



MARCLAIMED

Economic and financial aspects

Deliverable 1.3

WP1: Operational efficiency and economic sustainability in short, medium, and long-term perspective

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ABSTRACT	Report on the economic and financial aspects of MAR with AWR (RES5 and RE6, T1.5, T1.6). This deliverable highlights how Managed Aquifer Recharge (MAR) using Alternative Water resources (AWR) can bolster water security, reduce drought impacts, and support economic resilience. It introduces two economic tools under MARCLAIMED context: MARINSURE, which quantifies the “insurance value” of drought-proof water storage through ensemble modeling and sensitivity analysis, and RECOVER, which designs cost-recovery mechanisms (Tariffs) that fund these MAR systems while remaining equitable and feasible. Preliminary findings from three demo sites show that strategic use of reclaimed water for aquifer recharge can help safeguard productivity, maintain employment, and strengthen economic stability under growing climate uncertainties.		

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EXECUTIVE SUMMARY

Managed Aquifer Recharge (MAR) using Alternative Water Resources (AWR) emerges as a strategic adaptation solution to address growing water scarcity and increasing drought events exacerbated by climate change, especially relevant in semi-arid regions such as Southern Europe. MARCLAIMED project's deliverable D1.3 assesses the economic and financial aspects of MAR with AWR, emphasizing its potential to secure water supply resilience and sustainability through economic evaluations and cost-recovery strategies.

The document underscores the critical role of MAR with AWR in promoting water security by strategically storing surplus water underground during wet periods, thus creating a buffer against prolonged droughts. This practice supports economic stability in water-dependent sectors like agriculture, industry, and urban areas, by reducing vulnerabilities associated with water shortages. Additionally, MAR with AWR contributes to the sustainable management of groundwater resources, mitigating over-extraction risks and associated environmental challenges such as land subsidence and saline intrusion.

Two key economic tools, MARINSURE and RECOVER, are highlighted for their roles in evaluating the economic impacts and ensuring financial sustainability:

1. MARINSURE integrates Positive Mathematical Programming (PMP) models to assess the economic value of water security provided by MAR systems. It quantifies benefits in terms of agricultural productivity, employment, and economic resilience, factoring in uncertainties such as climatic variability, market fluctuations, and regulatory scenarios. Employing Global Sensitivity Analysis (GSA), MARINSURE evaluates how variations in economic and climatic parameters impact overall economic performance, thus providing stakeholders robust decision-making support.
2. RECOVER focuses on the financial sustainability of MAR through detailed cost-recovery tariff structures. It examines various tariff models and cost-sharing strategies among stakeholders, ensuring equitable distribution of costs and promoting responsible water consumption. The approach includes assessing the affordability and economic implications for different user groups, thereby securing broad stakeholder engagement and long-term viability of MAR investments.

Preliminary applications at project demonstration sites indicate significant potential for MAR with AWR to enhance regional water security and economic resilience. The outcomes emphasize the necessity of dynamic and context-specific economic strategies and robust institutional frameworks to optimize the benefits of MAR.

DS1 presents the most significant challenges for RECOVER due to its considerable technical, economic, and financial complexities. In contrast, DS2 and DS3, characterized by smaller systems and reduced reclaimed water production, facilitate a more thorough understanding of economic and financial strategies, as well as a more straightforward implementation process. For MARINSURE, preliminary results across the three demonstration sites highlight its value in quantifying the economic benefits of MAR with AWR under drought conditions. In DS1, MARINSURE shows that managed recharge significantly cushions economic losses, improving gross margins, labor income, and added value in agriculture even during severe water scarcity. In DS2, the tool identifies moderate economic gains, reflecting the site's mixed dependence on rainfed and irrigated systems. DS3 stands out for its high vulnerability to water shortages, with MARINSURE indicating that even limited recharge volumes can provide strong economic stability, especially in maintaining farm incomes and employment.

Moving forward, ongoing validation of these economic tools at demo sites will refine their capabilities, further guiding effective policy-making and stakeholder engagement strategies. These efforts will solidify MARCLAIMED's contribution to sustainable water resource management and climate adaptation strategies.

1. Introduction

○ 1.1 Context and background

Climate change is amplifying the frequency and severity of droughts worldwide, with semi-arid regions such as Southern Europe experiencing increasingly intense and prolonged dry periods (IPCC, 2014). These evolving drought patterns threaten water availability for agriculture, ecosystems, and communities, narrowing the window for recovery between drought events (Zeeuw, 2024). Building resilience against future droughts has therefore become a critical priority, necessitating innovative water management approaches that can buffer against climatic variability and secure reliable water supplies. A promising adaptation strategy is MAR – a sustainable method of enhancing groundwater storage to improve water security (Halytsia et al., 2022). Unlike conventional surface reservoirs, which are prone to evaporation losses, MAR stores water underground as a “water bank” that can be drawn upon in dry periods. A key feature of MAR under the context of MARCLAIMED project is its ability to use alternative water resources – such as reclaimed water, treated wastewater, and agricultural drainage – to recharge aquifers. In many drought-prone regions, significant volumes of water are currently wasted: for instance, in the Mediterranean basin, large quantities of treated and untreated wastewater and excess runoff are discharged to the sea. Capturing and repurposing these non-conventional sources through MAR turns a liability into an asset, creating additional stored water that would otherwise be lost. This practice promotes a more circular water economy by closing the loop between wastewater generation and freshwater supply. By broadening the range of source waters beyond rainfall and river flows, MAR with AWR provides flexibility and reliability in water supply, even as climate extremes intensify (Hiscock et al., 2024).

Implementing MAR using such alternative water sources yields multiple economic and environmental benefits, reinforcing its value as a drought adaptation measure:

- Long-term drought resilience: MAR effectively “banks” water during wet periods or from surplus sources, which can then be recovered in times of shortage to mitigate the impacts of prolonged drought. This enhances water supply reliability for farmers, cities, and ecosystems during multi-year dry spells, acting as an insurance against climate uncertainty.
- Resource sustainability: By augmenting groundwater reserves, MAR helps balance water budgets and alleviates the over-extraction of aquifers in water-stressed regions. The conserved groundwater reduces pressure on

surface water and existing wells, contributing to the sustainable management of the overall water resource. Storing water underground also minimizes evaporation losses and can prevent environmental problems associated with groundwater depletion, such as land subsidence or saline intrusion in coastal aquifers. In economic terms, the cost-effectiveness of MAR can be high – it often uses existing natural storage capacity and land, avoiding the need for expensive new surface reservoirs – and it safeguards economic activities (like agriculture and energy production) by ensuring a more consistent water supply during droughts (Reznik et al., 2022).

Therefore, MAR with AWR has emerged as a promising and increasingly adopted strategy for granting water supplies and mitigating groundwater depletion in water-stressed regions that face a high impact of climate change and drought (Thiloka Edirisooriya et al., 2024). MAR involves purposely recharging aquifers in ways that supplement natural replenishment, thereby providing reliable storage and reducing reliance on surface water systems and conventional resources. In particular, coupling MAR with AWR can help diversify supply portfolios, meet agricultural irrigation needs, protect against drought, and sustain water availability for future generations.

A critical aspect of implementing MAR using AWR lies in the rigorous assessment of its economic feasibility. This evaluation should account for the added value that AWR brings in fortifying the economic resilience of systems susceptible to drought and water scarcity, especially in contexts where numerous economic sectors depend on reliable water availability. In the long run, the viability of MAR rests on robust institutional arrangements and regulatory frameworks that govern both groundwater management and the utilization of reclaimed water. Policies that facilitate water reuse—while safeguarding public health—tend to reduce obstacles to implementation.

Furthermore, future scenarios introduce additional layers of uncertainty, since water availability constitutes only one variable influencing decision-making and stakeholder benefits; other considerations, such as political developments, price fluctuations, rising costs, and land-use changes, also warrant thorough examination. In particular, adopting a global sensitivity analysis under the context of MARINSURE is therefore essential to comprehensively evaluate the performance of MAR with AWR under diverse conditions. Such an approach considers all pertinent variables and sheds light on how various uncertainties may affect the economic feasibility of this solution. In order to ensure the successful implementation of a MAR system utilizing AWR) a

thorough analysis and evaluation of the existing economic conditions and prospective financial strategies is imperative. RECOVER will serve as a comprehensive tool to facilitate this implementation by assessing and recommending an adequate cost recovery strategy. RECOVER contributes to the financial sustainability of MAR with AWR by assessing cost-recovery strategies that are equitable, adaptive, and context-specific. The tool evaluates capital (CAPEX), operational (OPEX), environmental, and resource costs to develop dynamic tariff structures. These structures adjust to real-time conditions such as water availability, quality, and user type—ensuring fair cost distribution across agricultural, industrial, municipal, and domestic stakeholders. RECOVER supports economic planning and crisis response by simulating various pricing scenarios, identifying financial risks, and promoting responsible water use. Ultimately, it enables decision-makers to design resilient, affordable, and inclusive financing mechanisms for long-term viability

○ 1.2 Deliverable Objectives

The main objective of this deliverable is to demonstrate the ongoing work to achieve MARCLAIMED Specific Objective (SO2) which aims to ensure the long-term economic feasibility of MAR with AWR by analyzing the benefits on groundwater resources, assessing the economic value of water security and resilience, and implementing cost-recovery systems across different climate conditions, social contexts, and MAR schemes. Building upon the operational advancements outlined in D1.1 - Predictive Models, which focus on optimizing MAR efficiency through water quality improvements, operational risk assessment, and resource forecasting, D1.3 - Economic and financial aspects - expands this foundation by addressing the financial sustainability and economic resilience of MAR systems.

Water security is a fundamental pillar of economic resilience. MAR enhances groundwater storage by strategically recharging aquifers, reducing the vulnerability of water-dependent sectors, including agriculture, industry, and municipalities to hydrological variability and supply disruptions. By leveraging AWR, MAR reduces dependency on conventional water resources, mitigating risks associated with seasonal shortages, over-extraction, and long-term groundwater depletion.

To maximize the benefits of MAR, Economic tools such MARINSURE and RECOVER assess the economic impacts of improved groundwater security, focusing on:

- The financial benefits of stable and predictable water supplies for regional economic resilience considering the role of AWR in buffering against economic

losses caused by water shortages and uncertainties related to future scenarios (MARINSURE).

- The potential for cost-sharing among key stakeholders to enhance MAR's financial sustainability through a cost recovery approach (RECOVER).

◦ 1.3 Scope of work

The scope of this deliverable focuses on presenting a methodology in order to assess the long-term economic feasibility of MAR with AWR, quantifying the economic value of water security, and designing a cost-recovery system through tariff structures. The key areas of work include:

- Evaluating the economic value of water security: By employing tools such as MARINSURE, this analysis will quantify the benefits of water security under future scenarios and uncertainty in economic terms, particularly in mitigating financial losses during drought periods. The assessment will account for reduced risks to agricultural productivity as an essential economic sector that relies on water supply.
- Designing a cost-recovery system through tariffs: A critical component of ensuring the financial sustainability of MAR with AWR is the establishment of a robust cost-recovery mechanism. Using RECOVER, this work will explore viable tariff structures and cost-sharing models that distribute financial responsibilities among stakeholders. The objective is to develop pricing strategies that reflect the true economic value of MAR-enhanced water security while ensuring affordability and stakeholder participation.

Through these efforts, the deliverable aims to provide actionable insights into the financial sustainability of MAR with AWR, offering practical solutions for securing long-term investment and stakeholder engagement in water management strategies.

2. Theoretical Framework

This section provides a comprehensive conceptual foundation for understanding how MAR with AWR can enhance economic resilience in the face of climate change and socioeconomic uncertainties. By integrating key principles of economic resilience, water resilience, and deep uncertainty, this framework underscores MAR's role as a strategic intervention for mitigating risks associated with water scarcity and supply variability. This section highlights how MAR can stabilize economic activities, support

sustainable resource management, and foster adaptive decision-making in highly uncertain environments.

- *2.1. Key Concepts Related to the Specific Topic of the Deliverable*

- *2.1.1. Economic Resilience*

Economic resilience generally refers to the capacity of an economy—at various scales (local, national, or global)—to absorb disturbances (e.g., economic shocks, climate variability) and to recover or even transform in ways that maintain or improve long-term economic well-being (Rose, 2007). Economic resilience thus goes beyond merely “returning to normal” after disruptions; it also entails learning and adapting to emerging risks or opportunities.

A resilient economy demonstrates absorption and adaptation by mitigating immediate impacts, rapidly stabilizing production and employment, and adjusting supply chains or resource allocations in response to shocks. However, resilience extends beyond initial shock absorption; it also necessitates reorganization, allowing systems to restructure institutions, update policies, and invest in innovative solutions and strategies to enhance long-term stability. In cases where existing infrastructures and governance frameworks prove insufficient under new conditions, resilience may require transformation—a fundamental shift in water governance, resource pricing, or investment planning to ensure long-term sustainability and adaptability to future uncertainties.

Economic resilience is increasingly viewed as critical in a climate-changing world, especially for regions reliant on stable water supplies for agriculture, industry, and household needs. Since many economies hinge on the steady availability of water, ensuring water resilience underpins broader economic resilience.

- *2.1.2. Water Resilience for Economic Resilience*

Water resilience is a fundamental component of economic stability, ensuring that water systems can adapt to variability and shocks while maintaining their essential functions. A resilient water system that includes MAR and AWR must be able to absorb disturbances, recover efficiently, and continue supporting economic activities across sectors. Key pillars of water resilience are (WR4ER, 2025):

- **Robustness:** The ability of a MAR system to endure external shocks, such as prolonged droughts, extreme floods, or abrupt regulatory changes, without significant failure. A well-designed aquifer storage scheme incorporates sufficient infiltration capacity and diverse water sources, such as treated wastewater or reclaimed water, to reduce dependency on conventional surface supplies and enhance overall system reliability.
- **Recovery:** The speed and effectiveness with which MAR systems can return to stable operational conditions following disruptions. This requires institutional preparedness, strategic financial mechanisms such as insurance and emergency funding, and technical interventions like supplementary injection wells or contingency infrastructure. A well-prepared recovery framework ensures that disruptions do not lead to prolonged economic or environmental setbacks.

By leveraging alternative water resources and integrating adaptive management strategies, MAR strengthens water resilience, reducing vulnerability to water supply fluctuations and safeguarding critical economic sectors such agriculture. This proactive approach fosters long-term sustainability, economic stability, and enhanced capacity to manage future uncertainties.

○ 2.1.3. *Deep Uncertainty*

Deep uncertainty refers to situations where (a) the full array of potential future conditions cannot be known or exhaustively enumerated, (b) probabilities for key risks are highly uncertain or contested, and (c) decision-makers have limited ability to predict system behavior under unfamiliar future states. According to the literature, “policymakers are not aware of all possible futures (deep uncertainty type 2), while the probability of those futures that can be identified ex ante is typically unknown (deep uncertainty type 1).” (Pérez-Blanco, 2022).

In water resources management, deep uncertainty is especially pronounced because climate change can alter precipitation patterns, temperature regimes, and groundwater recharge rates in ways that are difficult to predict. Rapid shifts in socioeconomic variables—such as population growth, agricultural demand, and urban expansion—add further layers of complexity. Key elements include:

- **Uncertain Climate Signals:** Historical hydrological records, once the foundation for water management decisions, may no longer be reliable predictors of future supply or demand. Climate change is disrupting traditional rainfall patterns, increasing the frequency and severity of extreme weather events, and altering groundwater recharge rates. This unpredictability makes it difficult to forecast future water availability, requiring the adoption of dynamic, data-driven approaches to ensure sustainable water resource management.
- **Multiple Actors and Scales:** Water governance is inherently complex, involving numerous stakeholders across local, regional, and national levels. Government agencies, regulatory bodies, private sector entities, farmers, and civil society organizations all have different priorities and levels of influence. Coordinating among these diverse actors can be challenging, particularly when interests conflict or decision-making processes are fragmented. Effective governance structures must integrate multi-level decision-making mechanisms to facilitate collaboration and align policies with long-term water sustainability goals.
- **Socioeconomic Dynamics:** Rapid urbanization, shifts in agricultural practices, evolving industrial water needs, and changing economic priorities all contribute to fluctuating water demand. Infrastructure investments, land use changes, and economic growth patterns further complicate water supply and demand projections. As water availability becomes more uncertain, decision-makers must incorporate economic and demographic trends into scenario planning to develop resilient water management strategies that can accommodate future needs while mitigating potential conflicts over resource allocation.

Following the taxonomy by Marchau et al. (2019), we can distinguish the following sources of modeling uncertainty commonly encountered in the development and use of system models:

1. **Input Uncertainty** refers to uncertainty associated with data inputs and assumptions. This can be divided into two sub-categories:
 - i) **Uncertainty stemming from external driving forces (forcings)** that influence the modeled system, such as climate variability, economic trends, or demographic changes. These forces are often unpredictable in their timing, magnitude, or direction.
 - ii) **Uncertainty in baseline data inputs**, which describe the initial or current state of the system. These include data such as land use, resource

consumption, or economic indicators. In many cases, these datasets may be incomplete, outdated, or inconsistent across sources, limiting the reliability of the model's starting point.

2. **Parameter Uncertainty** arises from the methods used to assign or calibrate model parameters. These parameters may be:

- **Well-established constants**, such as physical or mathematical constants, which tend to involve minimal uncertainty.
- **Calibrated parameters**, estimated by adjusting the model to match observed data, typically by minimizing error metrics.
- **A priori chosen parameters**, selected based on expert judgment, assumptions, or literature values in the absence of empirical data.

Parameter uncertainty is particularly important when parameters significantly influence model outcomes and are either estimated from limited datasets or fixed arbitrarily. Quantifying and testing sensitivity to these parameters is a critical step in assessing model robustness.

3. **Structural Uncertainty** results from incomplete knowledge about the system or the simplifications and assumptions made in constructing the model. It includes uncertainty about:

- System boundaries
- Functional relationships between variables
- Model equations
- Algorithm design and mathematical representations
- Definitions of variables and parameters

Structural uncertainty also encompasses **technical uncertainty**, such as programming errors, software limitations, or numerical instability. These uncertainties can strongly affect model validity and predictive performance.

4. **Contextual Uncertainty** is related to the broader social, economic, political, or technological context within which the system operates. It concerns the framing of the system, including the assumptions made about external conditions and

the completeness of their representation.

Contextual uncertainty includes cross-scale interactions and uncertainties that arise from how different subsystems are coupled or integrated. For example, different choices between deterministic vs. stochastic modeling, static vs. dynamic structures, or unidirectional vs. bidirectional linkages introduce varying levels of contextual uncertainty.

In practice, distinguishing structural and contextual uncertainty can be difficult, as system models often represent certain processes while excluding others that may be relevant under different conditions. This makes uncertainty assessment both complex and case-specific. A more pragmatic approach (Gain et al., 2021) is to define **structural uncertainty** as uncertainty internal to the system model, and **contextual uncertainty** as that emerging from **external interactions and model interconnections**. Studies that explore alternative modeling frameworks or coupling setups are considered to explicitly address contextual uncertainty.

Therefore, Managing MAR under deep uncertainty requires an integrated approach that combines adaptability, robust decision-making, and institutional and financial preparedness. Given the unpredictability of climate change, economic fluctuations, and shifting regulatory landscapes, MAR projects must incorporate adaptive management strategies that allow for flexible adjustments to future conditions. By maintaining a dynamic approach, MAR systems can continue functioning effectively even as unexpected disruptions arise.

In parallel, robust decision-making frameworks must be employed to navigate uncertainty. Conventional water resource planning relies heavily on deterministic models that assume a single future trajectory, but deep uncertainty necessitates a broader approach. Scenario planning, stress testing, and robust optimization enable decision-makers to evaluate MAR strategies across a range of possible future conditions, ensuring that chosen interventions perform adequately even under highly variable circumstances. By avoiding reliance on best-estimate projections, MAR planning can incorporate multiple pathways that account for extreme events, socio-political changes, and economic volatility.

○ 2.1.4. Cost-recovery strategies

One of the key principles introduced by the Water Framework Directive (WFD) 2000/60/EC adopted in 2000, is the cost recovery principle for water services. As defined in Article 9, it requires EU member states to recover the costs associated with water services, including financial, environmental, and resource costs. This principle aims to ensure that water users effectively and proportionately participate financially in recovering the costs of water services.

On average, for the EU as a whole, revenues from water tariffs cover around 70% of the financial cost of providing water services (through water tariffs), with public financing covering the remaining 30% (OECD, 2024).

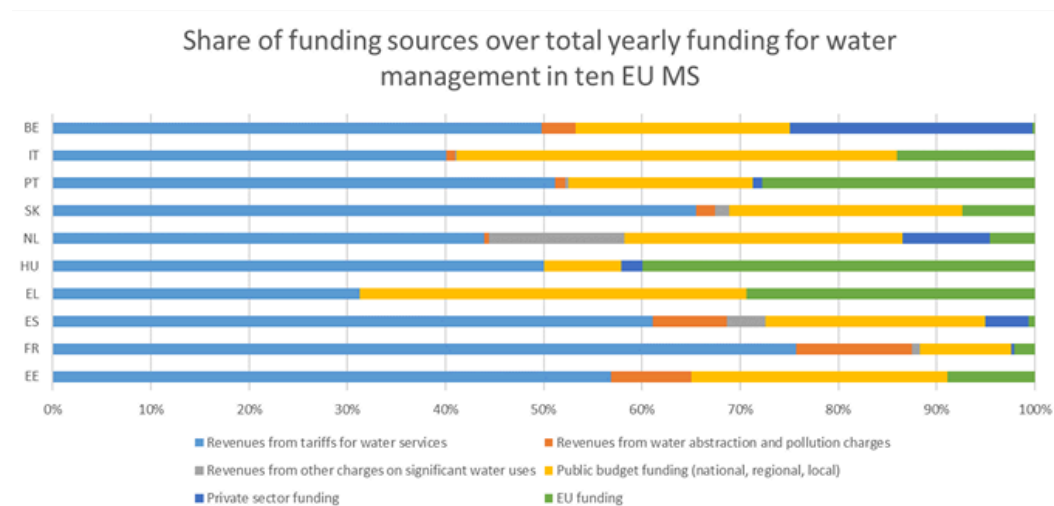


Figure 1: Share of funding sources for water management in selected Member States. Source: (European Commission, DG Environment, 2021[2]).

The implementation of this key principle has faced several challenges, summarized as follows:

1. Interpretation: The broad terms of the WFD have led to different interpretations of concepts linked to the principle among member states, in particular of the environmental and resource costs (Gawel, 2016).
2. Operational issues: Member States face political, societal and technical challenges in implementing the principle, including technical difficulties related to data availability (OECD, 2024).
3. Sector-specific challenges, such as irrigation, which threatens the continuity of production of the primary sector.

The WFD mandates at the same time, a water pricing policy that provides incentives to use resources efficiently, and that is affordable - considered to be under 3-5% of the household budget. However, this requirement has led to some unintended consequences, since reduced consumption due to efficient use can cause problems for water operators who may lack incentives to encourage water saving.

- **Cost recovery through tariffs**

Cost recovery through tariffs is regarded as a key factor for the financial sustainability of water service providers, as taxes and transfers tend to be more volatile (Hukka, 2016). It is increasingly evident that the sustainability of any investment depends on the ability to secure financing from local users (OECD, 2009). The tariff system for water provision and sanitation is well established and assessed in the Western world and in the European Union, in particular, being one of the 3 sources of financing, known as the 3 Ts by OECD (tariffs, taxes and transfers).

The necessity of improving the resilience of the water cycle has developed a new paradigm of technologies and infrastructures, introducing AWR production and MAR systems in the tasks assumed by water operators. There is no doubt about the benefits and needs of increasing water sources with AWR and MAR, but there are many questions about the financing mechanisms used to build and operate them.

In the literature there are authors affirming that the users who benefit from MAR should be responsible for funding them, whether through water rates, direct assessments, or ad valorem taxes (Maliva, 2014). However, the beneficiaries of economically feasible projects may not have financial resources for projects, for example, farmers (Maliva, 2014). Construction costs are up front, while benefits occur in the future.

The finance of large MAR and water supply projects is often controversial because of a dichotomy between the primary beneficiaries of a project and parties that pay for a project. Projects are often publicly funded so the direct beneficiaries do not pay for the outcomes of the new infrastructure (Maliva, 2014).

Government-financed projects are optimal when concentrated benefits are received by an influential target group and costs are shared in a diffuse manner by society as a whole (Boardman et al., 1996). Subsidies could be justified to achieve societal goals, such as equity (i.e., access of water to all) and food security, for example in agricultural contexts. Subsidies are justified when the price of a good does not fully reflect its

value, but can have the adverse impact of encouraging use in quantities greater than the economically efficient quantity (Maliva, 2014).

On the other hand, the operation of a MAR system may provide broader societal and environmental benefits, but the costs may be borne entirely by the system owner (e.g., local water utility and customers). A project may be economically efficient in terms of its total benefits and costs, but not feasible to the owner, because the owner will not receive sufficient personal benefits to cover costs. In other words, there is not an adequate “business case” to justify the investment in MAR. In this case, some sort of governmental subsidy or other means of financial support from more (ideally all) beneficiaries may be justified.

A widespread constraint in implementing reclaimed water in MAR systems is that water is often provided to customers at a low cost (and in some cases at no cost), leaving little financial incentive (benefits received) to invest in these systems, especially when a low-cost disposal option is available.

In Catalonia, the water supply tariff system is designed to ensure equitable access to this essential resource while promoting responsible and sustainable use. To guarantee a reliable service, a combined system of fixed and variable charges has been implemented, along with a water levy that reflects both the cost of the service and the environmental impact of water consumption. The tariff model aims to balance the recovery of operational and infrastructure costs while encouraging responsible consumption tailored to the needs of each user. In this context, differentiated tariffs are applied for households, businesses, industries, and vulnerable users.

a) Types of tariffs according to usage

According to Aigües de Barcelona (Aigües de Barcelona, 2025), different types of tariffs are outlined based on sector and water usage.

- **Domestic Tariff (Residential Use)**

This tariff is intended for households and consists of two components: a fixed fee and a variable fee.

- **Fixed Fee:** This fee is determined by the type of supply and the diameter of the meter, with prices varying according to its capacity. For a typical household, the fee is typically around €2.50 per month for a 15 mm meter.

- Variable Fee: This fee is linked to water consumption and is divided into consumption brackets. The first 6 cubic meters of water are priced lower, at approximately €0.77 per m³. As consumption increases, the price per cubic meter rises. For example, after 25 m³, the price increases to €1.01 per m³. The prices are structured progressively, higher consumption results in a higher cost.

- **Non-Domestic Tariff (Businesses and Commercial Activities)**

This tariff applies to non-residential users such as businesses, industries, and other commercial activities. It includes both a fixed and a variable fee.

- Fixed Fee: Depending on the meter diameter and the type of activity, the fixed fee varies. For example, for a 20 mm supply, the monthly fee is approximately €4.50.
- Variable Fee: The cost per cubic meter is similar to that of the domestic tariff in the initial consumption brackets, but the prices generally increase depending on the volume of water used, and the tariff may be higher if consumption is substantial.

- **Tariff for Large Consumers (Industry and Intensive Use)**

This tariff is designed for large water consumers, such as industries or activities that require significant volumes of water for their operations. This sector has specific tariffs that are better suited to their consumption needs.

- Fixed Fee: Similar to the non-domestic tariff but with values that vary depending on the meter diameter and the category of the supply. For a 50 mm meter, the fixed fee may be around €12.50 per month.
- Variable Fee: The cost per cubic meter also varies with the volume of water consumed, but a more competitive rate is generally applied to larger volumes of consumption.

b) Water levy

The water levy was implemented April 1, 2000, and is regulated by Legislative Decree 3/2003 of November 4, which approves the consolidated text of water legislation in Catalonia ("Plan De Gestión Del Distrito De Cuenca Fluvial De Cataluña 2022-2027," 2023).

The water levy, managed by the Catalan Water Agency (ACA), is a key element in Catalonia's water management system. It is designed to finance the conservation, improvement, and expansion of the region's hydraulic infrastructure. This levy applies to all users of the water service, whether domestic, commercial, or industrial, and is directly linked to the tariffs charged for water supply. The main contributions of the levy include:

- Investment and operating costs for sanitation systems (sewers and treatment plants), reservoirs, and other water production and transport infrastructure.
- Prevention of pollution at the source, implementation and maintenance of ecological flows, and restoration of degraded river ecosystems.
- Recovery of contaminated aquifers, infrastructure installation for high supply in municipalities, and the development of water reuse facilities.
- Costs related to water planning, including measure programs, inspections, and the control of water quality in coastal and inland waters designated for bathing use, as well as those scheduled under the PSiC, along with costs for managing hydraulic bodies.

• The Water Levy for Industrial Use

For industrial or similar uses, the water levy is calculated by combining two types of tariffs: a general tariff based on water use and a specific tariff based on the level of pollution generated.

Industries and activities that do not produce significant environmental impact are charged based on the volume of water consumed. In contrast, those with a higher potential for pollution or those that treat their wastewater are charged a more detailed levy, based on direct measurement of their environmental impact.

The ACA sends the water levy bill to these users on a quarterly basis, particularly for those with direct measurement. For users consuming water from private sources, the ACA also issues direct settlements, whereas if the water comes from public sources, the levy is included in the supply bill.

For 2018, the water levy values for industrial users were as follows:

- General Tariff: €0.1654 per m³
- Volume-based Tariff: €0.6486 per m³
- Individualized Tariff: Based on direct measurement of use and pollutant load discharged as seen in Table 1.

Table 1: Individualized tariff based on direct measurement of use and pollutant load discharged ("Plan De Gestión Del Distrito De Cuenca Fluvial De Cataluña 2022-2027," 2023)

Contamination parameters	Parameters costs
Suspension matter (MES)	0.5011/Kg
Oxidizable matter (MO)	1.0023 €/Kg
Soluble salts (SOL)	8.0198 €/Sm ³ /cm
Inhibitory matter (MI)	11.8889 €/Kequitox
Nitrogen (N)	0.7610 €/Kg
Phosphorus (P)	1.5222 €/Kg

c) Cost recovery

The level of cost recovery for water cycle services by users is calculated as the ratio between income and costs across the entire cycle. The income considered includes revenue derived from providing services to users, which is collected through tariffs or taxes. Income from capital transfers from public administrations is excluded from this calculation.

Table 2: Cost recovery balance by uses ("Plan De Gestión Del Distrito De Cuenca Fluvial De Cataluña 2022-2027," 2023)

By uses	Urban	Agricultural	Industrial
Cost (M€)	996.92	35.34	332.58
Revenue (M€)	768.23	23.90	288.07
Recovery (%)	77.1	67.6	86.6

In the cost recovery calculation (Table 2), both the costs and internal revenues of private agents are taken into account. As mentioned earlier, these costs correspond to expenses incurred by some users who perform certain services within the water cycle themselves, and these costs are reflected in the revenues, as they are included in the sale prices of the products they commercialize.

It is important to clarify that, to achieve full cost recovery, annual income must be equal to annual costs.

- The costs for urban uses total €996.92 million. With income from this use at €768.23 million, the recovery rate is 77.1%.
- The costs for agricultural uses total €35.34 million. With income at €23.90 million, the recovery rate is 67.6%.
- The costs for industrial uses total €332.58 million. With income at €288.07 million, the recovery rate is 86.6%.

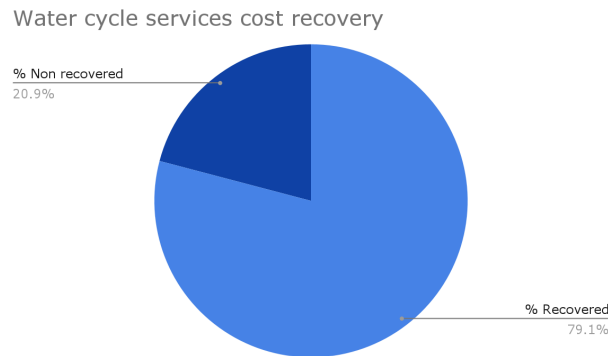


Figure 2: Water cycle services cost recovery ("Plan De Gestión Del Distrito De Cuenca Fluvial De Cataluña 2022-2027," 2023)

• Cross subsidization

Cross-subsidization is a financial strategy in which one group of consumers is charged higher prices to offset costs for another group, ensuring affordability and equitable service distribution. In the water utility sector, this typically means that industrial and commercial customers pay higher rates to subsidize lower residential tariffs or infrastructure projects. Within the framework of MAR, cross-subsidization manifests when all consumers contribute to the costs of recharge projects through their water bills, even if the direct benefits—such as increased agricultural water supply—are not evenly distributed across user groups (Pérez-Blanco and Gutiérrez-Martín, 2017).

Implementing MAR projects requires substantial financial investment, which can be sourced from multiple avenues, including government funds, user fees, and cross-subsidization. Public authorities at different administrative levels may allocate grants or loans to support MAR initiatives, providing essential financial backing for infrastructure development. Water customers may also contribute directly through their utility bills, either via general rate adjustments or dedicated surcharges designed to cover specific MAR-related expenses. Additionally, cross-subsidization plays a crucial role in redistributing costs among customer categories, allowing certain groups to bear a greater financial burden to support projects that benefit broader societal or environmental goals. In MAR contexts, cross-subsidization frequently occurs when all

consumers pay a uniform rate, ensuring sustained funding for recharge projects even when the advantages predominantly favor agricultural or urban water supply sectors.

- *2.2. State of the Art in the Field and MARCLAIMED specific tool breakthrough*

- 2.2.1. MARINSURE

- a) **literature review about mathematical programming models.**

Mathematical programming has progressively established itself as an essential instrument in both farm-level and regional policy analysis. Among the array of mathematical programming techniques, Positive Mathematical Programming (PMP) has garnered particular attention for its capacity to closely replicate observed baseline conditions compared to conventional linear programming (LP) approaches. Initially proposed by (Howitt, 1995), PMP addresses the propensity of LP to yield solutions and instead introduces a more adaptable methodological framework capable of capturing the complexities of farming decisions under evolving economic, environmental, and policy contexts. PMPs applications have extended to incorporate multiple dimensions, including risk preferences, diverse water sources, and the inherent uncertainty in resource availability. These factors hold particular importance in water-limited areas, where innovative measures such as MAR are increasingly employed to mitigate the impact of climate change and extreme events.

PMP was originally conceived as a response to the limitations of linear programming (LP), which often yielded corner solutions and failed to replicate observed water users' decisions. To correct this, PMPs introduce non-linear, often quadratic, cost or yield functions that are specifically "calibrated" to reproduce a known baseline scenario that reflects the decision and the behavior of water users (farmers). This calibration ensures that the model not only reflects real-world behaviors but also provides richer policy insights. The classic three-phase methodology:

Phase 1 (Preliminary LP) In this initial step, a baseline LP model is formulated with additional calibration constraints that precisely force the solution to match observed activity levels (for instance, actual acreage for each crop). Solving the LP under these constraints reveals shadow prices (dual values) for each calibration constraint. These dual values play a critical role in constructing the subsequent nonlinear cost functions.

Phase 2 (Non-Linear Cost Function Construction) Once the dual values have been extracted from the preliminary LP, they are combined with external information—such as known marginal costs, yield response coefficients, or supply and demand elasticities—to form non-linear cost functions. By embedding rising marginal costs into the model, expanding the cultivation of any crop becomes progressively more expensive, thereby mirroring the real-world diminishing returns and inter-crop trade-offs that farmers face.

Phase 3 (Policy/Scenario Analysis) In the final step, the calibration constraints introduced in Phase 1 are withdrawn, effectively freeing the model to respond flexibly to various exogenous shifts in market or policy conditions. Because the newly incorporated cost functions align so closely with observed data, the model replicates the baseline outcome under unchanged conditions while generating more realistic adjustments in scenarios involving price changes, technological innovations, or resource constraints.

Through this three-phase approach, PMPs ensure smoother and more continuous supply responses compared to the stark, polarizing solutions that frequently arise in standard LP formulations. By explicitly accounting for increasing marginal costs, PMP yields results that reflect observed economic behavior more reliably—thereby avoiding the "all-or-nothing" allocation patterns commonly criticized in LP (Heckelei and Britz, 2005; Merel et al., 2010).

b) Tool breakthrough: Ensemble of MPMs, Forecasting approach, and GSA (possible future and addressing uncertainty).

In water resource management, decision-making has historically relied on single-model approaches to simulate hydroeconomic outcomes. While such models provide insights, their limitations in capturing uncertainty, structural variability, and behavioral responses have increasingly come under examination (Pérez-Blanco, 2022). As water scarcity intensifies due to climate change, population growth, and economic expansion, ensuring water security demands a more robust and adaptable modeling framework. This is where the use of an ensemble of mathematical programming models emerges as a breakthrough, offering a more comprehensive and resilient analysis of water management strategies.

An ensemble of mathematical programming models leverages multiple distinct models to generate a range of possible outcomes rather than a single-point estimate. By

integrating various methodologies this approach captures diverse economic behaviors and responses to water management and water policies (Sapino et al., 2022). The ensemble approach accounts for structural and parametric uncertainties, thereby improving the robustness of decision-support tools used in water governance (Polasky et al., 2011).

Ensemble models have been successfully applied in various domains, including agricultural water pricing reforms, water buyback programs, and socioeconomic impact assessments of irrigation policies (González-López et al., 2023). These models enhance policy reliability by evaluating multiple scenarios, identifying tipping points, and enabling more effective risk management. Their predictive capabilities provide stakeholders with a better understanding of the socioeconomic trade-offs involved in alternative water resources strategies.

Designed within the MARCLAIMED project, MARINSURE employs an ensemble of mathematical programming models - PMP Standard, PMP Average, PMP Paris and PMP Ward - to evaluate the economic value of water security provided by MAR systems integrated with AWR. By assessing the performance of MAR strategies under a range of future uncertainties—including climate variability, market fluctuations, and socio-political changes—MARINSURE provides a comprehensive valuation of MAR's 'insurance value'.

Unlike traditional single-model assessments, MARINSURE's ensemble approach ensures that policymakers and stakeholders receive a spectrum of plausible economic outcomes rather than a rigid prediction. This allows for better-informed decisions regarding investment in MAR infrastructure, pricing mechanisms, and regulatory policies. By linking hydrological resilience with economic sustainability, MARINSURE facilitates the access of adaptive AWR strategies.

The adoption of an ensemble approach in mathematical programming models represents a significant advancement over conventional single-model frameworks. It addresses critical challenges in water management, such as:

- **Uncertainty Reduction:** By incorporating multiple modeling perspectives, ensemble approaches reduce uncertainty in policy evaluations, ensuring that decisions are not based on overly simplistic assumptions.

- **Enhanced Robustness:** Decision-makers gain a broader understanding of possible outcomes, allowing for the identification of resilient strategies that perform well across a range of scenarios.
- **Greater Stakeholder Confidence:** The ability to provide probabilistic assessments rather than deterministic forecasts fosters trust among policymakers, regulators, and water users.

The integration of an ensemble of mathematical programming models into tools like MARINSURE marks a transformative step in water resource management. By enabling a more nuanced and adaptable evaluation of MAR and AWR strategies, this approach ensures that water security planning is resilient, economically viable, and socially equitable.

Global Sensitivity Analysis (GSA) has emerged as a critical discipline for understanding how uncertainties in multiple hydrological and socioeconomic variables influence the outcomes of models, thereby enabling more robust and transparent decision-making - spatially in the context of mathematical programming models that deal with nonlinearity (Nossent et al., 2011; Saltelli et al., 2008). In contexts where water policy, aquifer management, and resource allocations are driven by huge uncertainty, GSA provides a structured methodology to identify which parameters drive the most significant changes in an objective function, as well as in model constraints and solutions. Under the context of MAR with AWR, where diverse water sources, demand uncertainty, and regulatory targets must be balanced, GSA becomes especially valuable for ensuring that proposed management decisions are both robust and resilient considering uncertain future conditions.

MARINSURE approach underscores the importance of exploring deep uncertainty that decision-makers must navigate, highlighting how different socioeconomic variables such prices, cost of production and yield of strategic crops that relate to water availability can be embedded in water resources management and governance.

Traditional, local “one-at-a-time” sensitivity is often insufficient when interactions among multiple uncertain parameters can drastically shift model outcomes. By contrast, GSA explores the entire parameter space simultaneously, capturing non-linear interactions and higher-order effects. In practice, the approach is based on defining probability distributions or plausible ranges for each parameter then systematically sample or vary them.

○ 2.2.2. RECOVER

a) Literature review about similar tools/methods and breakthrough

The literature about tariff design has grown significantly in recent years. So has evolved the water tariff design, driven by the increasing need for cost recovery of utilities, resource efficiency, and social equity, based on the principles of the WFD mentioned above.

Traditional approaches to tariff design have focused on static structures, with fixed prices and homogenous rates among different users, while more recent innovations leverage advanced technologies to implement dynamic pricing mechanisms, price discrimination based on users' marginal value or land value capture (OECD, 2024).

The most common water tariff systems include:

- Uniform or differentiated flat rates: In an environment without metering, customers pay a fixed fee regardless of their consumption. This fee can be uniform or differentiated based on customer characteristics, season, etc.
- Single volumetric tariffs with/without uniform or differentiated fixed charges: In a metered environment, a single rate is applied per cubic meter consumed, regardless of the volume. This may be charged with or without a recurring fixed fee, which can in turn be uniform or vary based on customer characteristics. The fixed charge can also be negative (e.g., as a coupon).
- Increasing Block Tariffs (IBTs): The volumetric charge changes in steps as the volume consumed increases.
- Adjusted IBTs: The volumetric rates applied to each block or the size of the blocks are adjusted based on specific customer characteristics (e.g., family size, income).

These structures aim to balance revenue stability with consumption-based pricing while promoting water conservation. Recent advancements in tariff design methodologies include:

- Optimization models: These ensure tariff structures comply with regulatory guidelines while simultaneously reducing fixed charges and adjusting consumption brackets to encourage conservation.
- Full cost recovery approaches: Tariffs are designed to cover operational and maintenance costs, depreciation, financing costs, and return on capital.

- **Participatory tariff setting:** Involving consumers in the tariff-setting process to increase acceptance and willingness to pay.

In California, traditional tariffs failed, leading to the development of an innovative tariff structure known as the Water Budget-Based Rate Structure (WBRS). This is a tiered rate system similar to increasing block tariffs but based on marginal cost pricing, allowing the rate structure to be tailored to each household. It consists of a fixed charge, independent of actual water use and kept at a reasonable level for both the customer and the company, and a variable charge based on consumption, distributed across several increasing tiers (EEA, 2013).

A case study of the Regione Emilia Romagna in Italy (C.D. Pérez-Blanco, 2016) explores how temporary levies on water use can mitigate environmental costs during droughts. By analyzing farmers' responses to incremental water charges, the study provides insights into how pricing mechanisms can influence water conservation and usage efficiency in agricultural settings.

Additionally, research on water demand elasticity in agriculture indicates that water tariff policies aimed at reducing over-irrigation may be ineffective if water prices are too low (Pronti & Berbel, 2024). In the Central Emilia Irrigation Water District, low water tariffs resulted in minimal reductions in water demand, highlighting the need for higher charges to promote efficient water use.

In fact, it is important to note that the tariff structure should have a fixed and a variable part (depending on consumption). In the case of agricultural tariff structure, only one block applies and, usually, water is subsidized.

b) Beyond State-of-the-Art: Dynamic Pricing Mechanisms

Dynamic pricing represents the cutting edge of water tariff design, leveraging smart metering technology to implement more responsive and efficient pricing strategies:

- **Time-of-use tariffs:** Higher rates are applied during peak demand periods to shift consumption patterns and reduce strain on water distribution systems.
- **Scarcity-based pricing:** Rates fluctuate based on water availability, with higher prices during dry periods to signal the increased value of water under scarcity conditions²⁶.

- **Combined approaches:** Some frameworks propose integrating time-of-use and scarcity-based pricing to address both daily peak consumption and seasonal water scarcity.

These innovative pricing schemes are made possible by the recent diffusion of smart water metering, enabling near real-time monitoring of consumption and facilitating the implementation of dynamic pricing strategies.

Research has demonstrated the potential of dynamic pricing to effectively manage peak water demand. For instance, a recent study showed significant shifts in water usage patterns, with increased off-peak consumption and decreased peak usage during a 4-month intervention.

Hydro-economic modeling is being used to evaluate the impacts of dynamic pricing on multiple sectors, including public water supply, environment, agriculture, and energy. Additionally, meta-analyses of price elasticity data are being employed to estimate consumption changes in response to dynamic pricing, given the current lack of field data.

While dynamic pricing shows promise, challenges remain in its widespread adoption. Water utilities have been hesitant to implement such systems due to concerns about customer readiness and the level of implementation of and trust in smart metering technologies.

In conclusion, water tariff design is evolving from static, block-based structures to more sophisticated, dynamic systems that can respond to real-time changes in demand and supply. These advanced methodologies offer the potential for improved resource management, cost recovery, and consumer behavior modification. However, further research and pilot studies are needed to fully understand their impacts and optimize their implementation in diverse contexts but, mainly, in urban context.

3. Methodology: General approach

○ 3.1. MARINSURE

MARINSURE is a tool that integrates a suite of mathematical programming models to evaluate the economic value of water security provided by MAR with AWR. By examining the interplay between hydrological cycles and economic factors, MARINSURE shows how additional water storage bolsters agricultural productivity and resilience against drought. It measures the economic contributions of AWR—encompassing gross margins, gross added value, and employment—key indicators of financial gains, broader socioeconomic benefits, and potential job creation. Compared to a baseline scenario where drought and water scarcity directly affect resources and dependent sectors, MARINSURE highlights how MAR systems buffer communities from severe shortages. MARINSURE focuses on the agricultural sector because, in extreme drought or emergency situations, water is often allocated first to urban users and environmental needs. Consequently, by offering a buffer, MAR with AWR provides an insurance mechanism that underscores its economic benefits amid regulated water restrictions and complements agricultural water needs.

MARINSURE employs positive mathematical programming (PMP) models that calibrate the observed land use in agricultural areas linked to the water system. These models incorporate real-world data on crop patterns, input usage, and farm-level decisions, ensuring outcomes reflect actual behavior. Such alignment enables more accurate simulations of policy scenarios and external stressors, including altered water availability from climate change, drought, or regulatory limits. The PMP approach captures diverse environmental conditions while revealing shifts in production prompted by changes in water policy or financial incentives. By illustrating how farmers might respond to resource constraints, MARINSURE produces results that inform policymakers seeking to balance economic returns with sustainable water use.

To address future scenarios, MARINSURE integrates outputs from PREDMAR, which offers long-term forecasts of water availability grounded in SSP and RCP scenarios. These projections inform drought status and the resulting water restrictions. With alternative water resources facilitated by MAR, potential losses are mitigated through a reserve of water accessible under uncertain conditions. This continuity stabilizes farm incomes, maintains food production, and shields communities from the worst effects of prolonged drought. Meanwhile, MARINSURE also explores cost-recovery strategies

(from RECOVER)—including tariffs or cross-subsidization—to ensure that managed aquifer recharge is financed equitably, strengthening the long-term economic viability of MAR and AWR. In doing so, it helps stakeholders balance financial obligations with the public interest in sustaining reliable water supplies.

Within the MARCLAIMED project, MARINSURE is implemented in three demo sites, each with unique environmental, social, and economic conditions. This adaptability ensures the approach accommodates varying climates, governance systems, and agricultural practices, generating targeted policy insights. Although the underlying mathematical programming approach remains consistent, specific constraints, opportunities, and data inputs differ, leading to site-specific recommendations that resonate with local conditions.

Developed from projects like TRANSCEND and TALANOA, MARINSURE advances the fusion of economic analyses with hydrological data. One key innovation is the integration of global sensitivity analysis, broadening the range of factors decision-makers can examine. By considering production costs, price fluctuations, and impact of climate change on crops' yield, MARINSURE illuminates how proposed strategies might fare under varied futures (eg. A sudden rise in energy costs, for instance, could affect aquifer recharge's affordability, while a steep drop in crop prices might reduce the profitability of irrigated production). MARINSURE's comprehensive view of socioeconomic and hydrological considerations enables stakeholders and decision-makers to assess trade-offs in a transparent, data-driven manner, ultimately guiding more robust policy decisions.

○ 3.2. RECOVER

The methodology established for RECOVER is based on the general water tariff design (OECD, 2017) but focusing on the specific design of the recovery of the costs incurred from MAR using AWR. It is composed of the following steps:

a) Delimitation of service activities

The first step is to classify and account for the activities of the water cycle that are subject to be covered by the water users through the tariff, in the context of MARCLAIMED they are the following:

- Regeneration and reuse: This involves the additional treatment of treated water to be used for MAR. Reclaimed water has other uses, such as watering gardens

or street cleaning. Therefore, it is necessary to specify the share of uses of the reclaimed water produced.

- Distribution network: reclaimed water has to be pumped and distributed to the sites where the aquifer is recharged

b) Estimation of costs of service activities

The cost structure is essential for the calculation and justification of water tariffs. The need to establish equitable and sustainable tariffs requires a detailed understanding of the costs associated with each component of the service. Therefore, it is very important to break down each activity and evaluate, through analytical accounting as well as the corresponding allocation of indirect costs.

There are two relevant characteristics of the water cycle that affect the cost structure related to the long-term nature of the strategic planning:

- Large infrastructures with significant construction costs, which will entail investments in their maintenance and replacement. They are subject to changes arising from regulations and technological developments.
- The concession contracts length requires careful planning and the ability to adapt to changes in operating costs over time, since they are subject to increasingly abundant regulations, in many cases supranational. Adequate attention to these circumstances is crucial to guarantee financial viability and continued quality of service.

Considering these characteristics, in the particular context of MAR with AWR, it is important also to account for the share of the costs of the infrastructure and construction of the tertiary treatment and distribution network corresponding to MAR.

Relative to the operating or recurrent costs, the most common expenditures of water operation are the following:

- Personnel: Human resources required for the operation and maintenance of water reclamation facilities, including skilled operators, technicians, engineers, laboratory staff, and administrative personnel essential for the proper functioning of the treatment processes.
- Provisioning of goods and services: The procurement and supply of necessary materials, chemicals, equipment, and utilities required for

water reclamation operations, including treatment chemicals, replacement parts, laboratory supplies, and energy resources.

- Subcontracting: The engagement of specialized third-party service providers for specific tasks or operations in the water reclamation process, such as maintenance services, laboratory analysis, waste management, or specialized technical support.
- Taxes: Mandatory financial obligations and levies imposed by governmental authorities on water reclamation facilities, including property taxes, environmental taxes, water discharge fees, and other applicable fiscal responsibilities.

c) Elements to consider in the justification of the tariff

Pricing frameworks for MAR projects should have, in order to recover costs, a floor based on a system-specific OPEX plus a CAPEX depreciation. Nevertheless and in the case of three MARCLAIMED case studies, the three different uses (agricultural, pre-potable and industrial fit for purpose) imply applying three different tariffs due to different cost drivers See table 3 below:

Table 3: Cost Structure and Tariff Differentiation in MARCLAIMED Case Studies. Breakdown of Cost Components and Tariff Application for Agricultural, Pre-Potable, and Industrial Water Uses

Uses	Cost drivers	Tariff Structure
Agricultural	Seasonal demand variability Lower quality requirements	Fix component: covers CAPEX depreciation Volumetric rate: Reflects OPEX
Pre-potable	Advanced treatment Stringent monitoring	Full cost recovery: including risk mitigation (pathogen removal, aquifer protection)
Fit for purpose	Custom treatment	Capacity charges: reserve infrastructure access Premium pricing: Up to potable water rates due to guaranteed supply

These differentiated tariff structures ensure financial sustainability while maintaining affordability for key user groups.

Each case study presents unique challenges and cost considerations, influencing the structure of tariff mechanisms. El Llobregat (Barcelona) integrates all three applications—agricultural, pre-potable, and industrial. Texel (Netherlands) primarily focuses on agricultural applications, with seasonal demand variability as a key driver. Comporta (Portugal), on the other hand, primarily utilizes regenerated water for aquifer recharge, leading to different infrastructure and monitoring requirements. These distinct approaches highlight the need for tailored economic assessments, which are reflected in the inputs and methodology of RECOVER.

The document titled 'Update of the Urban Water Cycle Services Tariff Guide' presents Table 4 attached in Annex 1, which details the cost components to be considered in the service tariff. The table is structured in four main columns: Cost Type, Tariff Item and Description.

Under the Fixed Costs type, we find several tariff items. The Personnel item encompasses salaries, social charges, compensation, and social expenses, including costs from same group companies. Conservation and Maintenance covers infrastructure operations and maintenance, including materials, tools, and subcontracting. Analytical Control focuses on water quality testing, while Reading, Billing, and Collection covers meter reading and collection management. Discharge Control relates to the Control Plan costs. Other non-referenced costs include administrative expenses, fuel, and insurance.

In the Variable Costs section, there are three items: Water Purchase, covering supply procurement including desalination; Water Treatment, considering reagent costs; and Energy, covering production process power purchases.

The Depreciation and Financing section includes Fixed Asset Depreciation, accounting for annual depreciation of assets, and Other fixed asset-derived expenses, covering financing costs and deterioration losses.

The final sections comprise the Canon category, with Concessional Canon for usage rights and profit sharing, and the Bad Debts category, with Bad Debt Provision for year-end corrective provisions.

d) Cost recovery mechanism

Figure 3 shows a diagram titled 'Cost-recovery mechanisms: from full to sustainable and broad cost recovery' (Farnault, A. and X. Leflaive, 2024 [4]). The diagram illustrates different types of cost recovery mechanisms in water management, organized into two main categories:

1. Financial costs, which include:
 - a. Tariffs (under full cost recovery)
 - b. Tariffs, Taxes, and Transfers (under sustainable cost recovery)
2. Environmental and resource costs, which include:
 - a. Abstraction and pollution charges
 - b. Charges on other significant water uses

The diagram demonstrates the progression from full cost recovery to sustainable cost recovery, and finally to broad cost recovery, with each level encompassing more comprehensive charging mechanisms. The note clarifies that 'charges on other significant water uses' refers to charges beyond abstraction and pollution, such as taxes on pesticides and/or nitrates.

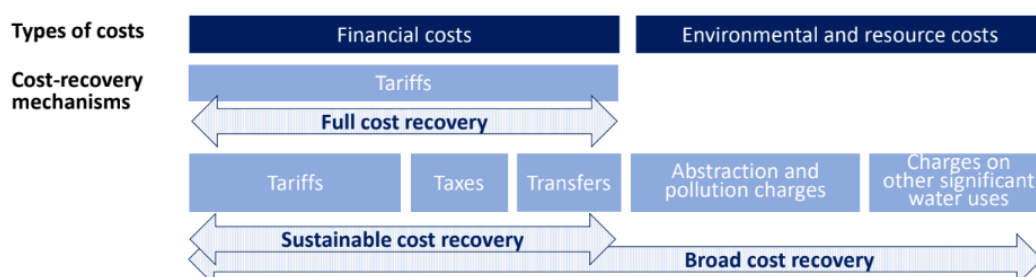


Figure 3: Cost-recovery mechanisms: from full to sustainable and broad cost recovery [4]

4. Description of the Tool

- 4.1. Conceptual scheme and main functionalities
- 4.1.1. MARINSURE

The main functionalities of MARINSURE include conducting a comprehensive economic analysis to quantify and articulate the economic value associated with water security. Specifically, it evaluates how AWR contributes to enhancing water security by providing resilience against drought conditions. By establishing a buffer capacity, MARINSURE

demonstrates the economic benefits of adopting these resources as insurance mechanisms to mitigate drought impacts and safeguard water availability. Additionally, MARINSURE provides critical insights into the effectiveness of cost-recovery policies. Through detailed policy impact analyses, the tool assesses how current or proposed policies influence economic outcomes related to water security. Decision-makers are thereby equipped with robust, data-driven analyses that enable informed adjustments to cost-recovery policies, optimizing them in response to evolving socioeconomic conditions. To manage the inherent uncertainties associated with hydrological and socioeconomic factors, MARINSURE incorporates Global Sensitivity Analysis (GSA). This approach systematically identifies the most influential parameters and evaluates the potential variability in model outcomes. By doing so, MARINSURE addresses the complexities and uncertainties inherent in real-world scenarios, especially under conditions of deep uncertainty, where future hydrological and socioeconomic changes are challenging to predict.

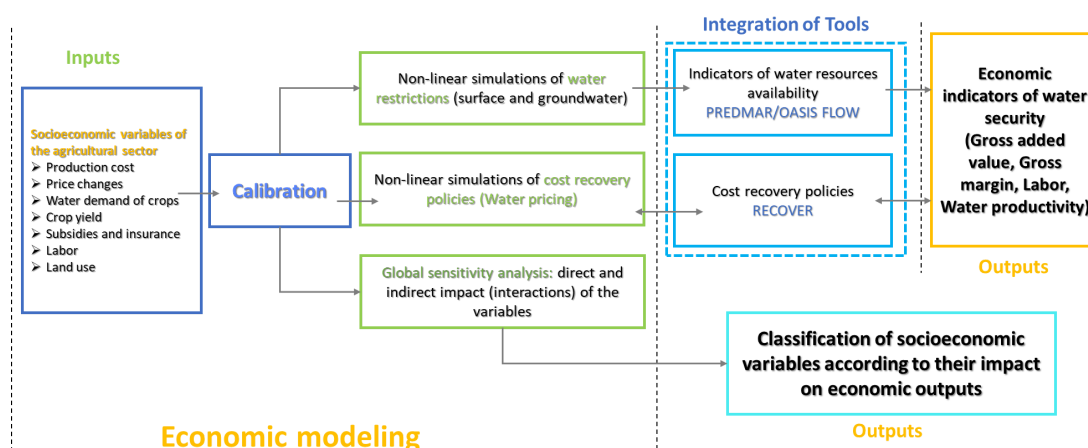


Figure 4: Conceptual scheme of MARINSURE Tool including connection with MARCLAIMED Tools and the expected outcomes

○ 4.1.2. RECOVER

RECOVER tool represents a significant advancement in the analysis of tariffs for Managed Aquifer Recharge (MAR) and Advanced Water Reuse (AWR) projects. It facilitates a comprehensive evaluation of cost recovery, incorporating both environmental and resource costs. Developed as an Excel model, it enables sophisticated financial simulations, allowing users to investigate diverse tariff scenarios and project future revenues.

A key strength is the platform's capacity to aggregate diverse costs, thereby facilitating informed and evidence-driven decision-making. Furthermore, the instrument allows for the adjustment of economic repercussions across various demographics, including residential, agricultural, and industrial sectors, whilst ensuring tariff structures are politically viable and fiscally robust, all within the parameters of sustainable water resource administration.

RECOVER tool is concisely illustrated in a diagram that depicts the calculation of the minimum tariff (USD/m³) through the division of total costs by the recharged volume. This serves to determine appropriate tariff levels. The total costs are classified into two primary categories.

- Annual Water Reuse production costs encompass capital expenditures for infrastructure and sampling, operational expenditures for basic and advanced tertiary treatment, and environmental and resource costs.
- MAR Costs, which include CAPEX for basin construction.

The system provides comprehensive tariff analysis capabilities, starting with the ability to evaluate cost recovery rates for MAR and AWR activities, taking into account both environmental impacts and resource-related expenses. It enables detailed financial modeling through the simulation of various tariff schemes, allowing stakeholders to project and analyze potential income generation under different scenarios. The Excel based model facilitates side-by-side comparison of multiple tariff scenarios, enabling informed decision-making based on projected outcomes. Furthermore, it includes sophisticated affordability assessment tools that evaluate the economic impact on diverse user groups, including domestic households, agricultural operations, and industrial users, ensuring that proposed tariffs remain viable and sustainable for all stakeholders while maintaining financial sustainability of the water management system.

The need to balance cost recovery (CAPEX and OPEX) depends on the use of the water coming from the aquifer. Usually, we could find three different uses: agricultural use, pre-potable use and fit for purpose use (basically, industrial use).

- *4.2. Data Collection and Processing*

- *4.2.1. MARINSURE*

The development of the MARINSURE tool followed four initial steps starting from the first month of the project. These steps laid the groundwork for an approach, ensuring that the tool could effectively analyze economic impacts and develop strategies to address water scarcity, drought, and climate change concerns.

Gathering socioeconomic data for the three demo sites was essential to ensuring that the analyses would be accurate. We drew upon a variety of direct sources, such as feedback from demo site leaders, to understand local conditions and adjust the models accordingly. This was complemented by data from officially recognized public sources. For DS1, Spain's "Estudios de Costes y Rentas de las Explotaciones Agrarias" (ECREA) served as a detailed reference, offering updated information on agricultural variable costs, market prices, and yield of crops. For DS2 in Portugal, we used the database provided by the Instituto Nacional de Estadística (INE), to gather informed data about socioeconomic indicators like labor markets, overall production values, and pricing fluctuations relevant to agricultural activities. For DS3 in the Netherlands, the Dutch Farm Accountancy Data Network (FADN) has been used, provided by Wageningen University & Research (BINternet). FADN systematically compiles comprehensive records of economic activities on Dutch farms, capturing yield variations, variable costs, and net economic values that come from the agricultural sector. By synthesizing all this data, we created a robust baseline that reflects the observed data to be used for the calibration of the four mathematical programming models included in MARINSURE.

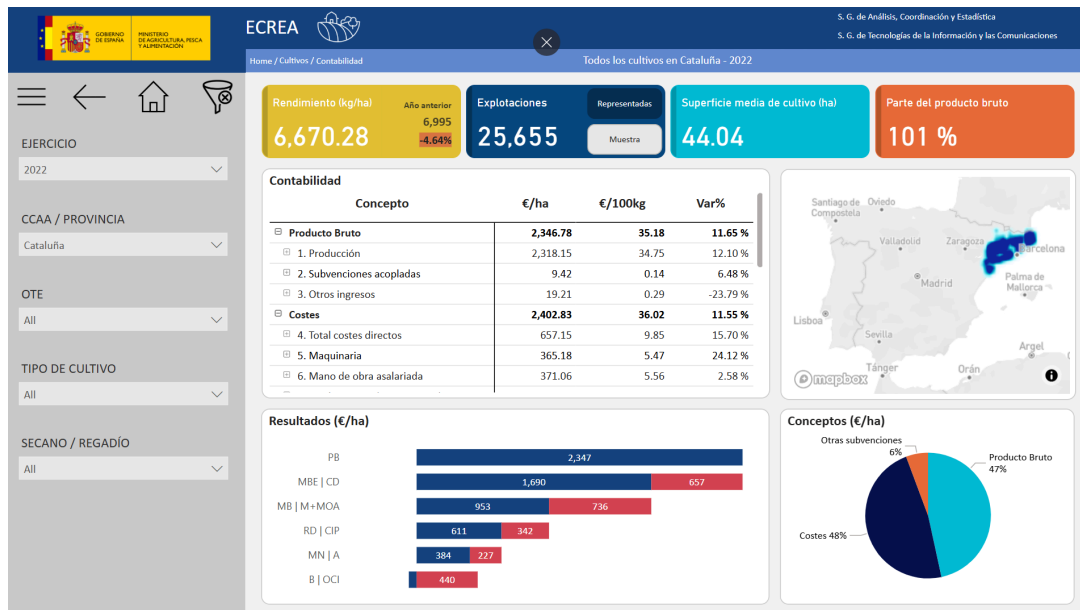


Figure 5: Example of socio-economic data provided by ECREA for MARINSURE (DS1).

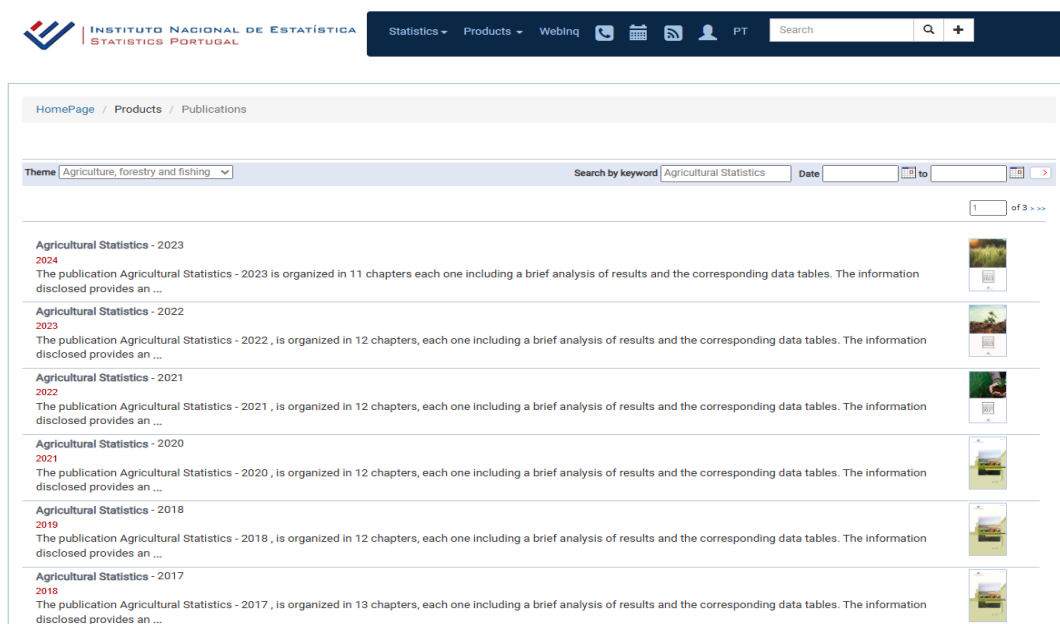


Figure 6: Example of socio-economic data provided by INE for MARINSURE (DS2).

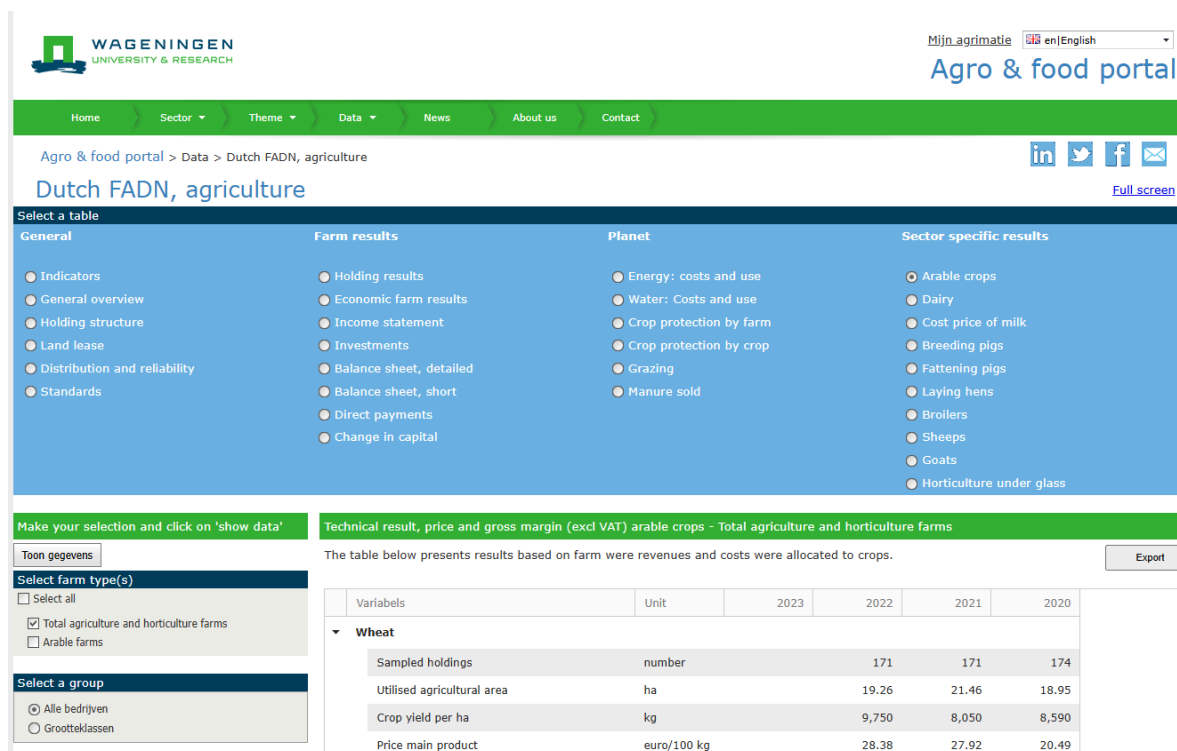


Figure 7: Example of socio-economic data provided by Dutch FADN for MARINSURE (DS3).

The Scale of the study was considered in the development of the tool as each demo site has its own specific hydrological and socioeconomic system. For the Llobregat (Demo site 1), we identified specific units of demand that reflect diverse cultivation practices, irrigation methods, and overall economic scales that include the demo site itself. In Comporta (Demo site 2), attention was given to municipalities that rely heavily on both irrigated and rainfed agricultural systems, capturing a broad range of farming approaches and risk profiles involving the demo site itself to assess the impact at the local level as well as the macro level. Meanwhile, for the Texel demo site (Demo site 3), we included municipalities that demonstrate varying degrees of sensitivity to water scarcity and climate variability. This step led to generating GIS maps for land use (crop maps) at each municipality or unit of demand which helped us visualize the relative distribution of crops, identify key patterns in water usage, and better account for how irrigation or natural rainfall influences agricultural outputs. This nuanced level of detail underpins our capability to scale up the analysis and apply it to broader regions of each demo site.

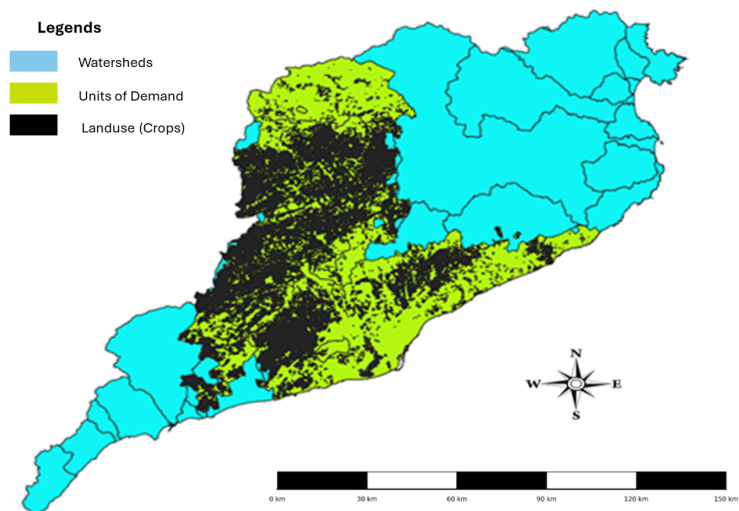


Figure 8: Selected units of demand to scale up the study led by MARINSURE (DS1).

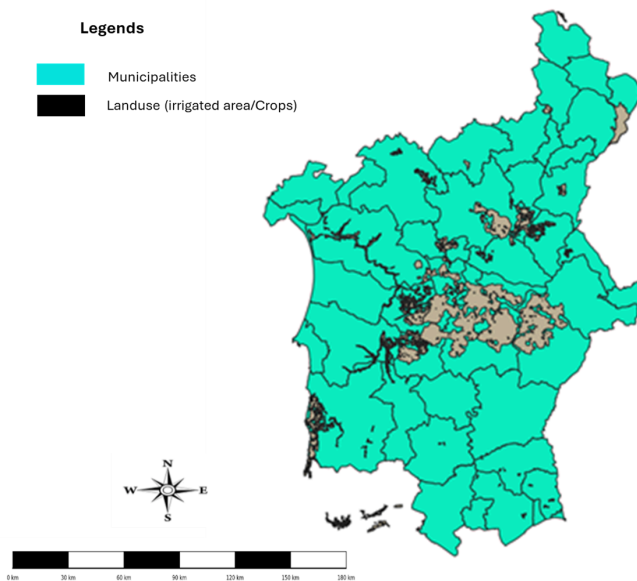


Figure 9: Selected municipalities to scale up the study led by MARINSURE (DS2).

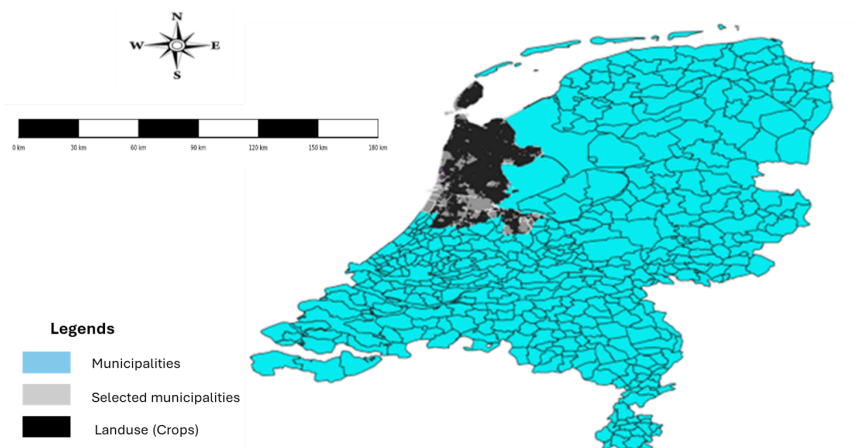


Figure 10: Selected municipalities to scale up the study led by MARINSURE (DS3).

Building and calibrating an ensemble of microeconomic models - mathematical programming models- was the third step in processing the data. These models incorporate a wide range of variables, including water demand, variability of prices, yields of crops, and production costs tied to agricultural activities. The four PMP models have been calibrated based on two approaches - cost function and yield function - which reflect the crop portfolio that is considered in the first step of assessing the impact of water scarcity. In order to simulate real-world challenges, we ran scenarios that applied varying degrees of water restriction, reflecting not only seasonal drought patterns but also more extreme conditions that may occur in the near future - the results of these simulations are also affected by the approach that is used to calibrate each model which required the consideration of the ensemble. The pre-results from the three demo sites have shown how even moderate changes in water availability can cause shifts in the net income of farmers, gross added value, and employment related to the agricultural sector. The second set of simulations focuses on water pricing to assess potential farmer behaviors in response to cost-recovery policies implemented across the demo sites. Preliminary results indicate that climatic conditions and different strategies play a crucial role in farmers' decision-making when facing policies such as tariffs or cross-subsidization. These findings suggest that clustering price ranges can help identify the most affordable options without causing huge shifts in decision-making.

Both water availability inputs and cost-recovery strategies will be integrated through a coupling process with three different tools—PREDMAR - (T1.2. PREDMAR: AI-based water availability and demand forecasting tool), OASIS FLOW (T1.4. OASIS FLOW: Digital tool for municipal scale water footprint performance), and RECOVER (T1.6. RECOVER: Tariff settings for cost recovery)—developed under WP 1 of MARCLAIMED. These tools will be interconnected during the application and validation of MARCLAIMED tools under Task 4.1 (Efficiency for reliability: validating innovative

technological tools in operational environments) and Task 4.2 (Economic feasibility for sustainability).

The development of an integrated protocol of global sensitivity analysis for the microeconomic models is a critical step in the development of MARINSURE . This approach is based on analysing the distribution of the socioeconomic inputs and considering all the possible combinations and their impact on the outputs of the model. This approach enhances the model's capacity to assess how variations in socioeconomic and climatic factors—such as shifts in the availability of water, fluctuation of prices or even decline or increase of the yield due to socioecological factors—impact economic performance of the agricultural sector across the demo sites. This integrated tool allows us to systematically vary key socioeconomic and climatic parameters to observe how these factors influence economic performance considering deep uncertainty. By deploying this sensitivity analysis across all three demo sites, we aim to capture a more holistic picture of how changes in water resources and broader market conditions might affect the end-users that are affected directly by the impact of climate change and assess the feasibility of a solution such as MAR with AWR. Preliminary results from this integrated tool will be shared for each case study and carefully reviewed by the demo sites' leaders under T4.2 , whose on-the-ground experience helps ensure the model's recommendations remain grounded in actual local practices.

○ 4.2.2. RECOVER

The RECOVER tool is a spreadsheet-based model designed to evaluate the cost recovery of MAR systems with AWR. To develop the tool various internal data sources were collected and processed. The collected data, related to capital expenditures, operational expenditures, environmental and resources costs, was standardized and integrated in RECOVER's analytical framework.

RECOVER complements the MARINSURE tool by focusing on long-term financial viability and tariff structures that ensure economic sustainability while promoting water reuse.

Economic costs associated with water reusing projects are divided into 3 main groups: capital expenditure (CAPEX) and Operating Expenditure (OPEX), Environmental costs and Resources costs:

- **Capex and Opex:**

CAPEX includes initial infrastructure investment and amendment to existing features, such as acquiring sampling equipment for quality control using Marclaimed analysis pack and special non-target analysis. In the case of MAR, Capex mainly covers the construction cost of infiltration ponds, including the installation of excavation, preparation and necessary infrastructure. OPEX water represents the ongoing expenses required to operate the facility of reuse. These costs include energy consumption for pumping and treatment, use of chemicals, labor expenditure, regulatory compliance and maintenance of recharge infrastructure.

The production of advanced water reuse (AWR) includes several stages of treatment.

- Basic tertiary treatment includes primary procedures such as coagulation, which helps remove suspended particles, flocculation, sand for filtration, and polyetroleoolite for removal of phosphorus. At this stage, energy consumption incorporates primary operation, while an early disinfection process is performed using hypochlorite. The quality of the rebuilt water varies depending on its intended application.
- Advanced tertiary treatment introduces more sophisticated purification techniques. This phase includes ultrafiltration (UF), which depends on membrane filtration for advanced purification and inverted osmosis (OI) to ensure a high level of water quality.

The infiltration plays an important role in AWR production, especially in relation to operating expenditure. In this context, OPEX is responsible for the total costs associated with running the reuse system of water. An important part of these costs stems from pumping operations, which are divided into two main categories: pumping the infiltration basin and general energy expenses. In the east, the water refers to the energy required to transfer water to the storage basin, which allows for natural filtration in the ground. Additional energy costs are possibly related to another pumping station or facility area.

All these elements are interconnected as they represent different aspects of the same water management process, from pumping the water, to moving it through the system, to its final destination in infiltration basins. Each component contributes to the total operational expenses required to maintain the water reuse system.

In sum and having a system approach, the cost components in MAR systems are:

CAPEX: includes infrastructure for:

- Water treatment (tertiary treatment, disinfection)
- Recharge facilities (infiltration basins, injection wells)
- Monitoring systems and conveyance networks

OPEX: encompasses:

- Energy consumption (pumping, treatment)
- Chemical usage (e.g., UV, chlorination)
- Maintenance of recharge infrastructure
- Labor and regulatory compliance costs

As an example, Ross et al. (2018) and Vamderzalm et al. (2015) indicate that MAR system OPEX costs vary widely (between 0.07\$/m³ and 0.15\$/m³).

- **Environmental costs**

The environmental costs “represent the costs of damage that water users impose on the environment and ecosystems and those who use the environment. This loss in welfare may encompass lost production or consumption opportunities as well as non-use values, which are harder to quantify.”(OECD, 2024)

It is important to distinguish between internal and external environmental and resource costs. Internal costs refer in this context to costs, which are part of the economic system related to specific water use, whereas external costs remain outside the economic system. According to Pearce and Turner (1990): ‘An external cost exists when the following two conditions prevail:

- An activity by one agent causes a loss of welfare to another agent.
- The loss of welfare is uncompensated.

Hence, if economic costs as a result of specific water use are compensated, financially or otherwise, we speak of internal or internalised environmental and resource costs. If, on the other hand, these economic costs remain uncompensated, we speak of external environmental and resource costs.

For example, a company located upstream along a river produces marketable output (e.g. food products or chemical products) and at the same time wastewater, which is treated before it is discharged into the river. Although the wastewater is treated before it is discharged in accordance with existing legislation, the discharge still pollutes the water. The polluted water results, for example, in higher purification costs for drinking water companies located downstream and loss of recreational fish stock. The higher (monetary) purification costs of the drinking water companies and the (non-monetary) damage caused to the recreational anglers downstream, who experience a real loss of recreational fishing opportunities, are not compensated by the polluter or through some other mechanism, and are therefore external costs.

These costs can include:

- Damage to water systems due to pollution, eutrophication, or changes in water quality
- Loss of biodiversity
- Morphological changes to water bodies
- Costs associated with activities and measures aimed at protecting the water environment

- **Resource costs**

Resource costs are defined as the costs of depriving the next possible user, if that user has a higher value for the water, then there are some opportunity costs experienced by society due to this misallocation of resources (OECD, 2024). “the costs of foregone opportunities that other users suffer due to the depletion of the resource beyond its natural rate of recharge or recovery (e.g. costs related to groundwater over-abstraction). These users can be either those of today, or those of tomorrow, who will also suffer if water resources are depleted in the future”.

Opportunity costs of resources are not reflected in the financial costs, therefore, the scarcity value of under-priced environmental resources, should be accounted for when estimating economic costs (OECD, 2024). Resource costs can exist even in the absence of environmental damage costs and may be based on the estimation of environmental costs.

The assessment of these costs is strongly dependent on the physical status of the water system and available knowledge about this status.

MARCLAIMED project consists of three separate demonstration sites: El Llobregat (Spain), Texel (Netherlands), and Comporta (Portugal). Of these, the Demo Site 1, Llobregat, presents the greatest complication in terms of economic management and cost recovery. Consequently, the location serves as the foundation for model calibration, as developing a model for the most challenging location will facilitate its subsequent simplification and adaptation of low complex sites.

To process all the collected data related to operation, production and reclaimed water infiltration, Excel has been chosen as the optimal platform to recover. Its versatility, ease of modification, and adaptability makes it ideal to make the RECOVER model suit each demo site. Below (Figure 11) is the operating structure, which outlines the input (already detailed information in the data collection section), processing and generated output (which will be analyzed in detail in Section 5.1.2 of the results).

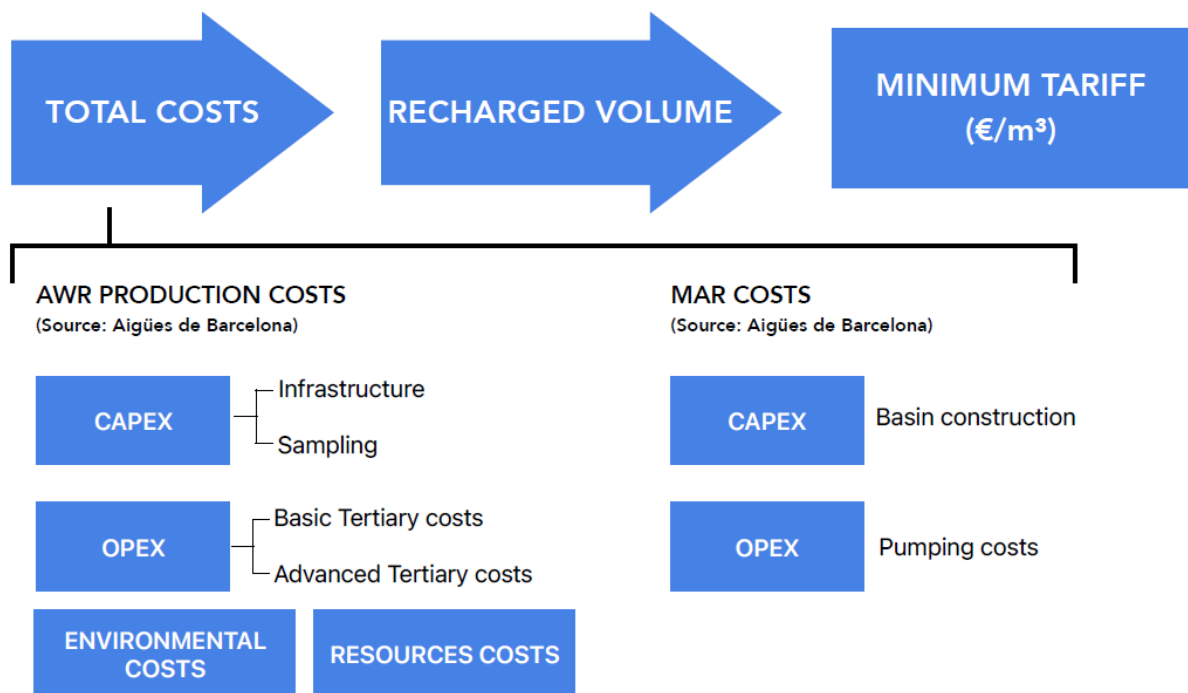


Figure 11 : RECOVER operating structure

An estimated tariff has been calculated to enable the cost recovery for the MAR system with AWR, related to the total costs from the amount of water recharged. This calculation requires considering the total amount of water produced, its respective economic costs, and the amount of recharged water effectively. The result section presents the result of the first recurrence of the minimum tariff calculation required to obtain cost recovery for this implementation.

- 4.3. *Tool Development: System architecture, algorithms and models used (MARINSURE)*

System Architecture

MARINSURE is a tool developed on two systems - GAMS (General Algebraic Modeling System) and Python. It consists of four mathematical programming models - PMP Standard, PMP Average, PMP Paris, PMP Dangnigo and Ward - (all GAMES-based) and a global sensitivity analysis code in Python using the SALib library. Each of these four models is implemented in GAMS, leveraging algebraic modeling and optimization capabilities. Meanwhile, the global sensitivity analysis is done in Python, specifically using SALib, to investigate the sensitivity of model outputs to variations in input parameters. This synergy between GAMS and Python ensures that complex optimization problems can be solved while also allowing robust and flexible sensitivity analysis. GAMS and the Python-based SALib library are two distinct yet complementary tools widely used in optimization and model analysis. GAMS is well-known for formulating and solving large-scale mathematical programs, particularly in agricultural economics through Positive Mathematical Programming (PMP) which is used for the ensemble of mathematical programming models of MARINSURE. Meanwhile, SALib focuses on global sensitivity analysis methods (Sobol indices) - which is included through a coupling protocol between the two systems - that helps modelers quantify the influence of uncertain parameters on model outputs. Despite their different core functionalities, integrating GAMS and SALib has become increasingly relevant for robust modeling and decision-making.

GAMS is a high-level modeling system designed to address a range of mathematical programming problems, including linear (LP), nonlinear (NLP), and mixed-integer (MIP) formulations. It uses a concise, algebraic syntax that enables domain experts—such as economists, engineers, and operations researchers—to translate theoretical models into solvable programs.

Global sensitivity analysis (GSA) systematically quantifies how uncertainty in a model's inputs influences the variability of the outputs. Unlike one-factor-at-a-time approaches, GSA methods examine interactions among parameters and capture the combined nonlinear effects on results (Saltelli et al., 2008).

SALib (Sobol indices) derived from variance-based sensitivity analysis, are especially popular in environmental sciences, engineering, and economics. They provide clear metrics:

- First-Order Sobol Index (S_i): The direct contribution of each parameter to output variance.
- Total-Order Sobol Index (ST_i): The overall contribution of each parameter, accounting for all interactions.

In agricultural economics, the Sobol method can help determine which parameters (e.g., yield coefficients, crop prices, input costs) drive the largest variation in model outcomes (gross margin, gross added value, and employment).

Bringing together GAMS and SALib yields a robust workflow:

- Model Definition and Optimization in GAMS: mathematical programming models are built, calibrated and optimized on GAMS.
- Parameter Variation in SALib: Through the GAMS Python API, parameters are programmatically varied across a defined parameter space (distribution of inputs).
- Sensitivity Analysis with SALib: The collected data is fed into SALib to compute Sobol indices.

Algorithms and Models Used

As described in the previous section, the models are built on a GAMS-based system, and each model is solved by following these steps:

Sets: The model considers the crop portfolio as a set, and operational constraints (such as resource limitations) are also represented within sets.

Parameters: All parameters—prices, yield, cost, labor, hired labor, water requirements, subsidies, insurance, and observed land use—are linked to the crop set.

Variables: Each model determines two key variables: the total gross margin and land use, which is introduced as a positive variable constrained by the available observed land.

Equations: The model includes a set of equations to solve the objective function. These equations include:

- ❖ Total Gross Margin Equation:

$$TGM = \sum cGM(c) \cdot X(c)$$

- ❖ Land Use Constraint:

$$\sum cX(c) \leq 1$$

- ❖ Gross Margin Calculation:

$$GM(c) = price(c) \cdot yield(c) + subsidy(c) + insurance(c) - cost(c)$$

- ❖ Equality Constraints:

$$\sum cconst_matrix(const, c) \cdot X(c) = rhs(const, 'limit'), \text{ if } rhs(const, 'type') = 0$$

- ❖ Greater-than Constraints:

$$\sum cconst_matrix(const, c) \cdot X(c) \geq rhs(const, 'limit'), \text{ if } rhs(const, 'type') = 1$$

- ❖ Less-than Constraints:

$$\sum cconst_matrix(const, c) \cdot X(c) \leq rhs(const, 'limit'), \text{ if } rhs(const, 'type') = 2$$

Calibration Constraints: These constraints adjust the model to replicate observed data by maximizing the gross margin while considering land and water limitations.

Cost Function: Each model calculates cost functions using different approaches, defining three parameters:

- ❖ **Alpha:** Marginal cost intercept
- ❖ **Beta:** Marginal cost slope
- ❖ **Mu:** Dual values from calibration constraints

Objective Function: The objective function integrates equations, constraints, and cost function parameters. It is designed to maximize gross added value, aligning the model with observed data while considering land and water resource limitations.

Water Restriction Simulations: Once the model is solved, water restriction scenarios are simulated by gradually reducing water availability from 100% to 0%. The model assesses how agents adjust their land use and resource allocation based on these constraints.

Water Pricing Simulations: The model also runs water pricing simulations, starting from the current water price (or from 0, assuming no cost for water) and gradually increasing it. This helps analyze the behavior of end users in response to changing water pricing policies.

Sensitivity Analysis: Each model incorporates data distribution and runs a series of simulations based on the Sobol index approach, $N(2D+2)$, where $N \geq 1024$ and $D = \text{number of parameters}$.

Calibration and Validation

Calibration is central to the positive mathematical programming models and involves systematically adjusting model parameters to align model outcomes closely with observed real-world data. Typically, this calibration occurs in three stages:

1. Initial Linear Programming (LP) Model

The initial phase in PMP calibration involves formulating and solving a linear programming model. This model mirrors observed resource usage and activity levels to establish baseline scenarios. It generally includes:

- **Objective Function:** Aiming for profit maximization to represent economic optimization realistically.
- **Constraints:** These include observed land allocation, resource constraints (water requirements and employment).

Solving this LP model generates outputs known as dual values (shadow prices), which reflect the implicit economic cost or benefit of incrementally relaxing each constraint.

2. Calculation of Dual Values

Dual values derived from the initial LP solution are used in the calibration process. They offer economic insights into the marginal value of resources that are constrained. Each dual value quantifies how much the objective (profit) changes if a resource

constraint is marginally relaxed. Thus, dual values serve as main inputs for determining the PMP parameters α (linear component- marginal cost intercept) and β (nonlinear component-dual values from calibration constraints).

3. Derivation and Calibration of α and β Parameters

The dual values are incorporated into a nonlinear programming structure, where the parameters α and β are explicitly calibrated. This step ensures that the calibrated model reproduces observed land use and resources allocation. PMP calibration employs a nonlinear cost function characterized by:

- α (alpha): Represents a linear marginal cost or revenue component, reflecting direct proportional changes in economic outcomes.
- β (beta): Captures nonlinear aspects, such as diminishing returns or escalating marginal costs associated with increasing resource utilization or production intensity.

Validation through Global Sensitivity Analysis (GSA)

GSA systematically assesses the extent to which uncertainties in input parameters influence model outcomes. GSA helps identify the parameters most critical to model outputs, thus highlighting where model accuracy and robustness must be most rigorously ensured.

1. Parameter Identification and Sampling:
 - Identifying all critical parameters influencing model outcomes.
 - Employing robust sampling techniques, including random method - Sobol indices.
2. Model Simulation Execution:
 - Conducting extensive simulations by running the calibrated PMP model multiple times with the diverse sets of sampled parameter combinations.
 - Generating comprehensive output distributions reflecting a wide spectrum of potential scenarios.
3. Calculation of Sensitivity Measures:

- Utilizing variance-based sensitivity indices techniques to statistically evaluate how variations in each input parameter influence the variance in model outcomes.
 - Clearly identifying and ranking parameters based on their relative impact.
4. Analysis, Interpretation, and Robustness Assessment:
- Analyzing results to determine critical parameters and their relative significance in influencing model behaviors and outcomes.
 - Assessing model robustness by examining whether the calibrated model remains reliable and realistic under significant parameter variability.

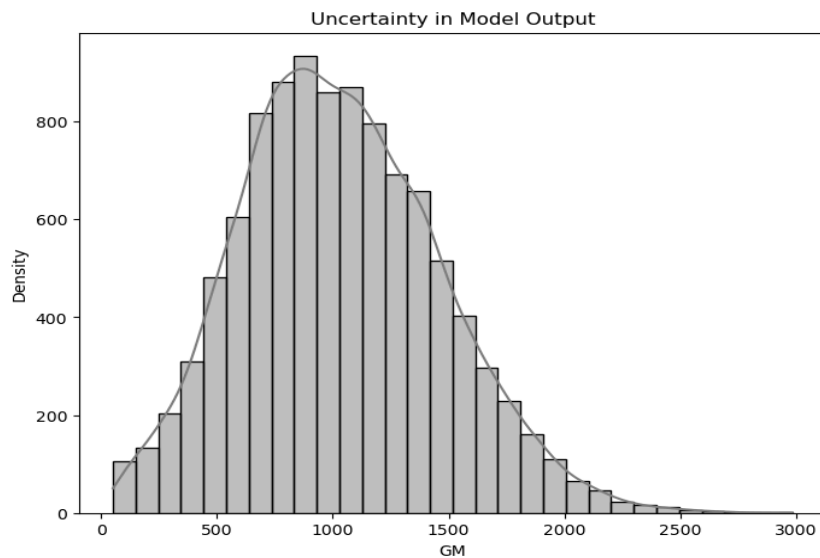


Figure 12: Example of quantifying model output uncertainty through sobol indices method included in MARINSURE

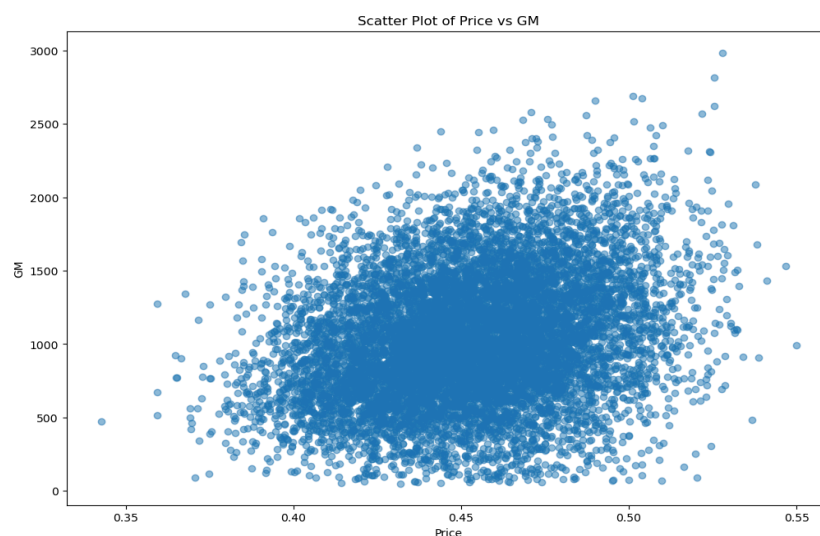


Figure 13: Example of quantifying model output uncertainty (Input-output) - Prices

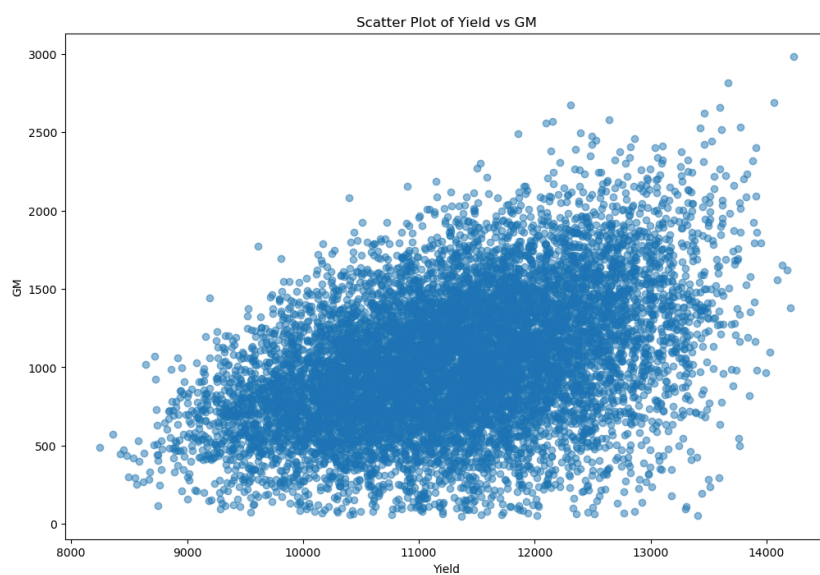


Figure 14: Example of quantifying model output uncertainty (Input-output) - Yield

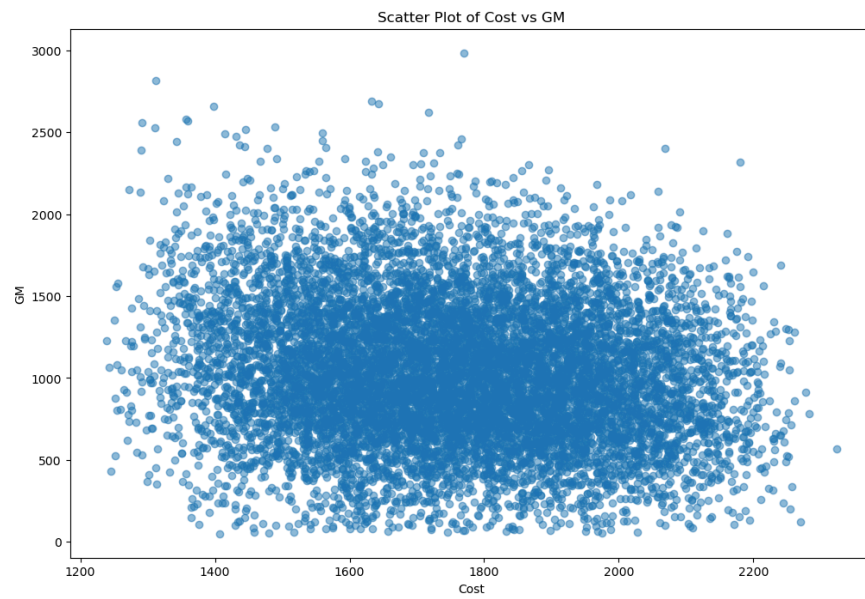


Figure 15: Example of quantifying model output uncertainty (Input-output) - Cost

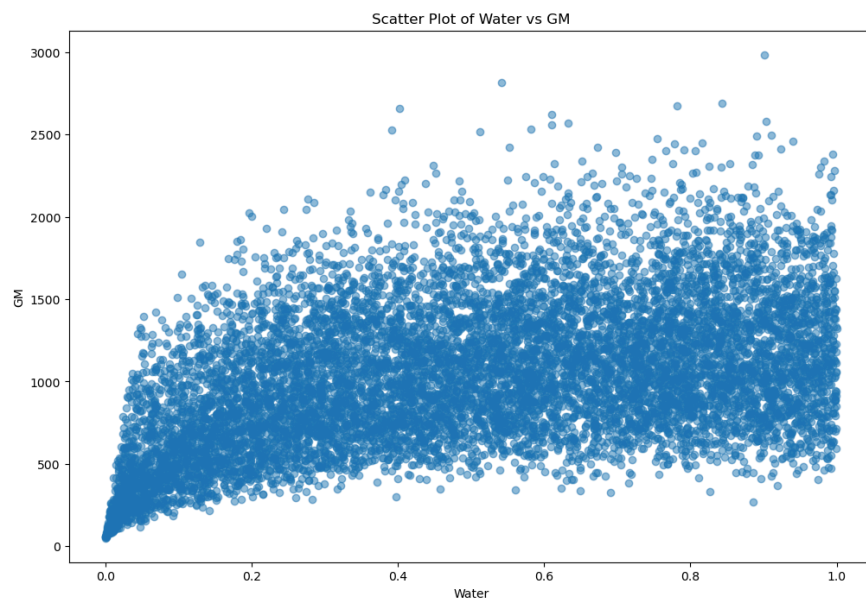


Figure 16: Example of quantifying model output uncertainty (Input-output) - Water

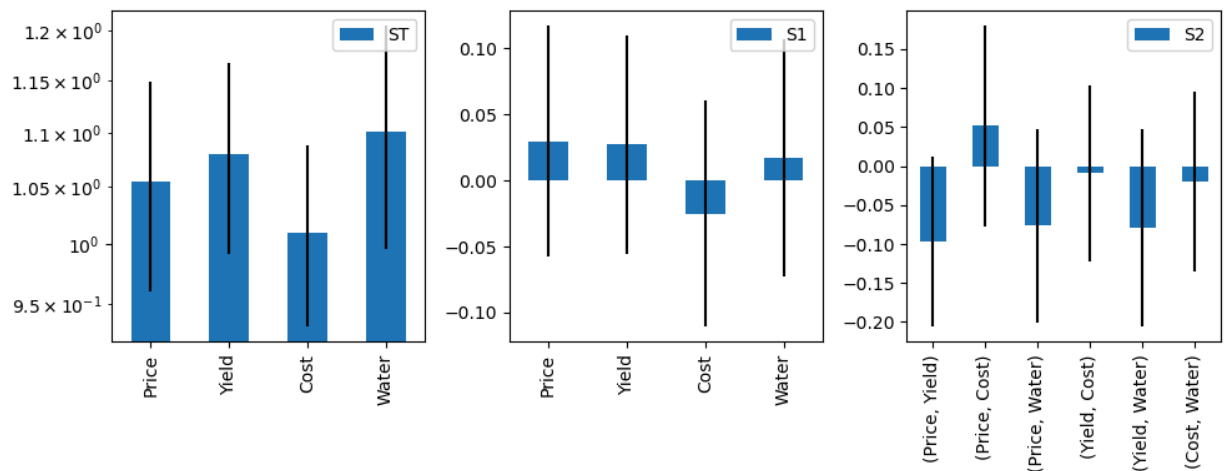


Figure 17: example of first, second, and total order of the inputs and their influence on the economic outputs of the models of MARINSURE

○ 4.4. Technical and Implementation Requirements for the integration in the MARCLAIMED IDST

The technical and implementation requirements for the integration in the MARCLAIMED IDST are described in deep detail in the following deliverables from WP2 “MARCLAIMED IDST: Integrated Decision Support Tool for MAR recommendations and early warning alert system” development:

- D2.1 Requirements and global architecture v1 (July 2024 - submitted to the Portal).
- D2.3 Data models (January 2025 - submitted to the Portal).
- D2.4 Open interfaces (January 2025 - submitted to the Portal).
- D2.5 MARCLAIMED Integrated Decision Support Tool v1 (July 2025 - to be submitted to the Portal).

5. Application and Demo Sites

○ 5.1. Preliminary Results Obtained

○ 5.1.1 MARINSURE

The preliminary results from MARINSURE, a tool designed to evaluate the economic insurance value of MAR and AWR, indicate that water security plays a crucial economic role in the three demo sites under study. Events such as drought, increasingly frequent and severe in these regions due to ongoing climate change, can lead to substantial economic damage, especially through direct impacts on surface water resources. This damage manifests itself predominantly in the agricultural sector, affecting crop yields, farmers' incomes, and regional employment rates. Consequently, these findings strongly support the strategic preservation and sustainable management of groundwater resources to enhance the resilience of water systems in the selected case studies.

Moving forward, the final results of MARINSURE will be further refined and validated by integrating it with complementary analytical tools such as PREDMAR and OASIS FLOW. These tools specialize in providing detailed scarcity indicators, essential for precisely estimating the insurance value of AWR. This integration will enable us to better understand and quantify how effectively AWR can function as a protective buffer against drought-related economic impacts. Such insights are critical for reducing economic vulnerabilities and promoting proactive adaptation measures in water resource management.

To provide comprehensive insights, we have already conducted a series of simulations contrasting the Business-As-Usual (BAU) scenario with an optimal management scenario. The optimal scenario considers various critical factors, including the availability and suitability of AWR for aquifer recharge, the current and projected severity of drought conditions, and the overall impact of MAR techniques on enhancing water availability. As integration with complementary tools progresses, these simulations will be expanded and refined to produce more precise and robust predictions of the insurance value provided by MAR and AWR under diverse future conditions. These predictive outcomes will be instrumental in guiding strategic decisions, ensuring long-term water sustainability, and securing regional economic stability.

It's particularly important to underline that these scenario-based evaluations focus explicitly on economic resilience rather than promoting direct economic growth. Economic resilience is prioritized because it ensures sustained productivity, stability, and security by systematically mitigating risks associated with increasing water scarcity and climate-induced disturbances. The emphasis is therefore on securing stable water supplies to protect and maintain essential economic activities and livelihoods, rather than pursuing short-term economic expansion at the potential expense of water sustainability.

Consequently, the continued application and refinement of MARINSURE will be a major component of WP4. The next essential steps in this process involve the systematic coupling of MARINSURE outputs with predictive outcomes from PREDMAR. This integration will allow for the precise annual recalculation of the added economic value provided by AWR, particularly within the agricultural sector, under varying scenarios of drought intensity and climate change trajectories.

Moreover, establishing robust feedback loops with the RECOVER tool is also planned. MARINSURE will generate critical economic outputs, such as detailed assessments of net income for end-users (primarily farmers), employment, and gross added value within the agricultural sector. RECOVER, in turn, will leverage these outputs to adjust water tariffs strategically and responsively. By aligning economic outputs with adaptive water pricing mechanisms, the combined efforts of MARINSURE and RECOVER will significantly enhance economic resilience, support the sustainability of water resource management, and facilitate adaptive governance practices in the face of climate variability and uncertainty.

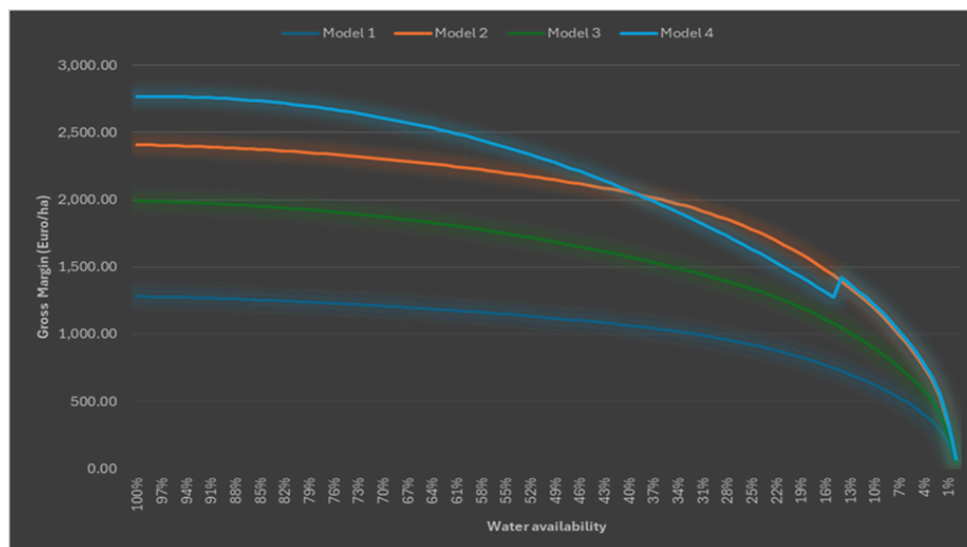


Figure 18: Pre-results: Impact of water scarcity on the gross margin (Euro/ha) - DS1.

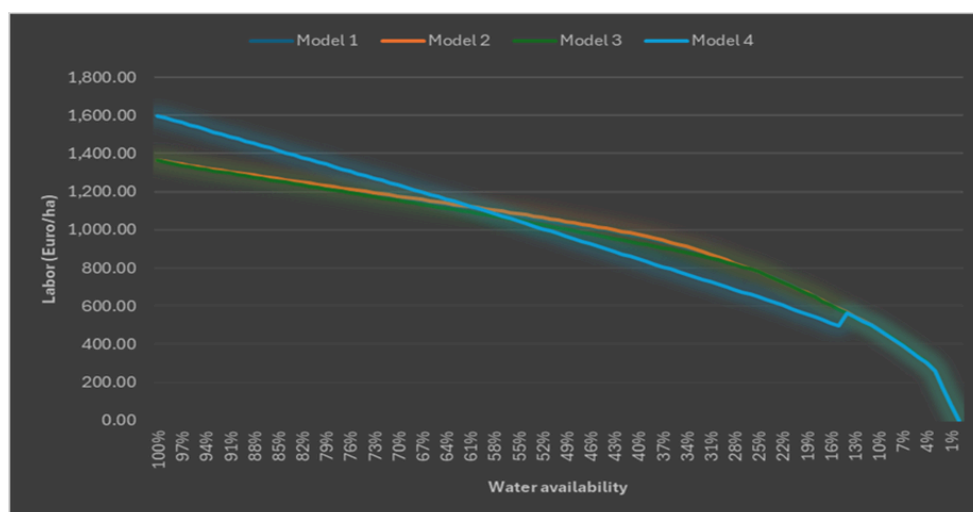


Figure 19: Pre-results: Impact of water scarcity on Labor (Euro/ha) - DS1.

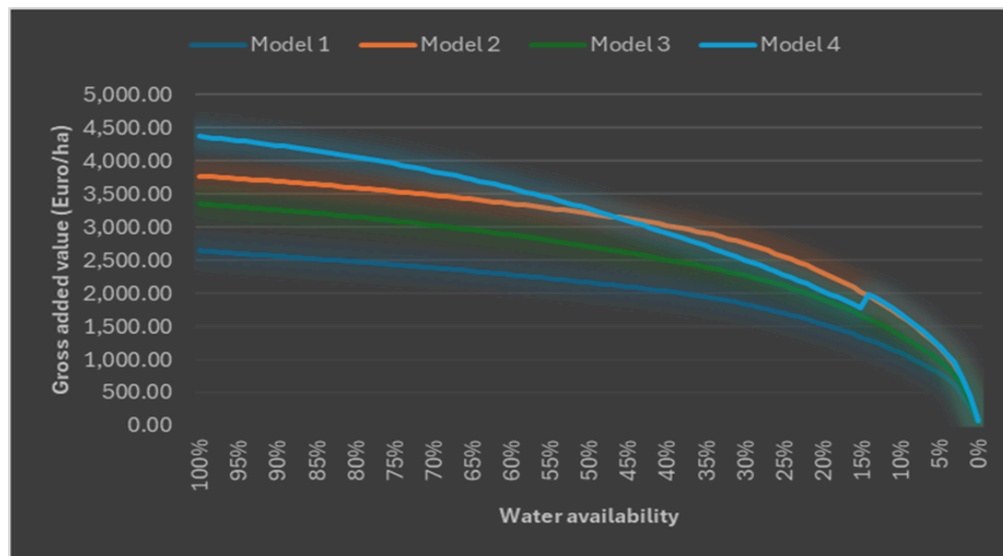


Figure 20: Pre-results: Impact of water scarcity on Gross value added (Euro/ha) - DS1.

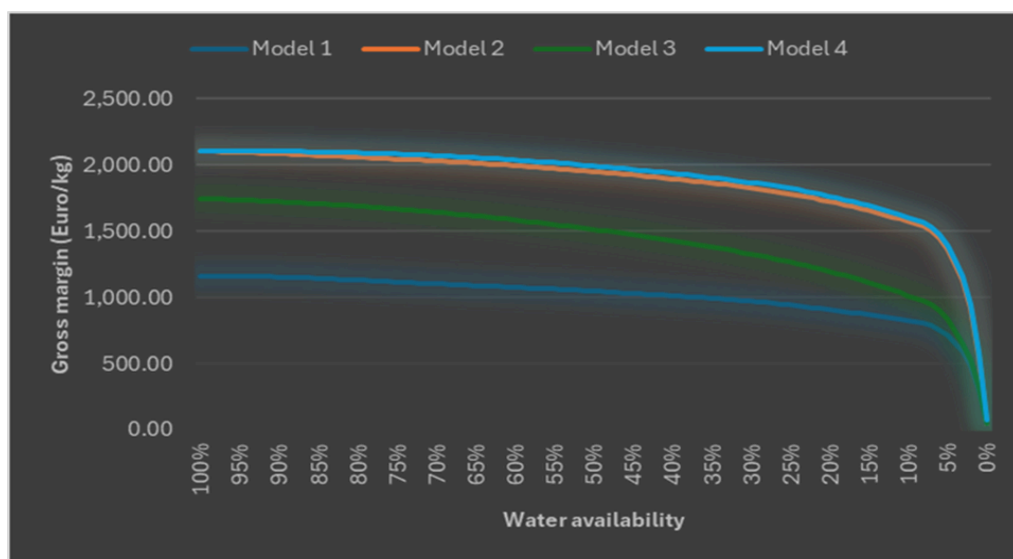


Figure 21: Pre-results: Impact of water scarcity on the gross margin (Euro/ha) - DS2.

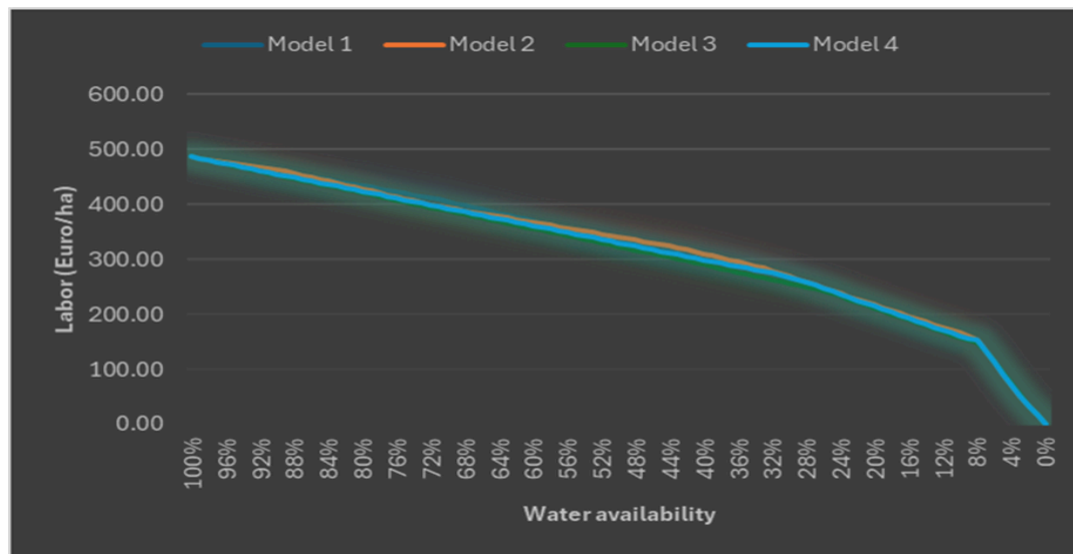


Figure 22: Pre-results: Impact of water scarcity on Labor (Euro/ha) - DS2.

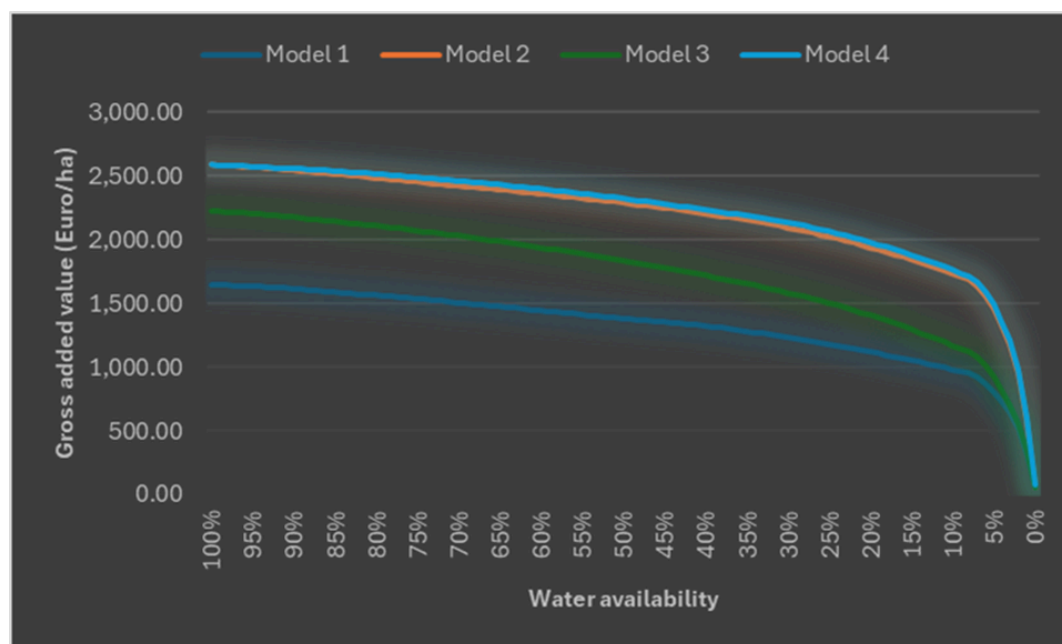


Figure 23: Pre-results: Impact of water scarcity on Gross value added (Euro/ha) - DS2.

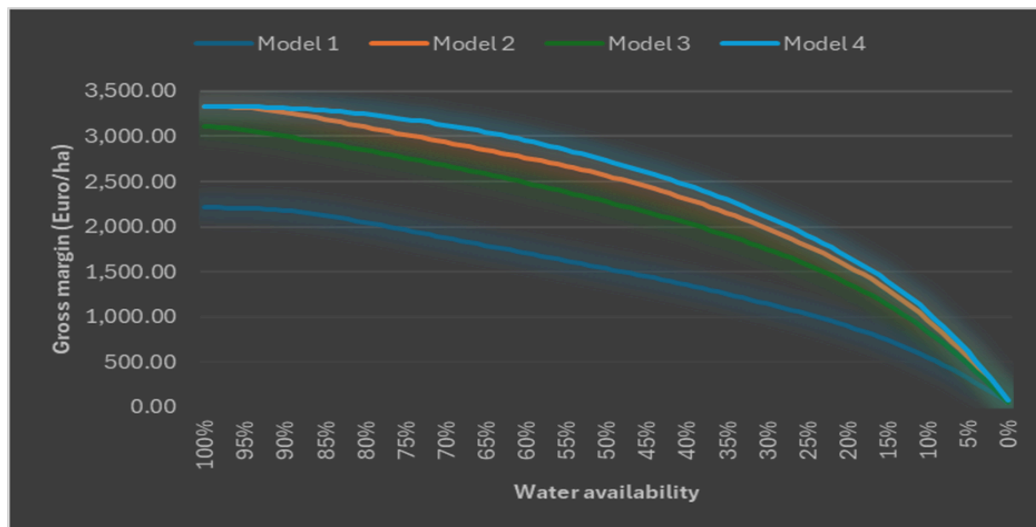


Figure 24: Pre-results: Impact of water scarcity on the gross margin (Euro/ha) - DS3.

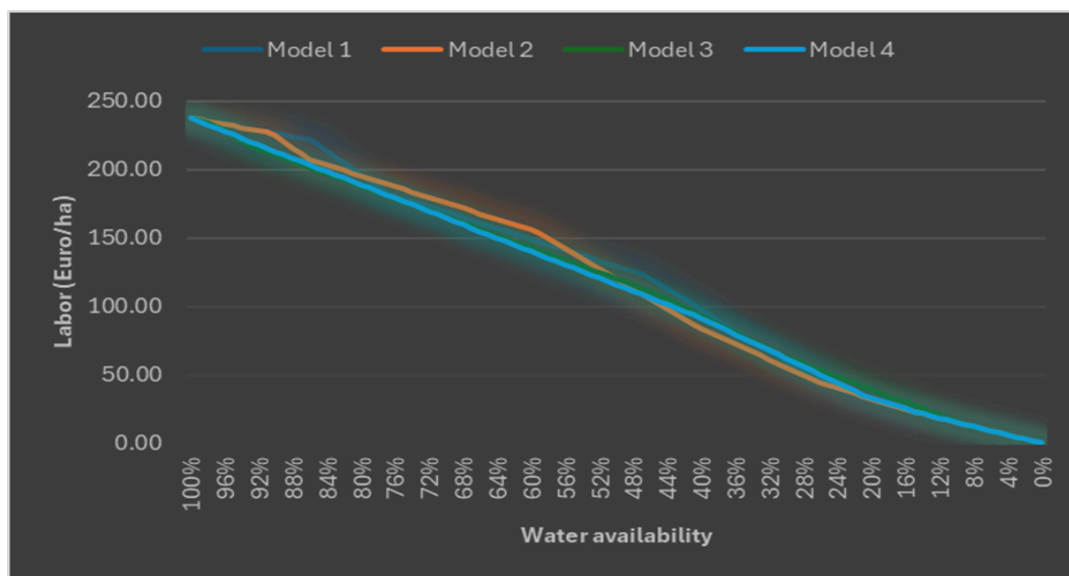


Figure 25: Pre-results: Impact of water scarcity on labor (Euro/ha) - DS3.

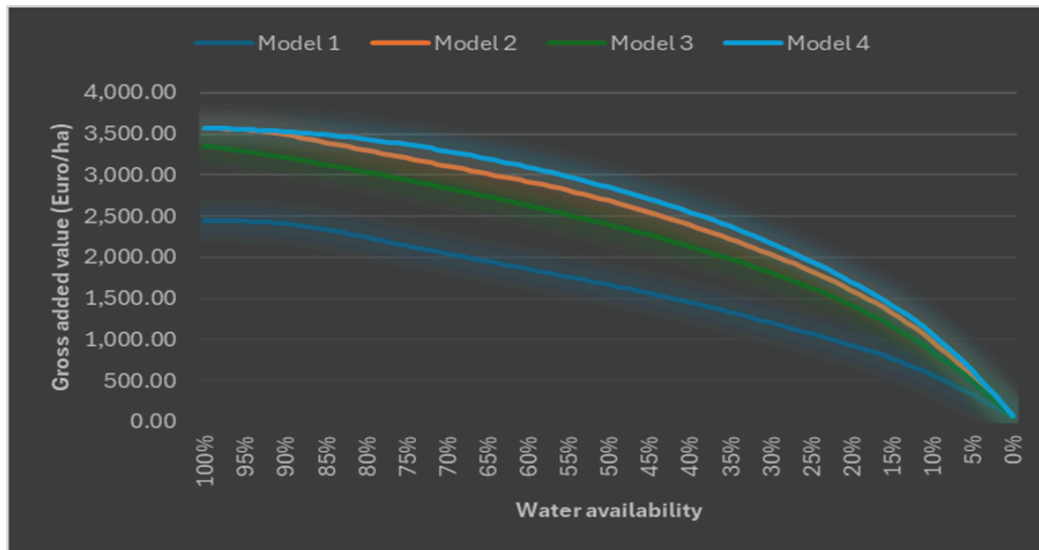


Figure 26: Pre-results: Impact of water scarcity on Gross value added (Euro/ha) - DS3.

○ 5.1.2 RECOVER

Understanding the economic viability of the MAR system with AWR is important for its successful implementation.

This segment analyzes the financial aspects of the system, which focuses on cost recovery through an estimated tariff. By evaluating operational expenditure, production costs and recharge efficiency, we install a framework to determine the minimum tariff required to maintain the system. Given the complexity of the DS 1 (Llobregat, Spain), this model serves as a primary case study for calibration. The insight obtained from this site provides a reference to the model adopting at less complex locations, results for each demosite are shown in 5.1.2 section. The model recovers major data points, enabling a structured evaluation of cost distribution and recovery strategies, using a spreadsheet-based platform.

The results presented here provide the first recurrence of tariff calculation, which highlights financial requirements for long-term stability. These findings serve as a basis for further refinement and adjustment to increase economic viability at various performance sites. Production cost and MAR system data are confidential; therefore, only derived results will be presented.

Estimating cost in this area is naturally complicated due to variation in technical configuration and various potential applications of the recharge process. Many major variables should be taken into consideration when analyzing the cost. The lifetime of

the infrastructure is usually between 20 to 50 years, while recharge efficiency is highly dependent on geological conditions, usually ranging between 70% and 95%.

Additionally, public subsidy, when applicable, plays an important role in determining the overall costs. In addition, several adjustment factors influence cost estimates, including the difference between water quality and project scale, as economies can significantly impact financial viability.

The cost baseline detailed in the subsequent table outlines the data requirements for the initial iteration of the RECOVER cost recovery model. Due to confidentiality concerns regarding the public disclosure of production costs for reclaimed water and the MAR system, sensitive original data has been protected. Therefore, the aggregated values presented are hypothetical and based on thorough information analysis.

Table 4 presents the cost baseline structure, detailing specific items and indicating their inclusion in the MAR system with AWR. A value of 1 signifies an item is included, while 0 indicates its exclusion.

Table 4: Cost Breakdown of CAPEX, OPEX, and Cost Components for MAR and AWR based on DS1 items needed.

COST BASELINE	Items	Allocated cost to activity (MAR/AWR)
AWR Production		
CAPEX		
Infrastructure		
Sampling		1
OPEX		
Basic tertiary costs		
Environmental use Q level	PAX	1
	Polyelectrolyte	1
	Sand	1
	Cl ₃ Fe	1
	Basic Energy	1
Irrigation Q level	Hypochlorite	1
Pre-potable use Q level	Nutrient removal energy	1

Advanced tertiary cost		1
	Energy	0
UF	Citric acid	0
	Sodium Hydroxide	0
	Hydrochloric Acid	0
	Sulfuric Acid	0
	Hypochlorite	0
OI	Sodium Bisulfite	0
	Antiscalant	0
MAR		
CAPEX		
Basin construction	Life expectancy (15 years)	1
OPEX		
Pumping cost	Energy cost (B SJD)	1
	Energy cost (B Molins)	1

After meticulous evaluation of the projected costs associated with the production of reclaimed water and the implementation of a controlled aquifer recharge system, estimated values have been assigned in order to protect original confidential data. These values will be instrumental in estimating an average cost recovery, which will be achieved by implementing a cost recovery tariff. This tariff will ensure that the financial outlay for the production and recharge processes is recuperated, contributing to the sustainability and long-term economic viability of the project.

Table 5: Estimated costs of production, reclaimed water produced and recharged per year in each location.

Annual flow	Units	Volume
Maximum cost production	€/year	4,000,000
Minimum cost production	€/year	700,000
Maximum Reclaimed Water Produced (Basic tertiary treatment)	m ³ /year	55,000,000.00
Minimum Reclaimed Water Produced (Basic tertiary treatment)	m ³ /year	10,000,000
Recharged volume DS1 (2024)	m ³ /year	1,500,000
Recharged volume DS2 (2024)	m ³ /year	60,000
Recharged volume DS3 (2024)	m ³ /year	25,000

Based on the collected and available information, the total cost of production is taken from OPEX and CAPEX of AWR production for all reclaimed water, as well as OPEX and CAPEX of MAR. Using this information, we formulated the equation expressed below. Since this equation is based on the first year of the operation, it cannot yet be annualized. Therefore, the results obtained represent the average tariff to ensure cost recovery for MAR system with AWR. These results are an early repetition that should be reassessed and validated in the coming years of growth and implementation.

$$\text{Cost recovery tariff (€/m}^3\text{)} = \left(\frac{\text{Annualized Capital Cost} + \text{Annual Operational Cost}}{\text{Reclaimed water produced}} \right)$$

Table 6: Estimated tariffs for cost recovery derived from estimated costs.

Tariffs for cost recovery	Average tariff
Maximum cost production	$\left(\frac{4,000,000}{55,000,000} \right) = 0.07 \text{ €/m}^3$
Minimum cost production	$\left(\frac{700,000}{10,000,000} \right) = 0.07 \text{ €/m}^3$

The resulting average tariff is 0.07 €/m³, which should be applied in order to recover costs related to the MAR system with AWR. The average cost recovered was calculated using three estimated values of recharged reclaimed water in square meters across the three demo sites.

$$\text{Cost recovery} = \text{Average tariff} * \text{Recharged volume}$$

Table 7: Estimated cost recovery derived from estimated costs for each demo site.

Demosite	Recharged volume (m ³)	Average tariff
DS1 (El Llobregat, Spain)	1,500,000	0.07 €/m ³ * 1,500,000 m ³ = 105,000 €
DS2 (Comporta, Portugal)	60,000	0.07 €/m ³ * 60,000 m ³ = 4,200 €
DS3 (Texel, Netherlands)	25,000	0.07 €/m ³ * 25,000 m ³ = 1,750 €

To accurately assess the economic viability of MAR projects with reclaimed water, it's crucial to use comprehensive economic evaluation tools. These tools should account for factors such as water volumes, capital and operating expenditures, avoided costs, and broader social and environmental benefits that should be included. Depending on the future use of treated water, a different tariff will be implemented.

○ 5.2. Follow up, implementation and validation (WP3 and WP4)

○ 5.2.1. MARINSURE

The implementation and validation of MARINSURE results will take place within Work Packages 3 and 4 (WP3: Co-creation of AWR strategies: social actions and EU regulatory framework, and WP4: CoPs-based implementation and validation at the demo sites). The initial phase began in WP3, where the tools were introduced to the Communities of Practice, and preliminary feedback was collected through workshops. This interactive process will continue through the co-creation activities defined in Task 3.2: Co-creation of AWR strategies, ensuring stakeholders remain informed of MARCLAIMED results. Regular workshops will be instrumental in identifying potential

improvements, addressing concerns raised by the community, and ensuring effective stakeholder engagement throughout the implementation phase.

Validation, as previously outlined, will occur through various tasks within Work Package 4, necessitating close collaboration between tool developers and demonstration site leaders to ensure accurate and effective implementation of the tools. The approach and initial outcomes of MARINSURE were presented during MARCLAIMED's second general assembly, enabling feedback from demonstration site leaders to guide essential adjustments tailored to each specific case study. These adjustments will be managed within Task 4.2 (T4.2) and further refined throughout the integration process with other complementary tools.

○ 5.2.2. RECOVER

Two workshops have been conducted at the DS1 El Baix Llobregat site in Barcelona, Spain. The initial workshop took place on November 27th, 2024, at the Ciutat de l'Aigua, the AGBAR headquarters. This session primarily aimed to establish initial contact with the Community of Practice and to assess their knowledge and acceptance of AWR systems integrated with MAR. The second workshop, held on January 29th, 2025, served to evaluate critical project aspects. Specifically, it focused on further assessing the acceptance levels, identifying principal barriers to AWR systems with MAR, and establishing a collaborative co-creation environment to facilitate the development of each component of the MARCLAIMED Tool.

The second working session was specifically dedicated to developing and implementing tools and aimed to establish an effective co-creation and co-design space in conjunction with the El Baix Llobregat community of practice.

The proposed scenarios encompassed several critical aspects, including:

- Prioritized cost recovery models:
The prioritized scenario has been expanded to focus on dynamic pricing, which incorporates variable rates based on different factors and conditions. This innovative approach to tariff structuring allows for more flexible and responsive pricing mechanisms that can adapt to changing circumstances, usage patterns, and resource availability. The dynamic pricing model has been designed to optimize resource allocation while ensuring fair distribution of costs among

users, taking into account peak usage periods, seasonal variations, and other relevant parameters that influence service delivery and operational costs. This sophisticated pricing strategy aims to enhance both efficiency and sustainability in resource management while maintaining equitable access for all stakeholders involved.

- Identification of key users who should contribute to cost recovery.
All users must contribute to cost recovery, establishing a fundamental principle of shared financial responsibility within the system. This comprehensive approach ensures that every stakeholder, regardless of their scale of operations or type of usage, actively participates in maintaining the system's financial sustainability. The universal cost recovery model promotes equitable distribution of financial obligations while securing the long-term viability of the infrastructure and services.

This collaborative approach ensures that the tool's development aligns with both practical requirements and stakeholder expectations, while maintaining a focus on long-term sustainability and effective resource management.

6. Discussion (Implications for MAR with AWR)

MAR combined with AWR management strategies presents significant potential to address future water security challenges. However, successful implementation requires addressing several critical implications, particularly related to resource allocation, financial responsibility, cross-subsidization, and the development of a robust legal and financial framework.

A key concern is ensuring that the allocation of additional resources is genuinely directed towards enhancing resilience rather than merely supporting economic expansion. Tools like MARINSURE, which assess the socioeconomic performance and insurance value of MAR systems under uncertain future scenarios, can support informed decision-making. Stakeholders must clearly define resilience objectives within resource allocation frameworks, emphasizing measurable resilience outcomes rather than economic outputs alone. Transparent monitoring and evaluation mechanisms, supported by MARINSURE, ensure accountability and confirm resources explicitly contribute to resilience-building rather than unintentionally enabling further exploitation of water resources for short-term economic gains.

Determining financial responsibility—answering the question "who pays?"—is a critical barrier to MAR with AWR implementation. Various stakeholders, including government agencies, water utilities, industries, agriculture, and citizens, benefit differently from MAR initiatives. Establishing equitable and clear financing mechanisms is crucial. MARINSURE can help quantify the economic benefits and resilience value delivered to different stakeholders, providing a basis for fair cost-sharing arrangements. Public-private partnerships (PPPs), government subsidies, and incentive programs might also play roles in distributing financial responsibilities fairly while encouraging broad stakeholder buy-in.

Cross-subsidization, where certain user groups subsidize water resilience measures for others, presents significant equity and acceptability challenges. If cross-subsidies are implemented, they must be justified transparently and ethically, clearly defining what is subsidized and why. The "beneficiary pays" principle highlights the importance of linking financial responsibility directly to the benefits received. MARINSURE can transparently assess and communicate the distribution of benefits, facilitating stakeholder acceptance. RECOVER, a tool designed for analyzing water tariff structures, can further ensure fairness in cross-subsidization by clearly identifying and justifying tariff allocations among different user groups. Transparent stakeholder engagement and clearly defined benefit assessments, informed by MARINSURE and RECOVER, can mitigate these concerns, ensuring cross-subsidies are used judiciously and equitably.

A robust legal and financial framework is fundamental for successful MAR with AWR management. Clear legal definitions of water rights, responsibilities, and regulatory oversight mechanisms ensure that MAR initiatives have strong institutional backing and legal clarity. Financial frameworks must outline investment mechanisms, cost-recovery models, risk-sharing agreements, and liability provisions. Harmonizing legal and financial systems across sectors and jurisdictions, supported by clear governance structures and tools like MARINSURE and RECOVER, facilitates streamlined implementation and encourages investment in MAR projects.

In addition to clarifying financial responsibilities and cost-sharing mechanisms, equitable implementation of MAR with AWR must also consider stakeholders' willingness to pay (WTP) and ability to pay (ATP). As emphasized by Young (2014), designing abstraction regimes that balance efficiency and fairness requires understanding both the economic benefits delivered by water access and the social equity of who bears the costs. High-value users, such as industrial or urban sectors,

often demonstrate greater WTP due to the economic returns they derive, while agricultural or marginalized communities may have lower ATP despite benefiting significantly from water security. A regime that fully assigns risks and allocates costs without accounting for ATP can lead to inequitable outcomes and reduce stakeholder participation. Incorporating differentiated pricing structures, informed by WTP and ATP assessments, can help target subsidies or cross-subsidization mechanisms more justly.

Tools like MARINSURE can further support this by modeling how benefits and costs distribute across user groups, while RECOVER can ensure tariff structures remain socially sustainable. Embedding these socioeconomic insights within financing frameworks strengthens the legitimacy and long-term viability of MAR initiatives.

In conclusion, addressing these implications proactively through transparent stakeholder collaboration, clear allocation principles, equitable financing arrangements, and robust legal-financial frameworks—supported by tools such as MARINSURE and RECOVER—is essential. This structured approach ensures MAR with AWR effectively contributes to long-term water resilience, sustainability, and equitable socio-economic benefits.

7. Conclusions and Next steps

This deliverable explores the economic and financial aspects of MAR combined with AWR within the MARCLAIMED project. It discusses MAR's essential role in strengthening economic resilience in areas that are potentially affected by drought and water scarcity where economic sectors such as agriculture are highly dependent on secure water resources. At the core of this deliverable are two analytical tools, MARINSURE and RECOVER, designed to address distinct but interrelated components of economic and financial assessment of MAR and AWR.

MARINSURE is designed to quantify the economic value -gross margin, employment, gross value added- of water security through an economic modeling approach. It calculates the "insurance value" associated with enhanced groundwater storage, demonstrating its ability to mitigate economic disruptions resulting from drought, water scarcity, and climate change. By incorporating mathematical programming models (MPMs) with Global Sensitivity Analysis (GSA), MARINSURE offers robust scenario-based evaluations. These analyses help CoPs and demo sites leaders to understand clearly how varying degrees of climatic and socioeconomic conditions -such as water availability, pricing shock or cost increasing- might impact agricultural productivity, regional employment, and economic stability. Consequently, MARINSURE

serves as a decision-support tool, enabling informed policy formulation under uncertain climatic and economic futures.

In parallel, RECOVER addresses the financial sustainability of MAR, focusing on the equitable cost-recovery. It advances beyond traditional cost recovery methods by proposing innovative tariff structures, including dynamic tariffs. These dynamic tariffs effectively allocate costs according to consumption patterns and the ability to pay among various stakeholder groups—domestic, industrial, municipal, and agricultural users. By dynamically adjusting tariffs mechanisms based on real-time water availability and quality, RECOVER aims to ensure economic viability. This adaptive structure encourages water conservation while ensuring that cost burdens are equitably distributed among all user groups, thereby promoting broader stakeholder acceptance.

Future steps outlined in the deliverable emphasize ongoing refinement and validation processes, deeply involving stakeholder collaboration. Continuous engagement through CoPs - In WP3 - is essential to integrate diverse stakeholder insights into scenario modeling and tariff-setting processes. Workshops systematically gather stakeholder inputs, experiences, and preferences, directly informing both economic scenarios and tariff strategies. This participatory approach ensures the relevance, practical applicability, and long-term effectiveness of MARCLAIMED's tools across various regional contexts.

Further, forthcoming project phases will integrate MARINSURE with complementary predictive tools like PREDMAR and OASIS FLOW. These integrations will enable more accurate, scenario-driven forecasts of water availability and associated economic implications. Moreover, MARINSURE will be integrated in MARCLAIMED IDST to offer a more friendly-use environment for users and present final results from the three demo sites.

The ongoing enhancement of RECOVER's tariff structures achieves an effective solution for assessing economic and financial impacts. Its approach enables a detailed analysis of economic losses and recovery costs, providing key insights for strategic decision-making. RECOVER follows the approach of MARINSURE, integrating into the MARCLAIMED IDST to facilitate an assessment of cost recovery in a system that includes AWR.

Through its structure, RECOVER facilitates the identification of financial risks and the optimization of resources in adverse situations. Its flexibility and adaptability across various sectors make it a valuable tool for economic planning and crisis management.

Developing RECOVER by incorporating new variables and methodologies is a key step to enhance its accuracy and applicability in increasingly complex financial contexts.

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ANNEX 1: Update of the Urban Water Cycle Services Tariff Guide

COST TYPE	TARIFF ITEM	DESCRIPTION	ACCOUNT CODES
Fixed costs	Personnel	Includes salaries, social charges, compensation, and social expenses of staff. Also includes assigned personnel costs from companies within the same group according to specific regulations	640, 641, 642, 643, 649, 607
	Conservation and Maintenance	Covers operational costs of infrastructure maintenance, including materials consumption, tools and subcontracting. Also includes repair, conservation and other related expenses	601, 603, 605, 607, 611, 622, 678, 693
	Analytical control	Includes water analysis costs for quality control according to current regulations	607
	Reading, Billing and Collection	Includes meter reading costs, billing, collection management	607, 623, 626
	Discharge control	Includes costs related to the Discharge control Plan	607
	Other professional services	Administrative expenses, fuel, supplies, insurance, taxes and other professional services	604, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 631, 651, 652, 668, 669, 670, 678
Variable costs	Water purchase	Water supply procurement, including desalination	600
	Water Treatment	considers the cost of reagents for water treatment	602, 607, 612
	Energy	Energy purchase for production process use	604
Amortizations and other expenses derived from fixed assets	Fixed Assets Amortization	Annual depreciation of intangible and material assets according to useful life	680, 681, 682
	Other expenses derived from fixed assets	Financing costs of fixed assets (when applicable), and losses derived from deterioration or impossibility of use	662, 669, 670, 671, 672, 678, 690, 691, 692
Fees	Concession Fee	Amount paid for the right to use assets affected by the service	621
Insolvencies	Provision for insolvencies	Amount corresponding to corrective provision, recorded at year-end closing, for reversible depreciation in clients and debtors	650, 694, 695, 697

MARCLAIMED will support decision makers to integrate Managed Aquifer Recharge (MAR) with Alternative Water Resources (AWR) in River Basin and Drought Management Plans supporting the adaptation and resilience of structural supply systems in the context of climate change. The main outcome will be the MARCLAIMED Integrated Decision Support Tool (IDST) that will provide solutions to tackle existing and emerging threats and support decision making and adaptation policies.



MARCLAIMED



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