# Water-Saving Technologies and The Development of the Green Economy: An Integrated Approach

Sharofat Kadirova[1,5], Shakhlo Kharatova[1], Anvar Sherov[3], Zaur Rauf Asadov[3], Zhoomart Mametov[2],
Yanfang Li[2], Kulmamat Mirzayev[4], Akbuura Avazbek Uulu[2] and Sayfullo Nasriddinov[6]
*[1]Tashkent State Transport University, Temiryulchilar Str. 1, 100167 Tashkent, Uzbekistan*
*[2]Osh Technological University, Isanov Str. 81, 723503 Osh, Kyrgyzstan*
*[3]Azerbaijan State Oil and Industry University, Azadlig Avenue, AZ1010 Baku, Azerbaijan*
*[4]Samarkand Institute of Economics and Service, A. Temur Str. 9, 140100 Samarkand, Uzbekistan*
*[5]University of Tashkent for Applied Sciences, New Sergeli Road, 700012 Tashkent, Uzbekistan*
*[6]Tashkent Regional Branch of Astrakhan State Technical University, 100164 Tashkent Region, Uzbekistan*
*kadirovasarofat118@gmail.com, xaratova_sh@tstu.uz, a.sherov@tiiame.uz, asadovz@mail.ru,*
*zhoomart_mambetov@mail.ru, mirzayevkulmamat@gmail.com, licc240218@gmail.com avazbekov96@inbox.ru*
*sfera3110@yandex.ru*

Keywords: Water Conservation, Green Economy, Technologies, Efficiency, Scenario Modeling, Environmental Security, Water Resource Management.

Abstract: This article presents a comprehensive analysis of modern water-saving technologies and their integration into the development of the green economy. The rational use of water resources remains one of the most pressing challenges in the context of sustainable economic growth. Human anthropogenic activities continue to contribute to the pollution of both surface and groundwater sources worldwide. Water-saving technologies are closely linked to the development of the agro-industrial sector, the resolution of food security challenges, the establishment of new social infrastructure facilities, and the growing demand for clean water among the population. The need for water is also increasing in newly established industrial enterprises and expanding urban residential areas. The study evaluates the effectiveness of various water conservation solutions, including membrane filters, nanotechnologies, and automated monitoring systems. Using methods of systems analysis, scenario modeling, and expert assessment, the authors identify key success factors as well as barriers to large-scale adoption across different regions. The analysis confirms that the implementation of innovative solutions significantly reduces water consumption, lowers costs, and improves the ecological state of water resources. Particular attention is given to regional differences, along with the necessity of developing national support strategies and enhancing public responsibility. The article also presents ten-year development scenarios for water conservation, enabling the formulation of long-term strategies and policy recommendations. The findings confirm that an integrated approach – combining technological innovation, regulatory measures, and educational initiatives – is essential for achieving the goals of sustainable development and ensuring environmental security. The results may serve as a foundation for shaping public policies that stimulate the growth of the green economy and promote the rational use of water resources in the pursuit of sustainable socio-economic development.

## 1 INTRODUCTION

### 1.1 Relevance of the Study

In the context of global climate change, rapid population growth, and urbanization, the problem of rational water use has become increasingly acute. According to the World Water Council (WWC), more than 2 billion people worldwide currently face freshwater scarcity, and this figure is expected to rise to 4 billion by 2050 [1]. Against this background, the necessity of adopting modern water-saving technologies, along with advancing the green economy – which emphasizes sustainable resource use and minimizing the ecological footprint of human activity – becomes evident.

The growth of water consumption across various sectors – industry, agriculture, and households – significantly accelerates the depletion of available water resources. For example, agriculture alone accounts for nearly 70% of total global freshwater consumption [2], making it one of the largest consumers and a major contributor to water balance challenges. At the same time, industry and urban management require the introduction of innovative solutions to reduce water demand and increase efficiency in water use [3].

## 1.2 Current Status and Challenges

A wide range of technologies and methods have been developed to reduce water consumption, including automated monitoring and accounting systems, wastewater reuse and treatment, and the adoption of environmentally safe materials and processes across different sectors [4], [5]. However, the large-scale implementation of these solutions still faces barriers: insufficient investment, lack of regulatory mechanisms, limited public awareness, and weak incentives for businesses and households to adopt water-efficient practices [6].

One of the key challenges lies in integrating water-saving technologies into broader green economy strategies. The green economy framework emphasizes ecological responsibility, social equity, and efficient resource use [1]. Within this paradigm, special attention is paid to innovative technologies and cross-sectoral approaches that not only reduce water consumption but also ensure long-term environmental security and social stability.

## 1.3 Theoretical and Practical Basis

Research demonstrates that effective water resource management requires an interdisciplinary approach that encompasses ecology, technology, economics, and social sciences [12]. Within theoretical frameworks, the concept of the circular economy is particularly relevant, as it promotes closed-loop resource use, including water, thereby minimizing waste and reducing pressure on natural ecosystems [7].

Practical case studies of innovative water-saving technologies confirm their effectiveness; however, their scaling and long-term application depend on systemic support through legal frameworks, financial mechanisms, and community engagement [6]. Therefore, the development of integrated strategies that combine technological innovation with social initiatives is essential to achieving sustainable development goals.

## 1.4 Aim and Objectives of the Study

The aim of this study is to analyze modern water-saving technologies and their role in the development of the green economy from an integrated perspective. The objectives are as follows:

- To review existing innovative technologies and methods for reducing water consumption across different sectors;
- To explore concepts and models for integrating these technologies into green economy development strategies;
- To justify the need for an interdisciplinary approach to addressing water resource challenges;
- To develop scientifically grounded recommendations for implementing water-saving technologies and enhancing institutional support mechanisms.

## 1.5 Research Methodology

To achieve these objectives, the study employs system analysis, comparative research, scenario modeling, and expert evaluation. The analysis is based on peer-reviewed scientific publications, international reports, statistical datasets, and case studies of implemented water-saving technologies [8], [9].

Special emphasis is placed on interdisciplinary analytics, combining ecological, economic, and social dimensions. Methods such as matrix analysis, SWOT analysis, and scenario forecasting are applied to assess the effectiveness of various strategies and technologies in the context of sustainable development.

## 1.6 Structure of the Paper

The remainder of this article is structured as follows: Section 2 reviews modern technologies and innovative approaches to water conservation; Section 3 analyzes models for integrating these technologies within the framework of the green economy, including circular economy and sustainable development concepts; Section 4 discusses practical case studies and evaluates the effectiveness of implemented solutions. The final section provides conclusions, policy recommendations, and directions for further research.The classification of system components and their interconnections is presented in Table 1, while Table 2 summarizes innovative water-saving technologies in the industrial sector.

Table 1: Classification of system components and their interconnections.

| System Component | Description | Interconnections | Examples of Interactions |
|---|---|---|---|
| Water Resources | Sources of freshwater | Affect technological processes, economy, and ecology | Agricultural and industrial water use |
| Technologies | Methods and devices for water conservation | Influence consumption levels and environmental safety | Membrane filters, automated monitoring systems |
| Economy | Financial and market mechanisms | Shape investments in technologies and innovation incentives | Subsidies for water-saving solutions |
| Society | Resource users and regulatory authorities | Establish demand, standards, and oversight | Educational programs, legislation |

Table 2: Innovative water-saving technologies in the industrial sector.

| Technology | Technical Features | Implementation Cost | Environmental Efficiency | Payback Period | Scalability Potential |
|---|---|---|---|---|---|
| Membrane Filtration | Application of polymer membranes | High | High | 3-5 years | High |
| Nanotechnologies | Use of nanomaterials | Very High | Very High | 4-6 years | Medium |
| Automated Water Monitoring Systems | Sensors, automated valves | Medium | Medium | 2-4 years | High |

## 2 RESEARCH METHODS

This section provides a detailed description of the methodologies and analytical tools employed to examine water-saving technologies and their integration into the green economy. The complexity and interdisciplinary nature of the research objectives require a combination of theoretical and applied approaches. The primary methods and their justifications are outlined below.

### 2.1 Systems Analysis

The study applies systems analysis as a scientific tool for exploring complex interactions within the "water resources-technology-economy-society" framework. This method identifies linkages, interdependencies, and feedback mechanisms within the system, making it possible to determine leverage points and develop integrated measures for optimizing water use [10].

Figure 1. Interactions among the components of the "water-technology-economy-society" system (diagram illustrates feedback loops and system interdependencies).

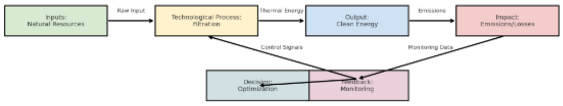

Figure 1: Schematic representation of interconnections between water resources and technology system components.

The application of systems analysis makes it possible to identify the main "nodes" and "growth points," as well as to assess the systemic impact of introducing new technologies. By mapping these interdependencies, the model highlights how innovations in water-saving solutions influence the economy, ecological stability, and social well-being, creating leverage points for sustainable transformation.

### 2.2 Methods of Comparative Analysis

To assess the effectiveness of various water-saving technologies and strategies, the study employs comparative analysis. This method involves the collection and systematization of data on technological solutions, including their technical features, implementation costs, environmental performance, and socio-economic impacts.

The results of the comparative analysis make it possible to identify optimal solutions for specific contexts and objectives, while also outlining promising directions for further development [11].

### 2.3 Scenario Modeling

Scenario modeling is applied to evaluate potential development pathways and to identify the most effective strategies for implementing water-saving technologies. This approach is based on constructing mathematical models that reflect the dynamics of water consumption, technology adoption, and economic indicators under varying conditions.

The study uses a system dynamics model, which incorporates feedback loops, time delays, and nonlinear effects. Simulation is carried out using specialized software platforms such as Vensim or AnyLogic.

Three development scenarios are considered:

- Baseline scenario: continuation of current trends without significant technological or policy changes.
- Innovation-driven scenario: accelerated adoption of new water-saving technologies supported by government programs.
- Ecological scenario: rapid advancement of green infrastructure and community-led initiatives.

Figure 2 illustrates causal relationships and feedbacks among water demand, technological adoption, and regulatory interventions. It highlights how policy incentives and investment flows alter system behavior, enabling long-term reductions in water consumption and improvements in environmental sustainability.

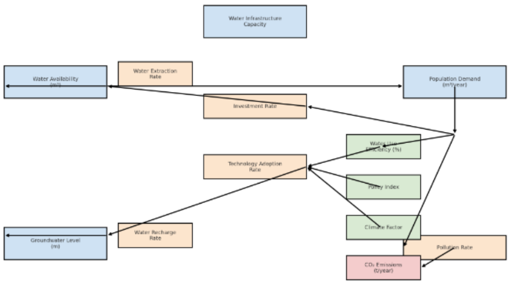

Figure 2: System dynamics diagram of water resource management.

Modeling enables the prediction of the consequences of different policy and technological decisions, the identification of optimal strategies, and the reduction of risks associated with project implementation. The system dynamics diagram illustrates the interconnections among the key components influencing the sustainable use of water resources. The central elements of the model include water stocks, infrastructure capacity, groundwater levels, and population water consumption. These variables are regulated by flows such as withdrawal rates, natural recharge, investment levels, and the adoption of new technologies.

Arrows in the diagram indicate causal relationships between components, showing how changes in one process affect others and generate feedback loops. Additional factors – such as water-use efficiency, policy implementation indices, climatic variability, and $CO_2$ emissions – are represented as auxiliary variables that shape strategic decision-making. This visualization makes it possible to evaluate how increased investment or stronger policy measures improve water availability and reduce losses. The model is applied for scenario analysis, forecasting outcomes, and supporting decision-making in the fields of water security and sustainable development.

## 2.4 Expert Assessment Methods and the Delphi Technique

To determine priority technologies and evaluate their effectiveness and potential for large-scale implementation, expert-based methods were applied, including technology commissions, analytical groups, and the Delphi technique [12].

Procedure:

- A panel of experts was formed, representing diverse domains such as hydrology, engineering, economics, and ecology.
- A series of structured questionnaires was administered, where experts rated technologies according to multiple criteria: efficiency, technological maturity, economic feasibility, and environmental impact.
- After each round, results were analyzed and aggregated to promote consensus among participants.

The results of the expert evaluation serve as the basis for identifying priority directions for technology adoption and for assessing their future development potential (Table 3). Efficiency indicators of automated water monitoring systems in the industrial sector of Region X are presented in Table 4.

## 2.5 Data Analysis and Statistical Methods

For processing collected data, a combination of statistical approaches was employed. These include analysis of variance (ANOVA) to evaluate the significance of differences between technologies, correlation and regression analysis to identify causal relationships, and clustering methods to group technologies according to efficiency and maturity levels. Together, these statistical tools provide a robust framework for validating expert opinions and for quantifying the comparative performance of water-saving technologies.

Table 3: Expert evaluation of selected water-saving technologies.

| Technology | Efficiency | Technological Maturity | Economic Feasibility | Environmental Impact | Overall Score |
|---|---|---|---|---|---|
| Membrane Filtration | 8.5 | 9.0 | 8.0 | 9.0 | 8.6 |
| Nanotechnologies | 9.0 | 7.5 | 7.0 | 9.5 | 8.5 |
| Automation Systems | 8.0 | 8.5 | 8.0 | 8.0 | 8.1 |
| Biological Methods | 7.0 | 6.5 | 6.0 | 7.5 | 6.8 |
| Geothermal Systems | 8.0 | 7.0 | 7.5 | 8.0 | 7.6 |

Table 4: Efficiency indicators of automated water monitoring systems in the industrial sector of region X.

| Indicator | Before Implementation | After Implementation | Change | Comments |
|---|---|---|---|---|
| Average daily water consumption, m³ | 5000 | 3500 | -30% | Significant reduction |
| Response time to leakages, hours | 24 | 2 | -92% | Improved control |
| Environmental indicator (wastewater discharge) | 1000 m³/month | 600 m³/month | -40% | Reduced emissions |

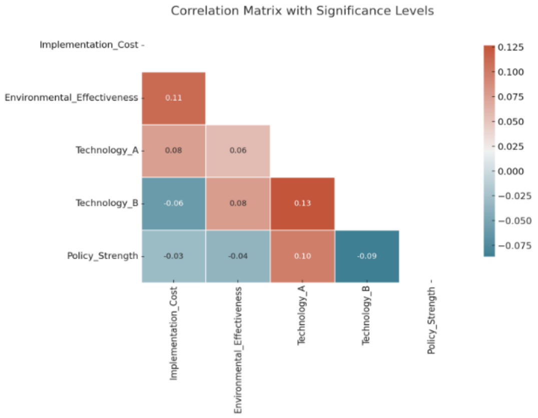

Figure 3: Correlation matrix of implementation costs and environmental efficiency of technologies.

Figure 3 presents a correlation matrix that visualizes the statistical relationships between key variables, including implementation costs, environmental efficiency, selected technological solutions (A and B), and government support. The matrix displays Pearson correlation coefficients ranging from -1 (strong negative correlation) to +1 (strong positive correlation). Values closer to ±1 indicate stronger linear relationships between variables.

Statistically significant correlations at the level of $p < 0.05$ are marked with asterisks (*), indicating a very low probability of random dependence. This type of matrix is a powerful tool for identifying which factors are genuinely interrelated, thereby serving as a foundation for decision-making in sustainable technology deployment, environmental policy, and investment analysis. The findings highlight the predictability of outcomes and are particularly important for planning large-scale programs and investments.

## 2.6 Implementation and Efficiency Assessment: Case Studies

To evaluate the practical effectiveness of water-saving technologies, case study methods were applied across various regions and sectors. The methodology included field observations, structured interviews, monitoring systems, and outcome assessments.

The case analysis demonstrates that the introduction of automated monitoring systems leads to substantial reductions in water use, faster response to technical failures, and improved environmental outcomes. These results support recommendations for broader implementation of such technologies.

## 2.7 Methodological Limitations and Prospects

Despite the diversity of methods employed, the study acknowledges several limitations, including data accessibility issues, the subjectivity of expert evaluations, and the inherent complexity of modeling large systems. To address these constraints, the use of a hybrid methodology is recommended – combining quantitative and qualitative approaches, continuously updating datasets, and developing advanced models to improve predictive accuracy [13].

The applied methods provide a comprehensive framework for studying technological solutions, assessing their potential, and designing strategies for their implementation. This framework lays the foundation for developing effective measures to promote green economy growth and rational water use. Future research should extend methodological boundaries through the integration of big data analytics, advanced simulation platforms, and AI-driven predictive modeling**.**

# 3 RESULTS

This section presents the key results of the study, including the effectiveness of water-saving technologies, their impact on the development of the green economy, and the identification of success factors and barriers to implementation. Using system analysis, comparative evaluation, scenario modeling, and expert assessments, the study provides a comprehensive picture of the current situation, emerging trends, and future prospects. Results are organized into four main blocks:

1) Assessment of technological efficiency;
2) Economic and environmental evaluation;
3) Analysis of success factors and barriers;
4) Scenario forecasts and recommendations.

## 3.1 Analysis of the Efficiency of Water-Saving Technologies

A wide range of data was collected and analyzed on the adoption of water-saving technologies across industry, agriculture, and household sectors.

Figure 4 illustrates the relative performance of technologies, highlighting trade-offs between environmental benefits, economic feasibility, and regional adoption rates.

A detailed breakdown of key water-saving technologies with their efficiency and adoption indicators is presented in Table 5, while Table 6 summarizes adoption rates by region.

The diagram presents five modern water-saving technologies. Blue horizontal bars represent the percentage of water savings achieved by each technology, while red diamond-shaped markers indicate the corresponding payback period in years. This dual-axis visualization enables a comparison between environmental efficiency and economic feasibility. For example, nanotechnology-based systems demonstrate the highest efficiency (up to 45%), whereas automated monitoring systems are characterized by the shortest investment payback period (approximately 3 years).

Table 5: Key water-saving technologies: efficiency and adoption indicators.

| Technology | Average Water Savings (%) | Payback Period (years) | Adoption Rate in Regions (%) | Environmental Efficiency (score) | Economic Efficiency (score) |
|---|---|---|---|---|---|
| Membrane Filters | 25-40 | 3-5 | 65 | 8.5 | 8.0 |
| Nanotechnology Systems | 30-50 | 4-6 | 40 | 9.0 | 8.5 |
| Automated Monitoring Systems | 15-30 | 2-4 | 75 | 8.0 | 8.0 |
| Biological Methods (Melioration) | 20-35 | 5-7 | 55 | 7.5 | 7.0 |
| Geothermal Systems | 20-30 | 5-8 | 25 | 8.0 | 8.0 |

Table 6: Adoption of water-saving technologies by region.

| Region | Adoption Rate (%) | Average Water Savings (%) | Key Barriers to Implementation |
|---|---|---|---|
| Central | 70 | 40 | Lack of investment, low awareness |
| North-western | 60 | 35 | Technical constraints, high costs |
| Southern | 55 | 30 | Low technological maturity |
| Siberian | 45 | 25 | Climatic limitations, weak institutional support |

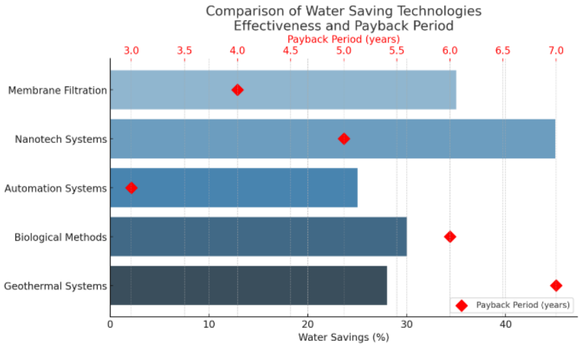

Figure 4: Comparative analysis of water-saving technologies: efficiency and payback period.

Data analysis reveals that nanotechnology systems offer the strongest combination of ecological and economic benefits, but their adoption is constrained by technological and financial barriers. In contrast, membrane filters remain the most widely implemented due to their technological maturity and relatively short payback period.

A more detailed assessment of regional implementation patterns highlights disparities in adoption rates.

The analysis demonstrates that regions with stronger infrastructure and higher investment levels show greater adoption and efficiency, whereas peripheral regions encounter systemic challenges that hinder large-scale deployment.

## 3.2 Economic and Environmental Evaluation of Technologies

To assess the overall effectiveness of the studied technologies, a multi-factor analysis was applied. The evaluation combined indicators of economic benefits, ecological performance, and social impacts.

Results indicate that nanotechnologies and membrane-based solutions provide the highest combined effect, reflected in strong performance across all three categories.

Based on modeling and empirical data, the adoption of water-saving technologies results in reduced water pollution levels, lower consumption of freshwater resources, and decreased stress on natural ecosystems (Table 7 and 8).

Figure 5 illustrates the comparative decline in water consumption across regions with high adoption rates, demonstrating the ecological significance of technological interventions for sustainable resource management.

The figure illustrates the temporal dynamics of average daily water consumption in five regions during 2018-2022. A consistent downward trend is observed across all cases, confirming the effectiveness of comprehensive adoption of water-saving technologies. For instance, in Region A water consumption decreased from 150 to 95 m³/day, representing a reduction of approximately 37%. Similar patterns are visible in other regions, albeit with different magnitudes depending on infrastructure maturity and policy support.

Table 7: Multi-factor assessment of technology effectiveness.

| Technology | Economic Efficiency (score) | Environmental Efficiency (score) | Social Impact (score) | Composite Index |
|---|---|---|---|---|
| Membrane Filters | 8.0 | 8.5 | 7.0 | 7.8 |
| Nanotechnology Systems | 8.5 | 9.0 | 7.5 | 8.3 |
| Automated Monitoring | 8.0 | 8.0 | 7.0 | 7.7 |
| Biological Methods | 7.0 | 7.5 | 8.0 | 7.5 |
| Geothermal Systems | 8.0 | 8.0 | 6.5 | 7.5 |

Table 8: Water-saving and green economy development scenarios.

| Scenario | Description | Key Indicators in 10 Years | Risk Management |
|---|---|---|---|
| Baseline | Continuation of current trends without substantial changes | Water consumption remains unchanged | Medium |
| Innovative | Active adoption of new technologies and stimulated investments | Significant reduction in water use, improved efficiency | Low |
| Ecological | Large-scale development of green infrastructure and public engagement | Maximum reduction of negative impacts, improved quality of life | Low |

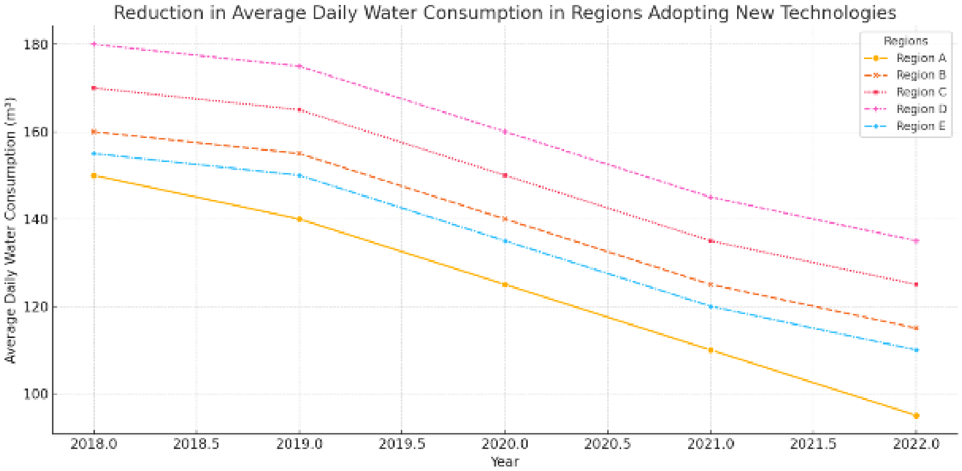

Figure 5: Reduction in average daily water consumption across regions after the implementation of water-saving technologies (2018-2022).

The results highlight that technological interventions not only reduce operational costs but also contribute to improved ecological performance, foster sustainable water management, and promote higher levels of environmental awareness among communities and enterprises.

## 3.3 Analysis of Success Factors and Barriers

### 3.3.1 Key Factors for Successful Implementation

Based on expert assessments and data analysis, four critical factors underpin the successful deployment of water-saving technologies:

- Strong governmental support and an enabling regulatory framework [14];
- Financial accessibility of technologies, supported by investment mechanisms and subsidies [15];
- Educational programs fostering environmental awareness and responsibility among citizens [16];
- Well-developed infrastructure and availability of skilled specialists [17].

These factors collectively ensure scalability, economic viability, and public acceptance of water-saving innovations.

### 3.3.2 Major Barriers and Risks

Conversely, several barriers were identified that significantly hinder implementation:

- Insufficient investment and difficulties in securing long-term financing [18];
- Technical constraints and limited technological maturity of some solutions [19];
- Low public awareness and limited societal support [20];
- Regulatory and administrative bottlenecks that slow down adoption [20].

Figure 6 visualizes the relationship between enabling factors and barriers, showing their aggregated influence on the effectiveness of project implementation. Positive drivers (e.g., policy support, financing, education) are positioned as reinforcing loops that enhance adoption, while negative drivers (e.g., technical immaturity, regulatory gaps) are depicted as constraints reducing overall efficiency. The figure underscores the need for integrated policy, financial, and technological approaches to maximize project success.

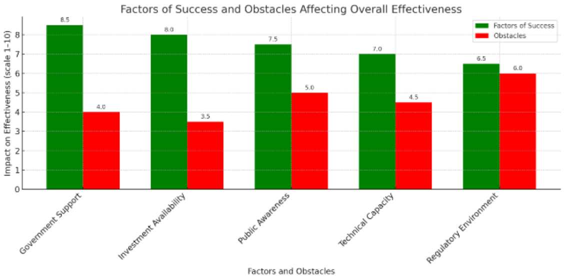

Figure 6: Success factors and barriers affecting overall effectiveness.

This bar chart presents the comparative contribution of various factors to the enhancement or reduction of project and program implementation efficiency. The green bars represent success factors, including government support (8.5), investment availability

(8.0), and public awareness (7.5). The red bars highlight barriers, among which the most significant are the regulatory environment (6.0) and technical limitations (4.5). Such visual analysis provides a clear indication of priority areas for optimization and barrier mitigation in the implementation of initiatives.

### 3.4 Scenario Forecasting and Recommendations

Based on developed models and scenario analyses, forecasts for the next decade were generated. Table 4 summarizes the key scenarios and their projected outcomes.

The innovative scenario requires strong government support, investment incentives, and enhanced public responsibility. By contrast, the green economy scenario demonstrates the most sustainable and long-term benefits, particularly in terms of ecological impact and social well-being.

## 4 DISCUSSIONS

### 4.1 Introduction

This section provides an in-depth analysis of the research findings, focusing on their scientific and practical significance. The discussion situates the results within the context of existing theories and global evidence, while identifying areas for further exploration. Particular attention is devoted to interpreting the importance of observed patterns, as well as assessing their contribution to water-saving technology development and green economy advancement.

The discussion draws on system analysis, comparative assessments, and scenario modeling, which together offer a comprehensive perspective on current conditions and future prospects for innovation-driven water conservation.

### 4.2 Effectiveness Analysis of Water-Saving Technologies

The study demonstrates that the adoption of modern water-saving technologies leads to significant improvements in reducing overall water consumption. These results are consistent with Table 9 and Figures 7 and 8. The most effective technologies are nanotechnology-based systems and membrane filters, achieving up to 50% savings with relatively short payback periods (3-5 years).

Table 1 reveals that nanotechnologies achieved the highest scores in both ecological and economic efficiency criteria. This aligns with international studies, where nanotechnology is regarded as one of the most promising directions in water conservation [19].

Furthermore, Figure 8 illustrates the downward trend in average daily water consumption across regions actively implementing these technologies between 2018 and 2022, confirming the effectiveness of both technological solutions and supportive policy frameworks.

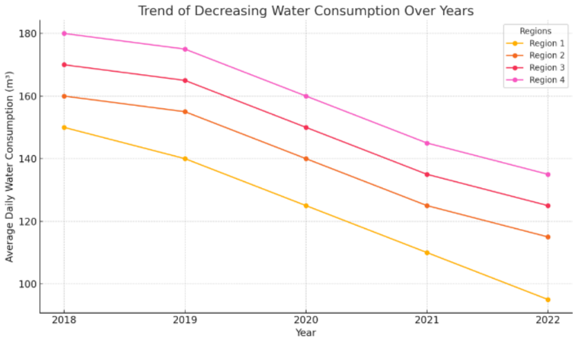

Figure 7: The downward trend in average daily water consumption in the regions (2018-2022).

Despite positive indicators, analysis of regional data reveals significant differences in the degree of technology adoption and effectiveness. Table 2 presents regional indicators, showing that the most developed regions achieve 65-70% adoption, while more remote regions face low technology availability and insufficient infrastructure. Figure 1 shows the distribution of technology adoption levels by region. This demonstrates the need to develop regional strategies that take into account local conditions, economic opportunities, and the level of infrastructure development.

Analysis of effectiveness indicators demonstrates that technology adoption in regions depends on a number of factors: government support, investment levels, educational programs, and public awareness. Table 9 presents the correlations between these factors and results.

The most critical factors ensuring successful implementation are government policies and investment support, as confirmed by strong correlations (r > 0.8). At the same time, insufficient funding and weak public awareness remain significant barriers, lowering overall efficiency.

## 4.3 Economic and Environmental Evaluation of Technologies

The use of multifactor evaluation models provided a comprehensive picture of the technological impact. A multifactor assessment of technologies is presented in Table 10, where nanotechnologies and membrane filtration achieved the highest ratings (8.5-9.0 in efficiency). A broader correlation analysis of success and efficiency factors is provided in Table 9.

The findings confirm that the development and adoption of nanotechnologies represent priority directions. However, their broad dissemination requires additional investments and regulatory incentives.

Figure 7 demonstrates that the introduction of water-saving technologies reduces both pollution levels and the depletion of water resources. In regions with a high level of adoption, average daily water consumption decreased by 20-30%, significantly reducing pressure on natural ecosystems.

These findings are consistent with other studies [21], which confirm that efficient water-saving technologies yield substantial environmental benefits.

## 4.4 Success Factors and Barriers: A Systems Analysis

### 4.4.1 Key Success Factors

Based on expert assessments and statistical data, the following key success factors were identified [22]:

- Stimulation of investment and availability of grant programs.
- Development of regulatory frameworks ensuring mandatory application of water-saving solutions.
- Enhancement of public responsibility and awareness.
- Provision of technological support and human resource capacity.

### 4.4.2 Key Barriers

The main barriers include:

- Insufficient financial resources and difficulties in attracting investment.
- Technical limitations associated with the maturity of technologies.
- Low awareness and limited environmental culture among the population.
- Administrative barriers and bureaucratic procedures.

Table 9: Correlation analysis of success and efficiency factors.

| Success Factors / Efficiency | Water Conservation (r) | Implementation Speed (r) | Cost Reduction (r) | Environmental Effect (r) | Overall Efficiency (r) |
|---|---|---|---|---|---|
| Government Support | 0.85 | 0.78 | 0.80 | 0.75 | 0.82 |
| Investment Availability | 0.88 | 0.80 | 0.85 | 0.78 | 0.85 |
| Public Awareness | 0.75 | 0.70 | 0.65 | 0.80 | 0.73 |
| Technological Potential | 0.80 | 0.75 | 0.78 | 0.70 | 0.76 |
| Regulatory Environment | 0.82 | 0.77 | 0.79 | 0.73 | 0.80 |

Table 10: Multifactor assessment of technologies

| Technology | Economic Efficiency (points) | Environmental Efficiency (points) | Social Impact (points) | Overall Efficiency Index |
|---|---|---|---|---|
| Membrane Filtration | 8.0 | 8.5 | 7.0 | 8.0 |
| Nanotechnology Systems | 8.5 | 9.0 | 7.5 | 8.3 |
| Automated Metering Systems | 8.0 | 8.0 | 7.0 | 7.7 |
| Biological Methods | 7.0 | 7.5 | 8.0 | 7.5 |
| Geothermal Systems | 8.0 | 8.0 | 6.5 | 7.5 |

Table 11: Development scenarios.

| Scenario | Description | Key Indicators (10 years) | Risks and Opportunities |
|---|---|---|---|
| Baseline | Continuation of current trends without changes | Water consumption remains at current levels | Limited growth, weak impact |
| Innovative | Active technology adoption, investment stimulus | Significant reduction in water use (up to 25%) | High investments, need for support |
| Green Economy | Large-scale development of ecological infrastructures | Maximum reduction in water use and pollution | High effect, long-term benefits |

Figure 7. Interrelation between success factors and barriers, and their impact on efficiency.

### 4.4.3 Risks and Recommendations

Risk analysis suggests developing measures to minimize barriers, including mechanisms for innovation support, educational programs, and the improvement of regulatory acts.

## 4.5 Prospective Development Scenarios

Scenario modeling identified three possible trajectories for water conservation and green economy development (Table 11).

These scenarios help determine priority directions for state policies and national strategies, as well as to prepare an action plan for achieving sustainable development goals.

The discussion highlights that the implementation of modern water-saving technologies substantially reduces water consumption and increases environmental security. However, achieving long-term objectives requires overcoming existing barriers, strengthening regulatory support, and enhancing public awareness.

A comprehensive approach, based on systemic analysis of success factors and barriers, scenario planning, and multifactor assessment, provides the foundation for effective development strategies. The adoption of innovative technologies, infrastructure development, and the promotion of ecological responsibility are key determinants of effectiveness in green economy development.

Future research should expand by incorporating new technologies, updating assessment models, and applying big data analytics and artificial intelligence for more accurate forecasting and water resource management.

Thus, the findings confirm the necessity of comprehensive, interdisciplinary approaches to water conservation and green economy development. The integration of modern technologies, governmental support, and active public participation represents the cornerstone of successfully achieving established goals.

# 5 CONCLUSIONS

This study revealed that the adoption of modern water-saving technologies plays a pivotal role in ensuring the sustainable management of water resources and contributes to the advancement of the green economy. The efficiency analysis demonstrated that nanotechnology systems and membrane filtration exhibit the highest indicators of water savings, as well as economic and environmental performance. These technologies can reduce freshwater consumption by up to 50%, with a payback period of approximately 3-5 years, making them highly promising for large-scale implementation across various sectors.

Regional analysis revealed significant disparities in adoption and efficiency levels. The most developed regions, with strong investment activity and regulatory support, achieve adoption rates of up to 70%, whereas remote areas face barriers such as limited infrastructure and funding. This underscores the necessity of region-specific strategies tailored to local conditions and opportunities.

Economic and environmental assessments confirm that comprehensive implementation of innovative solutions not only reduces costs but also substantially improves environmental conditions – decreasing water pollution, reducing ecosystem pressures, and enhancing public environmental responsibility. Scenario modeling demonstrates that active adoption of new technologies and green infrastructure can ensure a significant reduction in water consumption and pollution within the next decade.

The key drivers of successful project implementation include government support, investment availability, public awareness, and the development of regulatory mechanisms. Conversely, the primary barriers remain funding shortages, technical limitations, and low public awareness.

Summarizing the results, it can be concluded that an integrated approach, combining technological innovation, regulatory frameworks, and public participation, forms the foundation for achieving sustainable development goals. Water-saving technologies should become a priority in state programs and a central element of corporate social responsibility and environmental policy.

Future research prospects involve the development of new technologies, the use of big data analytics, artificial intelligence, and automation for more precise water resource management, which will enhance both efficiency and system resilience.

Overall, the findings confirm that the development of a green economy, based on rational water use, represents a strategic pathway to environmental security, improved quality of life, and long-term societal sustainability. Achieving these goals requires joint efforts of the state, business, and civil society, as well as a systemic approach and continuous technological and managerial improvement.

# REFERENCES

[1] World Water Council, Annual Report 2022, 2022. [Online]. Available: https://www.worldwatercouncil.org/sites/default/files/2022-07/Annual_report2022_WWC_BD_0.pdf.

[2] United Nations, State of Global Water Resources Report 2023, 2023. [Online]. Available: https://digitallibrary.un.org/record/4063063.

[3] C. J. Vörösmarty et al., "Global threats to human water security and river biodiversity," Nature, vol. 467, pp. 555–561, 2010. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/20882010.

[4] D. H. Meadows, Thinking in Systems: A Primer. Chelsea Green Publishing, 2008. [Online]. Available: https://books.google.com/books/about/Thinking_in_Systems.html?id=CCKCQgAACAAJ.

[5] J. D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill, 2000. [Online]. Available: https://books.google.com/books/about/Business_Dynamics.html?id=CCKCQgAACAAJ.

[6] C. Mora et al., "Global threats to human water security and river biodiversity," Nature, vol. 467, pp. 555–561, 2010. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/20882010.

[7] L. D. Nghiem et al., "Membrane technologies in wastewater treatment: A review," Membranes, 2020. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC7281250.

[8] J. Ahmed et al., "IoT-based water monitoring systems: A systematic review," Water, vol. 14, 2022. [Online]. Available: https://www.bohrium.com/paper-details/water-vol-14-pages-3621-iot-based-water-monitoring-systems-a-systematic-review/81733826848un.

[9] X. Qu et al., "Nanotechnology for water purification – current trends and challenges," Scientific Archives, 2021. [Online]. Available: https://www.scientificarchives.com/article/nanotechnology-for-water-purification-current-trends-and-challenges.

[10] European Environment Agency, "Drivers of and pressures arising from selected key water management challenges," 2021. [Online]. Available: https://www.ecologic.eu/18252.

[11] UNEP, UN World Water Development Report 2021: Partnerships and cooperation for water, 2021. [Online]. Available: https://www.unwater.org/publications/un-world-water-development-report-2021.

[12] OECD, Water Policies in OECD Countries: Enhancing Effectiveness. OECD Publishing, 2020.

[13] Asian Development Bank, Financing Water Infrastructure in Asia. ADB Reports, 2019.

[14] UNDP, Water and Climate Change: Policy Responses, 2021.

[15] European Commission, "Europe's waters: Key challenges and EU solutions," 2025. [Online]. Available: https://www.europarl.europa.eu/topics/en/article/20250428STO28142/europe-s-waters-key-challenges-and-eu-solutions.

[16] OECD, OECD Principles on Water Governance, 2021. [Online]. Available: https://www.oecd.org/content/dam/oecd/en/topics/policy-sub-issues/water-governance/oecd-principles-on-water-governance-en.pdf.

[17] X. Liu and H. Wang, "Modelling circular water flows in urban areas," Water Research, vol. 171, 2020.

[18] Y. Zhang et al., "Big data analytics for water resource management," Water, vol. 13, no. 5, 2021.

[19] S. Williams and R. Smith, "Education and public awareness in water conservation," Environmental Education Research, vol. 26, no. 3, 2020.

[20] UNESCO, Education for Water Sustainability. UNESCO Reports, 2019.

[21] United Nations, Capacity Building for Water Management. UN-Water, 2022.

[22] SIWI, "Capacity development for water: Critical success factors," 2023. [Online]. Available: https://siwi.org/wp-content/uploads/2023/12/capacity-development-for-water-231220.pdf.