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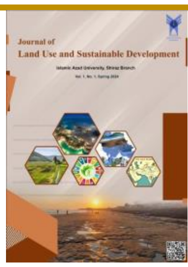

Original Research Paper

Explanation of The Feasibility of The Ecological City Model (Biocity) with An Emphasis on the Role of a Renewable Gray Urban Infrastructure

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Abstract

Ecological cities seek to create a sustainable balance between human activities and the environment. Based on the objective, this is applied-developmental research. In the qualitative section, grounded theory and MAXQDA software were used for qualitative data analysis. Interpretive-structural modeling and a structural self-interaction matrix were used to provide the initial model. In the quantitative analysis section, the partial least squares technique, structural equation modeling with PLS software, was used. The location and case study are the city of Qazvin. The characteristics and dimensions related to the ecological city in the community, geographical dimension, physical boundary, and sphere of influence with eco-urban dimensions have been studied and analyzed. The results seek to raise awareness and assist in generalizing to similar societies and expanding its application. The statistical population in the qualitative section includes experts, university professors, and urban management specialists. The sampling method combines two methods: purposive non-probability sampling and theoretical sampling. The questionnaire includes 15 main factors and 60 items. Using the power analysis rule at a %95 confidence level, with an effect size of 0.15 and a statistical power of %80, the minimum sample size was estimated to be 145 people. For greater certainty, 150 questionnaires were collected. Cohen's power analysis rule and G*Power software were also used to calculate the sample size. The relationships of the constructs affecting the model were investigated and identified. After identifying the sequence of constructs, they were classified in the MICMAC diagram based on the power of influence and the degree of dependence.

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INTRODUCTION

With the rapid growth of the world's urban population and increasing environmental concerns, the challenge of transforming urban environments into more sustainable ones has become a top priority for designers, academics, and government agencies. One solution considered to address these challenges is the idea of the ecological city. In recent decades, the construction of ecological cities has become a very modern trend worldwide. They serve multiple purposes, the two most important of which are to combat the decline in the value of the urban environment and, in the process of building them, to create new business opportunities through clean technologies and natural resource conservation measures. Meanwhile, new approaches in urban planning have emerged under the titles of ecological cities, which seek to alleviate these problems. The ecological city model proposes a design method that places the city in a healthy relationship with the natural environment and benefits from its vast potentials, in a way that causes the least harm and danger to the ecosystem, or it can be said that it minimizes negative impacts on the environment.

It is worth mentioning that modern cities have been formed and stabilized over the centuries based on technological infrastructures. Today, the city and urban life are unimaginable without highways and rail transport networks, airports, water supply networks, sewage networks, telephones, electricity, and, more recently, internet and mobile networks, and their fundamental presence seems as ordinary and natural to citizens as sunlight, trees, and clean air. These infrastructure networks have influenced the shape of cities and the relationship of modern humans with their surrounding environment and nature more than any other modern achievement of the industrial era. With the West's entry into the post-industrial era, from the late twentieth century, coinciding with the expansion and attention to the ecological hazards caused by the excessive development of modern cities and massive technical infrastructures, which led to critical approaches to urban planning and modern technology in the last decades of the twentieth century, the emergence of failures and crises in the infrastructure networks of the early twenty-first century and the failure of existing one-dimensional infrastructures to meet the multidimensional needs of the post-industrial society, highlighted the need to review the common approaches in defining and developing modern infrastructures.

It is very clear that urban infrastructures, especially gray and renewable ones, are a fundamental and essential part of urban facilities and equipment. Urban facilities and equipment are the elements, components, and processes of the urban fabric and space that facilitate the lives of citizens. Facilities and equipment are also the physical manifestation of public institutions and organizations in cities and towns. Therefore, in urban planning and design thinking, each set or institution and public service organization, in accordance with the needs of users, has a specific form of activity, based on which the economic, social, political, cultural, physical-spatial, and systemic identity of a settlement can be identified. From another perspective, it is clear that the decision-making process regarding networks, collection facilities, and treatment methods, combined with the morphology, natural characteristics, and the texture and structure of the city, not only affects the executive system of urban development but also can influence the patterns of organizing the environmental qualities of the city, which is one of the fundamental topics of urban design. Conversely, urban design policies can significantly and effectively influence how to select the type of network, locations for wastewater treatment, and mechanisms for recovering water from urban wastewater and utilizing it in the necessary infrastructure for ecological city (eco-city) foundations and programs.

In gray renewable urban infrastructure, wastewater is one of the environmental pollutants, so it must be collected and removed from cities, first refined and treated, and then returned to the water cycle in nature. In addition to this, the reuse of wastewater is increasingly being considered due to the growing need for water, water resource imbalances, climate change, and reduced rainfall. It seems that urban design combined with ecological design, which emphasizes the optimal use of existing resources and their appropriate reuse, can be a suitable solution to mitigate the adverse effects of water scarcity, compensate for the reduction in per capita green space, and address the gaps in creating ecological environments on the path to having a city for well-being by reusing renewable gray urban infrastructure resources. And what is raised as the main concern and problem in this research is how to apply the principles of this type of urban planning model in benefiting from the role of renewable gray urban infrastructure (the component considered in gray urban infrastructure: urban wastewater and wastewater treatment plant and treated effluent and resources from nutrient-rich sludge are the infrastructure of green urban infrastructure) in achieving the criteria of the ecological city and presenting a paradigm model of it in the city of Qazvin. Qazvin is one of the cities that, due to rapid, dispersed, and unbalanced growth, and taking on new political and administrative roles, and sometimes a sudden increase in the urban population, and especially the continuous increase and overflow of population from the sphere of influence, faces serious problems in various dimensions, especially sustainability in the current and future situation. Therefore, appropriate policies and planning must be adopted to achieve its balanced and sustainable future development. This city, with its ecological and natural potentials, is one of the cities that, despite its ecological background, has been prevented from moving towards sustainable urban development due to the sudden changes in urban population growth and unbalanced physical developments and the impact of not-so-correct and systematic urban planning policies and recent urban plans. Therefore, the ecological city approach is a suitable version for the sustainable development of the city of Qazvin. In fact, the present research seeks to answer the following questions: How can practical steps be taken by using renewable urban gray infrastructure as a way to address environmental justice issues, especially in the green urban infrastructure sector, and move towards the realization of the ecological city model? And considering the ecological city approach, what results can be inferred from clarifying the feasibility of the models of this model, given the potential of renewable urban gray infrastructure, and used in achieving the eco-city components for the city of Qazvin?

Literature Review

The Concept of the Ecological City

The concept of the ecological city aims to transform urban environments into sustainable and livable spaces by integrating nature with technology (Mayona & Sutriadi, 2024). It emphasizes the balance of urban metabolism through ecosystem independence and human adaptability (Mayona, 2021). Key dimensions include compact urban form, mixed land use, prioritization of public transportation and non-motorized modes, and the conservation of natural areas (Kenworthy, 2006). This concept considers community dynamics and the dynamic functions of the city, striving to balance development with environmental tranquility (Mandeli *et al*., 2022).

Ecological Cities

Ecological cities, as innovative patterns of urban development, aim to create a sustainable balance between human activities and the environment. These models emerge as solutions for improving quality of life and mitigating the negative impacts of urban development, especially in the face of environmental challenges and climate change. In this context, renewable gray infrastructures are considered key tools for achieving the goals of ecological cities. These infrastructures can enhance urban efficiency and sustainability by optimizing resource consumption and reducing waste generation (Carter *et al*., 2024). The feasibility of the ecological city model necessitates attention to the complex interactions between gray infrastructures and natural ecosystems, which can improve urban resilience and decrease vulnerability to environmental crises. Thus, exploring and explaining the role of renewable gray infrastructures in realizing ecological cities not only aids in better understanding existing challenges but also serves as guidance for policymakers and urban planners in the pursuit of sustainable development (Khalid *et al*., 2021).

Ecological Perspective by Robert Park

Ecology is a body of knowledge regarding the impacts of the environment on living organisms and vice versa, as well as the relationships among living beings. Park, a founding figure in urban sociology in the U.S. and a theorist of the Chicago School, investigated how changes in the physical and spatial structure of cities affect social behaviors. He argued that significant cultural changes within society are linked to spatial transformations. Park believed that there exists a spatial division in cities that corresponds with the division of labor in those spaces, such as residential neighborhoods, slums, and informal settlements. He also maintained that all natural areas result from environmental forces rather than government planning. According to Park, the shape of a city is influenced by processes of competition and population migration, leading to the emergence of natural areas (such as gray spaces) (Heidari et al., 2023).

Urban Ecology

From 189 to 1925, Patrick Geddes contributed extensively to the research and theorization surrounding urban ecology concepts. During this era, theories related to the harmony and interdependence between "cities and regions" and the use of urban land gained prominence. The legacy of Geddes's studies continued through renowned researchers in the field, such as Mark Jefferson, Patrick Abercrombie, and Louis Mumford, who paved new paths in urban studies and urban ecology. Urban ecology is a burgeoning science that seeks a comprehensive understanding of the interactions among environmental, economic, political, and socio-cultural factors based on ecological principles. It enables humans to thrive harmoniously and sustainably with nature.

2.5 Ecological Urban Development

Various approaches have been proposed for achieving urban balance and sustainability, one of which is the ecological city approach. The ecological city approach is interdisciplinary and comprehensive, integrating multiple specialties to address all dimensions of urban development with a focus on environmental sustainability, economic development, and social equity (Barati, 2022). Essentially, the ecological city approach does not solely focus on the physical structures of the city; it encompasses a multitude of dimensions and characteristics aimed at achieving sustainability. One of the theorists of the ecological city is Paul Downton, who defined the ideal ecological city and presented his theory under the term “eco-city.” He stated that cities should create environments that promote health and enhance sustainability, highlighting that human activities have significantly influenced the biosphere. This realization necessitates the reformulation of urban processes and objectives towards creating a net positive ecological system. Accordingly, Downton proposed principles for developing healthy human settlements, known as the Eco-Polis Development Principles (EDP), which include ten foundational principles emphasizing energy consumption optimization, ecosystem preservation, and wastewater recycling (renewable gray infrastructures) (Table 1).

Table 1: Downton's Ten Ecodesign Principles (EDP)

Principles	Components
Restoring Degraded Lands	Cleaning contaminated sites, healing damaged rural areas, restoring vegetation, promoting ecological agriculture, creating green corridors with native plants.
Ecosystem Focus	Preserving natural water and nutrient cycles, designing buildings and urban forms that fit the landscape and climate, conserving water, recycling wastewater, using local building materials, and addressing cultural needs through re-habitation.
Balanced Development	Reducing the city's impact beyond its borders, encouraging mixed-use development (residential, commercial, recreation, education), maximizing land surface area through biological means, developing urban food production through rooftop gardens, greenhouses, vertical farms, and creating wildlife reserves, recognizing the place of all living beings and designing for non-human species.
Energy Optimization	Using renewable solar and wind energy for local production, designing buildings for solar access, reducing fossil fuel consumption with the goal of eliminating it as an energy source, avoiding nuclear energy, and designing for climate responsiveness.
Community Building	Developing in a community-driven process, ensuring community participation in governance and public responsibility, designing urban environments with diverse spaces that enhance social interaction, and designing urban environments with diversity and connection.
Promoting Social Justice	Involving all levels of society in the development process, providing affordable housing, encouraging public use, and employing socio-political systems that foster direct democracy.
Supporting the Economy	Developing environmentally responsible industries, fostering regional trade, developing exportable green technologies and services, adopting fair trade practices, creating information technology, providing incentives for innovation in companies related to social responsibility, and using similar local currency systems to create local economic flexibility.

Principles	Components
Creating Compact Cities	Creating walkable and recreational cities with non-motorized transportation, developing integrated transportation networks that minimize car use, providing access through proximity, creating complex and effective 3D built forms, having well-defined boundaries for urban areas, and meeting daily needs at the city level.
Ensuring Health and Safety	Eliminating pollution, promoting and achieving environmental quality, ensuring safe water supply, recycling wastewater for reuse, maintaining clean air, designing built environments with surveillance, avoiding shutdowns when designing safety environments, ensuring food security, including urban agriculture, and providing habitat for animals.
Enriching History and Culture	Restoring and maintaining local landmarks, identifying and celebrating the spirit of place, celebrating and encouraging cultural diversity, respecting the habitation of indigenous people in the land, developing culture by comprehensively involving art, including music, electronic media, and digital technology, integrating art and science with daily life, promoting ecological awareness as part of cultural development, and supporting community art and crafts exhibitions, celebrations, and cultural festivals.

Eco-City

The concept of the eco-city arises from utilizing ecological principles in urban design and planning, viewing the city as an ecosystem. An eco-city is characterized as a healthy city designed in harmony with nature, aimed at achieving sustainable development. It possesses an ecological profile linked to landscape patterns and processes. This includes a complex interplay of natural, economic, and social ecosystems shaped by geological patterns, hydrological processes, biological diversity, anthropogenic movements, and aesthetic landscape contexts. In ecological landscape design, ecological connectivity, the restoration of landscape functions, and aesthetic, ecological, and spatial innovations (like renewable energy stations) are fundamental components.

Importance and Benefits of Eco-Cities

An eco-city is one where social, economic, and environmental development occurs harmoniously. The construction of eco-cities began following the introduction of the ecological city concept by the MAB (Man and the Biosphere) program in the 1970s, gaining widespread attention globally. Since the 1990s, many scientists, policymakers, and sociologists have focused on low-carbon ecological development, indicating that urban development patterns face new challenges. Undoubtedly, there is a clear trend towards the transformation of most cities into eco-cities, making urban transformation essential (Li *et al*., 2022).

Contemporary Concepts and Models of Ecological City Planning

Planning strategies in the 21st century have undergone significant changes, increasingly focusing on addressing environmental challenges and promoting sustainable practices. Environmental development tools have been employed to foster sustainable planning, as discussed in various conferences (Joss *et al*., 2021). The 21st century marks a new era in urban planning, necessitating innovative urban models and various advanced approaches. Urban and housing planning has diversified to include innovative concepts such as green cities, eco-cities, smart cities, and digital cities. The emphasis is on creating sustainable and resilient urban environments that effectively respond to contemporary global challenges.

Urban Gray Infrastructure

Many studies have focused on the interaction between green-gray infrastructures, gray-blue infrastructures, and green-gray-blue infrastructures to enhance urban resilience. However, several barriers hinder the implementation of green and blue infrastructures in real-world scenarios. In cities, small green and blue spaces may provide minimal cooling effects; therefore, there is a recommendation to create larger areas to maximize cooling benefits. This, in turn, puts additional pressure on land use. Clearly, larger green and blue infrastructures are not feasible in densely populated cities with limited open space. Additionally, since plants and water require significant volumes of water for evaporation and transpiration, green and blue infrastructures are more suitable for humid areas but not for arid regions (Riettmann, 2021).

Thus, in many regions—such as dense urban areas and dry zones—it becomes essential to prioritize gray infrastructures (like roads, buildings, and pipelines) to mitigate the urban heat island effect. Nevertheless, under traditional views, gray infrastructures have been perceived as contributors to the formation and intensification of urban heat islands. For example, impermeable surfaces can increase solar radiation absorption and hinder soil evaporation. However, this perception may change with the emergence of innovative gray infrastructures that can enhance solar reflectance and latent heat flux. Studies have shown that these gray infrastructures can provide substantial cooling potential, reducing temperatures by up to 3.5 degrees Celsius (Santamouris *et al.*, 2017). Nonetheless, some aspects of gray infrastructures (such as a lack of precise design tools for application) remain incompletely understood, limiting their practical implementation (Qi *et al*., 2019).

Renewable Energy

Renewable energy refers to energy sources that are naturally and continuously produced in nature and can be reused. These sources include solar, wind, hydroelectric, geothermal, and biomass energy. The significance of renewable energy lies in its potential to reduce dependency on fossil fuels and decrease environmental pollution. Given climate change and the need to preserve the environment, the use of renewable energy has increasingly become a sustainable solution for meeting the energy needs of human societies. These sources not only contribute to reducing greenhouse gas emissions but can also foster economic development and create new jobs in sectors related to advanced energy technologies.

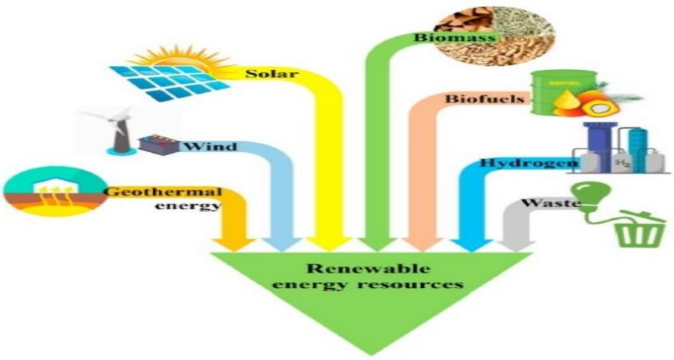

Figure 1: Renewable energy resources

Renewable Gray Urban Infrastructure

Renewable gray urban infrastructure refers to the systems and facilities designed and implemented to meet essential urban needs, including water, energy, transportation, and waste management, while being sustainable and renewable. This type of infrastructure includes water and wastewater networks, public transportation systems, renewable energy facilities like solar panels and wind turbines, and waste management systems. The primary goal of renewable gray infrastructure is to enhance the quality of life for citizens and reduce the environmental impacts associated with urban development. Given environmental challenges and the need for sustainable development, these infrastructures are recognized as key solutions for achieving ecological and sustainable cities (Li *et al*., 2022).

The benefits of renewable gray urban infrastructure are numerous. The foremost advantage is the reduction in dependence on non-renewable resources and fossil fuels, leading to decreased greenhouse gas emissions and improved air quality. Furthermore, these infrastructures can optimize energy and water resource consumption, ultimately lowering operational costs. Additionally, the creation of renewable infrastructure can enhance employment opportunities and foster local economic development due to the increased need for labor to design, build, and maintain these systems. Finally, renewable gray infrastructures can bolster urban resilience against climate change and natural disasters (Smith *et al*., 2023).

Urban Renewable Gray Infrastructure (Wastewater)

The primary goal of wastewater collection and treatment is to improve its quality to allow for the reuse of treated wastewater or its disposal into the environment without altering the receiving ecosystem. Wastewater is generated from water consumption in any community, and its quality depends on how water is used. It is evident that domestic wastewater contains substances from household use and human waste. Such a combination has a high potential for environmental pollution and, due to containing various pathogenic microorganisms, can lead to various diseases. One of the best ways to prevent the pollution of surface waters is to utilize treated wastewater.

A fundamental approach to the economical reuse of effluent from treatment processes is its use in protein production, whether through irrigation, agriculture, or aquaculture involving fish and algae. In the context of irrigating green spaces and meeting industrial needs, particularly in laying the groundwork for the ecological city's initiatives, wastewater treatment projects generally consider the prevention of health hazards and disease transfer as primary goals. Additionally, examining ancillary factors such as preserving natural resources, ensuring comfort, maintaining aesthetics, protecting the environment, and preserving ecological balance is crucial. Thus, the reuse of this renewable infrastructure and vital energy source, post-treatment and standardization, plays a significant role in urban planning and its incorporation into urban projects.

Figure 2: Output of the MLE Wastewater Treatment Plant in Mahmoudabad, Qazvin.

For instance, the shear wave velocity at shallow depth is key input parameter in estimating ground motion. The Vs_{30} values of sites can be determined by multichannel surface-wave analysis (MASW) using active sources such as a sledgehammer.

The Area under Study

Qazvin, the capital of Qazvin Province, is situated at an elevation of 1,278 meters above sea level. It lies at approximately 50.00° East longitude and 36.16° North latitude. Geographically, Qazvin is bordered by Lahijan to the north, Razmian to the northeast, Bidestan and Mohammadieh to the east, Alvand to the southeast, the industrial city of Lia to the south, Eqlabieh to the southwest, Mahmoudabad Nomuneh to the west, and Manjil to the northwest.

Figure 3: Geographic Location of Study Area (Source: Authors).

Due to its position on transportation routes connecting the east to the west and the south to the north of the country, as well as its proximity to Tehran and Karaj, Qazvin enjoys a favorable status in Iran. The city has several industrial towns, educational institutions, and a number of universities, including Imam Khomeini International University, Qazvin University of Medical Sciences, and the Islamic Azad University - Barajin.

The city of Qazvin is divided into six districts, covering a total area of 4,530 hectares. According to the 2016 census, the population of Qazvin was 402,748, with a projected population of 543,016 by 2046. The area south of the Qazvin-Zanjan highway encompasses approximately 3,506 hectares and includes districts 1 to 5. The development plan estimates the total area of the city at 6,143 hectares, with district 6 located in the northern section of the highway.

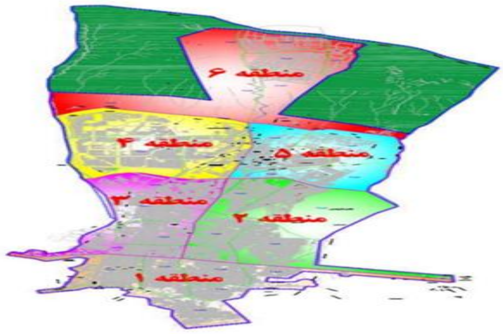

Figure 4: District and Zone Division in the Revised Detailed Plan (Source: Authors).

Qazvin Province is divided into mountainous and plain regions based on its natural conditions. According to the climatic map of the province, prepared using the De Martonne method, the predominant climatic condition is classified as semi-arid cold. This climate type represents the largest area within the central plain of Qazvin and the cities of Abeyk and Takestan. In the higher regions of these cities, along with the Kuhin area, a frigid semi-arid climate can be observed with lower average temperatures. As indicated in Figure 3, the most significant monthly precipitation occurs in Esfand (March), accounting for approximately 16.2% of the annual rainfall, while the least average monthly precipitation is recorded in Shahrivar (August), contributing around 0.34% of the annual total.

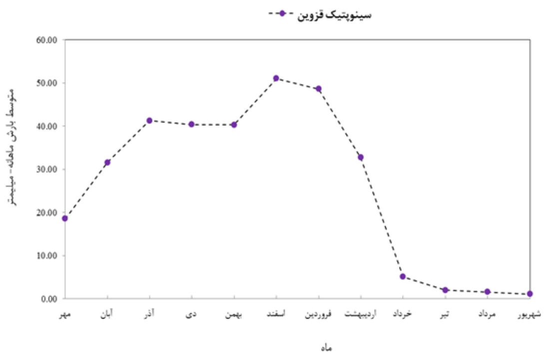

Figure 5: Average Monthly Rainfall Distribution at Qazvin Synoptic Station (Source: Authors).

The total area of parks in Qazvin is 84 hectares, resulting in a recreational space per capita of only 2 square meters for each Qazvini citizen, a figure that needs significant increase. Barajin Park (Fadak Forest Park), developed in late 1998 in collaboration with the Agricultural and Natural Resources Jihad Organization, spans 600 hectares and was expanded to 1,800 hectares by 2021, serving as a site for enhancing the environmental resilience of Qazvin. The necessity for improving this park is critical in achieving a standard urban green space.

According to international standards, the ideal per capita green space is 50 square meters, while the United Nations Environment Programme has deemed a per capita space of 20 to 25 square meters as suitable. Given the existing urban green space and the minimum space of 7 square meters considered in the recent comprehensive plan for Qazvin, the city should have approximately 245 hectares of green space. However, with only about 84 hectares currently available, Qazvin faces a deficiency of over 161 hectares of green space. The urban development process and changes in land uses have led to the loss of many natural areas, replaced by man-made surfaces. The land cover and land use in Qazvin are rapidly changing due to various factors, including its strategic position along major transportation routes, proximity to Tehran and Karaj, and the presence of several industrial towns along with significant construction activities in recent years. Historically, Qazvin has been characterized by numerous traditional gardens, yet urban development has resulted in the destruction of these gardens, green spaces, and natural areas, replacing them with human-centric land uses. This has adversely impacted the quality of life for residents, especially concerning access to green spaces and balanced urban green space ratios.

Ecological metrics and the assessment methods of land use changes, particularly in urban green spaces, are crucial for evaluating urban environments. Utilizing remote sensing data (Landsat 8), analyzed with less than %10 cloud cover for determining land use categories and trends, it was found that as of 2019, green spaces in Qazvin had diminished in both density and area. To mitigate the impacts of urban expansion, enhance residents' quality of life, and preserve urban green infrastructure, it is vital to plan and manage urban land use in a balanced manner, with an emphasis on expanding green spaces within Qazvin. This objective has been acknowledged and incorporated into the city's vision.

It is clear that achieving ecological sustainability and developing urban green projects are contingent on securing adequate water resources. Given the semi-arid climate of the region, along with rainfall variability and water scarcity, the existence of optimal renewable gray urban infrastructure is essential for making these ecological dimensions realizable and advancing towards an ecological city in Qazvin.

Considering the significance of water resources in developing the ecological dimensions and urban green spaces, the hydrological regime of rivers and the volumes of surface water flow in Qazvin are regularly measured using 17 gauging stations operated by the regional water company. The highest annual runoff is observed in the mountainous region overlooking Qazvin, particularly in the Alamut area, while the least comes from the Khar and Abhar rivers and the northern rivers of Qazvin. These rivers often run dry during agricultural seasons at the entrance to the plains and are utilized mainly to partially alleviate irrigation shortages for crops and gardens.

Methodology

The research is applied and developmental in nature. In the qualitative section, grounded theory analysis was used, employing the MAXQDA software for data analysis. For presenting the initial model, interpretive-structural modeling (ISM) and the Structural Self-Interacting Matrix (SSIM) were utilized. In the quantitative analysis, the Partial Least Squares (PLS) method, via Smart PLS software, was applied.

Results and Discussion

Demographic Characteristics

This section presents the demographic information of the experts and specialists participating in this study. The qualitative section analyzes data from interviews using the grounded theory qualitative data analysis method and MaxQDA software. The statistical population in the qualitative section includes experts, academic professors, and urban management specialists. The sampling method is a combination of purposive (judgmental) non-probability sampling and theoretical sampling. The questionnaire consists of 15 main factors and 60 items. Using power analysis at a 95% confidence level with an effect size of 0.15 and a statistical power of 80%, the minimum sample size was estimated to be 145 people. To ensure greater reliability, 150 questionnaires were collected. Cohen's power analysis rule and G*Power software were used to estimate the sample size. In the quantitative section of this study, the views of 384 people were used. In terms of gender, 216 (56%) were male and 168 (43%) were female. Regarding age, 99 (25%) were under 30 years old, 111 (28%) were 30 to 40 years old, 95 (24%) were 40 to 50 years old, and 79 (20%) were over 50 years old. In terms of education, 144 (37%) had a diploma or less, 64 (16%) had an associate degree, 125 (32%) had a bachelor's degree, and 51 (13%) had postgraduate education.

4.2 Data Coding in Grounded Theory

One of the most important strategies in qualitative research is grounded theory. Grounded theory is an "inductive" methodology for discovering theory, which allows the researcher to develop a theoretical report of the "general characteristics of the subject," while simultaneously grounding this report in the empirical observations of the data. Strauss and Corbin, in 1998, by codifying the procedures in their book "Basics of Qualitative Research (Grounded Theory Procedures and Techniques)", proposed three coding techniques: open coding, axial coding, and selective coding. This chapter of the present study will implement these coding techniques.

Open Coding

This stage involves categorizing different codes into potential themes and arranging all the coded data summaries into identified themes. In fact, the researcher begins analyzing their codes and considers how different codes can be combined to create an overall theme. In this stage, the indicators extracted from the interview texts are categorized by screening, removing duplicate codes, and integrating synonymous codes. Subsequently, the process of reviewing, analyzing, and performing open coding of all the collected categories of interviewees has been coded in Maxqda software.

4.5 .Data Coding in Grounded Theory

One of the most important strategies in qualitative research is grounded theory. Grounded theory is an "inductive" methodology for discovering theory, which allows the researcher to develop a theoretical report of the "general characteristics of the subject," while simultaneously grounding this report in the empirical observations of the data. Strauss and Corbin, in 1998, by codifying the procedures in their book "Basics of Qualitative Research (Grounded Theory Procedures and Techniques)", proposed three coding techniques: open coding, axial coding, and selective coding. This chapter of the present study will implement these coding techniques.

Axial Coding

Axial coding is the second stage of analysis in grounded theory. The goal of this stage is to establish relationships between the categories generated during the open coding phase. In this stage, the indicators extracted from the interview texts are categorized by screening, removing duplicate codes, and integrating synonymous codes. The relationship of other categories to the axial category can be realized in six aspects, which include causal conditions, the central phenomenon, strategies and actions, intervening conditions, contextual conditions, and consequences. Therefore, from all the indicators obtained from the open coding stage, this stage focuses on determining categories, resulting in 9 main categories and 56 sub-categories. Subsequently, these items are presented in separate tables.

Selective Coding

After axial coding, selective coding must be performed. In this step, the identified categories resulting from axial coding are classified into the 6 categories of the paradigm model. These categories include causal conditions, contextual conditions, intervening conditions, axial conditions, strategic conditions, and consequences.

Categories of Strategies and Actions

Strategies and actions consist of behavioral strategies and methods that actors undertake as a result of causal conditions. They are the actions and methods used, and the measures, tactics, and techniques that they adopt as required by the contexts and conditions in which they are located. Based on the results of the secondary coding of the research, the indicators of planning for more rational use of resources, energy conservation, improvement of recycling, use of appropriate and creative technologies, education and awareness, holding workshops and seminars, encouraging social participation, appropriate technology for the eco-city, and encouraging private investment were selected as categories of strategies and actions in the realization of the eco-city (biophilic city) model, with emphasis on the role of a renewable grey urban infrastructure.

Categories of Intervening Conditions

Intervening conditions consist of conditions that influence and modify the adopted strategies and interactions. Based on the results of the secondary coding of the research, the indicators of the existence of strict or insufficient laws and regulations, the lack of acceptance or resistance of society to changes and innovations, the lack of effective cooperation and coordination between governmental, private and community institutions, climate change and environmental crises, rapid urbanization and the occurrence of class divisions, the decrease in energy resources, spatial inequalities (affluent vs. deprived neighborhoods, informal settlements), the increasing trend of natural disasters, and lack of awareness and education were selected as categories of intervening conditions in the realization of the eco-city (biophilic city) model, with emphasis on the role of a renewable grey urban infrastructure.

Categories of Consequences

Finally, the result of the present study, as well as the combination of causal conditions and adopted strategies, leads to effects and consequences. Based on the results of the secondary coding of the research, the indicators of non-destruction of the ecosystem cycle and preservation of vital geography, protection of green spaces through the creation and maintenance of parks and green spaces, reducing fossil fuel consumption, protecting natural ecosystems in the region, improving air quality and reducing temperature, creating a safe, healthy and sustainable city, economic savings, reducing costs, creating employment, utilizing local and renewable resources, energy efficiency and technology, promoting social participation, developing local cooperation, considering equality and social justice, improving public health and cultural identity were selected as categories of consequences in the realization of the eco-city (biophilic city) model, with emphasis on the role of a renewable grey urban infrastructure.

Summary of the Qualitative Section and Presentation of the Paradigm Model (Explanation of the Initial Pattern)

In grounded theory, the integration of data is of great importance. In the research process, after collecting data, analyzing and interpreting it, it is time to present the model, draw conclusions, and summarize the research. Figure 6 shows the paradigm model (initial model explaining the biophilic city pattern) of the research.

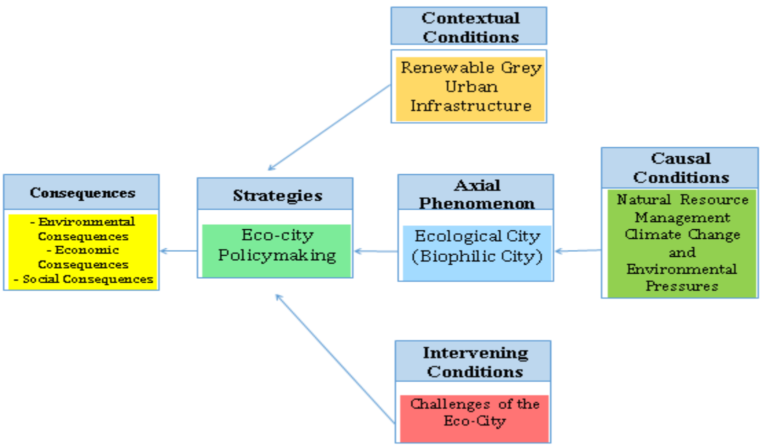

Figure 6: Research paradigm

Interpretive Structural Modeling (ISM)

To present the initial model for the realization of the eco-city (biophilic city), the ISM method was used. Interpretive Structural Modeling (ISM) is an exploratory method for identifying and leveling the relationships between constructs. The initial idea of the ISM method was proposed by Warfield (1974) and developed by Sage (1977). With this method, experts can identify and represent complex and multiple relationships between constructs. Interpretive structural modeling is based on the interpretive paradigm, so it is very suitable for management and decision-making studies in organizations. This method is an interactive learning process in which a set of different constructs are structured in the form of a systematic and comprehensive model. In fact, using this method, the impact of one construct on other constructs is examined. In this method, the relationships of constructs can be identified, a structural-interpretive model of the constructs can be presented, and finally, the constructs can be classified based on their driving power and dependence. The constructs examined to present the initial model of eco-city (biophilic city) realization are: Natural Resource Management (C1), Climate Change and Environmental Pressures (C2), Renewable Grey Urban Infrastructure (C3), Ecological City (C4), Challenges of the Eco-City (C5), Eco-city Policymaking (C6), Environmental Consequences (C7), Economic Consequences (C8), and Social Consequences (C9).

Forming the Structural Self-Interaction Matrix (SSIM)

The Structural Self-Interaction Matrix (SSIM) is the first matrix that is used to identify the internal relationships of constructs based on the views of experts. The matrix obtained in this step shows which constructs a construct affects and which constructs it is affected by. The structural self-interaction matrix consists of the research constructs and their comparison using four states of conceptual relationships. The resulting information is summarized using the interpretive structural modeling method, and the structural self-interaction matrix is formed.

Table 2: Structural Self-Interaction Matrix of Constructs for the Realization of an Ecological City (Biophilic City)

X	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1 (Natural Resource Management)		O	O	V	O	V	V	V	V
C2 (Climate Change & Environmental Pressures)			O	V	O	V	V	V	V
C3 (Renewable Grey Urban Infrastructure)				V	O	V	V	V	O
C4 (Ecological City)					A	V	O	V	V
C5 (Eco-City Challenges)						V	V	V	V
C6 (Eco-City Policymaking)							V	V	V
C7 (Environmental Consequences)								O	O
C8 (Economic Consequences)									O
C9 (Social Consequences)									

The Reachability Matrix (RM) is obtained by converting the Structural Self-Interaction Matrix into a binary (0 and 1) matrix. In the Reachability Matrix, the main diagonal entries are set to one. Therefore, the Reachability Matrix of constructs for the realization of an Ecological City (Biophilic City) is presented in Table 3.

Table 3: Reachability Matrix of Constructs for the Realization of an Ecological City (Biophilic City)

RM	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1 (Natural Resource Management)	1	0	0	1	0	1	1	1	1
C2 (Climate Change & Environmental Pressures)	0	1	0	1	0	1	1	1	1
C3 (Renewable Grey Urban Infrastructure)	0	0	1	1	0	1	1	1	0
C4 (Ecological City)	0	0	0	1	0	1	0	1	1
C5 (Eco-City Challenges)	0	0	0	1	1	1	1	1	1
C6 (Eco-City Policymaking)	0	0	0	0	0	1	1	1	1
C7 (Environmental Consequences)	0	0	0	0	0	0	1	0	0
C8 (Economic Consequences)	0	0	0	0	0	0	0	1	0
C9 (Social Consequences)	0	0	0	0	0	0	0	0	1

The Transitivity Matrix (TM) is formed by examining secondary relationships in the Reachability Matrix. Once the Reachability Matrix is formed, the secondary relationships should be checked to ensure transitivity. This means that if A leads to B, and B leads to C, then A must lead to C. That is, if, based on secondary relationships, direct effects should have been considered, but this has not happened in practice, the table should be corrected to also show the secondary relationship. After the initial Reachability Matrix is obtained, the final Reachability Matrix is obtained by entering transitivity into the relationships of the constructs. The Transitivity Matrix of constructs for the realization of an Ecological City (Biophilic City) is presented in Table 4.

Table 4: Transitivity Matrix of Constructs for the Realization of an Ecological City (Biophilic City)

TM	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1 (Natural Resource Management)	1	0	0	1	0	1	1	1	1
C2 (Climate Change & Environmental Pressures)	0	1	0	1	0	1	1	1	1
C3 (Renewable Grey Urban Infrastructure)	0	0	1	1	0	1	1	1	0
C4 (Ecological City)	0	0	0	1	0	1	0	1	1
C5 (Eco-City Challenges)	0	0	0	1	1	1	1	1	1
C6 (Eco-City Policymaking)	0	0	0	0	0	1	1	1	1
C7 (Environmental Consequences)	0	0	0	0	0	0	1	0	0
C8 (Economic Consequences)	0	0	0	0	0	0	0	1	0
C9 (Social Consequences)	0	0	0	0	0	0	0	0	1

To determine the relationships and level of the constructs, the reachability set and the antecedent set must be extracted from the reachability matrix for each construct. Reachability Set (row elements, outputs, or influences): Constructs that can be reached through this construct. Antecedent Set (column elements, inputs, or influenced by): Constructs through which this construct can be reached.
The reachability set includes the construct itself and the constructs that are influenced by it. The antecedent set includes the construct itself and the constructs that influence it. Then, the set of two-way relationships of the constructs is determined.
Construct Environmental Consequences (C7) is at Level 1.
Construct Economic Consequences (C8) is at Level 1.
Construct Social Consequences (C9) is at Level 1.
Construct Eco-city Policymaking (C6) is at Level 2.
Construct Ecological City (C4) is at Level 3.
Construct Natural Resource Management (C1) is at Level 4.
Construct Climate Change and Environmental Pressures (C2) is at Level 4.
Construct Renewable Grey Urban Infrastructure (C3) is at Level 4.
Construct Eco-City Challenges (C5) is at Level 4.

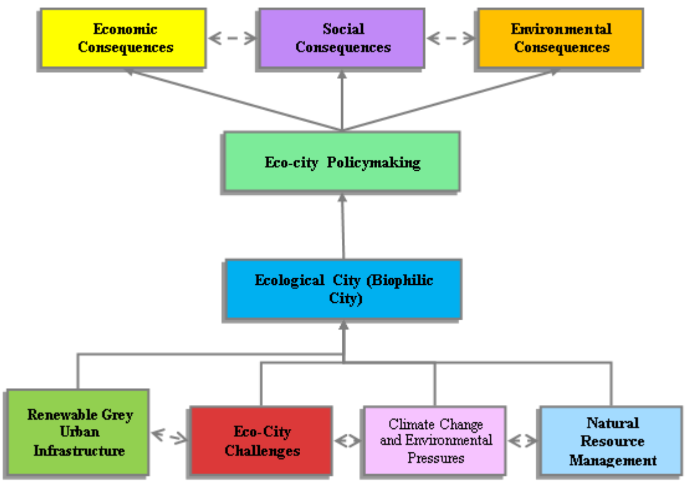

Figure 7: Realization Pattern of the Ecological City (Biophilic City)

The initial pattern of the levels of identified constructs is shown in Figure 7. In this figure, only the significant relationships of the constructs of each level on the constructs of the lower level, as well as the significant internal relationships of the constructs of each row, are considered. Natural resource management, climate change, environmental pressures, eco-city challenges, and grey urban infrastructure influence the development of the biophilic city. The Ecological City (Biophilic City) influences eco-city policymaking, and ultimately, eco-city policymaking leads to economic, social, and environmental consequences.

Influence-Dependence Analysis (MICMAC Diagram)

In the (ISM) model, the reciprocal relationships and influence between constructs and the connection of constructs at various levels are well shown, which leads to a better understanding of the decision-making space by managers. To determine the key constructs, the driving power and dependence of the constructs are formed in the final reachability matrix. The influence-dependence diagram for the research constructs is shown in Figure 8".

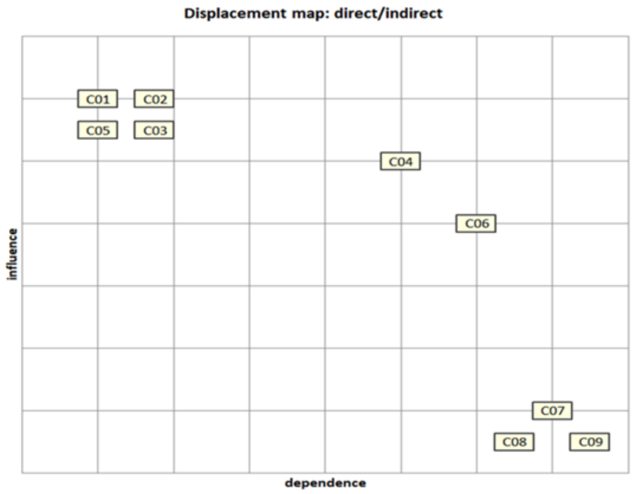

Figure 8: MICMAC Diagram of Influence Power and Dependence (MICMAC Output)

MICMAC analysis is based on the driving power (influence) and dependence (being influenced) of each variable and allows for further examination of the scope of each of the variables. In this method, first introduced by Duvigneau and Faudet (1973), the importance of variables is measured more based on indirect relationships between them, and in this analysis, variables are divided into four groups: autonomous, dependent, linkage (relay), and independent. In this research, some of the constructs were placed in the driver subgroup; these constructs have high driving power and low dependence. In the next category are dependent constructs, which are somewhat the results of the development process and are less likely to be the basis for other constructs.

In this analysis, constructs are divided into four groups: autonomous, dependent, linkage (relay), and independent:

Autonomous: Autonomous constructs have low dependence and driving power. These constructs are mostly removed from the analysis because they have weak relationships with other constructs in the system. A change in these constructs does not cause a significant change in the system.

Dependent: Dependent constructs have strong dependence and weak driving power. These constructs generally have high influence and little influence on the system.

Independent: Independent constructs have low dependence and high driving power. In other words, high influence and low influence are characteristics of these constructs.

Linkage: Relay or linkage constructs have high dependence and high driving power. In other words, the influence and influence of these constructs are very high, and any small change on these constructs causes fundamental changes in the system.

Model Validation with Partial Least Squares Method

The partial least squares technique was used to validate the model. The results obtained from running the model in standard estimation mode show the direction and intensity of the relationship between the variables. The output of Smart PLS software for standard estimation is presented in Figure 9. To examine the significance of the relationships of the model variables, the bootstrapping method was used, which gives the t-statistic. At the 5% error level, if the bootstrapping statistic is greater than 1.96, the observed correlations are significant. The t-statistic and the bootstrapping value for measuring the significance of the relationships are also given in the figure 10.

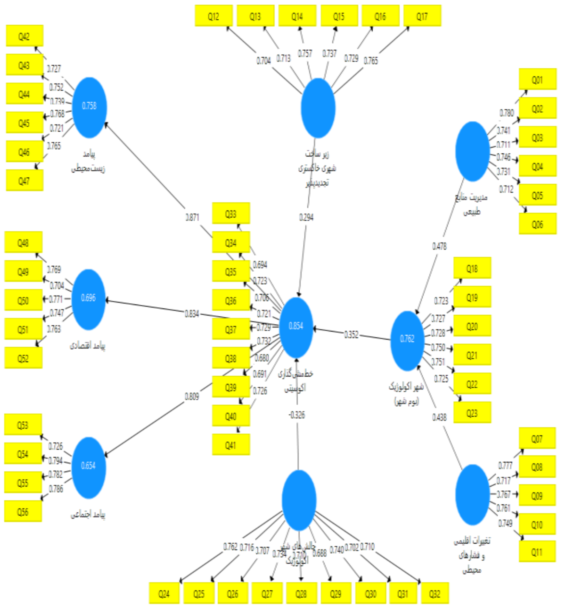

Figure 9: Model Validation Output with Partial Least Squares Method

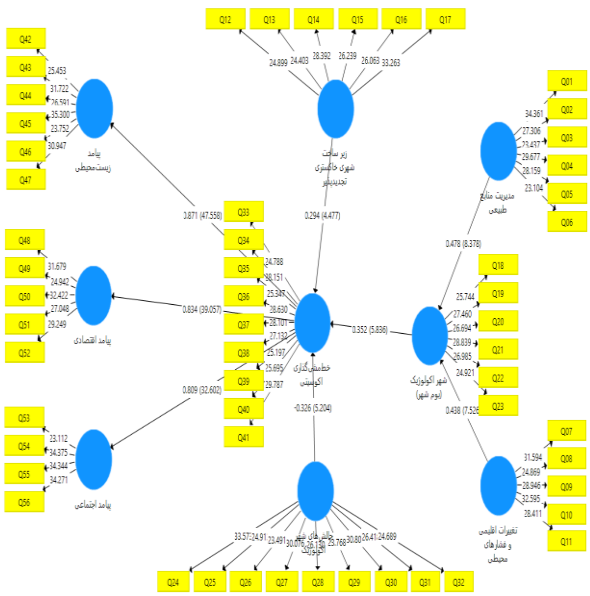

Figure 10: Significance of Variable Relationships with Partial Least Squares Method (Bootstrapping)

The outer part (measurement model) shows that the items considered to measure each of the main factors are sufficiently valid. The strength of the relationship between the items and the related factors is measured by the factor loading and their significance with the t-statistic. The values of the observed factor loadings are greater than 0.6, and the t-statistic is also greater than 1.96. Therefore, the outer (measurement) model is confirmed. Convergent validity shows how much the variables of a construct are aligned with each other. If the estimate of the average variance extracted (AVE) is greater than 0.5, the constructs of the measurement model have convergent validity. To check the reliability of each of the constructs, the rho coefficient, composite reliability (CR), and Cronbach's alpha were estimated

Table 5: Convergent Validity and Reliability of Research Constructs

Construct	AVE	Cronbach's Alpha	Composite Reliability (CR)	Rho
Eco-city Policymaking	0.507	0.878	0.878	0.902
Renewable Grey Urban Infrastructure	0.540	0.829	0.829	0.875
Ecological City (Eco-city)	0.539	0.829	0.829	0.875
Natural Resource Management	0.543	0.832	0.832	0.877
Social Outcome	0.596	0.774	0.776	0.855
Economic Outcome	0.564	0.806	0.806	0.866
Environmental Outcome	0.556	0.840	0.841	0.883
Ecological City Challenges	0.517	0.883	0.883	0.906
Climate Change and Environmental Pressures	0.570	0.811	0.811	0.869

The average variance extracted (AVE) for each of the constructs is greater than 0.5, so convergent validity exists. Cronbach's alpha, rho coefficient, and composite reliability (CR) of all constructs are also greater than 0.7, so reliability is confirmed.

Table 6: Summary of the Results of the Structural Part of the Model (Relationships of Model

Relationship	Path Coefficient	t-statistic	p-value	Result
Eco-city Policymaking → Social Outcome	0.809	32.602	0.000	Supported
Eco-city Policymaking → Economic Outcome	0.834	39.057	0.000	Supported
Eco-city Policymaking → Environmental Outcome	0.871	47.558	0.000	Supported
Renewable Grey Urban Infrastructure → Eco-city Policymaking	0.294	4.477	0.000	Supported
Ecological City (Eco-city) → Eco-city Policymaking	0.352	5.836	0.000	Supported
Natural Resource Management → Ecological City (Eco-city)	0.478	8.378	0.000	Supported
Ecological City Challenges → Eco-city Policymaking	-0.326	5.204	0.000	Supported
Climate Change and Environmental Pressures → Ecological City (Eco-city)	0.438	7.526	0.000	Supported

Based on the path coefficients and t-statistics (bootstrapping), the relationships between the constructs can be interpreted as follows:

The path coefficient for Eco-city Policymaking → Social Outcome was found to be 0.809, and the t-statistic was calculated as 32.602. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Eco-city Policymaking → Economic Outcome was found to be 0.834, and the t-statistic was calculated as 39.057. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Eco-city Policymaking → Environmental Outcome was found to be 0.871, and the t-statistic was calculated as 47.558. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Renewable Grey Urban Infrastructure → Eco-city Policymaking was found to be 0.294, and the t-statistic was calculated as 4.477. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Ecological City (Eco-city) → Eco-city Policymaking was found to be 0.352, and the t-statistic was calculated as 5.836. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Natural Resource Management → Ecological City (Eco-city) was found to be 0.478, and the t-statistic was calculated as 8.378. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Ecological City Challenges → Eco-city Policymaking was found to be -0.326, and the t-statistic was calculated as 5.204. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

The path coefficient for Climate Change and Environmental Pressures → Ecological City (Eco-city) was found to be 0.438, and the t-statistic was calculated as 7.526. Therefore, with 95% confidence, it can be stated that this hypothesis is supported.

Effect size (F^2) is the amount of change that independent variables exert on dependent variables. In fact, this index shows how much change would occur in the dependent variable if an independent variable were removed. This index was presented by Cohen. Values of 0.02 (small), 0.15 (medium), and 0.35 (large) are considered.

The predictive relevance index (Q^2) is also used to assess the predictive power of the model. This index was introduced by Stone and Geisser and is estimated using the blindfolding method. If the value of Q^2 is positive, it indicates that the model has good predictive ability. Also, the value of q^2 estimates the relative effect of the predictive relevance index. Here, the three values of 0.02 (small), 0.15 (medium), and 0.35 (large) are used to evaluate the degree of fit.

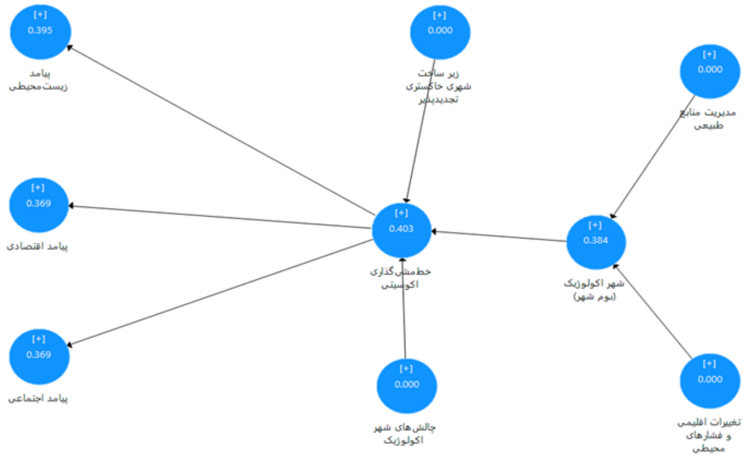

Figure 11: Predictive Relevance Index of Constructs (Blindfolding)

Model Fit Assessment

To evaluate the model fit, the GOF, RMS_theta, SRMR, and NFI indices are used. For the GoF index, the values of 0.01, 0.25, and 0.36 are introduced as weak, medium, and strong values, respectively. For the RMS_theta index, values below 0.12 indicate a good model fit, while higher values indicate a poor fit. The SRMR index should ideally be below 0.1, and more stringently, less than 0.08.

Table 7: Model Fit Assessment

Index	GOF	RMS_theta	SRMR	NFI	Normed Chi-Square
Acceptable Value	Greater than 0.36	Less than 0.12	Less than 0.08	Greater than 0.6	Less than 5
Estimated Value	0.629	0.094	0.049	0.671	2.994

In this study, the normed chi-square index was estimated to be 2.994, which is within the expected range. The GOF index was found to be 0.629, which is greater than 0.36. The RMS_theta index was 0.094, which is less than 0.12. The SRMR index was calculated to be 0.049, which is less than 0.08, and the NFI index was calculated to be 0.671, which is greater than 0.6. Therefore, the model fit is desirable.

Conclusion

The interpretation of the research data on the feasibility of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure, resulted in 9 main categories and 56 sub-categories. Based on the research paradigm model, it was determined that causal conditions (natural resource management, climate change, and environmental pressures) affect the central phenomenon (eco-city). The central phenomenon, contextual conditions (renewable gray urban infrastructure), and intervening conditions (eco-city challenges) influence strategies and actions (eco-city policymaking). Ultimately, strategies and actions lead to outcomes such as environmental, economic, and social consequences.

Based on the results of the secondary coding of the research, the causal conditions included indicators such as urban policy and planning, the development of support laws, changes in values and social culture towards sustainability and environmental protection, the production of clean and inexpensive electricity and processing of treatment plant products, protecting the environment for future generations, the application of technological advancements in the construction and management of infrastructure, the expansion of the global water crisis, climate change as a real threat, the vulnerability of cities to climate change and the water crisis, imbalances in urban architecture, social, economic, political, natural resources, and the need to respond to the challenges of climate change and crises. These were selected as categories of causal conditions in the realization of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure. Also, in the context conditions, indicators such as creating infrastructure that is resistant to climate change, the performance of cities in the face of crises, carbon removal and the use of renewable energy, financial resources and liquidity and provincial and national credit, support for legal and regulatory frameworks, creating public culture and awareness about the importance of environmental sustainability were selected as contextual categories in the realization of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure. And in the central phenomenon, indicators of the correct realization of sustainable development, the promotion of collective urban life, the improvement of the urban environment, the advancement of the city's economy, attention to the rights of future generations to the environment and resources, and optimizing energy consumption such as electricity, gas and water were selected as the central phenomenon category in the realization of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure.

In the intervening conditions, indicators such as the existence of strict or insufficient laws and regulations, lack of public acceptance or resistance to changes and innovations, lack of effective cooperation and coordination between governmental, private, and community institutions, climate change and environmental crises, rapid urbanization and the occurrence of class divisions, declining energy resources, spatial inequalities (affluent vs. disadvantaged neighborhoods, informal settlements), the increasing trend of natural disasters, and lack of awareness and education were selected as categories of intervening conditions in the realization of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure.

Finally, in the necessary strategies and actions, indicators such as planning for more reasonable use of resources, energy conservation, improved recycling, the use of appropriate and creative technologies, education and awareness, holding workshops and seminars, encouraging social participation, appropriate technology for the eco-city, and encouraging private investment were selected as categories of strategies and actions. In the resulting outcomes, indicators such as non-destruction of the ecosystem cycle and preservation of vital geography, protection of green spaces through the creation and maintenance of parks and green spaces, reduced consumption of fossil fuels, protection of natural ecosystems in the region, increased air quality and reduced temperature, the creation of a safe, healthy, and sustainable city, economic savings, reduced costs, job creation, exploitation of local and renewable resources, energy efficiency and technology, enhanced social participation, development of local collaborations, considerations of equality and social justice, and increased public health and cultural identity were selected as categories of outcomes in the realization of the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure.

In comparing the results with similar research, the presented model was ultimately validated using the partial least squares method. The path coefficient of eco-city policymaking → social outcome was 0.809, and the t-statistic was calculated to be 32.602. Therefore, with 95% confidence, it can be claimed that this hypothesis is confirmed.

The path coefficient of eco-city policymaking → economic outcome was 0.834, and the t-statistic was calculated to be 39.057. Therefore, with 95% confidence, it can be claimed that this hypothesis is confirmed.

The path coefficient of eco-city policymaking → environmental outcome was 0.871, and the t-statistic was calculated to be 47.558. Therefore, with 95% confidence, it can be claimed that this hypothesis is confirmed.

Renewable gray urban infrastructures are a novel concept in the design and management of urban infrastructures that specifically refers to the integration of renewable and sustainable technologies with traditional urban systems. This model is specifically designed to reduce dependence on fossil fuels and reduce negative environmental impacts and use vast renewable resources in controlling and eliminating energy imbalances.

Based on the results obtained, the following practical recommendations are offered:

Regarding the management of natural resources, it is suggested that while urban policy and planning are undertaken, supportive laws should also be developed. One of the important goals in realizing the eco-city model, with an emphasis on the role of a renewable gray urban infrastructure, is to change values and social culture towards sustainability and environmental protection. Also, with the help of producing clean and inexpensive electricity and processing products from treatment plants, which is subject to the management of natural resources, the goals of realizing the eco-city can be achieved. On the other hand, preserving the environment for future generations also greatly helps the rest of the planet. Also, the use of technological advancements in the field of construction and infrastructure management is important in this area. In research and planning related to eco-cities, the use of advanced technologies plays a key role in the design, construction, and management of infrastructure. Technologies can increase resource efficiency, reduce costs, enhance sustainability, and improve the quality of urban life. The following examines the most important areas of application of advanced technologies in the construction and management of eco-city infrastructure:

1. **Energy Management and Development of Sustainable Energy Infrastructure**

Smart Grids: These grids enable optimal energy production, distribution, and consumption, and support renewable energies such as solar and wind.

Smart Buildings: Equipping buildings with energy management systems to reduce consumption and increase efficiency.

Energy Storage: Using advanced batteries or hydrogen-based infrastructure to store energy generated from renewable sources.

2. Intelligent Transportation Systems

Intelligent Traffic Management Systems: Reducing traffic congestion and carbon emissions using technologies such as machine learning and urban sensor systems.

Electric and Self-Driving Vehicles: Construction of advanced charging stations and the use of self-driving cars that reduce energy consumption and pollution.

Multimodal Transportation: Designing systems that seamlessly support bicycles, buses, subways, and walking.

3. Water Resource Management

Smart Water Monitoring Systems: Leak detection, quality monitoring, and optimal consumption management.

Gray Water Recovery: Infrastructure that allows the reuse of used water (such as washing water).

Green Infrastructure Design: Includes the use of rain traps, artificial wetlands, and natural water absorption for managing surface runoff and reducing flooding.

5. Urban Waste Management

Advanced Recycling Technologies: Automatic separation of dry and wet waste using robots and artificial intelligence.

Energy Production from Waste: Using technologies such as anaerobic digestion or modern incinerators.

Organic Recycling: Converting organic waste into fertilizer or bioenergy (biogas).

6. Use of Information Technology (ICT) and the Internet of Things (IoT)

Smart City: Creating a "Unified Urban Management System" for monitoring infrastructure, energy consumption, and air quality.

Environmental Sensors: Located in green spaces, buildings, and streets to optimize resource consumption and environmental protection.

Big Data Analytics: Analyzing data collected from urban systems to predict problems and find optimal solutions.

Regarding climate change and environmental pressures, it is suggested that, given the expansion of the global water crisis and climate change as a real threat, a strategy should be adopted regarding eco-cities. In fact, climate change refers to long-term changes in weather patterns, including temperature, precipitation, and wind models, which can occur due to natural (such as volcanic eruptions or changes in the Earth's orbit) or human (such as increased greenhouse gas emissions) causes. Of course, human activities, especially the burning of fossil fuels, deforestation, and industrial agriculture, are major drivers of climate change. In fact, the vulnerability of cities to climate change and the water crisis is a serious matter, and the following measures are presented to reduce vulnerabilities in eco-cities:

Green Infrastructure Design: Using parks, green roofs, and permeable surfaces to absorb and retain rainwater.

Water Resource Management: Using modern technologies in water treatment and recycling and smart resource management measures.

Increasing Energy Efficiency: Developing environmentally friendly buildings and optimizing energy consumption.

Strengthening Early Warning Systems: To better cope with severe weather phenomena.

In addition to the above, relevant managers should take action to address imbalances in urban, social, economic, political, and natural resource architecture and respond to the challenges posed by climate change and the crisis in order to create stability in climate change and environmental pressures. Regarding renewable gray urban infrastructure, it is suggested that while creating infrastructure resistant to climate change, attention should also be paid to the performance of cities in the face of crises. What is important in this area is carbon removal and the use of renewable energies. Also, by providing financial resources, liquidity, provincial and national credits, and of course, supporting legal and regulatory frameworks, the goal of strengthening the renewable gray urban infrastructure can be achieved. It should be noted that achieving the above is subject to establishing a public culture and awareness about the importance of environmental sustainability. It is also recommended to use other important and influential elements in the renewable gray urban infrastructure:

1- Building environmental infrastructure using advanced materials

Sustainable Materials: Use of "green" concrete, recycled wood, and biodegradable materials.

3D Printed Buildings: Reducing construction waste and using resources more efficiently.

Green Roofs and Walls: Designing infrastructure to reduce heat load and improve air quality.

2- Promoting citizen participation through technology

Participatory Applications: To report urban environmental problems or provide collective solutions.

Virtual Education: Raising citizens' awareness of sustainable lifestyles.

Encouraging the Sharing Economy: Such as sharing cars or surplus energy.

Regarding the eco-city, it is suggested that in order to correctly achieve sustainable development and improve collective urban life, urban environmental improvement should be addressed. This is effective in advancing the city's economy and paying attention to the rights of future generations from the environment and resources, and by optimizing energy consumption such as electricity, gas, and water, it greatly helps to preserve natural resources for future generations. In fact, an eco-city refers to a type of urban design that places great emphasis on the sustainability of environmental, social, and economic activities and conditions. This concept seeks to make the best possible use of resources, reduce waste, and increase the livability and efficiency of cities by using new technologies and optimal design. The following are some of the features and principles of designing eco-cities:

Sustainable Transportation: Encouraging the use of public transport, cycling lanes, and walking to reduce air pollutants and traffic.

Smart Construction: Using sustainable and environmentally friendly materials in construction and designing energy-efficient and smart buildings.

Waste Management: Emphasizing the reduction, reuse, and recycling of waste to reduce environmental impacts.

Regarding the challenges of the eco-city, it is suggested that while reviewing strict or insufficient laws and regulations, resistance from society to changes and innovations should also be addressed. Also, with effective cooperation and coordination between governmental, private, and community institutions, the existing challenges can be overcome. Relevant managers, considering climate change and environmental crises and the rapid growth of urbanization and the occurrence of class divisions, should develop their strategies. Also, attention to the reduction of energy resources and spatial inequalities (underprivileged neighborhoods, informal settlements) will lead to the revision and amendment of laws in favor of disadvantaged areas. In fact, due to the increasing trend of natural disasters and lack of awareness and education, such challenges occur for the eco-city, which can be solved with meritocracy in human resources involved in this field and the development of appropriate strategies. Regarding the ecocity policy, it is suggested that while planning for a more rational use of resources, energy conservation should also be addressed. The eco-city is meaningful by improving the recycling situation and using appropriate and creative technologies. Also, increasing education and awareness-raising with the help of holding workshops and seminars to encourage social participation are effective in this field. In fact, with the help of using appropriate technology for the eco-city and encouraging private investment, the ecocity policy can be implemented. Policymaking in ecocities is usually divided into several stages, in which policies and strategies are identified and then implemented:

Problem and Opportunity Identification: In this stage, policymakers must identify the existing environmental, social, and economic problems in a specific area and assess the possible opportunities to improve the situation.

Definition of Goals and Priorities: The main goal of this stage is to set measurable goals for the ecocity.

These goals can include reducing greenhouse gas emissions, improving air quality, increasing green space, or reducing energy costs.

Policy and Strategy Development: After setting goals, various policies are developed to achieve these goals. These policies can include incentives for the use of renewable energies, stricter construction regulations, or educational programs for citizens regarding sustainability.

Implementation and Monitoring: This stage involves the implementation of policies and monitoring of their impact. In this stage, the financial and human resources needed to implement the programs are allocated, and the progress is carefully monitored.

Evaluation and Correction: After the implementation of policies, the results should be evaluated and, if necessary, necessary corrections should be made. This stage allows for continuous improvement.

Ultimately, consequences are achieved in the environmental, economic, and social dimensions. These results include non-destruction of the ecosystem cycle and preservation of vital geography, protection of green spaces by creating and maintaining parks and green spaces, reducing the consumption of fossil fuels, protecting natural ecosystems in the region, increasing air quality and reducing temperature, creating a safe, healthy, and sustainable city, economic savings, reducing costs, creating employment, exploiting local and renewable resources, energy efficiency and technology, promoting social participation, developing local cooperation, considerations of equality and social justice, and increasing public health and cultural identity.

Suggestions for Future Research

– In the quantitative section, in addition to citizens' opinions, the opinions of other stakeholders should also be considered, and the comparison of findings with the findings of this research is suggested to future researchers.
– The use of the present model for the eco-city, emphasizing the role of a renewable gray urban infrastructure in different provinces of the country and comparing them, is suggested to future researchers. Future researchers can conduct studies to conceptualize the discussion of the eco-city model, emphasizing the role of a renewable gray urban infrastructure from a theoretical point of view and also address the methods of implementing the said model from a technical point of view.
– Comparison of the eco-city model, emphasizing the role of a renewable gray urban infrastructure, with other countries
– Prioritization of stakeholders of the eco-city model, emphasizing the role of a renewable gray urban infrastructure
– Pathology of issues and obstacles facing the implementation and establishment of the eco-city model, emphasizing the role of a renewable gray urban infrastructure
– Implementation and evaluation of the strategies proposed in the present research.

Ethical considerations:

Following the principles of research ethics: In the present study, informed consent forms were completed by all subjects.

Sponsor:

Conflict of interest: According to the authors, this article was free of any conflict of interest.

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