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Water Management Adaptation to Climate Change in Mediterranean Semiarid Regions by Desalination and Photovoltaic Solar Energy, Spain

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Abstract: Integration of renewable energy sources and water production technologies is a must when facing water scarcity problems in semiarid regions, such as Mediterranean regions. The use of additional water resources and production methods, such as reclaimed water and, more specifically, desalinated water, means present and necessary water resources to introduce in the water balances to attend to water demands within a global warming and droughting scenario. These solutions have the inconvenience of energy/power needs and costs. However, the development of renewable energies like photovoltaic solar energy, with lower and lower costs and greater efficiency, makes these economically feasible facilities, reaching competitive production costs for marine or sea desalinated water by around 50% of reduction in energy costs and 20–30% of savings in final water production cost. This paper presents a practical project or action focused on the integration of renewable energies and new water resources by introducing a Photovoltaic Energy Plant (PVEP) as an energy source to feed a Seawater Desalination Treatment Plant (SWDTP). The PV facility is designed to cover all the energy demanded using the SWDTP during the day, and even studying the possibility of selling the energy production exceeds and injecting them into the energy supply network, covering the needs of buying energy needed during the high period where there is no photovoltaic energy production. Thus, savings related to energy costs and even incomes coming from energy sales mean an important reduction in operation costs or expenditures (OPEX), which makes economically feasible and sustainable the investment and the final price of water produced within the Mutxamel SWDTP. The final reduction cost in water desalination reaches 25% on average.

Keywords: Seawater Desalination Treatment Plant (SWDTP); non-conventional resources; climate change adaptation; water-energy nexus; renewable energy; photovoltaic (PV) energy

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1. Introduction

Most of the studies and scientific concerns point out that Mediterranean regions are among the most identified areas affected in a major way by Climate Change Effects worldwide, becoming more and more water-stressed areas with warmer temperatures, less precipitation, more extreme weather disasters and drier seasons [1–8].

The Spanish Mediterranean area suffers from an important structural water stress, with a tight balance between available water resources and existing demands; nevertheless, there exists a series of strengths and opportunities that may represent a solution to the problems of water deficit and its accentuation by the effects of climate change. These opportunities consist of improvements in new water treatment technologies, appliances of sustainable water use, and renewable energies [9,10]. Another very important aspect is the nature-based solutions, which are becoming the best ally to mitigate and even face the climate change effects and considering simultaneously the environmental face as a must in every current or future project regarding climate change adaptation [11,12].

The reduction in water resources' availability within the Mediterranean regions, according to climate model scenarios, may reach, by the end of the 21st century, between 30–45%, in comparison with historical average values of 60–90 decades, attending both aspects, temporal and spatial distribution, and availability. This will be a result of an increase in average and maximal temperatures, an increase in drought episodes, precipitation reductions, and an increase in evapotranspiration [4,13,14]. However, there also exist some strengths and opportunities, which are the availability of water, even seawater, in areas close to demand, on the one hand, and on the other hand, an important potential of photovoltaic solar energy production due to the existing irradiance throughout the year, with a large part of the days of the year being sunny.

Many different strategies and actions to face water scarcity and mitigate the effects of climate change have been taken into force during the last decade in several countries suffering from this water availability reduction [15–19]. The most important group of these strategies is faced with integrated management of water resources [20–23], improvement and increase in efficiency on irrigation systems or increase in water resources availability by the introduction of reclaimed water reuse for irrigation purposes [24–26], and a further development regarding desalination water treatments [27,28] counteracting the huge energy consumption handicap of these technologies using renewable energy sources.

Existing water deficits in areas with a structural scarcity of resources, accentuated by the effects of climate change, can be mitigated and even completely covered, thanks to the contribution of unconventional water resources, such as the production of water in desalination plants, in coastal areas. However, this solution, on many occasions, is economically unfeasible due to the energy costs associated with the operation of desalination plants. Photovoltaic solar energy could be a very important application among the existing alternatives to produce the necessary energy in the generation of additional water resources such as desalinated water.

Sea and brackish water desalination has become a real and feasible alternative source of water, thanks to the desalination-technology improvements and reduction in energy costs, reaching saves of 20–30% and achieving specific energy consumption within 1.5–4 kWh/m^3 [29–32].

Nowadays, the cost of desalinated water in the case of seawater and reverse osmosis technology is about 0.75–1.00 EUR/m^3 [33,34], and from the whole operational costs taking place within a SWDTP, the energy costs or bill means the major and highest cost, reaching 65% [35] and even more than 80% in some cases [36]. Thanks to technological progress, processes have become more energy efficient and less consumed regarding water desalination, but despite all these advances, the energy bill that must be afforded within a water treatment plant is still huge, being on average around 45%.

PV energy production cost has decreased dramatically by 300% in the last decade, reaching an average current cost of about 0.2 EUR/kWh [30,37,38]. With the integration of photovoltaic solar energy as an energy source for the SWDTP, these solutions are increasingly technically and economically feasible. The changes that make this possible are the reduction in PV initial establishment costs, the improvement in the production capacity of the PV panels, and the improvement in energy efficiency and the PV technology, in general, [39–45], jointly with desalination processes.

In the present study, the methodology is presented to evaluate the energy needs of a desalination plant and the corresponding field development of photovoltaic solar energy generation modules to cover the demand (self-consumption), as well as the possibilities of injection and sale of surplus energy produced, in order to optimize and reduce the recovery period of the necessary investment.

The first step deals with the assessment of the potential of energy production via a PV facility annexed to the SWDTP in Mutxamel. For this, an irradiance analysis in the area is held to evaluate the energy generation potential based on the development sizing variables, such as the number of inverters and the number of panels arranged in grids of rows and columns, which will make up the field or farm of photovoltaic solar panels. This PV facility will cover the energy demanded by the desalination plant.

The next step consists of an energy flow balance to compensate for the night hours or those with not sufficient sunlight for PV-energy generation, but there is still the same energy demand by the SWDTP, as well as taking advantage via the sale and injection of energy in the energy supply grid or network, taking place when the generation term is higher than the demand term, during the hours of the day with greatest production (bigger irradiance).

2. Study Case: Mutxamel SWDTP

The methodology applied within this study case has been assessed and developed for the Mutxamel Seawater Desalination Treatment Plant (SWDTP), located in the region of Alicante, on the eastern coast of Spain, as represented in Figure 1. This methodology analyses the annual energy consumption of the WDTP and the photovoltaic energy's production potential in the area, making an exercise of sizing the PV grid to be installed, considering several functioning scenarios regarding coverage rate of energy consumption and energy sale chances.

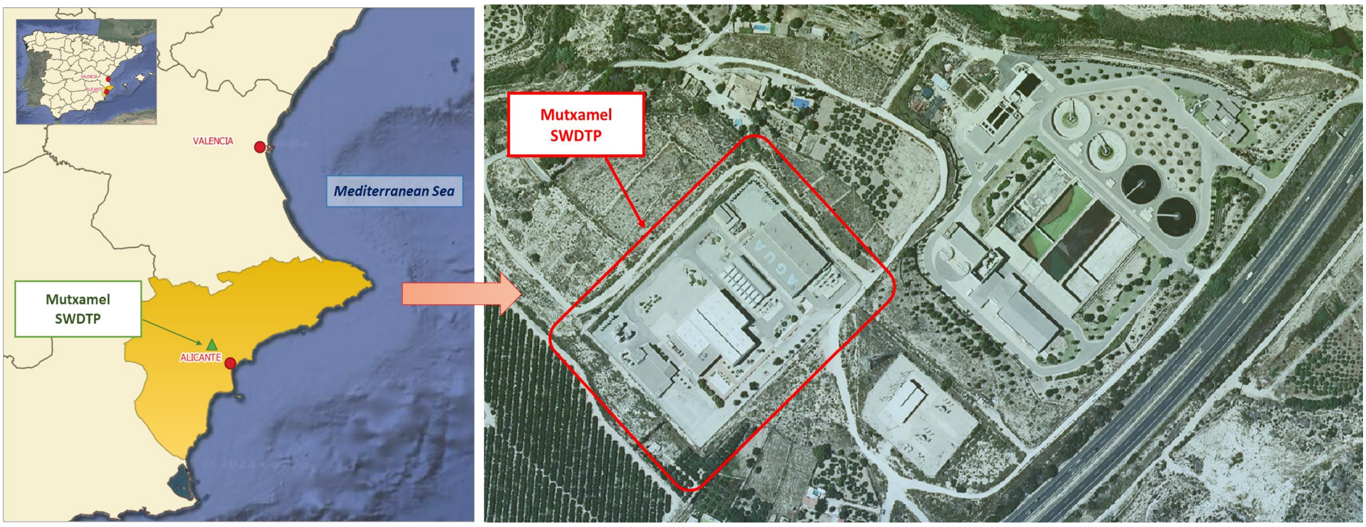


Figure 1. Mutxamel SWDTP location in the southeast Spanish region of Alicante in Spain, and satellite general view of the plant.

The plant produces 50,000 m^3/day using a reverse osmosis system, with three lines of 16,666 m^3/day. The annual water production reaches 18.25 hm^3/year or 18.25 million liters/year.

One outstanding feature of the works is the dual media pre-treatment system using dual-layer sand and anthracite with a first open and a second closed filtration phase. Water is transported using means of a pumping station buried under sea level on the coast, completely integrated into its surroundings. It also features a product water remineralization and pumping installation, a sludge treatment system, and electricity supply facilities with a power rating of 11,000 kW.

Based on the information from previous studies carried out for the Segura River Basin District [46], the annual energy consumption and the associated energy cost have been calculated. The collection and desalination energy consumption at the Mutxamel plant is 3.19 kWh/m^3 [47], with the energy consumption of distribution being more variable depending on the destination of the water. Figure 2 shows a scheme of the PV-SWDTP integrated solution designed within this paper.

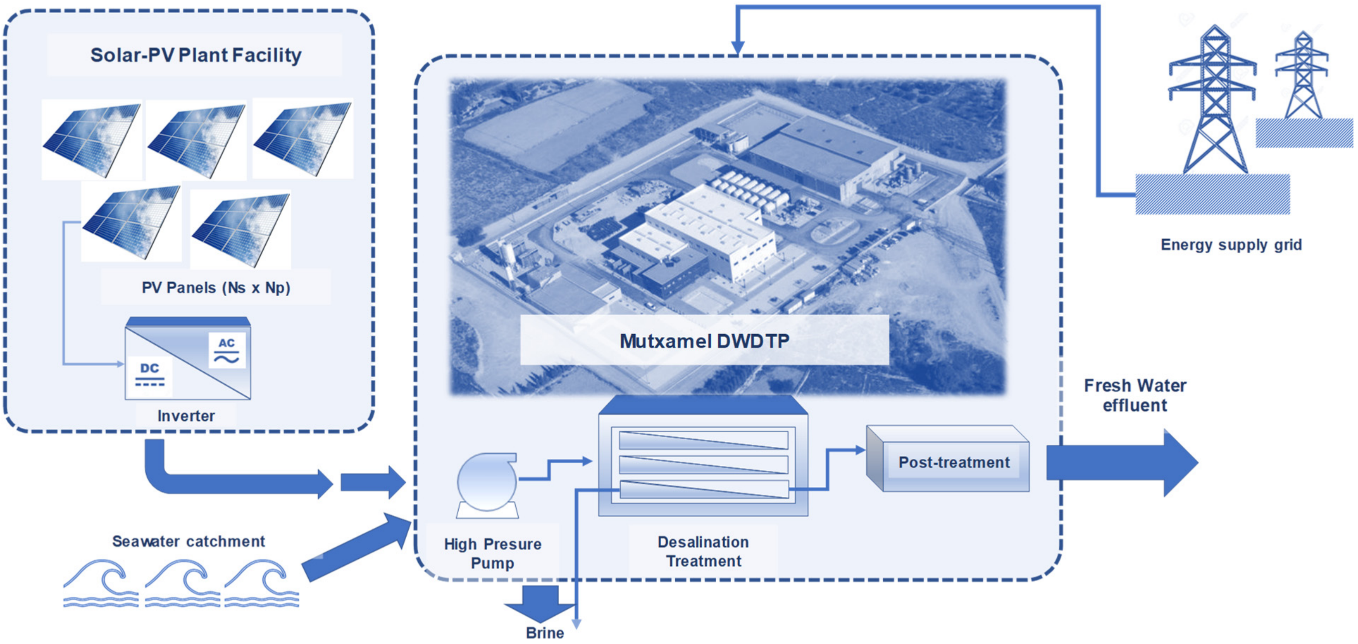


Figure 2. Scheme of the study case: PV facility to supply energy to the Mutxamel SWDTP.

The total cost of desalinated water for reverse osmosis technology, according to the studies and references consulted, would range between 0.6 and 1 EUR/m^3, and the first implementation or investment cost would be around an average value of 8027 EUR/m^3 of the capacity of the projected SWDTP [33,48]. Of this total cost, the breakdown into the different concepts that make up the cost structure of a plant is indicated in Table 1. The values presented within Table 1 correspond to ratios and reference values assumed as calculus hypothesis for our case in the costs assessment process, extracted from the references consulted.

Table 1. Costs structure of RO desalinated water (Investment and Operation) (source: own elaboration with FEDEA and AEDYR report 2020/22 [33]).

Cost of Desalinated Water with RO Technology	%	Min. EUR/m^3	Max. EUR/m^3	Average EUR/m^3
Maintenance and Operation (incl. Staff)	17.0%	0.10	0.17	0.14
Membranes	4.0%	0.02	0.04	0.03
Chemical products	2.0%	0.01	0.02	0.02
Energy bill	50%	0.37	0.62	0.50
Investment Amortization and Financial costs	15.0%	0.09	0.15	0.12
TOTAL	100.0%	0.60 EUR/m^3	1.00 EUR/m^3	0.80 EUR/m^3

The integration of a PV facility to cover SWDTP energy demand means reducing to 50% in the optimal cases of energy cost, which already means between 50–60% of the cost to obtain the final water price. As a result, this integrated management means a final saving of around 20–30% depending on several factors, such as the size of the infrastructures, energy purchase price, energy sale price, and treatment technology.

The energy cost is the highest, by far, within the costs of a SWDTP, being around 43–55%, and having an enormous influence on the final water price, as these costs can vary strongly, as shown in Table 2. Therefore, it is very effective to invest in projects to improve and optimize this cost within a water treatment plant.

Table 2. Comparison of main technical and economic values between Mutxamel SWDTP (case study) and existing Torrevieja SWDTP in the same area. (Source: own elaboration with Acuamed data [49] and FEDEA and AEDYR report 2020/22 [33]).

SWDTP	**Mutxamel SWDTP**		**Torrevieja SWDTP**	
Daily capacity m^3/day	50,000 m^3/day		219,178 m^3/day	
SWDTP production capacity	18.25 hm^3/year		80.00 hm^3/year	
Installation/Investment Costs	71.30 MEUR		246.85 MEUR	
Investment ratio: EUR/m^3/day	8027 EUR/m^3/day			
Amortization Costs (25 years)	2.85 MEUR/year		9.87 MEUR/year	
Operation and Maintenance Costs	4.37 MEUR/year		15.14 MEUR/year	
Specific Energy consumption ratio	3.2 kWh/m^3		3.2 kWh/m^3	
Annual energy consumption	58.40 GWh/year		256.00 GWh/year	
Energy price	90 EUR/MWh	120 EUR/MWh	90 EUR/MWh	120 EUR/MWh
Energy costs	5.43 MEUR/year 0.30 EUR/m^3	7.01 MEUR/year 0.38 EUR/m^3	23.81 MEUR/year 0.30 EUR/m^3	30.73 MEUR/year 0.38 EUR/m^3
Total annual costs	12.66 MEUR/year	14.24 MEUR/year	48.82 MEUR/year	55.74 MEUR/year
Water price (only WDTP)	0.69 EUR/m^3	0.78 EUR/m^3	0.61 EUR/m^3	0.70 EUR/m^3
Ratio energy cost/total cost (%)	43%	49%	49%	55%

3. Methodology

The main objective is to evaluate, size, and optimize the characteristics of the PV facility to be held in order to improve the economic balance of the SWDTP of Mutxamel. With that purpose, the methodology used is based on the study of different technical and economic variables present in a real market situation that influence the energy bill and the final water production cost. It focuses on the analysis of the effect of reducing the purchasing energy amount from the energy supply network using the substitution of this energy with energy coming from the PV facility. That represents the self-consumption scenario where 100% of the energy needed by the DWTP processes is covered with energy produced in the PV facility. Firstly, all the characterization and energy requirements of the SWDTP are presented in Tables 1 and 2.

During the hours when there is no PV energy production, the energy consumption by the desalination plan must be covered using the energy coming from the energy supply network, so the cost of purchasing energy plays an important role in the economic balance. The PV energy surplus produced, sold, and injected into the energy supply network is another of the different scenarios analyzed within this study case. All this energy balance between energy produced using the PV facility and the energy demand by the SWDTP is presented in Table 3 and final sizing values of the PV facility needed are presented in Table 4.

Table 5 presents the economic assessment for water price before and after integrating PV facility into the SWDTP operation, and Table 6 explains the assumed energy prices to make the optimization analyze. Finally, Table 7 makes a further explanation of the integrated PV-SWDTP solution regarding costs and savings.

The following Figure 3 summarizes the different steps in order to carry out this methodology to obtain the optimal PV facility size:

Some hypotheses and premises have been considered within the assessment process, such as:

- Operational costs are estimated to be about 50% of annual Investment costs. The Investment ratio relating energy costs and the facility's investment costs is about 0.85 EUR/kW, according to several specific studies in similar facilities in the area.
- SWDTP operation costs concept includes mainly costs regarding staff or personnel, chemical products, and membrane repositioning.
- The different costs to obtain the total PV energy direct costs include amortization costs, operation and maintenance costs, and energy costs, as shown in Table 7. Finally, costs related to general expenses, industrial benefit, and terrain acquisition have been

established as a percentage of direct costs, according to previous projects and studies held in the same area, as indicated in Table 4.

- The internal Rate of Return (IRR) of the investment is 37%.
- The life cycle considered for PV panels and the amortization period considered is 25 years.
- The module production efficiency is about 21%, and the electrical efficiency is considered about 75%.
- Range of energy price (purchase) considered 65–200 EUR/MWh or 0.065–0.2 EUR/kWh, and the same in the cases of selling opportunity.

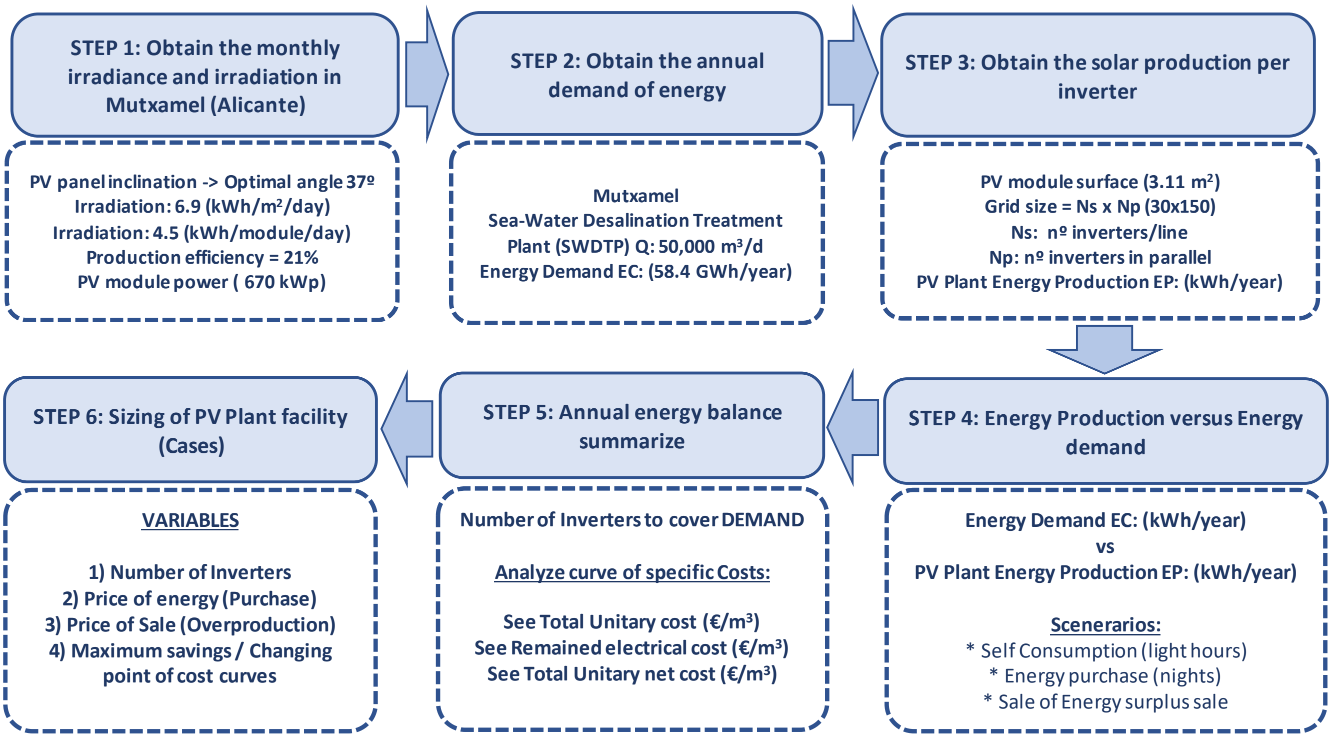


Figure 3. Scheme of the methodology used in order to optimize the size of the PV Plant facility and the economic feasibility.

The first step carried out (Step 1) within this methodology is the assessment of the energy production potential, completely depending on solar irradiance (G: kW/m^2/year) in the geographical location (kWh/year), solar module, and the electrical efficiency.

In parallel, in step 2, the energy demand of the Mutxamel facility is obtained (kWh/year), and the water production capacity (hm^3/year).

Regarding PV-energy production, the following step consists of obtaining the solar energy production per inverter. In order to obtain the number of inverters needed to cover a major part of the energy demand or the most economically feasible configuration, the production rate, the surface (3.11 m^2/inverter), and finally, the number of units in series (Ns) and in parallel (Np) which will conform the final PV grid, by combining in a calculation sheet, energy production versus energy demand.

The analysis includes the possibility of increasing the PV-Plant facility size and increasing the number of inverters, and it also considers in the economic assessment the next three terms:

1. Self-consumption component: The energy produced and consumed in the water pumping process for desalination treatment.
2. Sale of energy: the energy exceeding the SWDTP energy demand and that is sold to the energy supply grid.

3. Buy of energy: the amount of energy bought from the grid in order to supply the energy demand during night hours.

The sizing of the PV facility is carried out based on the economic analysis where the investment costs and the reduction in the energy costs produced using the PV are integrated, considering different scenarios or simulations depending on the number of inverters needed and the three previous terms.

Self-consumption is the energy produced whenever it is less than the energy needed for the operation of the desalination plant during sunny hours. The energy purchased from the grid is the energy necessary to fully supply the desalination plant with energy and is developed mainly in the hours with less solar radiation and at night. The energy that could potentially be fed into the grid is the excess production of the photovoltaic plant above the maximum energy demand, and it is carried out mainly in the central hours of the day in summer when there is more solar radiation.

In this case, several alternatives have been studied being the most unfavorable the situation in which the PV Plant cannot supply energy to the network so that the income term for sale of energy becomes null in the economic analysis.

Each of these three energy terms has an economic valuation associated with it. Self-consumption and the purchase of energy from the grid have both been considered with 65 EUR/MWh based on the energy cost data from previous Institute of Water Engineering and Environment 17 studies [46], while the energy that could be poured into the network is considered not to produce any income.

The necessary investment of the PV facility depends on its size, considering an average cost of 0.65 EUR/Wp installed, to which general expenses (13%), industrial benefit (6%), and the cost of land are added, so that the final price is 0.85 EUR/Wp (Table 4). On the other hand, 0.5% of the initial investment is considered as annual operation and maintenance expenses. With all these ratios of average installation and OPEX costs in Table 1, Table 2, and Table 4, all the costs have been calculated, and specific cost curves will depend on the water production and energy consumption.

The operation and maintenance costs can be adjusted a lot due to the fact of being large photovoltaic installations where there is an important economy of scale.

4. Results and Discussion

4.1. STEP 1: Assessment of Irradiance Potential in the Study Case Area

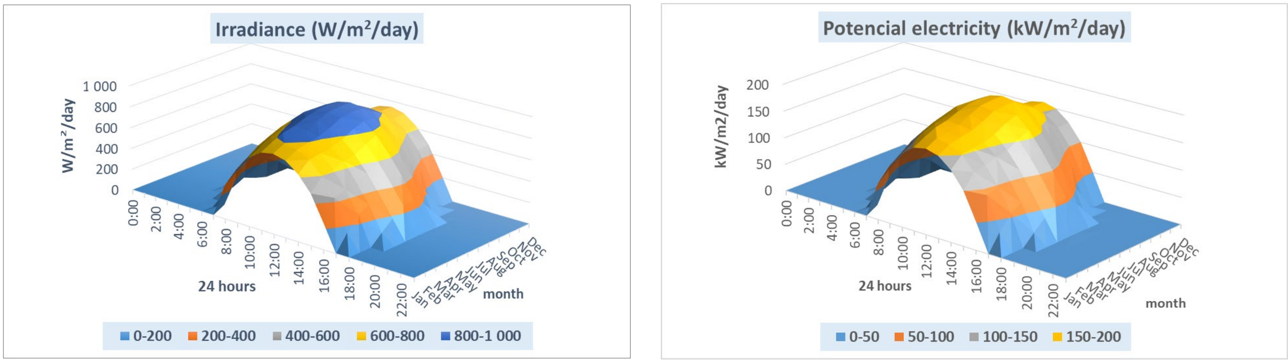
Different type of data hereby used for the assessment of energy irradiance potential was extracted from the European Union official website regarding irradiance and photovoltaic calculations PVGIS (https://re.jrc.ec.europa.eu/pvg_tools/es/, accessed on 1 January 2022).

PVGIS provides information about solar radiation and photovoltaic (PV) system performance for any location in Europe and Africa, as well as a large part of Asia and America. In our specific study case, data used was solar radiation and temperature, as monthly averages or daily profiles, and full-time series of hourly values of both solar radiation and PV performance.

The results obtained for irradiance and potential of energy production in the Mutxamel area are drawn in the following Figure 4.

From the PV-GIS application of the European Commission [50], solar irradiance is obtained (Figure 4) for fixed panels with optimal angle and for panels with two-axis solar tracking in the area close to the desalination plants.

For fixed panels, the energy coming from the sun is maximized with an inclination of 37° and reaches a maximum value of 944 W/m^2/day at noon in July (Figure 4). The average daily energy, irradiation, with fixed panels is 5.8 kWh/m^2/day, while the average energy received with solar panels with two-axis solar tracking is 7.9 kWh/m^2/day. In equivalent terms of hours of sunshine per day, considering an irradiance of 1000 W/m^2, the use of panels with solar tracking on two axes represents going from 6 h of sun at maximum power to 8 h of sun at maximum power per day, which increases the time period in which solar energy can be supplied to the facilities.



(**a**) (**b**)

Figure 4. (**a**) Hourly irradiance throughout the year (W/m^2/day) with optimum angle (upper); (**b**) Hourly energy potential generation (W/m^2/day) for fixed panels with optimum angle (upper) considering 21% electrical efficiency for Photovoltaic Panels in Mutxamel area (Alicante)—Spain.

Solar tracking increases the amount of time in the day when the panels receive radiation more perpendicularly and, therefore, produce greater amounts of energy for more hours, supplying consumer facilities for longer. Currently, solar tracking on one axis is being implemented more and more by increasing the energy received without a considerable increase in investment. The energy received with solar tracking on one axis has been estimated as an intermediate situation between the available solar radiation data for fixed panels with optimum angle and panels with 2-axis solar tracking (Figure 5).

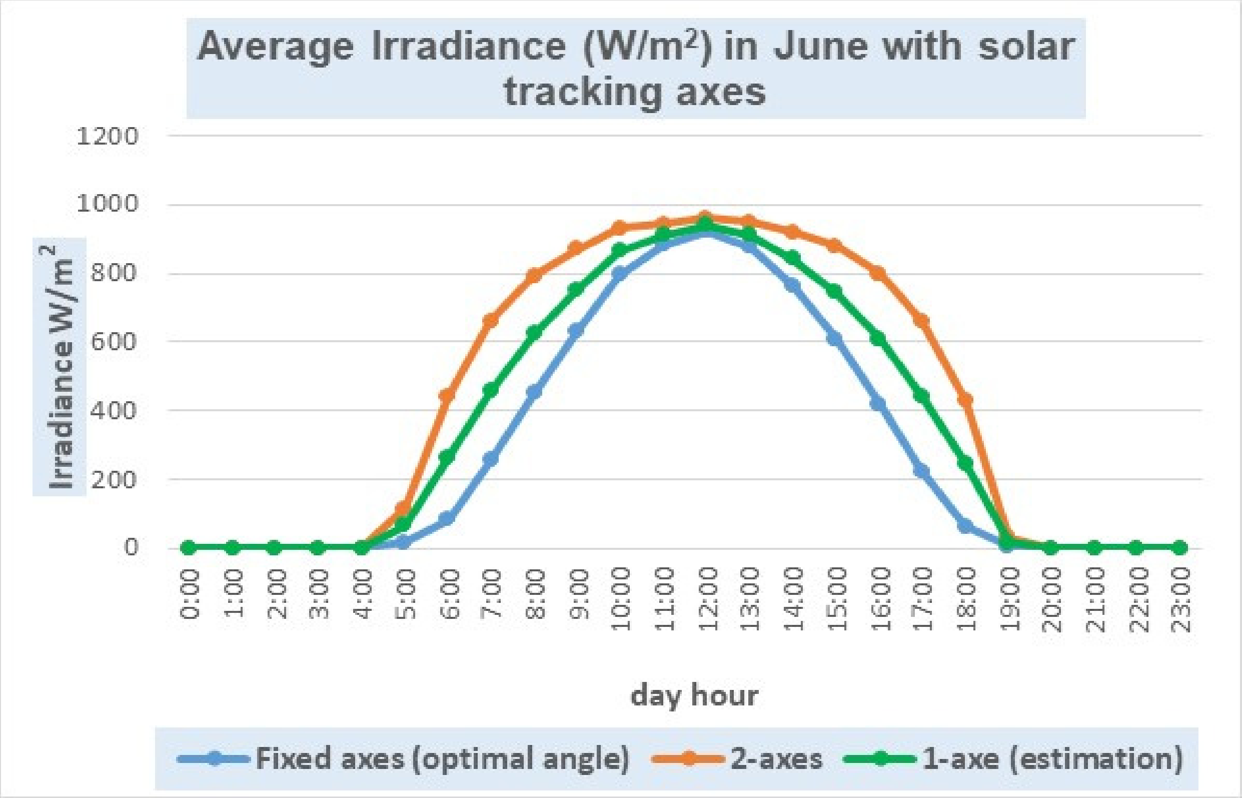


Figure 5. Hourly irradiance (W/m^2/day) in the month of June for fixed panels with optimal angle (blue), 2-axis tracking (orange), and estimation with 1-axis tracking (green).

Total daily energy, irradiation (kWh/m^2/day), for panels with 1-axis solar tracking is obtained as a daily sum of irradiance (W/m^2) ranging from 5 kWh/m^2/day in December to 9 kWh/m^2/day in July, with an average annual value of 6.9 kWh/m^2/day. This average value is equivalent to 7 h a day at maximum power. 1-axis solar tracking is equivalent to increasing the self-consumption capacity of the plant by one hour compared to having fixed panels, going from 6 equivalent hours per day to 7 equivalent hours per day.

In Mutxamel, there are around 3461 h of sunshine throughout the year. On average, there are 113.68 h of sunshine per month. In June, the highest number of daily hours of sunshine is measured in Mutxamel on average. In June, there is an average of 12.23 h of sunshine per day and a total of 379.24 h of sunshine throughout June. (Source: Climate-data.org, accessed on 1 January 2022)

In order to obtain the optimal solution for the PV Plant, which needs to cover the whole SWDTP and maximize at the same time the economic feasibility of the facility, several cases have been carried out comparing the results table in Appendix A, varying several variables. These results are summarized in STEP 6: Sizing of PV Plant facility and economical assessment.

4.2. STEP 2: Obtain the Annual Demand of Energy

The annual energy demand of the Mutxamel SWDTP reaches 6759 kWh/h, which means a total of 58.4 GWh/year. Based on the information from previous official studies carried out in the area, for example, for the Segura River Basin Authority [16], the annual energy consumption and the associated energy cost have been calculated. The total unit energy consumption of a SWDTP in the area varies between 3.48–4.23 kWh/m^3, with an average consumption of 3.95 kWh/m^3.

The collection and desalination energy consumption in Mutxamel SWDTP reaches 3.2 kWh/m^3 (source [47]), making the energy consumption for pumping and distribution more variable as it depends on the final water allocation point. The operation of the plant at a maximum capacity 24 h a day has been considered, considering the total unit consumption of each facility, so that the annual energy consumption is approximately 58.4 GWh/year, which could produce emissions of annual CO_2 of 20,848 tons.

Energy consumption for the desalination process has a constant distribution throughout the day and year, associated with a constant production of water.

The energy costs considered correspond to the average cost of energy for the periods studied in the same study [46] between June 2019 and July 2019 and between April and June 2021. The average cost of energy considered hereby is 90 EUR/MWh, which represents an annual energy cost of EUR 3.8 million and a unit energy cost of water of 0.21 EUR/m^3 produced, but it can vary considerably according to the energy prices oscillation.

The integration within the structure of costs of the SWDTP of the PV facility means important savings in the final water price because of the influence of energy consumption costs. This can be extracted from Table 5 when adding to the water cost considering just the SWDTP operation (Table 7) the water cost from the PV facility, savings on the electrical bill, and reducing the dependence from energy prices variability simultaneously:

To this energy, the cost must be added to the amortization cost of the installation and the operation and maintenance costs to obtain the total cost of desalinated water.

Thus, with the specific consumption for Mutxamel SWDTP 3.2 kWh/m^3 and its production capacity of 18.25 hm^3/year, the total energy consumption assumed reaches 58.4 GWh/year.

4.3. STEP 3: Dimensioning and Solar Production per Inverter

The defined photovoltaic installation is based on the installation of photovoltaic modules with 1-axis horizontal tracking (one-axis horizontal tracking). The solar modules considered are bifacial, with a power of 670 W and a yield of 21%. For better environmental integration, the solar modules are arranged with a separation corresponding to GCR (ground coverage ratio) = 0.3, which means 1/0.3 = 3.3 square meters of land area occupied for each useful square meter of solar installation.

The photovoltaic installation (PV facility) will be made up of "n" grids, each made up of 1 inverter plus a transformer, to which are connected: Ns = 30, in series, x, Np = 150, in parallel, bifacial solar panels of 3.11 m^2 of surface, each one, and 670 W of power with 1-axis solar tracking (one-axis horizontal tracking) and with a separation between panels corresponding to GCR = 0.3 (ground coverage ratio), which means that 3.3 m are required square meters of land surface occupied by each usable square meter of solar installation, in order to improve the environmental integration of the installation. Thus, the total energy production of our facility is determined.

The energy consumption of the solar tracker has not been considered as it represents only a 6% maximum of the PV device energy production [51], and it can be covered using the PV facility production during sunny hours. This little amount of energy does not have an important or significant influence on results, and that is the reason why it has not been taken into consideration.

4.4. STEP 4 and STEP 5: Energy Production versus Energy Demand and Energy Balance

In this step, a comparison between the energy produced using the PV Facility and the energy demand of the SWDTP is made, resulting in three components of the energy balance, which are the self-consumption component consisting of the energy consumed by the SWDTP during the sunny hours and completely covered using the energy produced in the PV facility; the energy purchase component which is the energy obtained via the energy distribution gris during the night hours when there is no PV-energy production; and the energy sale component which results the amount of extra energy produced within the FV facility during the sunny hours that exceeds the SWDTP energy needs. All these three components are observed in the following Figure 6.

In this step, we make a comparison between the SWDTP energy demand and the total amount of energy produced using the PV facility within an iterative calculus process depending on the number of inverters that will form the final PV facility to cover at least the self-consumption component of the SWDTP.

The objective of the annual energy balance is to cover this energy demand during the sunny hours to reduce the maximum possible energy bill for energy purchases.

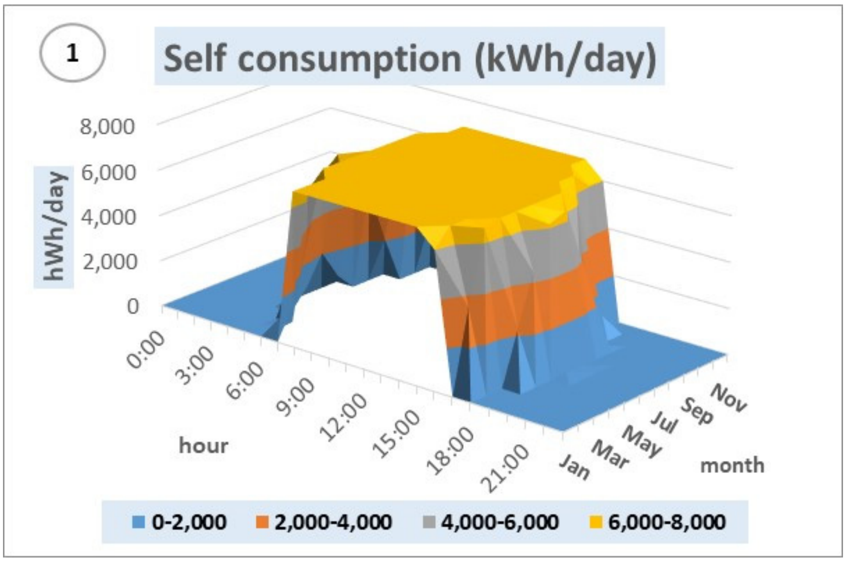


Figure 6. *Cont.*

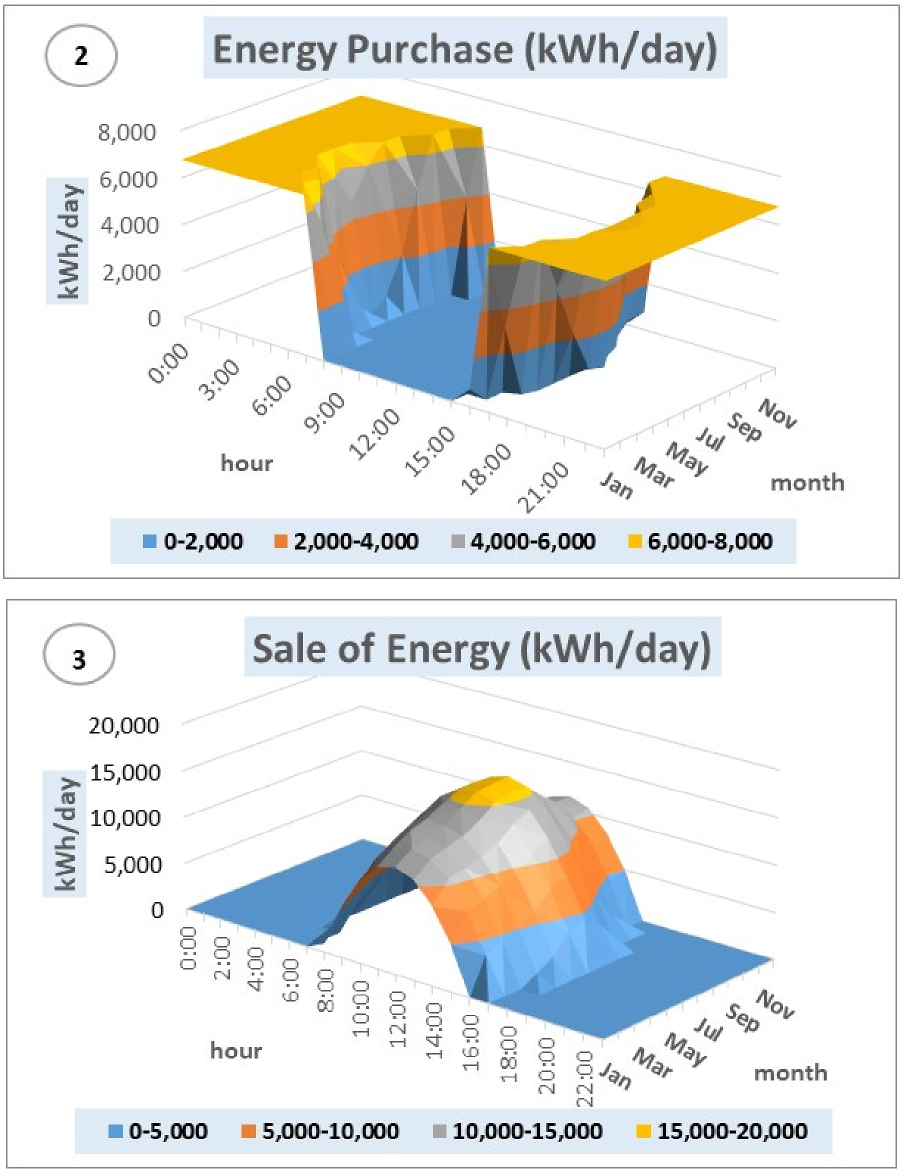


Figure 6. Graphs of the three energy balance components: (**1**) Self-consumption component (during sunny hours); (**2**) Purchase of energy for night hours (without PV energy feed); (**3**) Sale of energy component (surplus of PV production when it exceeds SWDTP energy demand).

4.5. STEP 6: Sizing of PV Plant Facility and Economical Assessment

The total costs of the facility are formed using the investment component, including, from one hand, the purchase cost of the solar or photovoltaic modules and the inverters needed to cover the energy demand and the installation cost and terrains or parcels purchased and from the other hand the operational component, including the energy bill, which means the energy purchased from the energy supply grid.

In this way, the total energy cost of the production of desalinated water (green line) is obtained as the sum of the remaining electricity bill (orange line) and the amortization and operating expenses of the PV facility. If there is no PV facility, the total energy cost is equal to the remaining energy bill as shown in Figure 7. On the other hand, the more a photovoltaic solar installation is implemented, the greater the distance between the orange and green curves is since it corresponds to higher amortization and maintenance costs, and the component of the remaining electricity bill decreases due to that less and less energy is purchased from network or grid till the base value (consumption during nights).

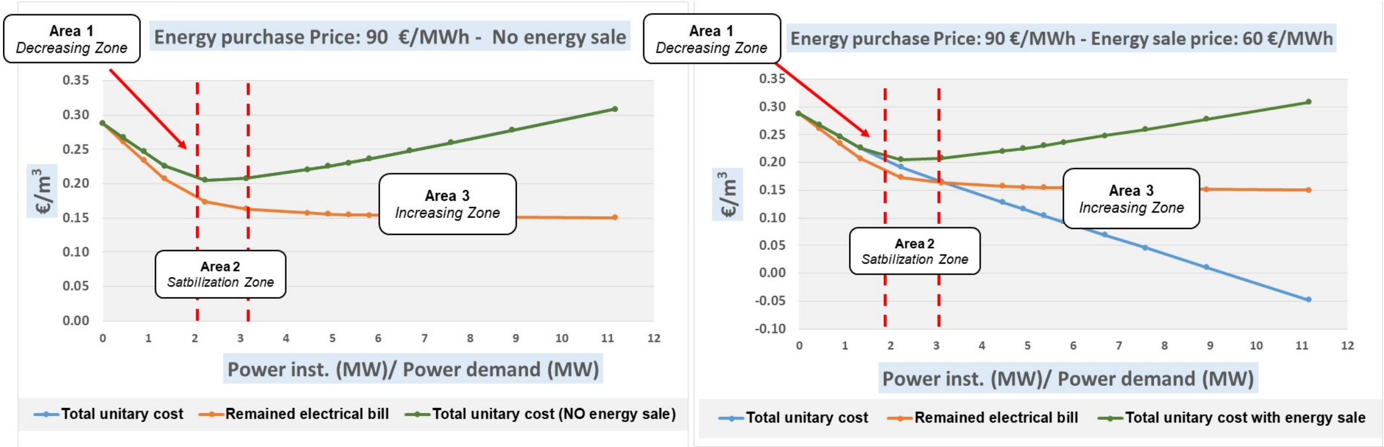


Figure 7. Comparison of cost curves within PV facility's sizing process, between two situations: left side without energy sale chance, and right side considering monetary incomes for sale energy surplus.

In the first area (decreasing zone), the larger the PV facility, the more total energy costs, and the remaining electricity bills are reduced. In the second zone (stabilization zone), the total energy costs stabilize, and in the third zone (increasing zone), the total energy cost increases since the investment cost is increasing and does not compensate for the reduction that occurs in the electricity bill. In this way, the economic optimum zone would be located in the zone in which the total cost curve is more horizontal, moving to the right in order to continue reducing the remaining electricity bill.

Furthermore, the comparison between two studied cases, 3 and 4, shows the difference between total unitary cost and total net unitary cost depending on the chance or not of the sale of surplus energy (PV production exceeds SWDTP demand).

The initial search for the optimal size consists of an assessment of the necessary number of inverters (grid of NsxNp modules) that can produce the maximum possible power to reach the SWDTP facility energy demand at least during the sunny hours to cover the self-consumption component.

Thus, the global values regarding energy demand versus production for the Mutxamel SWDTP are 6759 kWh/h and 58.4 GWh/year, regarding energy demand and potential of energy production using the PV facility of 59.4 GWh/year, as indicated in Table 3, and being the three components distribution of energy produced as follows:

Table 3. Results for energy balance between energy produced using the PV facility and the energy demand by the SWDTP, in the case of no chance of sale of energy.

General Study Case	Value	(Units)
Power installed	33.2	MWp
Energy production (PV)	59.98	GWh/year
Energy Demand (SWDTP)	58.40	GWh/year
Energy production/Power ins.	1.8	kWh/Wp
Specific energy demand	3.2	kWh/m^3
Desalination Volume hm^3	18.25	hm^3/year
Total Surface	563,802.89	m^2
Production per surface	106.39	kwh/m^2
Self-Consumption	26.82	GWh/year
Energy Purchase	31.58	GWh/year
Sale of Energy	33.16	GWh/year

An important aspect to focus on is the importance and need to improve the environmental integration of these kinds of facilities so they cover a big surface of the terrain. Regarding this aspect, it is important to adjust the GCR factor, which means the ground cover ratio, in order to obtain more environmentally sustainable and lower-impact solutions. Thus, in this study, the considered GCR was 0.3, so it results in a more acceptable and better solution landscape speaking.

This aspect could represent a worse soil usage rate regarding the number of modules to be installed, but it means an enormous benefit regarding environmental aspects such as landscape integration and climate change adaptation.

The results obtained are strongly conditioned using three main elements: the investment cost, the purchase price of energy, and the possibility or not of selling energy.

The lower the investment cost (total cost considered EUR 0.85/Wp), the more profitable the use of the photovoltaic solar installation will be and the greater the reduction in the remaining electricity bill that occurs. The price used is in the upper range of the prices used in other technical studies of the Administration in the study area, which could be between 0.72–0.85 EUR/Wp, so lower costs will give more favorable results. On the other hand, it is convenient to check the resistance of the project against higher prices, also used in other studies, such as EUR 1/Wp or EUR 1.15/Wp [2]. In both cases, the optimal design range proposed in the project continues to reduce the energy costs of water generation and the remaining electricity bill, but to a lesser extent.

Regarding the price of purchased energy (EUR 65/MWh), the increase in the price of energy also increases the savings obtained with the photovoltaic solar installation, so in the current context of the energy crisis, the savings in the coming years could be much higher than that obtained in this analysis. The price of EUR 65/MWh has been maintained to consider the possible return to prices similar to the pre-crisis energy situation during the useful life of the project.

In the scenario where there is no possibility of selling the excess energy generated, this has a direct effect on the price of water and on the remaining electricity bill.

In the case of being able to compensate for the energy produced in the hours of the greatest sun by energy demanded in other hours of the day, the reduction in the average cost of water and in the remaining electricity bill could range between 25% and 50%, depending on the price of energy.

Once all the assessments and considerations have been addressed, the global results of sizing of our PV facility needed to cover the SWDTP energy demand are presented as shown in Table 4 below:

Table 4. Final assessment of PV facility size and economic aspects.

Unitary Investment Costs			**Resulting PV Facility**			
PV Module	0.25	EUR/W	SWDTP Energy Demand		58.40	GWh-year
Inverter	0.10	EUR/W	PV energy production		59.98	GWh-year
Installation	0.30	EUR/W	SWDTP treatment capacity		18.25	hm^3/year
Total	0.65	EUR/W	Number of Inverters		11	units
General Expenses	13	%	Number modules		49,500	units
Industrial Benefit	6	%	Total Surface		56.38	ha
Terrains	12	%	Lifetime		25	years
Total	31	%	Payback period		7	years
final Investment Ratio	0.85	EUR/W	Investment costs		28.24	Million EUR
Operational and Exploitation Costs	0.50%		OPEX	0.50%/Inv.	141,200	EUR/year

The integration within the structure of costs of the SWDTP of the PV facility means important savings in the final water price because of the influence of energy consumption costs. This can be extracted from Table 5 when adding to the water cost considering just the SWDTP operation (Table 7), the water cost from the PV facility, savings on the electrical bill, and the dependence on energy prices variability simultaneously:

Table 5. Economic assessment for water price before and after integrating PV facility into the SWDTP operation for Mutxamel SWDTP.

PV Facility	**Mutxamel SWDTP**	
Non-energetic costs (Amortization + Operation cost)	0.40 EUR/m^3	
Energy Price range	90 EUR/MWh	120 EUR/MWh
Energy cost without PV	0.29 EUR/m^3	0.38 EUR/m^3
Energy cost with PV	0.15 EUR/m^3	0.18 EUR/m^3
Energy cost savings	48%	47%
Total cost WDTP without PV	0.69 EUR/m^3	0.78 EUR/m^3
Total cost WDTP + PV	0.55 EUR/m^3	0.58 EUR/m^3
Total Costs' Savings	21%	26%

The use of a renewable energy source, such as photovoltaic solar, reduces operating costs between 20–30%, and therefore improves the economic viability of the investment, provides energy self-sufficiency, and reduces carbon emissions, improving the footprint of carbon and helping to fight climate change effects such as water scarcity and drought periods.

In addition, if it is carried out with an adequate environmental integration with greater separation between the modules, for example, GCR = 0.3, and higher ground elevation, the installation allows the recovery of vegetation and pollinators, also being a local environmental added value and economic boost in the local economy where the facility is located. In addition, the installation of vegetal barriers around the solar installations reduces the visual impact and the reflections and flashes that they can produce.

5. Sensitivity Analysis

The sensitivity analysis deals with the influence on the specific-cots (EUR/m^3) curves varying the most significant variables influencing the feasibility of the configuration, for instance, the number of inverters, the cost of the purchased energy, and the selling price of the energy surplus. The following Table 6 represents the values of these variables, which configure the multiple cases compared in the specific-cost curves in Figure 8.

Table 6. Assumed energy prices: energy-specific costs for different case analyses depending on the price of energy and the number of inverters.

	Units	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
SWDTP-specific consumption (kWh/m^3)	kWh/m^3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Self-Consumption (EUR/MWh)	EUR/MWh	65	65	90	90	120	120	200	200
Purchase energy price—Cost of Energy (EUR/MWh)	EUR/MWh	65	65	90	90	120	120	200	200
Sell Price of Energy (EUR/MWh)	EUR/MWh	0	40	0	60	0	80	0	120

The results calculated for each case varying the number of inverters are presented in Figure 8 and in Table A1, attached in Appendix A.

In the following case, the influence on the specific-cost curves for different scenarios regarding energy price. As previously explained, energy consumption is the main variable affecting total cost, and its price affects the operation costs as it is necessary to buy energy from the supply network during the hours without light to cover SWDTP's energy demand.

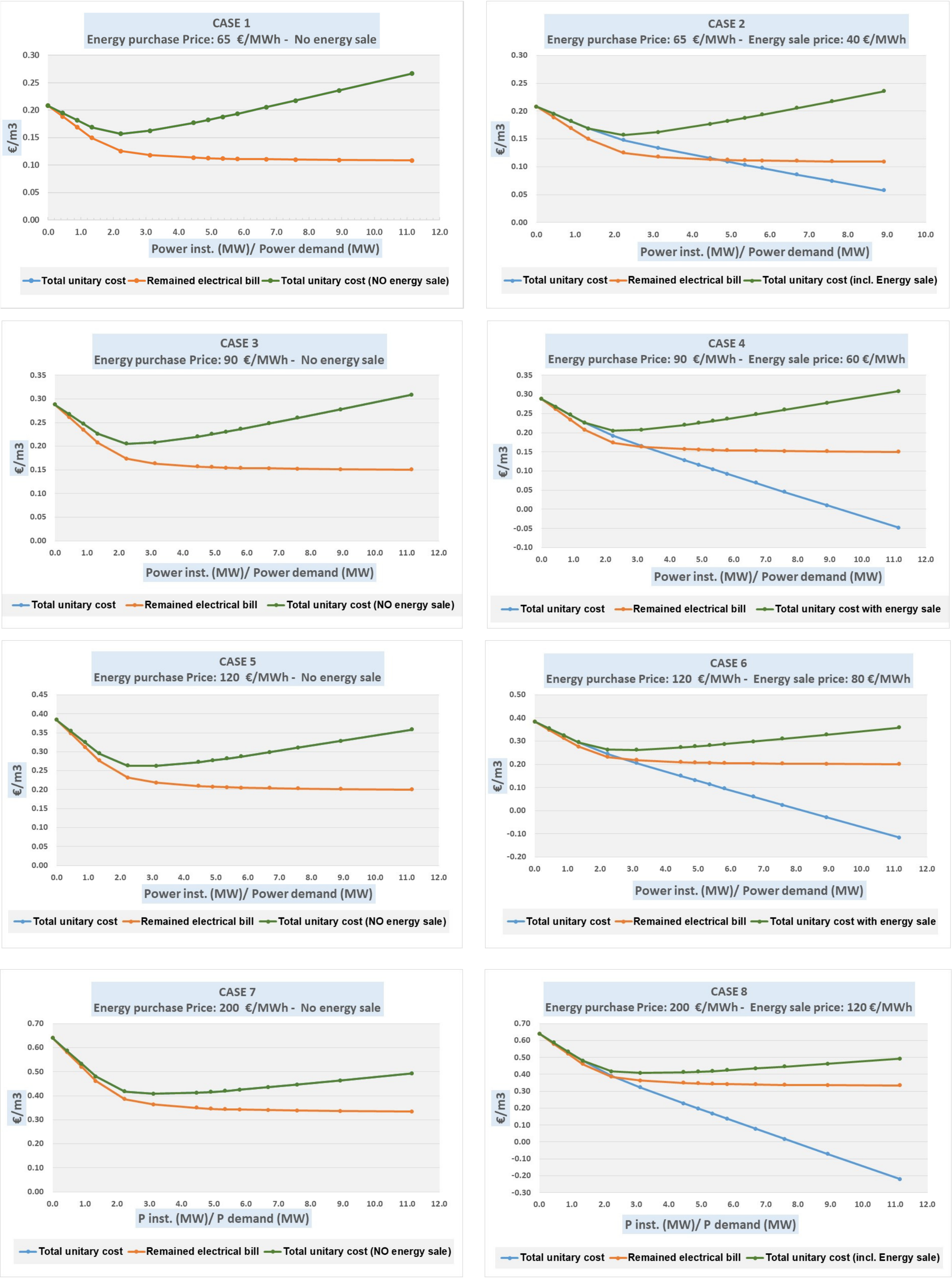


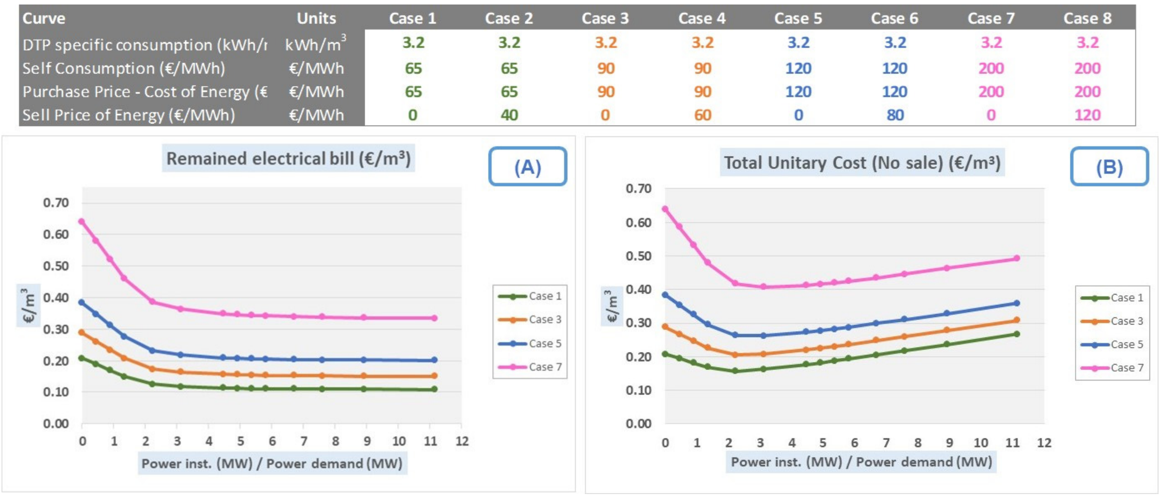
Figure 8. Comparison graphs of specific cost curves (EUR/m^3) for the eight cases varying price of purchased energy and considering the chance of surplus energy sale. Left side: Cases with No sale of energy; Right side: Cases with Sale of energy surplus.

Another important variable is the energy selling price, in the case of being possible to inject the energy surplus produced by the PV plant during the sunny days, with a higher irradiance, and it is injected into the supply network, receiving money incomes for this sale. This energy-selling scenario improves the economic balance of costs and incomes.

Blue curves represent the total unitary net cost detracting from the total unitary cost (green curve) of the obtained incomes from selling surplus energy. Finally, orange curves represent the remaining electrical bill, which remains constant as it reflects the energy purchased to cover SWDTP energy demand during night hours.

The importance lies in the fact that introducing savings on energy bill by energy surplus sale make the unitary net cost decrease. This decrease is proportional to both the number of inverters (or power installed) and the price of the sold energy, being more notorious with more power installed.

These specific cost curves can be represented in a comparison graph simultaneously for the previous cases to analyze trends. Focusing on odd number cases, as represented in Figure 9, these graphs put in evidence, in Figure 9A, how for a PV facility with more than five inverters or near the optimal of twice the power installed compared to the demanded, the remained energy bill starts decreasing with more strength till stabilization; and finally, in Figure 9B, it is shown the necessity of selling surplus energy in order to make economically feasible the PV facility, so with more inverters the investment is not worth despite the savings in self-consumption energy term.



Curve	Units	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
DTP specific consumption (kWh/r	kWh/m^3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Self Consumption (€/MWh)	€/MWh	65	65	90	90	120	120	200	200
Purchase Price - Cost of Energy (€	€/MWh	65	65	90	90	120	120	200	200
Sell Price of Energy (€/MWh)	€/MWh	0	40	0	60	0	80	0	120

Figure 9. Curves comparison analysis among the different cases: (**A**) Comparison among remaining electrical cost or energy bill; (**B**) Comparison of total unitary cost for odd number cases (without the component of surplus energy sale); Specific cost (EUR/m^3).

Within this part of the analysis, we focus on the comparison among the different curves' cases 1–2, 3–4, 5–6, and 7–8, where the difference lies in the price of the purchased energy (EUR/kWh) for each pair and considering or not the chance of selling the surplus of energy produced within the PV facility between the odd and even case. This variable affects, on the one hand, the level of the specific cost, so the energy is more expensive although the yield remains equal, and at the same time, it produces higher saving levels, so the influence is higher for more expensive energy.

In cases (1.A) (odd number cases) against cases (1.B) (even number cases), the difference remains in the introduction of the energy-sale factor, which makes the curves move away from each other, so the more energy it is sold, the more the total unitary net cost decreases.

Comparison for each pair of curves show that they are equivalent regarding PV costs, but the total unitary cost (blue curve), which represents the net specific cost discounting the incomes from energy sale, make this curve decrease more dramatically because of the major energy sale-price, so it considers a sale price of 40, 60, 80 and 120 EUR/MWh in cases 2, 4, 6 and 8 cases, respectively.

When the difference between total and net specific costs is lower, or it can be said they are closer, it represents a scenario where energy costs (purchase) are not very high, and the curves will get distance as the energy price stages are higher. That increases the initial specific energy cost, rising from 0.21 EUR/m^3 in cases 1 and 2 to 0.64 EUR/m^3 in cases 7 and 8. That situation could also be a consequence, for example, of a high inflation scenario where the facility investment costs could also reach high.

When considering the sale of energy surplus, reaching from 40 to 120 EUR/MWh, it makes the Total Unitary cost decrease considerably as the incomes also increase.

Paying attention to all these results, the sensibility analysis shows that the increase in the power installed over the power demand ratio, in order to cover the demand, means an increase in the total cost because of the major investment needed, and later the scale factor has an effect and the reduction in energy bill makes the curve go down rapidly till a changing point where the costs rise more rapidly than savings and curves start rising again but with a lower gradient. The price of the purchased energy has the effect of moving away from the optimal number of inverters, and the increase in energy selling price makes the decrease in the total net cost curve's slope more noticeable.

In summary, in a scenario of high prices of energy, increase the optimal sizing of PV farms to cover energy demands.

6. Reduction in Final Cost of Desalinated Water

The previous results shown in Table 5 have been assessed and are more detailed explained in Table 7, where the water costs to produce desalinated water within the SWDTP have been previously obtained and compared with results in another existing SWDTP but with a bigger production capacity (Torrevieja SWDTP). From this table, it can also be appreciated that with bigger facilities, savings are also bigger, taking advantage of the scale economy.

Table 7. Comparison of main technical and economic values between Mutxamel PV (case study) and Torrevieja PV needed to reduce final water price. (Source: own elaboration with Acuamed data [49] and FEDEA and AEDYR report 2020/22 [33]).

SWDTP	Mutxamel SWDTP		Torrevieja SWDTP	
Installation/Investment Costs	71.30 MEUR		246.85 MEUR	
SWDTP production capacity	18.25 hm^3/year		80.00 hm^3/year	
Specific Energy consumption ratio	3.2 kWh/m^3		3.2 kWh/m^3	
Annual energy consumption	58.40 GWh/year		256.00 GWh/year	
Energy price	93 EUR/MWh	120 EUR/MWh	93 EUR/MWh	120 EUR/MWh
Operation and Maintenance Costs	4.37 MEUR/year		15.14 MEUR/year	
Amortization Costs (25 years)	2.85 MEUR/year		9.87 MEUR/year	
Specific initial energy costs	5.43 MEUR/year 0.30 EUR/m^3	7.01 MEUR/year 0.38 EUR/m^3	23.81 MEUR/year 0.30 EUR/m^3	30.72 MEUR/year 0.38 EUR/m^3
Total annual costs	12.66 MEUR/year	14.23 MEUR/year	48.82 MEUR/year	55.73 MEUR/year
(a) Water price (only WDTP)	0.69 EUR/m^3	0.78 EUR/m^3	0.61 EUR/m^3	0.70 EUR/m^3
Ratio energy cost/total cost (%)	43%	49%	49%	55%

Table 7. *Cont.*

PV Facility	**Mutxamel PV**		**Torrevieja PV**	
Installation/Investment Costs	28.20 MEUR		115.50 MEUR	
Energy Price (normal vs. crisis)	90 EUR/MWh	120 EUR/MWh	93 EUR/MWh	120 EUR/MWh
Number of Inverters	11		45	
PV energy production	59.98 GWh/year		245.00 GWh/year	
Operation and Maintenance Costs	0.56 MEUR/year	0.56 MEUR/year	2.31 MEUR/year	2.31 MEUR/year
Amortization Costs (25 years)	1.13 MEUR/year	1.13 MEUR/year	4.62 MEUR/year	4.62 MEUR/year
Energy costs (night demand)	1.90 MEUR/year	2.45 MEUR/year	8.33 MEUR/year	10.75 MEUR/year
Incomes for energy sale	−0.82 MEUR/year	−0.82 MEUR/year	−3.58 MEUR/year	−3.58 MEUR/year
Total annual costs (PV)	2.78 MEUR/year	3.33 MEUR/year	11.68 MEUR/year	14.10 MEUR/year
Water price (PV part)	0.15 EUR/m^3	0.18 EUR/m^3	0.15 EUR/m^3	0.18 EUR/m^3
Water price (only WDTP without Energy)	0.40 EUR/m^3	0.40 EUR/m^3	0.31 EUR/m^3	0.31 EUR/m^3
(b) Total Water Price WDTP + PV	0.55 EUR/m^3	0.58 EUR/m^3	0.46 EUR/m^3	0.49 EUR/m^3
Savings (Integration PV + SWDTP)	21.0%	25.9%	24.8%	29.8%

As important conclusions, it is demonstrated that the optimal installed power with respect to the power demand by the SWDTP is around 2. That is, about two times the installed desalination power, with about 11 inverters in our case.

The higher the price of energy, the greater the reduction in costs, or what is the same, the savings, being 15% for energy prices of EUR 90/MWh, 20% for EUR 120/MWh, and 30% for EUR 200/MWh.

7. Conclusions

Photovoltaic energy is a renewable energy that integrates perfectly with water pumping stations, desalination plants, and other high-energy consumption systems in order to make feasible energy high-demand strategies or actions to face water scarcity and climate change effects. The use of renewable energy reduces CO_2 emissions, the average cost of producing desalinated water, and the energy bill.

The photovoltaic solar installation will consist of 49,500 bifacial solar modules with a power of 670 W, fed by 11 inverters, arranged in one-axis horizontal tracking systems with a spacing corresponding to CGR = 0.3 and a higher ground elevation to make compatible photovoltaic activities and the environment, covering SWDTP energy demand.

The dimensioning of the size of the photovoltaic solar installation is carried out seeking the greatest reduction in the unit energy cost for producing desalinated water (EUR/m^3) and trying to reduce as much as possible the remaining electricity bill for the end user (EUR/m^3). The form of the unit cost of producing desalinated water and of the final electricity bill is similar for the range of values currently existing, corresponding to the unit cost of the installation and the price of electricity in the market. The specific economic optimal size of the installation depends on the total initial investment, the price of energy in the market for purchase during the night hours operation, and the selling price of the surplus of PV energy.

Thus, for the Mutxamel desalination plant (18.25 hm^3/year), the optimal size of the photovoltaic solar installation is 5–7 MW with a land occupation of 56 ha and a cost of 28.2 million euros. With these facilities, the unit energy cost would be reduced by 25% and the electric bill for the end user by 40%. In addition, as a guarantee, it has been verified that the defined installation would continue to be viable for higher investment costs (1.25 EUR/Wp).

The total cost of desalinated water for reverse osmosis technology, according to the studies and references consulted, would range between 0.6 and 1 EUR/m^3. Of this total cost, the breakdown into the different concepts that make up the cost structure of a plant is indicated in Table 7. The energy cost is the highest, by far, within the costs of a SWDTP, being around 50% on average. Therefore, it is very effective to invest in projects to improve and optimize this cost within a water treatment plant.

The use of a renewable energy source, such as photovoltaic solar, reduces operating costs by up to 20–30%, and therefore improves the economic viability of the investment, provides energy self-sufficiency, and reduces carbon emissions, improving the footprint of carbon and helping to fight climate change. The final PV facility to be installed in order to make the SWDTP water production cost-competitive results have twice the power demanded by the desalination plant.

Thus, we can afford strategies to face climate change effects in semiarid regions with structural water scarcity that could require important investments.

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Appendix A. Results

Table A1. Table of economic results: calculations of energy specific costs for different cases depending on the price of energy and the number of inverters.

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
0	65	65	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.21	0.21	0.21	0.21	0.00	58.40	0.00	0.00%	0	0.00
0	65	65	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.21	0.19	0.19	0.19	5.45	52.95	0.00	6.29%	9	0.45
0	65	65	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.21	0.18	0.17	0.18	10.91	47.49	0.00	12.59%	9	0.89
0	65	65	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.21	0.17	0.15	0.17	16.36	42.04	0.00	18.88%	9	1.34
0	65	65	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.21	0.16	0.13	0.16	23.20	35.20	4.06	24.51%	11	2.23
0	65	65	6	3.2	58.4	32.72	18.25	307,528.85	106.39	32.72	58.40	32.72	0.21	0.16	0.12	0.16	24.42	33.98	8.30	23.55%	13	2.68
0	65	65	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.21	0.16	0.12	0.16	25.24	33.16	12.93	21.91%	15	3.12
0	65	65	8	3.2	58.4	43.62	18.25	410,038.46	106.39	43.62	58.40	43.62	0.21	0.17	0.12	0.17	25.77	32.63	17.86	19.78%	18	3.57
0	65	65	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.21	0.18	0.11	0.18	26.52	31.88	28.01	14.98%	26	4.46
0	65	65	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.21	0.18	0.11	0.18	26.82	31.58	33.16	12.45%	27	4.91
0	65	65	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.21	0.19	0.11	0.19	27.18	31.22	43.71	6.98%	27	5.80
0	65	65	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.21	0.21	0.11	0.21	27.37	31.03	54.43	1.22%	27	6.69
0	65	65	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.21	0.22	0.11	0.22	27.55	30.85	65.15	−4.57%	27	7.58
0	65	65	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.21	0.24	0.11	0.24	27.72	30.68	81.34	−13.40%	27	8.92
0	65	65	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.21	0.27	0.11	0.27	27.92	30.48	108.40	−28.27%	27	11.15
40	65	65	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.21	0.21	0.21	0.21	0.00	58.40	0.00	0.00%	0	0.00
40	65	65	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.21	0.19	0.19	0.19	5.45	52.95	0.00	6.29%	9	0.45
40	65	65	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.21	0.18	0.17	0.18	10.91	47.49	0.00	12.59%	9	0.89
40	65	65	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.21	0.17	0.15	0.17	16.36	42.04	0.00	18.88%	9	1.34
40	65	65	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.21	0.15	0.13	0.16	23.20	35.20	4.06	28.79%	9	2.23
40	65	65	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.21	0.13	0.12	0.16	25.24	33.16	12.93	35.54%	10	3.12
40	65	65	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.21	0.12	0.11	0.18	26.52	31.88	28.01	44.49%	12	4.46
40	65	65	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.21	0.11	0.11	0.18	26.82	31.58	33.16	47.39%	12	4.91

Table A1. *Cont.*

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
40	65	65	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.21	0.10	0.11	0.19	27.06	31.34	38.38	50.25%	12	5.35
40	65	65	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.21	0.10	0.11	0.19	27.18	31.22	43.71	53.04%	12	5.80
40	65	65	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.21	0.09	0.11	0.21	27.37	31.03	54.43	58.57%	13	6.69
40	65	65	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.21	0.07	0.11	0.22	27.55	30.85	65.15	64.09%	13	7.58
40	65	65	20	3.2	58.4	109.06	18.25	1.025,096.16	106.39	109.06	58.40	109.06	0.21	0.06	0.11	0.24	27.72	30.68	81.34	72.31%	14	8.92
40	65	65	25	3.2	58.4	136.33	18.25	1.281,370.20	106.39	136.33	58.40	136.33	0.21	0.03	0.11	0.27	27.92	30.48	108.40	85.96%	14	11.15
0	90	90	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.29	0.29	0.29	0.29	0.00	58.40	0.00	0.00%	0	0.00
0	90	90	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.29	0.27	0.26	0.27	5.45	52.95	0.00	7.14%	6	0.45
0	90	90	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.29	0.25	0.23	0.25	10.91	47.49	0.00	14.28%	6	0.89
0	90	90	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.29	0.23	0.21	0.23	16.36	42.04	0.00	21.42%	6	1.34
0	90	90	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.29	0.21	0.17	0.21	23.20	35.20	4.06	28.74%	7	2.23
0	90	90	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.29	0.21	0.16	0.21	25.24	33.16	12.93	27.83%	10	3.12
0	90	90	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.29	0.22	0.16	0.22	26.52	31.88	28.01	23.43%	15	4.46
0	90	90	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.29	0.23	0.16	0.23	26.82	31.58	33.16	21.75%	17	4.91
0	90	90	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.29	0.23	0.15	0.23	27.06	31.34	38.38	19.96%	19	5.35
0	90	90	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.29	0.24	0.15	0.24	27.18	31.22	43.71	17.97%	22	5.80
0	90	90	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.29	0.25	0.15	0.25	27.37	31.03	54.43	13.90%	27	6.69
0	90	90	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.29	0.26	0.15	0.26	27.55	30.85	65.15	9.80%	27	7.58
0	90	90	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.29	0.28	0.15	0.28	27.72	30.68	81.34	3.51%	27	8.92
0	90	90	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.29	0.31	0.15	0.31	27.92	30.48	108.40	−7.14%	27	11.15
60	90	90	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.29	0.29	0.29	0.29	0.00	58.40	0.00	0.00%	0	0.00

Table A1. *Cont.*

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
60	90	90	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.29	0.27	0.26	0.27	5.45	52.95	0.00	7.14%	6	0.45
60	90	90	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.29	0.25	0.23	0.25	10.91	47.49	0.00	14.28%	6	0.89
60	90	90	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.29	0.23	0.21	0.23	16.36	42.04	0.00	21.42%	6	1.34
60	90	90	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.29	0.19	0.17	0.21	23.20	35.20	4.06	33.38%	6	2.23
60	90	90	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.29	0.17	0.16	0.21	25.24	33.16	12.93	42.59%	7	3.12
60	90	90	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.29	0.13	0.16	0.22	26.52	31.88	28.01	55.41%	7	4.46
60	90	90	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.29	0.12	0.16	0.23	26.82	31.58	33.16	59.61%	7	4.91
60	90	90	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.29	0.10	0.15	0.23	27.06	31.34	38.38	63.77%	7	5.35
60	90	90	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.29	0.09	0.15	0.24	27.18	31.22	43.71	67.87%	8	5.80
60	90	90	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.29	0.07	0.15	0.25	27.37	31.03	54.43	76.03%	8	6.69
60	90	90	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.29	0.05	0.15	0.26	27.55	30.85	65.15	84.18%	8	7.58
60	90	90	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.29	0.01	0.15	0.28	27.72	30.68	81.34	96.36%	8	8.92
60	90	90	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.29	−0.05	0.15	0.31	27.92	30.48	108.40	116.6%	8	11.15
0	120	120	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.38	0.38	0.38	0.38	0.00	58.40	0.00	0.00%	0	0.00
0	120	120	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.38	0.35	0.35	0.35	5.45	52.95	0.00	7.69%	4	0.45
0	120	120	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.38	0.32	0.31	0.32	10.91	47.49	0.00	15.38%	4	0.89
0	120	120	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.38	0.30	0.28	0.30	16.36	42.04	0.00	23.07%	4	1.34
0	120	120	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.38	0.26	0.23	0.26	23.20	35.20	4.06	31.49%	5	2.23
0	120	120	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.38	0.26	0.22	0.26	25.24	33.16	12.93	31.68%	7	3.12
0	120	120	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.38	0.27	0.21	0.27	26.52	31.88	28.01	28.93%	10	4.46
0	120	120	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.38	0.28	0.21	0.28	26.82	31.58	33.16	27.79%	11	4.91

Table A1. *Cont.*

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
0	120	120	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.38	0.28	0.21	0.28	27.06	31.34	38.38	26.56%	12	5.35
0	120	120	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.38	0.29	0.21	0.29	27.18	31.22	43.71	25.11%	14	5.80
0	120	120	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.38	0.30	0.20	0.30	27.37	31.03	54.43	22.14%	17	6.69
0	120	120	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.38	0.31	0.20	0.31	27.55	30.85	65.15	19.15%	21	7.58
0	120	120	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.38	0.33	0.20	0.33	27.72	30.68	81.34	14.50%	27	8.92
0	120	120	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.38	0.36	0.20	0.36	27.92	30.48	108.40	6.60%	27	11.15
80	120	120	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.38	0.38	0.38	0.38	0.00	58.40	0.00	0.00%	0	0.00
80	120	120	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.38	0.35	0.35	0.35	5.45	52.95	0.00	7.69%	4	0.45
80	120	120	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.38	0.32	0.31	0.32	10.91	47.49	0.00	15.38%	4	0.89
80	120	120	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.38	0.30	0.28	0.30	16.36	42.04	0.00	23.07%	4	1.34
80	120	120	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.38	0.25	0.23	0.26	23.20	35.20	4.06	36.13%	4	2.23
80	120	120	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.38	0.21	0.22	0.26	25.24	33.16	12.93	46.44%	5	3.12
80	120	120	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.38	0.15	0.21	0.27	26.52	31.88	28.01	60.90%	5	4.46
80	120	120	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.38	0.13	0.21	0.28	26.82	31.58	33.16	65.65%	5	4.91
80	120	120	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.38	0.11	0.21	0.28	27.06	31.34	38.38	70.36%	5	5.35
80	120	120	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.38	0.10	0.21	0.29	27.18	31.22	43.71	75.01%	5	5.80
80	120	120	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.38	0.06	0.20	0.30	27.37	31.03	54.43	84.27%	5	6.69
80	120	120	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.38	−0.03	0.20	0.33	27.72	30.68	81.34	107.4%	6	8.92
80	120	120	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.38	−0.12	0.20	0.36	27.92	30.48	108.40	130.4%	6	11.15
0	200	200	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.64	0.64	0.64	0.64	0.00	58.40	0.00	0.00%	0	0.00
0	200	200	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.64	0.59	0.58	0.59	5.45	52.95	0.00	8.35%	2	0.45

Table A1. *Cont.*

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
0	200	200	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.64	0.53	0.52	0.53	10.91	47.49	0.00	16.70%	2	0.89
0	200	200	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.64	0.48	0.46	0.48	16.36	42.04	0.00	25.05%	2	1.34
0	200	200	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.64	0.42	0.39	0.42	23.20	35.20	4.06	34.78%	3	2.23
0	200	200	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.64	0.41	0.36	0.41	25.24	33.16	12.93	36.29%	3	3.12
0	200	200	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.64	0.41	0.35	0.41	26.52	31.88	28.01	35.52%	5	4.46
0	200	200	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.64	0.42	0.35	0.42	26.82	31.58	33.16	35.05%	6	4.91
0	200	200	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.64	0.42	0.34	0.42	27.06	31.34	38.38	34.47%	6	5.35
0	200	200	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.64	0.42	0.34	0.42	27.18	31.22	43.71	33.69%	7	5.80
0	200	200	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.64	0.44	0.34	0.44	27.37	31.03	54.43	32.03%	8	6.69
0	200	200	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.64	0.45	0.34	0.45	27.55	30.85	65.15	30.36%	10	7.58
0	200	200	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.64	0.46	0.34	0.46	27.72	30.68	81.34	27.69%	12	8.92
0	200	200	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.64	0.49	0.33	0.49	27.92	30.48	108.40	23.09%	17	11.15
120	200	200	0	3.2	58.4	0.00	18.25	0.00		0.00	58.40	0.00	0.64	0.64	0.64	0.64	0.00	58.40	0.00	0.00%	0	0.00
120	200	200	1	3.2	58.4	5.45	18.25	51,254.81	106.39	5.45	58.40	5.45	0.64	0.59	0.58	0.59	5.45	52.95	0.00	8.35%	2	0.45
120	200	200	2	3.2	58.4	10.91	18.25	102,509.62	106.39	10.91	58.40	10.91	0.64	0.53	0.52	0.53	10.91	47.49	0.00	16.70%	2	0.89
120	200	200	3	3.2	58.4	16.36	18.25	153,764.42	106.39	16.36	58.40	16.36	0.64	0.48	0.46	0.48	16.36	42.04	0.00	25.05%	2	1.34
120	200	200	5	3.2	58.4	27.27	18.25	256,274.04	106.39	27.27	58.40	27.27	0.64	0.39	0.39	0.42	23.20	35.20	4.06	38.96%	2	2.23
120	200	200	7	3.2	58.4	38.17	18.25	358,783.66	106.39	38.17	58.40	38.17	0.64	0.32	0.36	0.41	25.24	33.16	12.93	49.58%	2	3.12
120	200	200	10	3.2	58.4	54.53	18.25	512,548.08	106.39	54.53	58.40	54.53	0.64	0.23	0.35	0.41	26.52	31.88	28.01	64.30%	3	4.46
120	200	200	11	3.2	58.4	59.98	18.25	563,802.89	106.39	59.98	58.40	59.98	0.64	0.20	0.35	0.42	26.82	31.58	33.16	69.12%	3	4.91
120	200	200	12	3.2	58.4	65.44	18.25	615,057.70	106.39	65.44	58.40	65.44	0.64	0.17	0.34	0.42	27.06	31.34	38.38	73.90%	3	5.35

Table A1. *Cont.*

Sale Price of Energy EUR/MWh	Self-Consumption Energy Price EUR/MWh	Energy Purchase Price EUR/MWh	Number of Inverters	Specific Energy Demand kWh/m^3	SWDTP Energy Demand (GWh/year)	PV-energy Production (GWh/year)	SWDTP Production Capacity (hm^3/year)	Total PV Modules Surface (m^2)	Surface Production (kWh/m^2)	PV Total Energy Production (GWh/year)	SWDTP Energy Demand (GWh/year)	PV Energy Production (GWh/year)	Initial Electrical Cost (EUR/m^3)	Total Unitary Energy Specific Cost (EUR/m^3)	Remained Electrical Bill (EUR/m^3)	Total Unitary Cost No Sale	Self-Consumption (GWh/year)	Energy Purchase (GWh/year)	Sale of Energy (GWh/año)	Reduction cost	Payback (years)	Power inst./Power Demand
120	200	200	13	3.2	58.4	70.89	18.25	666,312.50	106.39	70.89	58.40	70.89	0.64	0.14	0.34	0.42	27.18	31.22	43.71	78.59%	3	5.80
120	200	200	15	3.2	58.4	81.80	18.25	768,822.12	106.39	81.80	58.40	81.80	0.64	0.08	0.34	0.44	27.37	31.03	54.43	87.95%	3	6.69
120	200	200	17	3.2	58.4	92.70	18.25	871,331.74	106.39	92.70	58.40	92.70	0.64	0.02	0.34	0.45	27.55	30.85	65.15	97.30%	3	7.58
120	200	200	20	3.2	58.4	109.06	18.25	1,025,096.16	106.39	109.06	58.40	109.06	0.64	−0.07	0.34	0.46	27.72	30.68	81.34	111.3%	3	8.92
120	200	200	25	3.2	58.4	136.33	18.25	1,281,370.20	106.39	136.33	58.40	136.33	0.64	−0.22	0.33	0.49	27.92	30.48	108.40	134.5%	3	11.15

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