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Is It Possible to Improve Energy Efficiency in Water Purification Plants? The Case of Drinking Water in La Presa DWPP in Valencia, (Spain)

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Featured Application

Energy in water purification plants plays a critical role for the sustainability of the entire water supply network, as multiple factors affect flow quality and pressure. This paper analyzes the possibilities of installing turbines to optimize the operation of one of these plants in the city of Valencia (Spain), integrating them with reservoirs and implementing hydraulic machinery for energy recovery. This analysis could be extrapolated to many other cities' water purification plants with significant benefits for the sustainability of the whole system, considering their local variations of consumption and pressure levels.

Abstract

This research analyzes the energy balance of the purification water pumping system at the La Presa drinking water purification plant (DWPP) in Manises (Valencia) and evaluates alternatives to improve its energy efficiency. These alternatives include the construction of a storage tank at an elevation of 75 m between La Presa Plant and Valencia city, allowing the lower area of the city to be supplied independently from the upper zone. This configuration will adapt to the pressure levels of the whole city and control the residence time in the tanks, thereby improving both energy and quality parameters in the whole network. Hydraulic simulations were conducted in EPANET using models representing the system from the La Presa gallery to the delivery points under various demand scenarios and operational criteria. Three alternatives for feeding the new tank are studied: using additional pumps; using turbines; and a combination of both. From the data obtained in the simulations (flows and heads), the net energy consumed was calculated, and the average water residence time in the tanks was simulated as an indicator of water quality, using certain theoretical criteria. The results indicate that all alternatives represent a significant energy saving and maintain water quality at any moment. The best solution is proposed, which involves combining pumps and turbines and minimizing residence time in the tanks. In this case, a saving of 42.26% of energy is achieved when compared with the actual situation, with an average residence time in the tanks of less than 50 h. The combination of both restrictions of quality and energy savings represents a novelty in the management of future decisions for purification plants supplying real networks.

Keywords: sustainability; digital energy systems; supply networks; hybrid systems

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Academic Editors: Michal Zielina, Filippo Mazzoni and Valentina Marsili

Received: 10 September 2025
Revised: 18 October 2025
Accepted: 21 October 2025
Published: 22 October 2025

Citation: Fabián, H.d.L.; Llorens, P.A.; López-Jiménez, P.A.; Pérez-Sánchez, M. Is It Possible to Improve Energy Efficiency in Water Purification Plants? The Case of Drinking Water in La Presa DWPP in Valencia, (Spain). *Appl. Sci.* **2025**, *15*, 11340. https://doi.org/10.3390/app152111340

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1. Introduction

Energy optimization in water treatment plants is of paramount importance for the entire supply chain, as energy expenditure constitutes a significant portion of operational costs for both purification and pumping, and because these facilities represent a strategic component of the network. The benefits of performing analyses to optimize sustainability in such plants are numerous. First, energy consumption—often one of the largest operational items—is reduced, leading to lower operating costs. Second, environmental sustainability is enhanced, as reduced energy use lowers greenhouse gas emissions and the plant's carbon footprint. Third, reliability and safety are improved, since more efficient equipment experiences less wear and tear, reducing the risk of failures and ensuring continuity of the water supply. Fourth, water quality is maintained at a higher and more consistent level by implementing stable and optimized purification processes. Fifth, energy efficiency regulations and quality standards are more readily achieved, potentially providing incentives or favorable tariffs for efficient consumption. Finally, system resilience is improved, as operations can be adapted to variations in demand or energy availability, which is critical in such strategic systems as water treatment plants. This is a crucial part of the whole energy strategy in the water distribution system [1]. Several researchers have considered these improvements in drinking water treatment plants within the networks [2–6]. In the present research, the novelty of the work introduces the consideration of several possibilities for the use of hydraulic machinery to recover energy, combined with the installation of reservoirs to ensure the supply in any circumstance and taking into account the energy and the residence time in the supply network, and also improving the resilience of the whole system.

The use of hydraulic machinery by combining pumps and turbines (or even complex systems with both pumps and turbines) is a very promising strategy for improving efficiency in the whole water distribution system [7]. Furthermore, the implementation of systems for recovering energy combined with reservoir implementation is very important for reducing pressures in the whole system, and furthermore, reducing water losses [8–10].

This work presents a novel approach to the design of drinking water treatment plants while combining pumping stations, turbines for recovery, pressure control (to reduce leakage), and water quality considerations. The topic of analyzing the energy optimization in systems through the use of hydraulic pumps and reservoirs has been considered in the past, for instance, in the research from [11], where combinations of pumps and reservoirs were analyzed in a real network, although residence time was not considered. Moreover, in the research performed in [12], an in-depth review of management strategies for water distribution networks focused on energy efficiency and leakage control is presented. In addition, several studies have explored the relationship between energy efficiency and water quality in treatment plants [13], but not in purification plants. Furthermore, the authors also have extensive experience in energy recovery and pressure control in other sorts of water networks, such as irrigation systems [14], where the interaction between pressure control based on recovery energy with turbines and leakage volume has been investigated.

The research described in [15] presents an interesting study analyzing the optimization of water treatment plants sitting in existing systems. A multi-objective optimization approach is presented here that includes three objectives: minimizing cost, maximizing system-wide residual chlorine, and minimizing demand-weighted water age (an indicator of water quality); however, in this case, system-wide energy recovery through the potential use of turbines is not implemented.

Several energy management strategies in water distribution systems have been studied in the last few decades, as discussed in [16], which provides a comprehensive review of technologies developed for energy recovery in such networks. The study considers different turbine types, design parameters, and performance characteristics, such as generation

efficiency and pressure regulation accuracy. Furthermore, a methodology for determining the optimum locations of energy recovery and leakage reduction was presented in [17]. In this case, the location of the turbines is defined by the position of the reservoir and the availability of space in the utility's management plants, as only the purification plants are considered part of the whole water distribution system.

The combination of all these factors—pumping stations with different reservoir locations, the implementation of turbines, pressure control, and water quality considerations through residence time—constitutes a novel approach to the management of real water distribution systems within the reviewed literature.

The present study aims to analyze different alternatives to improve the energy efficiency of drinking water pumping at the La Presa Drinking Water Purification Plant (DWPP), located in the municipality of Manises (Valencia, Spain). The drinking water produced by this DWPP supplies part of the population of Valencia and its metropolitan area, while the remaining population is supplied by another plant, the El Realón DWPP. The Valencia water distribution network is highly optimized, as described by several authors [18,19]; however, the specific influence of purification plant optimization on system-wide energy recovery has not been extensively studied. This represents a significant contribution of the present research to the optimization of the entire distribution system and highlights the importance of purification and treatment plants within the overall network.

The water distribution system of Valencia is complex, and several models have been developed to represent the performance of the entire system, including the two existing DWPPs. Although La Presa has a greater capacity for treatment and drinking water production, El Realón supplies a larger proportion of the population due to its higher energy efficiency in treatment and pumping processes. This imbalance provides an opportunity to reconsider and improve the energy efficiency of La Presa.

The primary objective of the present research is to determine the optimal operation mode, select the hydraulic machinery for system management, estimate potential energy savings, and ensure appropriate water quality conditions in the tanks while maintaining network-wide conditions across the city. Each analyzed alternative considers the use of a new drinking water storage tank to independently supply the lower zone of Valencia. This allows for hydraulic separation from the upper stratum, aiming to reduce the piezometric height and, consequently, the plant's energy consumption. The proposed alternatives, which involve the use of turbines, pumps, or a combination of both types of hydraulic machines to feed this tank, are compared with each other and with the current configuration to identify the most viable solution in terms of energy efficiency and water quality, while considering hydraulic and operational aspects and maintaining pressure levels that ensure supply and minimize water losses.

The combination of these constraints, while reducing pressure levels across the entire supply system, represents a novel approach for the future design of purification plants and reservoirs within the network. The analysis of the alternatives was conducted using the hydraulic simulation software EPANET V2.2, complemented by other computational tools, taking into account detailed hydraulic knowledge of the city's supply system and the available system data.

2. Materials and Methods

The water supply system of Valencia and its metropolitan area serves approximately 1.6 million inhabitants and is based on two water treatment plants supported by a series of regulating reservoirs. The system sources water from two major surface water bodies, the Turia and Júcar rivers, which are treated at the two aforementioned plants. Coupled with a highly reliable meshed distribution network and advanced digital management, the system

represents a benchmark in Spain and Europe. The high degree of digitalization is particularly critical for the effective management and optimization of the water supply network.

Since 2009, Valencia has undertaken significant efforts to develop a digital twin of its water distribution network, based on available data and continuous calibration and validation of the hydraulic model [20,21]. The implementation of digital twins in water networks requires substantial digitalization efforts but offers significant advantages for sustainability, particularly by supporting model calibration for future decision-making, as exemplified in the present study [22]. Currently, a digital twin exists for the entire network, virtually replicating the water supply system of Valencia and its metropolitan area. This digital twin incorporates the network of pipes, tanks, pumps, and valves and is connected to real-time sensors, monitoring up to 600 hydraulic variables—including pressure and flow at up to 10,000 nodes [20]. The system provides a comprehensive virtual representation of the network and is capable of predicting behaviors over a 24 h horizon, thereby supporting decision-making during emergencies or at locations lacking telemetry through the use of virtual sensors. This digital twin is central to the present research, as, following calibration, it enables decisions regarding the proposed scenarios with a high degree of accuracy and confidence.

The objective of this research is to improve the energy efficiency of the La Presa purification plant in coordination with the El Realón plant through the evaluation of different scenarios. The proposed strategy incorporates a storage tank at an elevation of 75 m, located between La Presa and the city of Valencia, which enables the independent supply of the lower zone of the city from the upper zone. This configuration reduces pressure levels in sectors where high pressures are not required, thereby enhancing overall energy efficiency. To evaluate this proposal, three alternatives are considered to supply the tank:

1. Using additional pumps.
2. Using turbines.
3. Using a combination of both (Mixed).

Taking this into account, multiple hydraulic simulations were conducted in EPANET for models representing both the current system configuration and the proposed future scenarios. The simulations aimed to assess the energy performance of the network under specific operational conditions [23], considering variations in demand depending on which of the two treatment plants (La Presa or El Realón) is prioritized. The results of each simulation were compared with one another and with the current system configuration. Figure 1 illustrates the methodology implemented in this study, which can be extrapolated to other water supply systems.

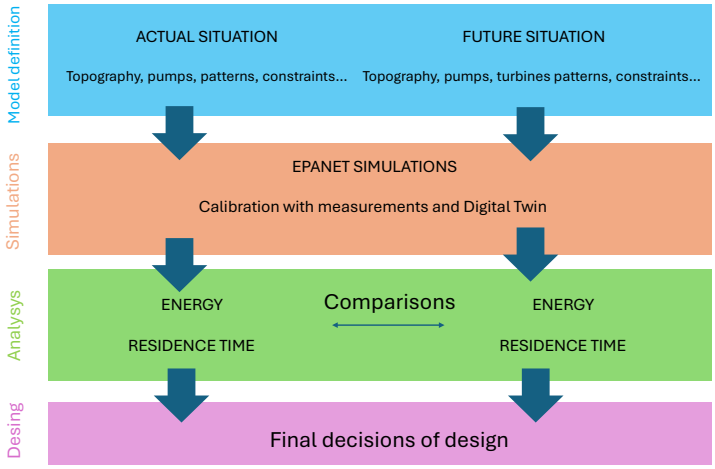


Figure 1. Methodology implemented for determining the new management in La Presa DWTP.

Figure 2 describes the actual situation and the proposed one by considering hydraulic machinery implementation. These are the diagrams of the models for the current situation and the proposed future situation of drinking water pumping at La Presa:

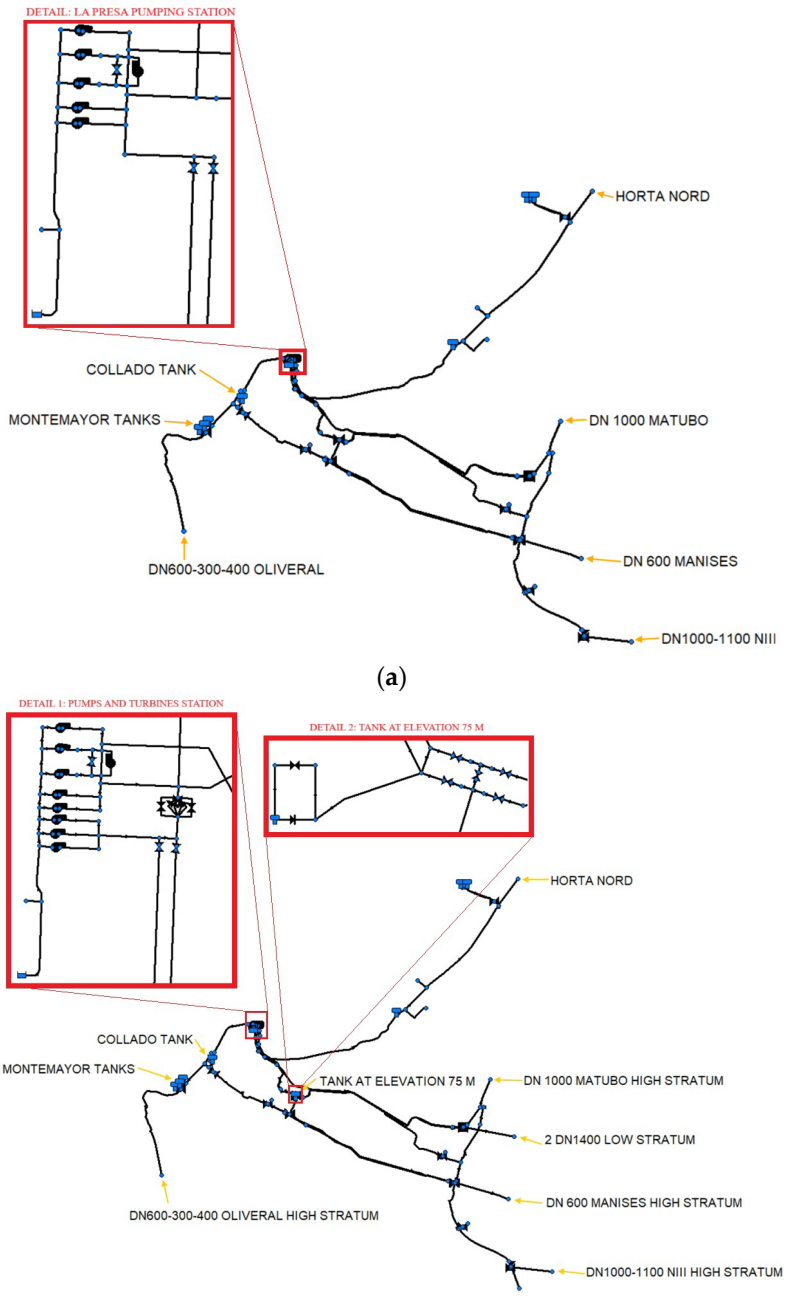


Figure 2. Hydraulic model topology in EPANET of the future situation of drinking water pumping at La Presa. (**a**) Current situation; (**b**) future situation.

The EPANET models representing the initial and future situations of drinking water pumping at La Presa include the three Montemayor tanks (DM1, DM2, and DM3) and the Collado tank (DC). The future situation models additionally include the regulating tank at an elevation of 75 m (D75), as shown in Figure 2. Each model contains valves for flow regulation. All models include the pumps that supply water to Valencia and Horta Nord (BVCIA1, BVCIA2, BVCIA3, BVCIA_HN, BHN1, and BHN2). The future situation models have pumps that feed the tank at 75 m elevation (B75_1, B75_2, and B75_3).

The characteristic curve of pumps used in the EPANET models is shown in Figure 3:

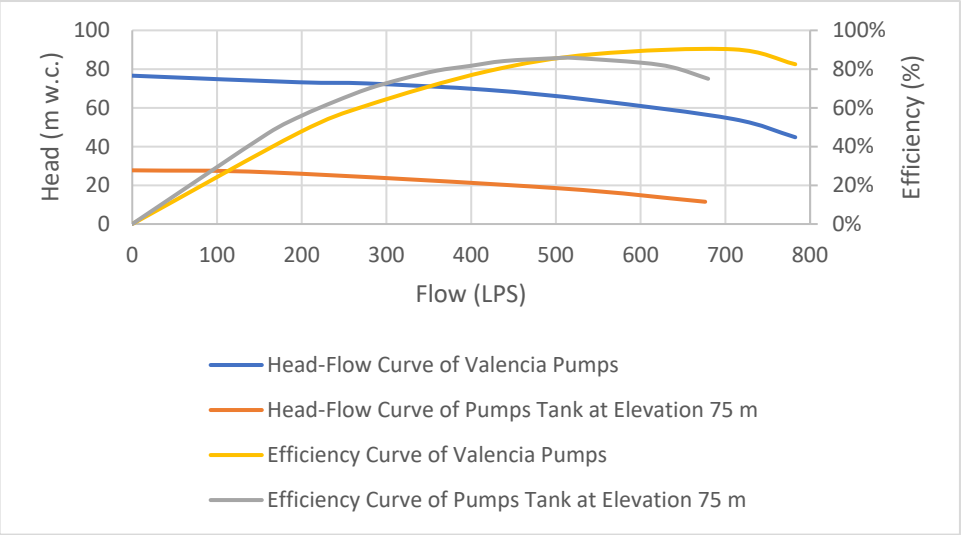


Figure 3. Head–flow curve of pumps.

The EPANET model used for the present research is a scheme of the main modeled facilities. It represents a total pipe length of 40,139.04 m, with diameters ranging from 150 mm to 1600 mm, as detailed in Table 1.

Table 1. Characteristics of the pipes represented in EPANET model.

Diameter (mm)	Length (m)
150	9.254
200	287.924
250	7.054
300	179.989
500	472.336
600	6254.738
800	121.073
850	1359.335
900	412.204
1000	11,516.074
1100	5763.27
1200	1139.751
1400	12,441.656
1600	174.382
Total	40,139.04

The main materials present in the pipes are concrete with (and without) sheet metal casing (bigger diameters), steel, and cast-iron pipe (among others in small proportions). La Presa can supply up to 60% of the population in the Valencia metropolitan area, although it typically supplies around 40% due to the higher efficiency of the El Realón plant. The total population served by the Valencia metropolitan area is approximately 1,700,000 inhabitants.

It is necessary to know the efficiency of the pumps in order to determine the power and energy consumed by them. These parameters are essential for the present research. The efficiency–flow curve of pumps was also described in Figure 3. Regarding these turbines, the future situation models consider 6 turbines (Turbine1_1, Turbine1_2, Turbine2_1, Turbine2_2, Turbine3_1, and Turbine3_2), modeled as general-purpose valves in parallel, in order to be managed in EPANET.

This research proposes locating a reservoir at an elevation of 75 m to supply water to the sectors located in the lowest supply pressure area of the city. This is a good pressure

control action, ensuring that the entire flow is not pumped at maximum pressure. The utility company has indicated that the elevation of 75 m is appropriate for providing the minimum supply pressure conditions at the most unfavorable nodes of the lower-pressure area in the network, ensuring that all consumption points in the city have a minimum pressure greater than 25 m. This was determined by the utility using the digital twin model of the entire city, as part of a separate research study.

To pump water into this reservoir, three new pumps, each with a capacity of 500 L per second, were proposed, taking into consideration possible commercial machines with known curves. These machines are designed to boost the flow required by this part of the town (low-pressure area), while also providing the necessary pressure to overcome the elevation difference between the La Presa pumping station (18.5 m) with this flow rate and the reservoir at an elevation of 75 m with this required flow rate.

The six proposed turbines, each with a capacity of 250 L per second, were selected based on the same maximum flow rate and the elevation difference between the Collado and Montemayor reservoirs (35 m). Commercially available machines were chosen, and the efficiency curves, along with the head–flow curves for both pumps and turbines, were provided by the manufacturer. Key characteristic points from these curves were then used as input data in EPANET. The characteristic and efficiency curves of these turbines in the analyzed future situation models are shown in Figure 4:

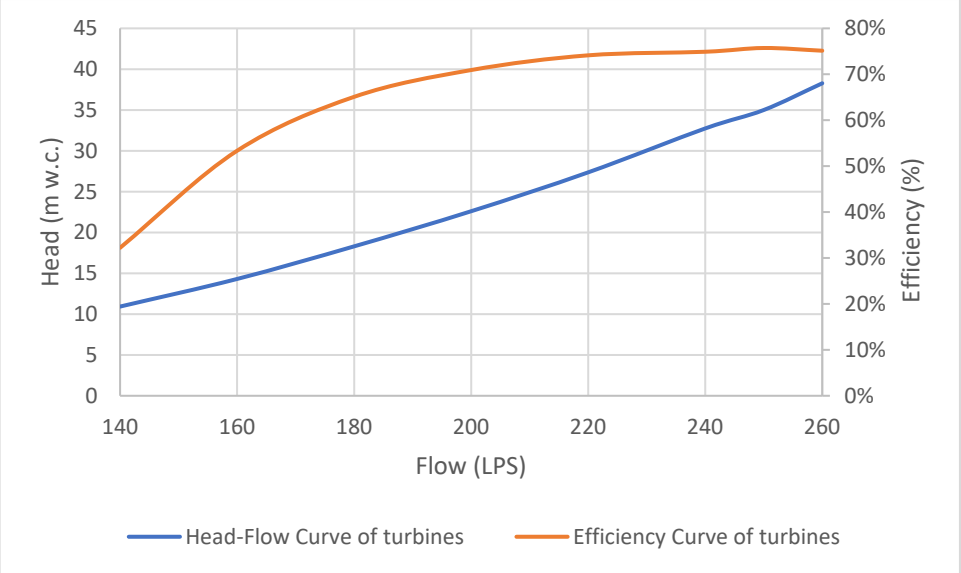


Figure 4. Efficiency–flow curve of turbines in the future situation models of drinking water pumping at La Presa.

The topography of the considered future network is proposed in Figures 5 and 6.

Regarding the tanks, their geometric characteristics are shown in Table 2. All reservoirs actually exist, except Deposito75, which will be constructed in the future.

Table 2. Characteristics of the reservoirs considered in the network.

Tank	Elevation (m)	Maximum Level (m)	Diameter (m)	Area (m^2)	Total Volume (m^3)
DM1	111	4.15	67	3537.77	14,681.73
DM2	111	4.15	109.6	9433.98	39,151.03
DM3	111	4.15	67.12	3537.77	14,681.73
DC	111	4.15	77.5	4717.05	19,575.78
Deposito75	75	5.00	112.84	10,000	50,000

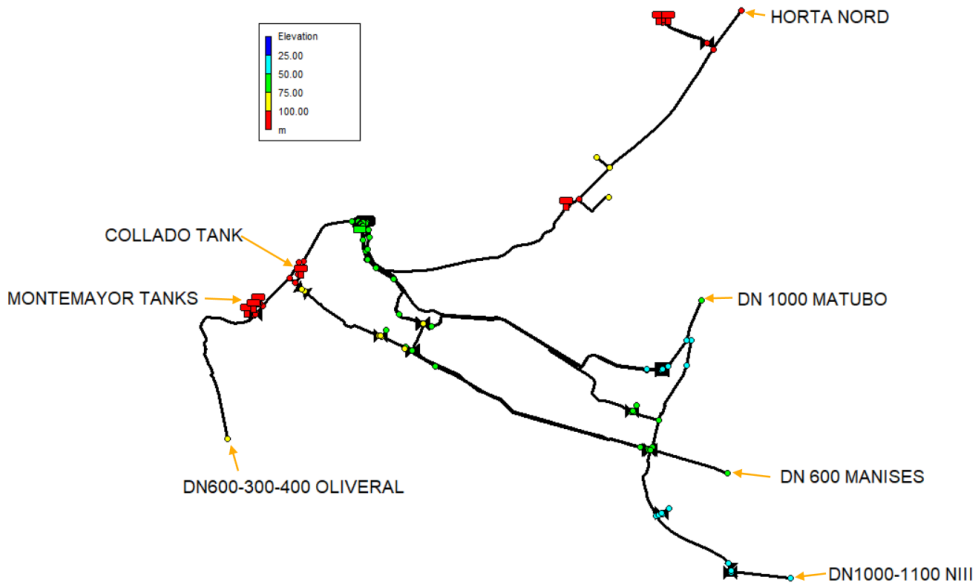


Figure 5. Topography of the network modeled in EPANET for the current situation scenarios of drinking water pumping at La Presa.

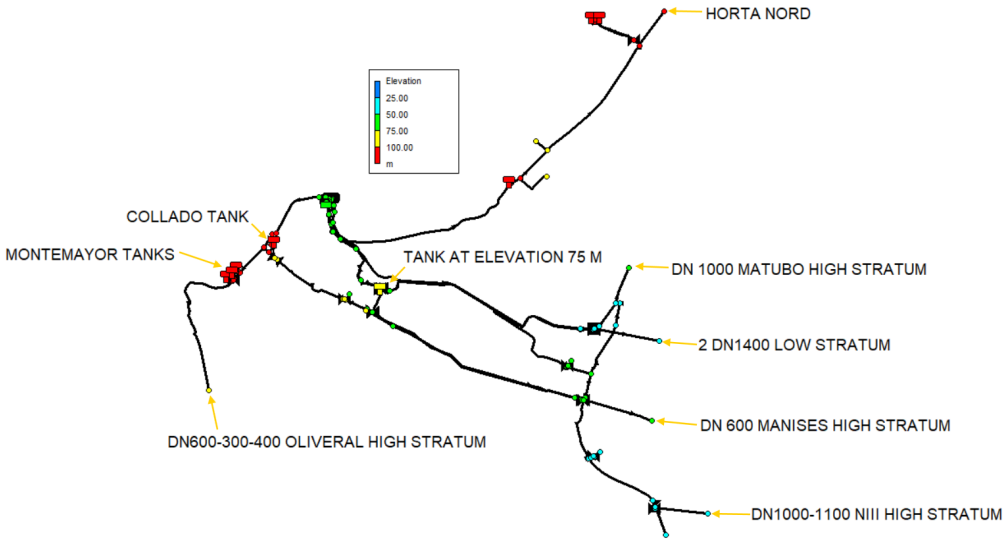


Figure 6. Topography of the network modeled in EPANET for the future situation scenarios of drinking water pumping at La Presa.

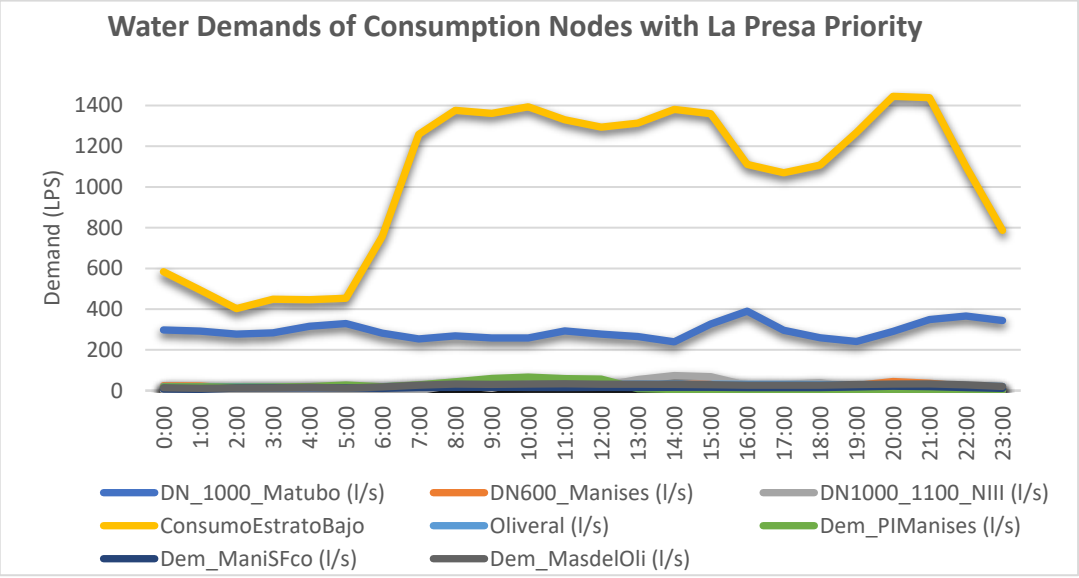
Both the model of the current situation of drinking water pumping at the La Presa DWPP and the model of its future situation, which considers the proposed alternatives (Turbines, Pumps, and Mixed), include two demand scenarios, defined according to which WTP has priority in the distribution of water flows supplied to the network. This means that the DWPP with priority treats higher flow rates and, consequently, satisfies a larger proportion of the total demand of the Valencia metropolitan area.

These two demand scenarios are:

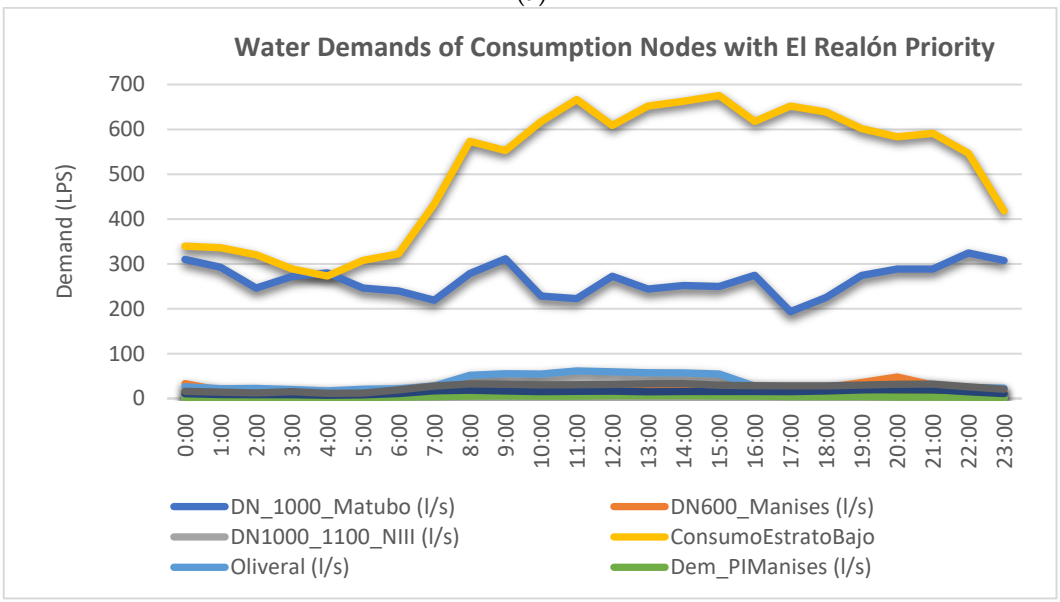
- Priority to La Presa DWPP: 60% of water is supplied by La Presa.
- Priority to El Realón DWPP 60% of water is supplied by El Realón.

The current scenario models have already been calibrated using data from the system manager's digital twin, so no further calibration is required; data will only be extracted for energy calculations. In contrast, the future scenario models will be calibrated based on projected demands and specific operational criteria, as described later. In these models,

the total system demand from the current scenario was allocated between the lower and upper zones, assigning a higher demand to the lower zone. Figure 7 illustrates the demand scenarios of the consumption nodes over an average day as analyzed in the different models.



(**a**)



(**b**)

Figure 7. (**a**) Flow through the La Presa DWPP adductions with priority service to La Presa DWPP; (**b**) flow through the La Presa DWPP adductions with priority service to El Realón DWPP.

Considering the demands, alternatives, and temporal situations, a total of 8 scenarios were simulated, which are as follows:

1. Current situation with priority to La Presa DWPP.
2. Current situation with priority to El Realón DWPP.
3. Future situation with priority to La Presa DWPP using turbines.
4. Future situation with priority to La Presa DWPP using pumps.
5. Future situation with priority to La Presa DWPP using both turbines and pumps (Mixed).
6. Future situation with priority to El Realón DWPP TP using turbines.
7. Future situation with priority to El Realón DWPP using pumps.

8. Future situation with priority to El Realón DWPP using both turbines and pumps (Mixed).

Once the demands were input into the future situation models in EPANET, the calibration of these models in the simulations is the next step [24]. For the calibration of these models, the following operational and hydraulic criteria were considered: minimum pressure downstream of the high-pressure water main branches was 25 wmc; initial state and properties of control valves and pipes are defined; rule-based controls (statements specifying the status of a line) will be applied based on tank levels and schedules according to simplified tariff periods; no variable speed drives are implemented; the interconnection pumps between subsystems BVCIA_HN will remain off during all simulations; a minimum level of 2.80 m will be required in the Collado and Montemayor tanks for safety volume storage purposes in case of emergency; and the turbines must operate in pairs. There will be no odd number of turbines running; pumps and pairs of turbines will operate in constant flow increments of approximately 500 LPS; the tanks have an initial level of approximately 3.00 m, with a tolerance of ± 0.05 m, to ensure a fair comparison in the energy analysis; pumps and turbines must be working near their best efficiency point; and priority will be given to operating the pumps during the early hours of the simulated day, as energy costs are much lower during these hours compared to the rest of the day, according to the tariffs shown later. In very high-demand situations, the necessary pumps will be allowed to be turned on to meet the demand; turbines were prioritized during periods of higher energy costs.

For the management of Valencia's water distribution network, a digital twin is maintained to represent the behavior of both the main and detailed networks, including interactions with the water production plants [25]. The digital twin is continuously calibrated using actual network measurements. For the simulation of the current scenario, data provided by the utility were used to calibrate the model.

Calibration parameters included valve coefficients, which were adjusted to match the flow rates and pressures indicated by the digital twin (itself validated with actual data from the current system). For the simulation of the future scenario, the digital twin results under these conditions were used to validate the hydraulic analyses performed with this model, as well as the energy and water quality parameters applied in this study. Considering these restrictions, the methodology used for energy calculation was as follows:

Based on the data obtained from the models (flows and heads of the hydraulic machines), the energy consumed or recovered was calculated by applying power and energy formulas [26], based on the efficiency of each hydraulic machine (pumps and turbines) [27].

Then, the absorbed power of each pump (1) and the generated power of any turbine were calculated at each time instant using the following equations [28]:

$$P_{abs} = \gamma QH/\eta \quad (1)$$

$$P_{gen} = \gamma QH\eta \quad (2)$$

where P_{abs} = absorbed power at each instant of the pump (kW), P_{gen} = generated power at each instant of the turbine (kW), γ = specific weight of water (kN/m3), Q = flow rate at each instant of the pump or turbine, H = head at each instant of the pump or turbine (m), and η = efficiency at each instant of the pump or turbine. Equation (1) is applied for pumps and Equation (2) for turbines.

The calculated powers were used to determine the energy consumed by the pumps and the energy recovered by the turbines by estimating the area under the power vs. time curve for each hydraulic machine [29]. This energy is estimated by applying the mean value theorem [30]. Therefore, the net energy consumed is obtained by subtracting the energy recovered by the turbines from the energy consumed by the pumps in each scenario. Finally,

EPANET was used to simulate the average residence time in the tanks as a global and indirect indicator of the drinking water quality in the simulated scenarios of the proposed future situation for the pumping system of the DWPP La Presa to determine the most energetically viable alternative, while considering drinking water quality.

In this research, the water mixing model within the tanks was considered during the residence time simulations, as it affects the calculation. A complete mixing model was used for simulations. Moreover, the average residence time of the tanks in the analyzed scenarios was simulated using EPANET. The simulation was run over a period of 480 h since it is necessary to reach a periodic behavior of the tank levels and residence times, where the values at the start and end of the simulation are equal for a proper analysis. Consequently, the Average mode was activated in EPANET to obtain the average residence time values in the tanks.

The power and energy calculations were determined using the flow and height results at each instant and time interval analyzed in the EPANET simulations. The efficiency was also estimated, which is associated with each flow rate according to the efficiency curves of each of the hydraulic machines provided by the manufacturer, with great accuracy.

Simulations show a cyclical behavior of the residence time in the deposits within the considered period in the model, which represents very well the maintenance of the main level in the represented time period.

3. Results and Discussion

Based on all the explanations provided in the previous section, the following tables show the final results, which are the outcome of the methods and calculations described above. On the one hand, the energy considerations were analyzed, presenting the energy consumed in the proposed supply conditions, and compared with the current situation.

Tables 3 and 4 describe these comparisons with the different scenarios analyzed in the simulations.

In terms of the economic impact of the actions, a general tariff has been considered to analyze the pricing structures' impact on the total costs of energy [31]. In this particular case, the tariff is not the real one used by the company, but it is useful to compare the potential energy savings.

Table 3. Net energy consumed and savings compared to the current situation in each analyzed hydraulic model A (priority La Presa) and B (priority El Realón).

Energy Consumed by Analyzed Scenario						
Current (priority La Presa)	Turbines (priority La Presa)		Pumps (priority La Presa)		Mixed (priority La Presa)	
Net energy consumed (kWh)	Net energy consumed (kWh)	Percentage saved (%)	Net energy consumed (kWh)	Percentage saved (%)	Net energy consumed (kWh)	Percentage saved (%)
21,127.82	13,803.03	34.67%	10,985.82	48.00%	12,200.01	42.26%
Current (priority El Realón)	Turbines (priority El Realón)		Pumps (priority El Realón)		Mixed (priority El Realón)	
Net energy consumed (kWh)	Net energy consumed (kWh)	Percentage saved (%)	Net energy consumed (kWh)	Percentage saved (%)	Net energy consumed (kWh)	Percentage saved (%)
12,190.43	8382.13	31.24%	7498.78	38.49%	7653.08	37.22%

Table 4. General-purpose tariffs for energy [31].

	Prize (€/kWh)
Energy cost P1	0.171
Energy cost P2	0.147
Energy cost P3	0.117
Energy cost P4	0.097
Energy cost P5	0.083
Energy cost P6	0.077

The hour periods P1 to P6 considered in the tariff are provided by the company, and the cost of energy is adjusted to these periods, with the general prices shown in Table 4.

In this particular case, the comparison between the actual and future situation with the proposed tariff system is depicted in Table 5.

Table 5. Estimated cost of energy in the different simulated scenarios.

	Energy		Cost per Year	
Scenario	Consumed Energy (kWh/Year)	Percentage of Saving (%)	Cost per Year (€/Year)	Percentage of Saving (%)
E0: Actual (priority La Presa)	7711.653	-	820.065	-
E1: Turbines (priority La Presa)	5038.105	34.67%	563.681	31.26%
E2: Pumps (priority La Presa)	4009.826	48.00%	393.577	52.01%
E3: Mixed (priority La Presa)	4453.005	42.26%	429.773	47.59%
E0: Actual (priority El Realón)	4449.508	-	454.308	-
E4: Turbines (priority El Realón)	3059.477	31.24%	307.876	32.23%
E5:Pumps (priority El Realón)	2737.054	38.49%	234.174	48.45%
E6: Mixed (priority El Realón)	2793.374	37.22%	261.608	42.42%

In this case, it can be observed that under this hypothesis of tariffs, the economic advantage is similar to energy savings, and it is even greater when comparing the cost of the several proposals with the actual ones.

In terms of quality considerations, the residence time is modeled in the tanks in order to ensure the best water quality by considering the shortest residence time in the network. Tables 6 and 7 consider this residence time in the modeling.

Table 6. Average residence time (age) per model (priority La Presa).

Tank	Average Residence Time per Scenario (Hours)		
	Turbines (Priority La Presa)	Pumps (Priority La Presa)	Mixed (Priority La Presa)
DCollado	67	75	73
DMontemayor1	69	76	75
DMontemayor2	69	78	77
DMontemayor3	69	76	75
Deposito75	56	35	39

Table 7. Average residence time (age) per model (priority El Realón).

Tank	Average Residence Time per Scenario (Hours)		
	Turbines (Priority El Realón)	Pumps (Priority El Realón)	Mixed (Priority El Realón)
DCollado	55	86	75
DMontemayor1	54	87	73
DMontemayor2	59	90	79
DMontemayor3	54	87	73
Deposito75	57	34	56

Average time in tanks, considering the presence of the new tank at height 75 wmc, is depicted in Figure 8.

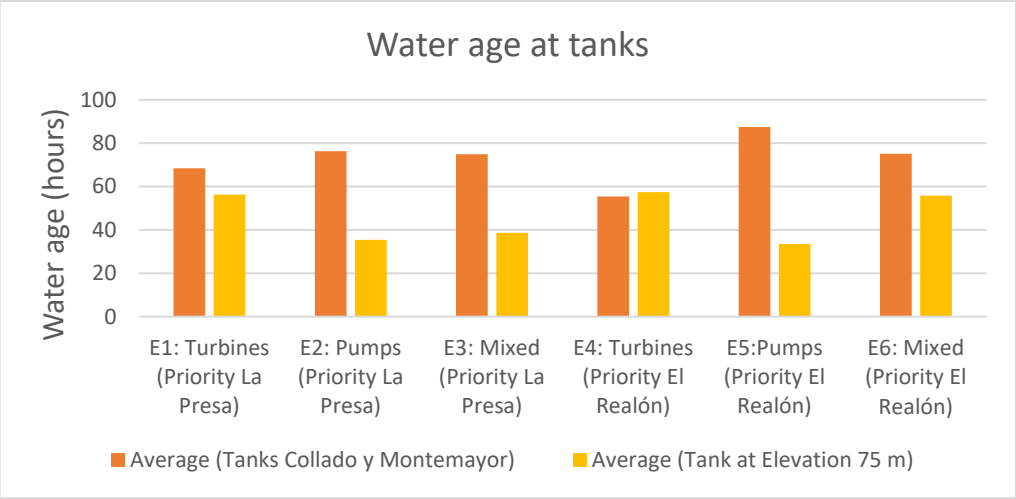


Figure 8. Water age at tanks considering several possible modeled scenarios.

As can be seen, when making energy comparisons in the models, all future scenarios represent a significant energy saving compared to the current situation, both with priority for La Presa and with priority for El Realón.

The future scenario with additional pumps achieves the greatest energy savings (48%). This is because the new proposed pumps allow the existing (more energy-consuming pumps) to operate for a fewer number of hours. This fact involves less power and energy consumption at the end of the day.

Nevertheless, the energy considerations must join sustainability and water quality considerations for the total system, with a 42.26% energy savings and 47.59% energy cost savings when compared with the actual situation. Some related references about energy savings when proposing actuations on water treatment plants proposed smaller improvements, for instance [6], with (20–30%) energy savings. The present research proposes (at least in the modeled considerations) great improvements when combining machinery implementation with the new reservoir at a lower height and also decreasing the pressure level in the city and, thus, the future leakage water in the system.

The scenario that considers only pumps showed the best energy savings, but showed much longer residence times in the tanks than those with turbines or mixed operation, indicating that the water quality in the pump-only scenario is lower than in the other scenarios.

The combination of pumps and turbines is also a very good option in terms of energy, and the water quality is much better ensured with less residence time in the tanks, as

indicated by the model. Furthermore, the presence of the new tank at a lower elevation will involve an improvement in overall energy levels, as can be seen from this research, but it will also have additional advantages related to pressure and leakage control.

The pressure reduction proposed in this research, combining micro-energy production with a lower-level reservoir, brings additional advantages beyond lower energy consumption: loss and leak levels will be reduced throughout the network supplied by the plant, improving volumetric efficiency and extending the network's useful life by reducing mechanical stress on pipes and joints; the frequency of breakages is reduced, as the probability of bursts and structural failures decreases; and uncontrolled consumption is improved by lowering network pressures. As a result, the resilience and sustainability of the whole network is improved by decreasing energy consumption, improving water quality, and inducing fewer incidents, allowing resources to be focused on long-term improvement and planning.

The presented research has considered a balance in the network, taking into account energy consumption, energy production, pressure level in the network, and residence time in the tanks. Furthermore, the cost of energy, considering a general tariff, has been presented, introducing an economic aspect of optimization. Other economic assessments should be considered in the future, such as investment costs, operational and maintenance expenses, or payback periods. These aspects will be addressed in future research on network and plant improvements.

In this sense, it is crucial to have a digital twin of the supply model; the decisions taken based on the modeling have been calibrated with the digital twin of the network, and this is the result of a digitalization process carried out in the actual network in previous years that can be used in future decisions.

Therefore, the use of turbines for recovering a part of the energy is the final recommendation of the present modeling for supplying the tank at elevation 75 m and the lower-pressure area of the metropolitan area of Valencia due to the better conditions resulting from combining energy, water quality, and sustainability for the whole network.

4. Conclusions

The operation of purification plants within urban water distribution systems is a key factor in enhancing the overall energy efficiency of the supply network. However, achieving optimal energy performance remains challenging due to conflicting objectives, such as minimizing energy costs, maintaining adequate pressure levels, and ensuring appropriate water storage and quality conditions, among other operational constraints. In this context, digitalization plays a crucial role, as future actions must be simulated and supported by calibrated digital twins of the systems, developed through the management and analysis of large datasets. Accordingly, this research presents a series of simulated scenarios based on a real water supply system, enabling a detailed assessment of energy consumption under different operational configurations of a purification plant serving a major Mediterranean city—Valencia—while preserving pressure requirements and water quality standards.

It was concluded that all proposed alternatives yield significant energy savings compared to the current configuration. In particular, the use of pumps to supply the tank located at an elevation of 75 m proved to be the most energy-efficient option; however, it is the least viable in terms of water quality. Therefore, the use of turbines is recommended.

It is worth emphasizing the consideration of turbines to recover part of the energy typically dissipated in the distribution process as one of the most innovative aspects of this research. This approach is seldom implemented in conventional water supply systems and enables the conversion of surplus hydraulic energy into other useful forms, thereby promoting a circular economy model in water management.

The research was carried out using most-likely-case consumption data provided by the utility company, considering two demand scenarios from the water treatment plants supplying the city of Valencia. The analysis presented herein represents a first approximation to support decision-making in the selection of hydraulic machinery from an energy perspective while also accounting for water quality conditions. For this purpose, a steady-state condition corresponding to a typical day was considered to obtain the most representative results possible. It is acknowledged that neither transient models nor flow variations related to actual consumption patterns were included in this study. Any solution derived from this simulation is therefore understood to form part of a subsequent, more comprehensive analysis based on the selected configuration, incorporating complex models. These should account for temporal variations, incomplete mixing in tanks, machine start-up and shutdown sequences, and different consumption patterns, including potential population growth.

This study demonstrates the potential of integrating renewable energy sources into urban water systems as a strategy to enhance energy efficiency and reduce environmental impact. In particular, the incorporation of photovoltaic and wind power technologies could further contribute to achieving net-zero emissions targets within the water sector. The findings presented here should be regarded as a preliminary step to support decision-making, acknowledging current implementation limitations that are expected to be addressed in future developments.

We hope this work serves as a foundation for future studies exploring additional alternatives to enhance the energy efficiency of the La Presa Water Treatment Plant (ETAP La Presa), whether through comparisons with the El Realón facility (ETAP El Realón), the incorporation of other energy efficiency improvement techniques such as photovoltaic power generation, or research based on alternative approaches. The availability of a digital twin to support system modeling is essential and encourages cities to adopt such technologies for improved management and operational decision-making. Furthermore, the proposed methodology can be applied to water treatment plants in medium-sized cities to optimize both plant management and the overall performance of urban water distribution systems in the context of the Digital Transition Era.

Author Contributions: Conceptualization, P.A.L.-J. and M.P.-S.; methodology, H.d.L.F., P.A.L.; validation, H.d.L.F. and M.P.-S.; formal analysis, H.d.L.F., P.A.L.-J.; investigation, H.d.L.F.; data curation, P.A.L.; writing—original draft preparation, H.d.L.F. and P.A.L.-J.; writing—review and editing, H.d.L.F.; supervision, M.P.-S. and P.A.L.-J. All authors have read and agreed to the published version of the manuscript.

Funding: The Cátedra Aguas de Valencia for funding the scholarship of the first author.

Institutional Review Board Statement: No applicable.

Informed Consent Statement: No applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: We thank Empresa Mixta Metropolitana (EMIMET, S.A.) and Empresa Mixta Valenciana de Aguas, S.A. (EMIVASA) for providing all the data and information to carry out this analysis.

Conflicts of Interest: Author Pura Almenar Llorens was employed by the company Global Omnium. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DM1	Montemayor Tank1
DM2	Montemayor Tank2
DM3	Montemayor Tank3
DC	Collado Tank
DWPP	Drinking Water Purification Plant
kW	Kilo-Watts
m	Meters
kN/m^3	Kilo-Newton per cubic meter

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