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# Participatory Adaptive Planning for Sustainable Industrial Treated Wastewater Reuse in the Mediterranean: Evidence from Case Studies in Türkiye and Tunisia

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**Abstract**

The Mediterranean region faces severe water scarcity exacerbated by climate change. The reuse of treated industrial wastewater for industrial processes or agricultural irrigation offers a sustainable mitigation strategy, yet its implementation is hindered by low social acceptance and institutional fragmentation. This study aims to enhance treated wastewater reuse (TWWR) uptake within the textile and pharmaceutical sectors in Türkiye and Tunisia through structured stakeholder engagement, hydrological modelling, simulation, and co-design of preferred strategies. Data were collected from regional water authorities, industries, farmers, and civil society, chosen based on their influence, interest, and capacity regarding integrated water management. A Participatory Adaptive Planning framework was applied across three co-designed workshops per site, and interviews. Data were charted using the Natural Assurance Schemes Business Canvas and a conceptual visual support framework. Stakeholders identified key barriers, including legislative gaps in Türkiye and financial capabilities and farmer reluctance in Tunisia. Through the conceptual visual support framework, holistic strategies combining TWWR, water savings, urban treated wastewater quality improvement by tertiary treatment, desalination, and Managed Aquifer Recharge were co-created, simulated and ranked. Technological innovation in wastewater treatment is insufficient without robust “social readiness”. Participatory governance effectively aligns environmental engineering solutions with societal needs, establishing a foundation for resilient and integrated water management action plans.

**Keywords:** treated wastewater reuse (TWWR); stakeholder engagement; Participatory Adaptive Planning; strategies co-creation; climate change adaptation; Mediterranean basin



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## 1. Introduction

The Mediterranean basin is increasingly recognised as a global “hotspot” for water stress, a crisis compounded by the combined effects of climate change, demographic growth, and intense industrial and agricultural water demand [1–3]. To mitigate this vulnerability, the transition towards a circular economy in water management is important. The reuse of non-conventional resources, particularly industrial treated wastewater, stands out as a critical adaptation strategy [4,5]. However, the current state in this research field reveals that while the technological readiness of wastewater treatment (e.g., membrane bioreactors, ultrafiltration, reverse osmosis) is advancing rapidly [6–8], the actual global adoption of treated wastewater reuse (or TWWR for short) remains alarmingly low [8–11].

This discrepancy stems from significant non-technical barriers. A prominent challenge within the field is that while engineers and policymakers typically view TWWR as an economically and environmentally optimal solution, end-users (including industries, farmers, and local communities) frequently perceive water quality risks associated with potential health hazards. These perceptions often explain socio-cultural resistance toward reclaimed water, which often translates into restrictions on crop irrigation and a perceived lack of financial incentives or institutional support. Consequently, technological solutions often fail upon implementation due to a deficit in "social readiness" and participatory governance [12–14]. In this context, "social readiness" is operationally defined here as the level of socio-cultural compatibility and mutual trust achieved between engineered technical options and local end-users. It is theoretically grounded in the multi-stage innovation-decision process defined by Rogers [15], which underscores that widespread technology adoption is also a social process driven by information exchange and uncertainty reduction within interpersonal networks rather than a mere function of technical efficacy.

The overall objective of the EU PRIMA TRUST (Management of industrial Treated wastewater ReUse as mitigation measures to water Scarcity in climaTe change context in two Mediterranean regions) project and its section on Participatory integrated planning of water reuse is to mitigate water scarcity in Mediterranean regions through the sustainable treatment and reuse of industrial wastewater within a circular economy approach. To address this challenge holistically, the project encompassed the implementation and scale-up of wastewater treatment technologies, environmental and socio-economic impact assessments, hydrological modelling of climate change, management and investment scenarios, and the development of business models for market uptake, all supported by dedicated communication, and participatory integrated planning of water reuse. Within this comprehensive framework, the specific aim of the research presented in this paper zooms in on how to increase TWWR uptake by actively engaging stakeholders through Participatory Adaptive Planning (PAP). This study focuses on two water-stressed regions: the Torbalı-Fetrek sub-basin in Izmir (Türkiye) and Monastir Governorate (Tunisia).

## 2. Materials and Methods

The methodology was implemented and validated within the 45-month TRUST project, initiated in June 2021, which addresses acute water stress exacerbated by groundwater overexploitation and climate change impacts on crop water requirements and precipitation regimes across the Mediterranean basin. The approach was deployed in two distinct pilot regions where textile industries are highly developed and facing severe water scarcity and increasing groundwater overuse and pollution.

The Izmir (Türkiye) case study is focused on the Torbalı district within a prominent hydrological basin under severe pressure from both acute water scarcity and groundwater overexploitation. Mirroring the multi-level governance approach, this pilot involved key regional water, environmental, and development authorities (such as İzBB, İZSU, DSİ, and İZKA), the provincial agricultural directorate, district-level municipal governments, local agricultural cooperatives, and a textile factory.

The Monastir (Tunisia) case study is centred on industrial textile wastewater management and its potential for safe reuse in Managed Aquifer Recharge, industrial process recycling, and irrigation. This pilot involved multi-level governance, a local farmer cooperative (GDAs) managing collective irrigation systems, the regional farmer union (URAP), the regional commission of agricultural development (CRDA) of Monastir, the National office of sanitation (ONAS), regional extension services (CTV), and eight localised textile manufacturing firms; among them, two are already treating and reusing more than 80% of their industrial wastewater.

### *2.1. Participatory Adaptive Planning (PAP) Framework*

To facilitate inter- and transdisciplinary knowledge exchange, this study presents the Participatory Adaptive Planning (PAP) approach. This framework builds upon the strategic Integrated Water Resources Management (IWRM) planning framework [16] to bridge technical innovations with regulatory, economic, technical and social realities. As illustrated in project planning, the PAP framework operates through five sequential, iterative phases designed to advance Technology Readiness Levels (TRL), better document social readiness and build a business model to mobilise the different business cases as shown in Figure 1.

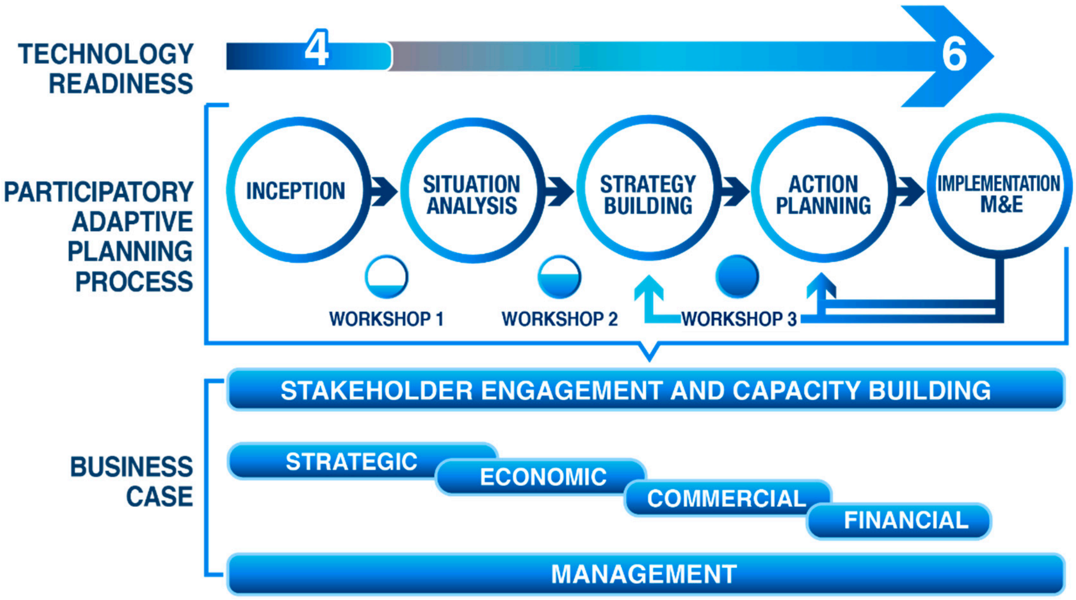


**Figure 1.** Participatory integrated planning of water reuse. Dark blue horizontal arrows indicate the sequential execution of the planning phases, while curved bottom arrows denote the iterative feedback loops from implementation monitoring and evaluation (M&E) back into strategy building and action planning. Partially filled circles represent stakeholder workshop progression, aligned with parallel Technology Readiness Level (TRL) advancement (top arrow), planning phases and business case steps (source; Authors' own).

Within this framework, "social readiness" is operationally defined as the level of socio-cultural compatibility and mutual trust achieved between technical infrastructure parameters and local stakeholder networks. Grounded in Rogers' Diffusion of Innovations theory [15], which posits that technology adoption is a social process driven by compatibility (alignment with local norms) and complexity reduction, social readiness is evaluated comparably across pilots through three qualitative diagnostic pillars:

- Technology Readiness (TR):
    a. TR1 (Infrastructure): Presence and operational adequacy of wastewater treatment and recycling systems on-site.

  b. TR2 (Trust and Adaptability): End-users' willingness to accept reclaimed water standards and technical capacity to adapt operational processes.
  c. TR3 (Cruciality): Stakeholder awareness and perception of water scarcity and water-saving technologies as critical to business and livelihoods.

- Institutional Readiness (IR):
  a. IR1 (Dedicated Resources): Availability of internal administrative units or personnel dedicated to water protection and climate adaptation.
  b. IR2 (Collaboration): Active inter-organisational collaboration and knowledge exchange regarding treated wastewater reuse.
  c. IR3 (Regulatory Clarity): Stakeholder understanding of treated wastewater reuse regulations, standards, and administrative jurisdictions.
- Investment Readiness (VR):
  a. VR1 (Financial Autonomy): Capacity of local entities to invest in water infrastructure without total reliance on external institutional funding.
  b. VR2 (Socio-Economic Viability): Perceived long-term economic viability, operational cost-efficiency, and payback feasibility of water investments.
  c. VR3 (Incentive Accessibility): Availability and accessibility of government subsidies or tax benefits for circular water investments.

Rather than utilising a rigid quantitative index, these dimensions are mapped systematically using a comparative diagnostic matrix to identify specific regional deficits, thereby guiding the co-creation of targeted, consensus-built adaptation strategies. To ensure methodological transparency and reproducibility, this multi-dimensional assessment was operationalised using structured stakeholder diagnostic surveys developed during the project's inception phase. Stakeholders scored nine core indicators across the three readiness pillars on a standardised 5-point Likert scale (1 = Totally Disagree, indicating a severe barrier; 5 = Totally Agree, indicating high readiness/enabling driver). By aggregating these diagnostic indicators, regional teams established a comparable baseline to identify the specific socio-institutional deficits of each catchment, which was then validated and refined through subsequent multi-stakeholder workshops.

While the PAP framework builds on strategic IWRM planning principles [16], it explicitly distinguishes itself from traditional participatory approaches. The innovative nature of the proposed PAP framework lies in its dual-track synchronisation: it actively aligns the multi-phased stakeholder dialogue with the continuous advancement of Technology Readiness Levels (TRL 4 to TRL 6), while concurrently embedding a rigorous, five-tiered Business Case development pathway (Strategic, Economic, Commercial, Financial, and Management). Consequently, the PAP framework transitions the transdisciplinary co-creation process from an open-ended consensus-building exercise into an institutionalised, bankable, and socio-technically durable diagnosis to make projects ready for regional operationalization.

The approach consists of several interconnected steps: establishing a conceptual Multi-Stakeholder Platform (MSP); defining the context, boundaries, and mandate (Inception); diagnosing core issues alongside current and future barriers and drivers for TWWR (Situation Analysis); building alternative scenarios to assess their socio-economic, technical, and environmental impacts (Strategy Building); translating the preferred strategy into concrete actions with assigned roles, responsibilities, liabilities, and funding mechanisms (Action Planning); and finally, executing the Implementation, Monitoring, and Evaluation phases.

The sources of evidence comprised local, regional, and national stakeholders involved in the water management of the two case study areas. Eligibility was determined through a comprehensive stakeholder mapping and analysis exercise, based on a stakeholder matrix evaluating their roles, influence [17] on watershed management, willingness to cooperate, and funding potential. Eligible entities included public water authorities, regional and local branches of the ministries (Environment, Agriculture, Health), municipal governments, textile and pharmaceutical industries, agricultural cooperatives, civil society organisations and local residents. The most recent search and engagement cycle ran from November 2021 to February 2025.

### 2.2. Conceptual Design of the Visual Support Framework

To anchor stakeholder capacity building and manage systemic uncertainty, a conceptual visual support framework was developed. This framework was designed as the primary tool for data synthesis, allowing stakeholders to visualise KPIs under different climate scenarios. The underlying hydrological, environmental, and socio-economic metrics were derived from independent physical and economic simulation models, specifically utilising the Soil and Water Assessment Tool (SWAT; USDA and Texas A&M AgriLife, College Station, TX, USA) [18], the Water Evaluation and Planning system (WEAP; Stockholm Environment Institute, Boston, MA, USA) [19], and MODFLOW (U.S. Geological Survey, Reston, VA, USA) [20] standalone modelling engines.

MCDM methods [21] were then applied to handle the charted data, enabling stakeholders to rank alternative TWWR strategies. A Participatory Multi-Criteria Assessment (MCA) framework was subsequently applied to evaluate and rank the co-designed strategies. Rather than relying on closed, algorithmic mathematical models, the participatory multi-criteria evaluation of scenarios was tailored and adapted to the administrative and governance context of each pilot catchment.

In the Turkish pilot (Izmir), stakeholders evaluated, prioritised, and ranked alternative configurations through consensus-driven focus groups, brainstorming exercises with post-its matrices, and direct voting on scenario–action combinations.

In the Tunisian pilot (Monastir), a qualitative multi-criteria scoring matrix, combining feasibility and effectiveness, was deployed to systematically score and rank scenario combinations.

Across both pilot case studies, stakeholders appraised the strategies based on three co-developed Key Performance Indicators (KPIs): Groundwater Saving (GWS), Investment Cost (IC), and Return on Investment (ROI). The weighting procedure was qualitative and consensus-driven, captured empirically through stakeholder voting percentages (where participants prioritised options according to regional regulatory mandates and operational priorities) and focus group negotiations. Sensitivity analysis was structurally integrated into this participatory process by simulating and presenting the performance of each scenario under contrasting climate scenarios. This enabled stakeholders in both regions to directly observe how the physical and economic KPIs of each strategy responded to varying levels of future hydrological stress before casting their final votes and co-creating implementation roadmaps.

### 2.3. Data Collection and Engagement Modalities

Data collection and stakeholder engagement were driven by a blended regime of field visits, semi-structured interviews, localised surveys, and interactive workshops in the case study areas. They were tested and utilised by the regional teams and centrally synthesised by the respective research lead. During strategy co-creation, data charting was facilitated using a modified NAS Business Canvas [22] to capture problem definitions, value propositions, customer segments, and life-cycle costs.

To ensure the representation of key actors within the water–energy–food nexus, a purposive, non-probabilistic sampling strategy was adopted to build regional Multi-

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Stakeholder Platforms (MSP). Stakeholder mapping and screening were conducted during the inception phase based on a structured influence–interest matrix evaluating four eligibility criteria: (i) statutory regulatory mandate, (ii) operational influence on local water allocation, (iii) willingness to cooperate in circular economy initiatives, and (iv) financial and technical capacity to adopt non-conventional water resources.

While preliminary semi-structured interviews were conducted at inception by local partners as a qualitative scoping tool to chart initial socio-economic barriers, the core analytical and co-creation activities of the Participatory Adaptive Planning (PAP) framework were executed through three sequential multi-stakeholder workshops in each pilot site. These workshops brought together balanced cohorts of decision-makers, industrial consumers, agricultural end-users, and researchers.

The stakeholder workshops were co-organised to gradually build institutional and group readiness:

- Workshop 1 (inception and situation analysis): This workshop started with a situation analysis, identifying agreements, disagreements, justifications, changes, different perceptions of the same problem and previously unidentified problems. This workshop aimed to produce a realistic and accurate idea on baseline readiness (institutional, technology and investment).
- Workshop 2 aimed to consolidate the situation analysis and discuss potential industrial and urban TWWR alternatives and other needed information. In this workshop, the understanding of needs, barriers and drivers based on the initial interviews and cross-referencing with the work in the different WPs, and the exercise of a NAS Business Canvas were carried out.
- Workshop 3 aimed to discuss simulation results of proposed scenarios, co-design strategies, and develop action plans. In this workshop, alternative scenario configurations for industrial and urban treated wastewater reuse were simulated and evaluated, enabling stakeholders to compare and select preferred strategies based on a structured set of economic, social, and environmental impact criteria. In the Izmir pilot (Türkiye), configurations comprised urban drinking water savings, advanced industrial wastewater reuse oriented towards internal recycling and agricultural allocation, and aquifer recharge. In the Monastir pilot (Tunisia), the evaluated scenarios integrated urban water savings, combined industrial and urban wastewater reuse, seawater desalination, and Managed Aquifer Recharge. In the second part of this workshop, stakeholders were involved in strategy building (aggregation of a set of positive-impact scenarios) and discussed the operational components to be included in the action plan, alongside agreements for long-term monitoring and evaluation (M&E).

Qualitative data compiled from workshop discussions, interactive flipcharts, and focus groups were analysed using a standard thematic content analysis. Stakeholder inputs and records were systematically categorised into core thematic areas (focusing on technological feasibility, institutional barriers, and socio-economic readiness) to identify consensus pathways and structure the scenario-ranking results presented in Section 3.

To manage potential power imbalances during co-creation—specifically the risk of highly resourced industrial executives or public regulatory authorities dominating the discourse over smallholder farmers or local village headmen—a strict transdisciplinary grouping protocol was implemented. During the strategy co-design exercises, participants were partitioned into small, heterogeneous, multi-actor tables. Each table was designed to include exactly one representative from each primary stakeholder category: one farmer or local representative, one industrial operator, one public regulator, and one academic facilitator. Discussions were structured using silent-writing techniques (where participants drafted concerns individually on post-it notes before presenting them verbally) and moderated consensus-building protocols. This setup guaranteed that local smallholders and farmers had an equal voice, mitigating authority hierarchies and ensuring that technical options were democratically negotiated rather than technocratically imposed.

### 2.4. AI Use Statement

An AI tool (Gemini; Google, Mountain View, CA, USA) was not used as part of the research methodology, standalone model, or the project's actual planning platform. It was used exclusively by the design team as a hybrid illustrative aid to generate the central isometric icons within the Figures in the Section 3. All other graphical elements, layouts, lines, and text were created manually. The authors take full responsibility for the accuracy, validity, and integrity of the final figures.

## 3. Results

To provide a comprehensive overview of the transdisciplinary evidence gathered, Table 1 structurally synthesises the multi-level stakeholder configurations, core institutional, economic, and socio-cultural barriers, and the final co-created planning strategies selected for both Mediterranean pilot regions.

**Table 1.** Comparative synthesis of stakeholder engagement, diagnostic readiness barriers, and co-created planning strategies across the Mediterranean pilot regions.

| Evaluation Metric/ Dimension | Türkiye Case Study | Tunisia Case Study |
| --- | --- | --- |
| Multi-Level Stakeholders Engaged | Regional & local water/health authorities, Provincial & district agricultural directorates, Local agricultural unions & cooperatives, Textile industry representatives | Regional Commission for Agricultural Development of Monastir, National Sanitation Office, Drinking Water Utility, Regional Farmer Union, Local Farmer Cooperatives, and eight localised textile manufacturing firms |
| Primary Baseline Barriers Identified | Economic: High initial investment and operational/maintenance costs. Legal–Administrative: Absence of a specific legal framework for treated wastewater reuse and overlapping agency jurisdictions. Social: Socio-cultural prejudice and low farmer awareness. | Hydrological: Severe water stress (available supply of 1 million $m^3$ vs. a demand of 7 million $m^3$). Legal: Strict restrictions prohibiting TWW use on raw vegetables Social: Severe reluctance among local farmers to adopt TWWR for crop irrigation. |
| Co-Created Resilient Strategy (Selected Scenarios *) | Combined Strategy (S1 + S2 + S3): Urban Water Supply Loss Reductions + Advanced Industrial Wastewater Internal Recycling + Increased Managed Aquifer Recharge | Combined Strategy (S1 + [S2 + S5] + [S3 + S4]): Urban Water Supply Loss Reductions + Industrial Self-Recycling & Urban Agricultural Irrigation + Managed Aquifer Recharge & Seawater Desalination |

Note(s): * S1 to S5 represent the co-designed adaptive planning scenarios detailed in Sections 3.3.1 and 3.3.2.

While Table 1 provides a consolidated, high-level synthesis of the final co-created outcomes, these comprehensive insights were achieved through an iterative, multi-phased participatory process executed over the project timeline. During the inception phase, initial interviews and focus groups were conducted to establish the empirical baselines necessary to systematically unpack these multi-level institutional and socio-economic dynamics. This diagnostic phase allowed the regional research teams to map out the foundational perceptions before deploying the full strategic workshops.

In Türkiye, site visits and participatory workshops engaged public authorities responsible for water and climate change topics [including the İzmir Metropolitan Municipality (IzBB), the State Water Works (DSİ) 2nd Regional Directorate, the Izmir Water and Sewerage Administration (İZSU), the İzmir Province Health Directorate, the Provincial Directorate of Agriculture and Forestry, and the İzmir Development Agency (İZKA) at the regional level, alongside the Torbalı Municipality, the Torbalı District Governorship, the Torbalı District Health Directorate, the Torbalı District Agriculture and Forest Directorate, local Village Headmen (Muhtars), and the Küçük Menderes Irrigation Union at the local level], as well as local residents, farmers and one textile industry in the case area.

In Tunisia, public authorities were engaged—Governorate, National Agency for the Promotion of Industry and Innovation and the Regional Commission for Agricultural Development (CRDA) of Monastir, Tunisian Sanitation office (ONAS), Drinking water utility (SONEDE), textile industries, regional farmer union (URAP), farmer cooperative, extension cells, etc.

A total of six workshops were successfully executed (three in each country), as shown in Table 2, which details the chronological execution, participant numbers, sectoral profiles and gender distribution for the workshop cohorts in both case studies.

**Table 2.** Chronological overview, participants and gender profiles of the attendees of the Multi-Stakeholder Platform (MSP) workshops.

| Case Study | Workshop | Total Cohort | Sectoral & Institutional Distribution | Gender |
|---|---|---|---|---|
| Türkiye | 1 (18 May 2022) | 36 participants | Government/Regulators (42%)<br>Academia (22%)<br>Private Sector/Industry (25%)<br>Civil Society and Farmers (11%) | Balanced attendance (detailed individual gender registry not recorded for WS1) |
| Türkiye | 2 (3 Oct 2023) | 24 participants | Government/Regulators (38%)<br>Academia (29%)<br>Private Sector (8%)<br>Civil Society and Farmers (25%) | Females: 12 (50%)<br>Males: 12 (50%) |
| Türkiye | 3 (12 Jun 2024) | 13 participants | Government (8%)<br>Academia (31%)<br>Private Sector (46%)<br>Corporate/Regulators (15%) | Females: 3 (23%)<br>Males: 10 (77%) |
| Tunisia | 1 (5 Jul 2022) | 40 participants | Government/Regulators (51%)<br>Academia (27%)<br>Private Sector/Industry (11%)<br>Civil Society and Farmers (11%) | (Detailed individual gender registry not recorded for WS1) |
| Tunisia | 2 (27 Apr 2023) | 38 participants | Government/Regulators (37%)<br>Academia (34%)<br>Private Sector (11%)<br>Society/Farmers (18%) | Females: 10 (26%)<br>Males: 28 (74%) |
| Tunisia | 3 (24 Jan 2025) | 33 participants | Government/Regulators (67%)<br>Academia (15%)<br>Private Sector (6%)<br>Civil Society/Farmers (12%) | Females: 16 (48%)<br>Males: 17 (52%) |

To illustrate the practical application of the diagnostic framework, Table 3 presents the completed Socio-Institutional Readiness (SIR) Baseline Scorecard, comparing the qualitative and quantitative diagnostic ratings (1–5 scale) for both the Turkish (İzmir) and Tunisian (Monastir) pilot catchments based on the baseline survey and workshop diagnostics.

**Table 3.** Socio-Institutional Readiness (SIR) Baseline Scorecard for the İzmir (Türkiye) and Monastir (Tunisia) pilot case studies.

| Readiness Pillar | Baseline Indicator (Operationalised Survey) | İzmir Pilot (Türkiye) Score | Monastir Pilot (Tunisia) Score | Qualitative Baseline Diagnostic Context & Grounding Evidence * |
|---|---|---|---|---|
| Technology Readiness (TR) | TR1 Infrastructure Adequacy: On-site technical capacity and treatment infrastructure availability | 4/5 | 2/5 | İzmir's anchor textile firm operates its own physical and biological treatment plant, while Monastir's public treatment plants managed by ONAS are overloaded and only a few are equipped with tertiary treatment. |
| | TR2 Trust & Adaptability: End-user trust in treatment standards and physical capacity to adapt operations | 3/5 | 1/5 | High technical willingness for process-water recycling in İzmir's industry, but agricultural crop bans and severe psychological "yuck factor" aversion trigger strong farmer resistance in Monastir. |
| | TR3 Scarcity Cruciality: Stakeholder perception of water scarcity as a critical business/livelihood threat. | 5/5 | 4/5 | High awareness of severe groundwater overexploitation in Izmir and extreme irrigation water stress in Monastir after the Nebhana Dam quota dropped. |
| Institutional Readiness (IR) | IR1 Dedicated Resources: Availability of administrative units or personnel dedicated to water and climate adaptation. | 4/5 | 3/5 | Active public and academic research groups are present in both pilots, but regional administration in Tunisia (CRDA) faces severe material and resource limits. |
| | IR2 Inter-Sectoral Collaboration: Presence of formal coordination and data-sharing between industrial and local actors. | 2/5 | 2/5 | Baseline diagnostics in both pilot catchments identified a critical lack of communication and cooperation between private industrial facilities and local basin stakeholders. |
| | IR3 Regulatory Clarity: Understanding of water reuse laws, standards, and administrative jurisdictions. | 1/5 | 2/5 | Severe legislative vacuum and lack of procedures for groundwater recharge in Türkiye, and rigid, outdated agricultural TWWR crop regulations in Tunisia. |
| Investment Readiness (VR) | VR1 Financial Autonomy: Capacity of local entities to self-invest in water infrastructure without external aid. | 4/5 | 1/5 | Izmir's private anchor firm has high financial capacity to self-fund system upgrades, while Tunisian agricultural cooperatives (GDAs) completely lack capital for distribution networks. |
| | VR2 Socio-Economic Viability: Perceived economic benefits, cost-efficiency, and payback feasibility of the circular model. | 4/5 | 3/5 | Clear cost savings by avoiding high municipal freshwater tariffs in İzmir, whereas Monastir farmers bypass reuse and demand seawater desalination despite its high cost to secure market trust. |
| | VR3 Incentive Accessibility: Availability and ease of accessing public subsidies or tax benefits for circular investments. | 2/5 | 3/5 | Complete absence of public subsidies or financial incentives for wastewater reuse in Türkiye, while Tunisia's regional APIA offers tax benefits, though they remain hard to access. |

Note(s): * Diagnostic data triangulated from the baseline stakeholder surveys and co-creation planning workshops of the TRUST project.

### *3.1. Data on Barriers and Drivers*

In the Izmir case study (Türkiye), the charted data revealed that the primary barriers to TWWR were economic (high investment and operational costs) and legal–administrative (the absence of a specific legal framework for treated wastewater reuse and confusion over authority among agencies). Social prejudice and farmers' lack of awareness were also significant hurdles.

In the Monastir case study (Tunisia), stakeholders highlighted severe water stress driven by the critical deficit in the agricultural irrigation quota allocated from the Nebhana Dam system. Historically managed and reported in 2022 by the Regional Commission for Agricultural Development (CRDA) of Monastir, the regional public irrigation perimeters faced a restricted supply of less than 1 million m$^3$ against a planned agricultural quota of 7 million m$^3$ due to prolonged climate-induced drought. For a broader basin context, this specific dam quota deficit is situated within Monastir's total governorate-wide water demand of approximately 49 million m$^3$ (hm$^3$/year) as of the 2021 baseline, which is heavily dominated by agricultural irrigation (~40 million $m^3$, 85% share), followed by domestic potable water (~6 million $m^3$, 10% share), and industrial water requirements (~3 million $m^3$, 5% share).

Although advanced industrial membrane treatment technologies demonstrated strong technical feasibility, workshop findings revealed a significant social constraint: the reluctance among local farmers to adopt TWWR for irrigation. This resistance was primarily driven by multi-dimensional socio-cultural and institutional barriers. Culturally, farmers exhibited a profound psychological aversion (commonly referred to as the "yuck factor") associated with the perceived impurity of recycled wastewater. This aversion translates directly into market-related economic fears, as farmers expressed deep concerns that local consumers and competitive export markets would reject their agricultural products if wastewater irrigation became public knowledge. These perceptual barriers are reinforced by strict national regulatory crop restrictions that prohibit the use of treated wastewater on raw vegetables, which constitute the main crop type in the region.

### 3.2. Visual Support Framework for Scenario Assessment

The visual support framework was designed to facilitate communication, innovation, and multi-stakeholder administration rather than serve as an active computational runtime interface. Reflecting adaptive shifts in project decision-making over the implementation timeline, the initial planning was converted into a structured conceptual matrix that integrated stakeholder-derived multi-criteria priorities and aggregated dataset indicators designed to structurally support future regional data exchanges and scenario visualisation. This support framework was successfully updated and structured to integrate the different case studies' contexts, facilitating a cohesive evaluation.

While the visual support framework was conceptually architected to host and integrate the underlying modelling frameworks, the Key Performance Indicators (KPIs) presented in the subsequent sections were calculated externally using standalone simulation engines (SWAT, WEAP and MODFLOW), owing to the project's focus on macro-level participatory planning rather than active digital execution during the concluding phase. Consequently, the detailed biophysical calibration, numerical validation metrics, and raw volumetric water balance projections of these hydrological models are outside the analytical scope of this paper, which is strictly focused on the socio-institutional dynamics of the co-creation process. For comprehensive technical details on the coupled SWAT-WEAP-MODFLOW simulations and aquifer dynamics under the climate scenarios, readers are referred to the project's public technical repositories and associated hydrogeological publications. Similarly, financial indicators (such as ROI and lifecycle investment costs) represent aggregated decision-support metrics synthesised by the project's water economics work package to facilitate stakeholder trade-off negotiations during the workshops.

### 3.3. Strategy Co-Creation

During the dialogue, three main types of scenarios were identified:

- Investment scenarios: Scenarios requiring high financial investment for new infrastructure and equipment to reduce water use, recycling TWW, and for non-conventional water-source production.
- Management scenarios: End-users and managers' behaviour change oriented scenarios requiring low financial investments.
- Combinations of "Investment–Management" scenarios.

### 3.3.1. Türkiye

The standalone simulation engines revealed that groundwater storage in the sub-basin decreases steadily over time across all configurations, with the most accelerated depletion occurring under the most severe climate change projections. Furthermore, the modelling indicated that downstream streamflow will exhibit heightened seasonal variability and extreme fluctuations under future climate stress, a challenge that is only slightly moderated by the urban distribution loss reductions outlined in Scenario 1.

Stakeholders evaluated scenarios including smart water distribution and aquifer recharge (Figure 2). The consensus identified the most resilient strategy as a combination of:

- S1: Urban drinking water savings,
- S2: Advanced industrial wastewater reuse,
- S3: Increased aquifer recharge.


**Figure 2.** Izmir (Türkiye) scenarios and operational actions consensually negotiated and agreed upon by the stakeholders during the participatory workshops (Source: Authors' own based on workshops; central standalone icons conceptually drafted using Gemini and manually finalised by the design team).

This combined strategy (S1 + S2 + S3) was proposed to be supplemented by new grassroots actions, such as rainwater harvesting. Action planning focused heavily on overcoming institutional fragmentation.

Unpacking the qualitative dynamics of the Turkish pilot workshops reveals distinct preferences and tensions between the stakeholder groups. While Scenario 2 (Wastewater reuse) came to the forefront as the primary operational priority, concerns were raised regarding high investment and operating costs, public prejudices regarding water reuse, and the lack of state support. During the focus groups, each stakeholder evaluated the alternative scenarios from their own perspective, allowing them to become aware of the needs and demands of other stakeholders. Rather than selecting a single strategy, stakeholders co-designed a combined approach (S1 + S2 + S3). Disagreements and safety concerns regarding wastewater reuse were managed by making this combined strategy strictly conditional on being subject to long continuous testing and inspection. Furthermore, to ensure balanced basin management and to build trust, stakeholders proposed that crop patterns should be determined according to water availability in the basin, and that institutional cooperation must be formally strengthened.

### 3.3.2. Tunisia

The standalone simulation projected that a business-as-usual trajectory would result in a dramatic decline in regional groundwater storage alongside a surge in water demand by 2050 under a worst-case climate change scenario. To mitigate this ecological risk, the simulation results confirmed that the combined integration of urban agricultural reuse and industrial self-recycling represents the most impactful management response to the stressed hydrological system.

Because of the documented lack of social readiness in terms of acceptability of agricultural TWWR, the participatory ranking resulted in the co-creation of a holistic strategy (Figure 3). Stakeholders concluded that relying solely on TWWR was socially unfeasible; therefore, they selected a combined approach integrating:

- S1: Urban water savings,
- S2 + S5: Industrial and urban treated wastewater reuse: Industrial TWW for industries and urban for irrigation,
- S3: Managed Aquifer Recharge,
- S4: Seawater desalination (costly but socially demanded).

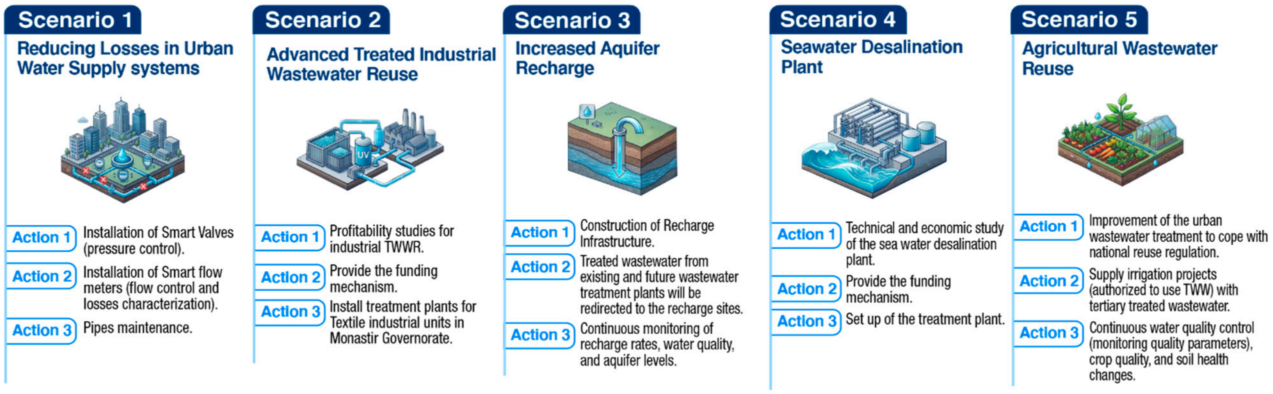


**Figure 3.** Monastir (Tunisia) scenarios and operational actions consensually negotiated and agreed upon by the stakeholders during the participatory workshops (Source: Authors own based on workshops; central standalone icons conceptually drafted using Gemini and manually finalised by the design team).

This combined strategy (S1 + (S2 + S5) + (S3 + S4)) offered an estimated ROI of 26.77%.

The co-evaluation exposed a clear divergence in stakeholder preferences regarding Scenario 1 (industrial treated wastewater reuse). While 47.8% of the participants ranked it as the best option, 34.8% considered it the least favourable. Public wastewater utility (ONAS) and regional agricultural commissioners (CRDA) supported wastewater reuse as a promising alternative, whereas local communities and farmers showed a clear reluctance to accept treated wastewater (TWW) for agricultural purposes. To manage these co-evaluation divergences and resolve conflicts, participants were partitioned into three multi-actor working groups, each comprising a representative from every stakeholder category. Disagreements were negotiated through structured dialogue, resulting in a co-created compromise. Since farmers remained reluctant to use TWW for crops and demanded a high-cost desalination unit instead, the final co-created strategy was structured as a combined, holistic portfolio: S1A (Water Saving) + (S2 + SB) (Urban + Industrial Reuse) + (S3 + SC) (Recharge + Desalination). This successfully integrated the farmers' demand for desalination (SC) to achieve social acceptance alongside utility water-saving and reuse targets.

## 4. Discussion

The experimental and participatory results of the TRUST project demonstrate that engineering and hydrological modelling, while foundational, are insufficient on their own to solve the Mediterranean water crisis. The application of the PAP framework helped to validate the working hypothesis: the successful implementation of TWWR heavily relies on addressing local socio-economic and political contexts.

In Türkiye, the results highlighted that even when industrial actors possess technological readiness, legal vacuums regarding aquifer recharge and unclear institutional jurisdictions act as primary bottlenecks. In Tunisia, the divergence between the scientifically optimal solution (TWWR in agriculture) and social readiness in terms of acceptance (Financial constraints, farmer reluctance) was a critical finding.

Studies conducted in arid and semi-arid regions revealed that the acceptance of TWWR by both public and agricultural stakeholders is influenced by more than water-quality parameters alone [23,24]. In many cases, perceptions of potential health risks, cultural and even religious norms explain the reluctance toward reuse practices, together with a lack of confidence in institutional monitoring and regulatory compliance that tend to override the technical assurances provided by scientific assessments [25–28]. Public perception can heavily influence infrastructure choices, leading to the inclusion of other options like energy-intensive alternatives to achieve social consensus. Consequently, this intersection of cultural aversion, prior negative experiences with municipal utilities, and institutional distrust explains why farmers bypassed the scientifically modelled efficiency of agricultural reuse and instead demanded a seawater desalination plant. Desalination was perceived by local communities as a trustworthy, high-quality technical alternative capable of ensuring public health and market viability for their greenhouse crops, illustrating that infrastructure adaptation cannot succeed without actively aligning technical choices with the lived experiences, trust in institutions and risk perceptions of local users.

From a methodological perspective, a critical reflection arises from the temporal framing of the finalised conceptual visual support framework. This qualitative decision support architecture was systematically validated through iterative workshops and exercises conducted with regional stakeholders throughout the different phases [29]. The framework's underlying logic reflects consensually negotiated regional priorities.

When viewed through the lens of previous IWRM studies, these findings reinforce the need to build "social and institutional readiness" alongside physical treatment plants [30–33]. The scenarios presented in the third workshop proved highly effective at translating complex hydrological data into accessible metrics (i.e., Key Performance Indicators (KPIs) on Groundwater Savings (GWS), Investment Costs (IC), and Return on Investment (ROI)) that empowered non-expert stakeholders to make informed decisions.

Furthermore, a key limitation of the Turkish pilot study was the restriction of direct physical pilot-scale testing to a single industrial partner. While this partner acted as an essential technological and operational "anchor" to validate the advanced integrated treatment sequence under real industrial conditions, this single-facility focus limits immediate sectoral generalisability across the basin. To address this constraint, the research methodology incorporated a comprehensive regional stakeholder mapping during the inception phase, identifying and cataloguing eight other major textile manufacturing firms in the Türkiye case study (Torbalı–Fetrek sub-basin). These secondary industrial actors were integrated into the participatory workshops to capture broader sectoral concerns regarding water tariffs, quality demands, and operational barriers. Consequently, while the technical baseline is anchored in a single pilot, the co-created strategies and associated circular business models were designed to serve as a scalable blueprint directly transferable to these neighbouring textile facilities.

Future research should focus on long-term monitoring to track how regional water authorities and industrial basin managers interact with the proposed visual support framework over time, evaluating its actual efficacy in bridging transdisciplinary science with daily water management routines, and assessing the actual operationalisation of the co-designed Action Plans. Further investigations into behavioural economics could also provide insights into developing financial incentives that successfully shift farmer and consumer perceptions of reclaimed water. Moreover, future initiatives should explore the operationalisation of shared, decentralised wastewater recycling infrastructure within the case studies industrial zones to allow small and medium-sized enterprises (SMEs) to collectively split capital costs (CAPEX) and overcome individual technological investment barriers.

*Systematic Cross-Case Comparison: Türkiye vs. Tunisia*

To enhance the comparative value of this study, Table 4 provides a systematic, side-by-side synthesis of the two pilot catchments, highlighting how a shared macro-vulnerability to climate-induced water scarcity manifests as distinct socio-institutional dynamics and co-created planning pathways in different Mediterranean contexts.

**Table 4.** Systematic comparative matrix of the Turkish (Izmir) and Tunisian (Monastir) pilot regions.

| Dimension | Türkiye Case Study | Tunisia Case Study |
|---|---|---|
| Primary Water Stress Driver | Severe industrial groundwater overexploitation, continuous decline in water tables, and seasonal flow variability of surface streams. | Overextraction for agricultural irrigation, seawater intrusion into the coastal aquifer, and high soil salinity. |
| Priority Water Sector | Industrial water reuse (focusing primarily on the finishing loop of the local textile industry). | Securing agricultural irrigation, municipal potable water supply security, and rural public irrigation perimeters. |
| Main Climate Threats | Increased evapotranspiration, aquifer recharge, and extreme seasonal flow variability of the Fetrek Stream. | Severe projected groundwater storage decline and critical crop water demand spikes for greenhouse perimeters. |
| Co-Created Preferred Strategy | Domestic water savings + Advanced industrial textile reuse + Managed Aquifer Recharge. | Domestic savings + Municipal/industrial reuse + Managed Aquifer Recharge + Seawater desalination. |
| Key Non-Technical Bottlenecks | Legal vacuums regarding groundwater recharge and unclear or overlapping local administrative jurisdictions. | Socio-cultural aversion (the "yuck factor") towards agricultural reuse, strict regulatory crop bans, and fragmented local governance. |
| Stakeholder Conflict & Resolution | Industrialists prioritised economic process-water recycling, while local farmers feared chemical/pigment residues. Resolved by making reuse strictly conditional upon a long-term public inspection and continuous testing protocol. | Public authorities pushed for agricultural treated wastewater reuse (TWWR) to offload treatment plants; local farmers strongly resisted due to public health and market viability fears. Resolved by integrating a high-cost seawater desalination plant into the final portfolio to achieve social acceptance. |
| Key Infrastructure Actions | Managed Aquifer Recharge basins, industrial WWTP upgrades (membrane bioreactors, photo-Fenton, and ultrafiltration), and local flowmeters. | Seawater desalination plant, municipal WWTP upgrades to tertiary treatment, and automated smart water-saving distribution valves. |

Analysing these pilots' side by side reveals deep socio-technical insights. First, the two cases share a critical similarity: in both Türkiye and Tunisia, stakeholders systematically rejected isolated, single-measure engineering solutions in favour of holistic, combined

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strategies. This common preference demonstrates that stakeholders intuitively recognise that biophysical resilience under extreme climate change (RCP 8.5) cannot be achieved through technocratic silos, but requires a diversified portfolio of interventions (combining conservation, recycling, and active groundwater management).

However, the comparative analysis also exposes stark differences in the nature of Socio-Institutional Readiness. In the Tunisian case, the primary barrier is socio-cultural and deals with perception—the "yuck factor". Here, local farmers' agricultural livelihoods are directly tied to crop acceptability, causing them to bypass the modelled financial and environmental efficiency of wastewater reuse in favour of high-cost seawater desalination. This represents a compatibility bottleneck where technical plans had to be modified to align with social risk perception. Conversely, in the Turkish case, the primary bottleneck is institutional and regulatory. The barrier is not psychological aversion (as industrial textile actors are highly willing to reuse processed water), but rather a legal vacuum regarding groundwater recharge laws and a lack of trust in administrative monitoring. Türkiye's stakeholders thus focused their co-creation efforts on establishing robust governance, demanding a "long continuous testing and inspection" framework and new institutional coordination platforms. Therefore, this comparison proves that while water scarcity is a shared Mediterranean crisis, successful implementation requires diagnostics that target the specific socio-institutional deficit of each region, be it socio-cultural compatibility in Tunisia or regulatory–administrative clarity in Türkiye.

## 5. Conclusions

Adapting existing hydraulic infrastructure to combat climate change and water scarcity in the Mediterranean requires a paradigm shift from purely technocratic management to participatory governance. This work within the TRUST project demonstrates that engaging stakeholders through a structured, transparent, and data-supported process enables the co-creation of resilient water strategies. By identifying and addressing specific local barriers (whether social resistance among Tunisian farmers or legislative gaps in Türkiye), PAP ensures that treated wastewater reuse transitions from a theoretical model into a socially readily accepted, economically viable, and actionable reality. Therefore, the principal conclusion is that bridging the gap between technical scenario modelling and real-world implementation requires robust, multi-stakeholder co-creation, which successfully aligns engineering propositions with social and institutional readiness to produce actionable water plans.

The primary long-term legacy of the TRUST project extends beyond localised, static action plans to include the finalised conceptual visual support framework and PAP process. This represents the concrete institutionalisation of the PAP framework, transforming non-technical stakeholder consensus into a functional, structured socio-technical asset ready for future regional uptake and institutional adaptation.

By embedding co-created multi-criteria priorities and structured scenario indicators into a cohesive evaluation matrix, the conceptual visual support framework is structurally poised to bridge the historical divide between complex hydrological modelling and real-world implementation. The finalised analytical framework stands as a permanent conceptual infrastructure, establishing a clear pathway and process for regional ministries, basin commissions, and industrial end-users to assume full institutional ownership and a solid basis to help operationalise resilient water circularity across the Mediterranean basin.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| CRDA | Regional Commission for Agricultural Development |
| EU | European Union |
| GIS | Geographic Information System |
| GWS | Groundwater Saving |
| IWRM | Integrated Water Resources Management |
| KPIs | Key Performance Indicators |
| MCDM | Multi-Criteria Decision Making |
| MODFLOW | Modular Finite-Difference Groundwater Flow Model |
| MSP | Multi-Stakeholder Platform |
| M&E | Monitoring and Evaluation |
| NAS | Natural Assurance Schemes |
| PAP | Participatory Adaptive Planning |
| PRIMA | Partnership for Research and Innovation in the Mediterranean Area |
| RCP | Representative Concentration Pathway |
| ROI | Return on Investment |
| SWAT | Soil and Water Assessment Tool |
| TRUST | Management of industrial Treated wastewater ReUse as mitigation measures to water Scarcity in climaTe change context in two Mediterranean regions |
| TWWR | Treated Wastewater Reuse |
| WEAP | Water Evaluation and Planning System |
| WP | Work Package |

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