013). Climate-responsive landscape architecture design education. *Journal of Cleaner Production*, *61*, 89–99. https://doi.org/10.1016/j.jclepro.2012.12.038

Li, Z., He, Y., Lu, X., Zhao, H., Zhou, Z., & Cao, Y. (2021). Construction of Smart City Street Landscape Big Data-Driven Intelligent System Based on Industry 4.0. *Computational Intelligence and Neuroscience*, Article 1716396. https://doi.org/10.1155/2021/1716396

Liiv, J., Mefti, M., Poolakese, M., Rikmann, E., & Shanskiy, M. (2025). Innovative reforestation strategies to combat desertification in Algeria: Insights from the Djelfa region. *Sustainability*, *17*(2), Article 715. https://doi.org/10.3390/su17020715

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature*, *405*, 243–253. https://doi.org/10.1038/35012251

Mupfumira, P., Mutingi, M., & Sony, M. (2024). Smart city frameworks SWOT analysis: A systematic literature review. *Frontiers in Sustainable Cities, 6*, Article 1449983. https://doi.org/10.3389/frsc.2024.1449983

Natural Earth. (n.d.). *Countries of the World* [GIS data]. https://www.naturalearthdata.com

Nijhuis, S. (2016). Applications of GIS in landscape design research. *Research in Urbanism Series, 4*, 43–56. https://doi.org/10.7480/rius.4.1367

Office National des Statistiques. (2020). *Recensement général de la population et de l'habitat* [General Census of Population and Housing]. http://www.ons.dz

Olazabal, M., Chelleri, L., Waters, J. J., & Kunath, A. (2012, November 5–6). *Urban resilience: towards an integrated approach*. 1st international conference on urban sustainability & resilience. London, UK. https://www.researchgate.net/publication/236236994_Urban_resilience_towards_an_integrated_approach

OpenLandMap. (n.d.). *Global geospatial datasets for land science* [Data Set]. https://openlandmap.org

Sayad, B., Helmi, M. R., Osra, O. A., Abed, A. M., & Alhubashi, H. H. (2024). Microscale Investigation of Urban Heat Island (UHI) in Annaba City: Unveiling Factors and Mitigation Strategies. *Sustainability*, *16*(2), Article 747. https://doi.org/10.3390/su16020747

Thomson, A. M., Calvin, K. V., Smith, S. J., Kyle, G. P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M. A., Clarke, L. E., & Bond-Lamberty, B. (2011). RCP4.5: A pathway for stabilization of radiative forcing by 2100. *Climatic Change, 109*(1), Article 77. https://doi.org/10.1007/s10584-011-0151-4

United Nations. (2019, May 6). *UN Report: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating'*. United Nations. https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/

United Nations Environment Programme. (2021, June 15). Renewables 2021 global status report. UNEP. https://www.unep.org/resources/report/renewables-2021-global-status-report

United Nations Framework Convention on Climate Change. (2011). *Socioeconomic baseline scenarios and RCP overview*. https://unfccc.int/sites/default/files/ch_3_socioeconomic_baseline_scenarios_rev1.pdf

Vasilevska, L., & Slavković, M. (2024). Urban resilience: Definitions, understanding and conceptualization. *Facta Universitatis - Series: Architecture and Civil Engineering*, *22*(2), 97–103. https://doi.org/10.2298/FUACE230630023V

World Bank. (n.d.). *World development indicators*. Retrieved January 11, 2025, from https://data.worldbank.org

Wu, J. (2021). Landscape sustainability science (II): core questions and key approaches. *Landscape Ecology*, *36*, 2453–2485. https://doi.org/10.1007/s10980-021-01245-3

Xue, Y., & Zhao, Y. (2023). Research on digital design and experience of urban landscape based on parametric model. *Applied Mathematics and Nonlinear Sciences*, *9*(1), 1–17. https://doi.org/10.2478/amns.2023.2.00886

Ye, F. (2025). Application of IoT monitoring and maintenance management systems in urban parks under the background of smart landscaping. In X. Qinghe (Ed.), *2025 International Conference on Architecture, Civil Engineering, and Landscaping (ICACEL 2025)* (pp. 541–545). Francis Academic Press.

Yi, L. (2023). Research on the Application of Computer Aided Design Software SU in Landscape Design. *Highlights in Science, Engineering and Technology*, *48*, 11–16. https://doi.org/10.54097/hset.v48i.8227

Yu, W., Zhou, X., Wang, D., & Dong, J. (2025). The Development and Construction of City Information Modeling (CIM): A Survey from Data Perspective. *Applied Sciences, 15*(9), Article 4696. https://doi.org/10.3390/app15094696

Zhu, M., Zhu, D., Huang, M., Gong, D., Li, S., Xia, Y., Lin, H., & Altan, O. (2025). Assessing the Impact of Climate Change on the Landscape Stability in the Mediterranean World Heritage Site Based on Multi-Sourced Remote Sensing Data: A Case Study of the Causses and Cévennes, France. *Remote Sensing*, *17*(2), Article 203. https://doi.org/10.3390/rs17020203