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Article

EU Green Deal and opportunity cost: a comparison between the viability of different wastewater treatment project

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Abstract: The European Union Green Deal aims at curbing planet-warming greenhouse gas emissions and introducing clean energy production. But to achieve energy efficiency, the opportunity cost of different energies must be assessed. In this article, we analyse two different systems for the treatment of wastewater that, at the same time, produce energy for its own operation. On the one hand, high-rate algal ponds system (HRAP) is considered; on the other hand, we study a conventional activated sludge system which uses photovoltaic power (AS+PV). This paper offers a viability analysis of both systems based on the capacity to satisfy their energetic consumption. In order to assess this viability, the probability of not achieving the energy consumption threshold at least one day is studied. The results point that the AS+PV system self-sufficiency is achieved using much lesser surfaces than those of HRAP system (for the former, less than 6.500 m^2, for the latter 40.000 m^2). However, the important AS capital cost makes still the HRAP system more economic, although storage provides a great advantage for using the AS+PV in locations where we have a lot of irradiance. This viability analysis, along with the opportunity cost analysis, will be used to assess these two projects devoted to the treatment of wastewater.

Keywords: EU Green Deal; Horizon 2030; clean energy production; High-rate algal ponds (HRAP); activated sludge system (AS); photovoltaic power (PV)

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1. Introduction

In the last decade, the international institutions have a strong commitment with the climate neutral economy, as goal for Horizon 2030 [1, 2]. Into this commitment, from 2019, the European Union (EU) pass the EU Green Deal, to promote the clean energy production [3, 4]. Growing energy demand and water consumption have increased concerns about efficient wastewater treatment. For this basic utility, at least two possible systems may be used. One is the activated sludge process, a conventional biological process used for reduction of organic matter present in the wastewater. It involves the oxidation of carbonaceous biological matter for reduction of the organic pollutants. The process takes advantage of aerobic micro-organisms that can digest organic matter in wastewater and is then wasted as sludge. Thereby, they remove the non-active microbes from the system and provide an effective reduction of pollutant parameters. This system has been installed for various municipalities and industries. Another system of wastewater treatment is the high rate algal ponds system (HRAP) that have great potential for biofuel production where climate is favourable, since the costs of algal cultivation and harvest for biofuel production are covered by the wastewater treatment function. It can be used to provide community-level energy supply [5]. Microalgae are promising alternative renewable sustainable energy sources as they produce large amounts of biomass which can be used for production of "third-generation biofuels" [6].

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HRAP system shows important advantages as compared to the AS, among which we can cite the biomass production [7], the atmospheric CO2 fixation [8, 9] and a lesser energy consumption [10, 11]. Indeed, the wastewater tertiary and quandary treatments take advantage from the microalgae culture as, while generating biomass, they take inorganic nitrogen and phosphorus for their growth [12, 13]. Moreover, microalgae avoid secondary pollution as they remove heavy metals, as well as certain toxic organic compounds.

Regarding the economic aspect, HRAP is considered a low-cost wastewater treatment system as compared to conventional electromechanical systems with construction costs typically 70% less than AS [14]. Operation cost is also less in HRAP as it requires substantially less energy than activated sludge systems [15, 16, 17]. This also cuts down greenhouse gas emissions [18]. Even in HRAPs the electricity requirement is only 0.04–0.15 kWh kg^{-1} O2 produced [19]. The integrated wastewater treatment amortized capital and operation costs in HRAP are only 25–33% of those of secondary-level activated sludge treatment [20, 21]. However, if we intend to cover the same wastewater needs, that is, to serve the same population equivalent, as we shall see, the algal wastewater systems have a clear disadvantage as compared to activated sludge systems: HRAP takes up a much larger surface than the activated sludge systems [18]. The availability of large surface areas, as well as the cost of these wide terrains, are the main inconvenient of these algae systems. Thus, they are best fitted for rural, suburban and remote communities as they require minimum power and little on-site management [23, 18, 14].

On the other hand, the algal growth is affected by several aspects, such as the interactions among physical factors, the nutrient availability, biotic factors, the temperature and the light intensity [12, 24]. Thus, under outdoor conditions, the meteorology is a decisive element in the algal productivity. Indeed, excessively high or low values of temperature or light intensity can lead to the algal productivity inhibition. Thus, in the case of outdoor conditions, it is important to analyze the viability of algal wastewater plant projects according to these two variables, which can strongly vary along the year.

The viability of wastewater treatment plant projects can be assessed by the exceedance probabilities, in the same way as the viability of solar plant projects [25]. Indeed, every project output is exceeded with certain probability (exceedance probability). Then, as this probability increases, the output decreases. That is to say, every exceedance probability is associated with the complementary percentile: for example, P90 (exceedance probability of 90%) is associated with percentile 10; P99 (exceedance probability of 99%) is associated with percentile 1, and so on. According to [26], in the assessment of the viability of solar plant projects three exceedance probabilities are recommended (P950, P90 and P99). These probabilities represent bad cases (small percentiles) and thus, they allow us to estimate damaging outcomes in the project. However, for now we do not have a threshold which allows us to qualify a project as viable, or not viable, and this viability depends on each case considered. Indeed, the storage capacity, as well as the energy demand, plays a main role in this qualification. This handicap is even more evident if we intend to compare several systems, whose power needs are very different. Thus, we have to focus the study on their capacity of storage and energy demand.

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Actually, the discontinuity in the productivity can be largely diminished by storage. When we use the photovoltaic technology, we may consider solar energy as a random, uncertain, but we can make it certain by compensating energy lacks below a certain threshold with energy surpluses. Then, entropy as a measure of uncertainty is reduced. Self-sufficiency may be attained taking the conventional threshold as the demand, and guaranteeing the supply that meets this demand. In economic theory, this is the flow-fund model, the stock being the storage hoarded and the flow being the inflows of energy that pass by. We move from a linear economy to a circular economy or even a 'Spiral Economy' [27, 28].

Besides, we need to have more environment-concerned storage design and then, natural biomass derived carbons are excellent alternatives for substituting conventional carbon materials toward a wide range of applications [29, 30]. Some biomass is even recycled from the agricultural or daily wastes [31]. In particular, the HRAP system can achieve energetic self-sufficiency from its own biomass; the activated sludge system needs an external system that provides energy, for example the photovoltaic technology. The different needs of both space and energy consumption between the two wastewater treatment systems lead us to assess their viability considering surface needed and consumption. We try to achieve the self-sufficiency capacity, in the sense that the energy consumption associated to the system is covered by the energy supplied by the system itself.

According to the previous considerations, the main aim of this work is to compare the viability of wastewater treatment projects under outdoor conditions by HRAP and by activated sludge conventional systems, reinforcing this last system with a PV facility. This viability is based on the capacity of project self-sufficiency, and it is assessed from the probability of meeting certain consumption thresholds, considering two cases: absence of storage and full capacity of storage. Obviously, self-sufficiency does not always imply cheaper energy prices, but we must make the most of energy needs for wastewater treatment projects.

The work is organized as follows: first, the models performed to estimate the algal productivity and the PV power have been described, as well as the stations where the study takes place. Second, the methodology for achieving the aims of the work is presented. Next, the results are shown and discussed. In this sense, we develop a large analysis, according to the PV surface, where systems with and without storage are considered and compared. Finally, an opportunity cost analysis is included.

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2. Materials and Methods

The two wastewater systems compared in this work (HRAP and AS+PV) are designed to serve a population equivalent to 10,000. The HRAP system defined in this work only consumes 0.06 kwh/m^3, while the activated sludge conventional system defined in [28] consumes 0.89 kwh/m^3. We intend to analyse the viability of covering these consumptions in a self-sufficient way: the necessary energy for the activated sludge system is provided by a PV system, while the energy for the HRAP system will come from algal productivity. In this sense, two aspects must be taken into account: on the one hand, the surfaces which must be covered by algal ponds and by PV panels in order to satisfy the respective demands; on the other hand, the economic aspect of both systems.

1.1. *Algal and PV productivity*

The algal productivity depends on two meteorological variables: photo-synthetically active radiation (PAR) and temperature. In the case of the PV system, its productivity depends on the Global Horizontal Irradiance (GHI). We use two scenarios described in [28] to perform two productivity models, one for the HRAP system and the other for the activated sludge system.

1.1.1. Algal productivity model

A revision of models developed to estimate the algal productivity can be seen in [29]. In this work, we have used the model performed in [30], according to which the productivity P_{bio_est} can be estimated from the difference between the specific growth rate, G, and the specific respiration rate, R. In turn, these rates can be assessed as follows [31].

$$G = \frac{1}{l_p} \int_0^{l_p} \mu_m \, x \frac{\sigma \, I \, e^{-\sigma x z}}{K_I + \sigma \, I \, e^{-\sigma x z}} dz \quad (1)$$

$$R = \lambda_r \, x \quad (2)$$

The parameters of these expressions are shown in Table I.

Table 1. Productivity model parameters

Parameter	Units	Description
z	M	local depth
σ	$m^2\ kg^{-1}$	extinction coefficient
μ_m	s^{-1}	specific growth rate
I	$W\ m^{-2}$	Photo-synthetically active radiation at the pond top surface
K_I	$W\ kg^{-1}$	half-saturation parameter
l_p	M	pond depth
T_p	ºC	pond temperature
x	kg/m^3	biomass concentration

λ_r	s-1	respiration coefficient

Where:

$$\mu_m = \mu_{m,max}\emptyset_T \qquad K_I = K_{I,max}\emptyset_T \qquad \lambda_r = \lambda_{r,max}\emptyset_T \tag{3}$$

being $\emptyset_T$ the temperature-dependent function:

$$\emptyset_T = 0 \text{ if } T_p \leq T_{min} \text{ or if } T_p \geq T_{max}$$
$$\emptyset_T = \frac{(T_p - T_{max})(T_p - T_{min})^2}{(T_{opt} - T_{min})[(T_{opt} - T_{min})(T_p - T_{opt}) - (T_{opt} - T_{max})(T_{opt} + T_{min} - 2T_p)]} \text{ otherwise} \tag{4}$$

T_{min} and T_{max} are the minimum and maximum temperatures, respectively. Thus, they show the minor and major thresholds for the specific growth rate; T_{opt} is the optimum temperature for this rate.

Experimental values for these parameters have been taken from [32] (Table II)

Table II. Experimental parameters [31]

x (kg/m3)	l_p (m)	σ ($m^2\ kg^{-1}$)	T_{min} (ºC)	T_{max} (ºC)	T_{opt} (ºC)	$\mu_{m,max}$ (s^{-1})	$K_{I,max}$ ($W\ kg^{-1}$)	$\lambda_{r,max}$ (s^{-1})
0.4	0.3	120	-10	42.1	35.8	$6.48\ 10^{-5}$	7192.92	$2.01\ 10^{-6}$

Besides, in this work we have considered the HRAP system described in [28]. The scenario 1 of this work considers a system with a total area surface of 40,000 m^2 and a flow rate of 1,950 m^3d^{-1}, whose total energy consumption is 0.06 kwh/m^3.

1.1.2. PV productivity model

PV power can be estimated from GHI and temperature using the following expression [33, 34]:

$$PV_{est} = GHI\ PV_{ins}\ PCS_{loss}\ System_{loss}\ \frac{1}{G_s} T_{loss}$$

where PV_{est} is the power generation estimation, PV_{ins} is the PV installation capacity, PCS_{loss} are the power losses due to the power conditioning system, $System_{loss}$ are the losses associated to PV system, G_s is the GHI at standard test conditions and T_{loss} is a reduction parameter related to the PV module temperature. This last parameter can be estimated as follows:

$$T_{loss} = 1 + \frac{\alpha_{pmax}(T_{air} + \Delta T - 25)}{100}$$

where α_{pmax} is the temperature dependency of PV power generation, T_{air} is the atmospheric temperature and ΔT is the difference in PV module temperature.

The values taken from [34] for the different parameters are shown in Table III.

Table III. Estimation of parameters for PV productivity model

parameter	Units	Estimation
PCS_{loss}		
0.95		
$System_{loss}$		
0.95		
G_s		kw/m²
1.0		
α_{pmax}	%	-
0.485		
ΔT		ºC
20.0		

The model above described has been performed again from a scenario described in [28] (scenario 3 of this work, corresponding to an activated sludge system). The flow rate is the same than in the HRAP system (1,950 m^3d^{-1}), but the total surface area is much lesser than in the algal pond system (only 900 m^2 vs. 40,000 m^2). The total energy consumption in this system is 0.89 kwh/m^3 (much higher than that of the first system).

1.2. Data

GHI, PAR and temperature collected from two measurement stations are used for the work. The coordinates and type of climate corresponding to both stations are shown in Table IV.

Table IV. Measurement stations

Station	Coordinates	Climate
Tabernas	37.09ºN 2.35ºW	Arid Mediterranean
Lugo	42.99ºN 7.54ºW	Oceanic

The station located in Tabernas (Spain) has an arid Mediterranean climate (BShs in Köppen classification) with cool winters and very warm summers. Temperatures range from -5 ° C to 45 ° C. Rainfall is very low, accumulating an average of only 243 mm.

On the other hand, Lugo is a city in north-western Spain. It has a humid oceanic climate with dry summers, Cfb in the Köppen climate classification. Due to its remoteness from the Atlantic, its annual precipitation of 1,084 millimetres can be considered low compared to the near areas.

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1.3. Methodology

Below we list the steps followed to carry out this work:

a) Algal and PV productivities are estimated from PAR and temperature data in the study stations. These estimations are carried out for the two systems studied (HRAP and AS + PV), considering the results both with storage and without storage. In turn, the PV facility is performed for different surfaces.

b) Probabilities of not achieving the energy consumption threshold (0.89 kwh/m^3) one day in the activated sludge system, according to the surface occupied by PV panels, are determined for each station and for different PV surfaces.

c) Probabilities of not achieving the corresponding HRAP energy consumption threshold (0.06 kwh/m^3) are also determined for each station.

d) A PV facility viability assessment by exceedance probabilities is also included. For it, P50, P90 and P99 are estimated according to the PV surfaces for both cases, with and without storage.

e) Finally, an opportunity cost analysis is included. For this analysis, we have compared the costs associated to both studied systems (HRAP and AS + PV). For HRAP case, two costs are considered: the capital cost and the terrain cost. For AS + PV, apart from the capital cost of AS, the capital and operation cost of PV, the terrain cost and, in case of storage, the economic storage pack cost, are considered. Other possible opportunity costs are pointed out.

3. Results and discussion

1.1. Surface analysis

1.1.1. No storage

The intra-annual variability of the HRAP system productivity, along with that of the meteorological variables (PAR and temperature) affecting this productivity are shown in Figure 1. This productivity has been estimated from the model and scenario previously described (40,000 m^2 of surface and flow rate of 1,950 m^3 d^1).

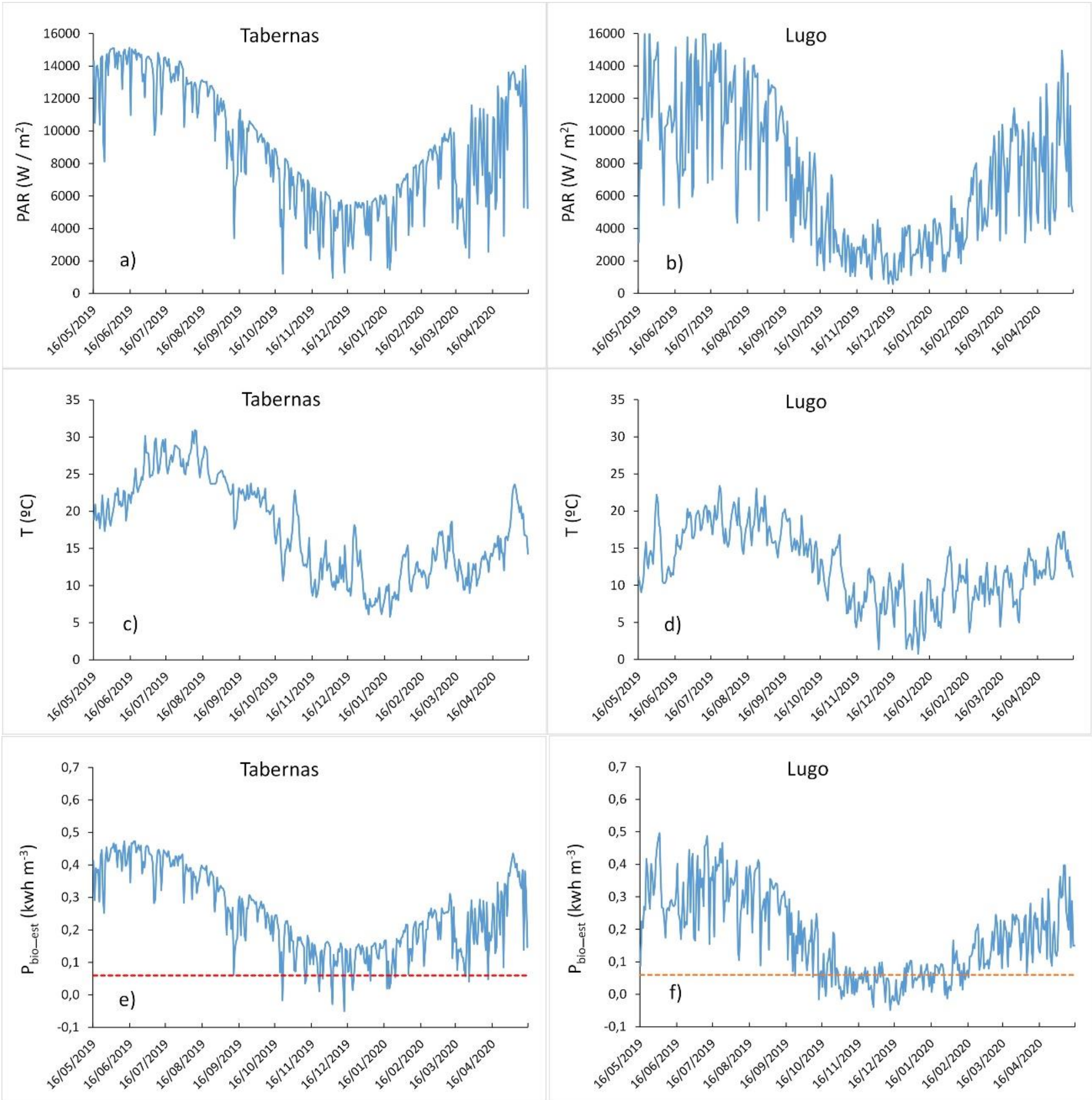

Figure 1. Temporal evolution of: PAR (a) and b)); Temperature (c) and d)); Power from biomass estimated along with HRAP energy consumption (0.06 kwh/m^3) (e) and f)).

The seasonal variability of PAR and temperature can also be observed in the power curves. Regarding PAR, Lugo station shows more fluctuations than Tabernas station, due to the oceanic climate of the former. In this climate, precisely, the seasonal variation is less pronounced. Thus, as mentioned, the power curves under outdoor conditions are clearly affected by these climatological aspects.

On the other hand, the difference between the surfaces occupied by both systems (HRAP and activated sludge system) is very large (40,000 m^2 vs. 900 m^2). The energy consumption of the HRAP and of the activated sludge system is also very different (0.06 kwh/m^3 vs. 0.89 kwh/m^3), so the power need is much lower in the case of the algal system. In fact, the power derived from HRAP covers this consumption most of the year. However, covering the 900 m^2 of the activated sludge system with PV panels of 2 m^2 with an installation capacity of 400 w (450 solar panels), the PV power never reaches this threshold.

Thus, in order to achieve self-sufficiency, we need to increase the PV power and thus, the surface occupied by panels. In Figure 2, we show the PV power obtained for different areas.

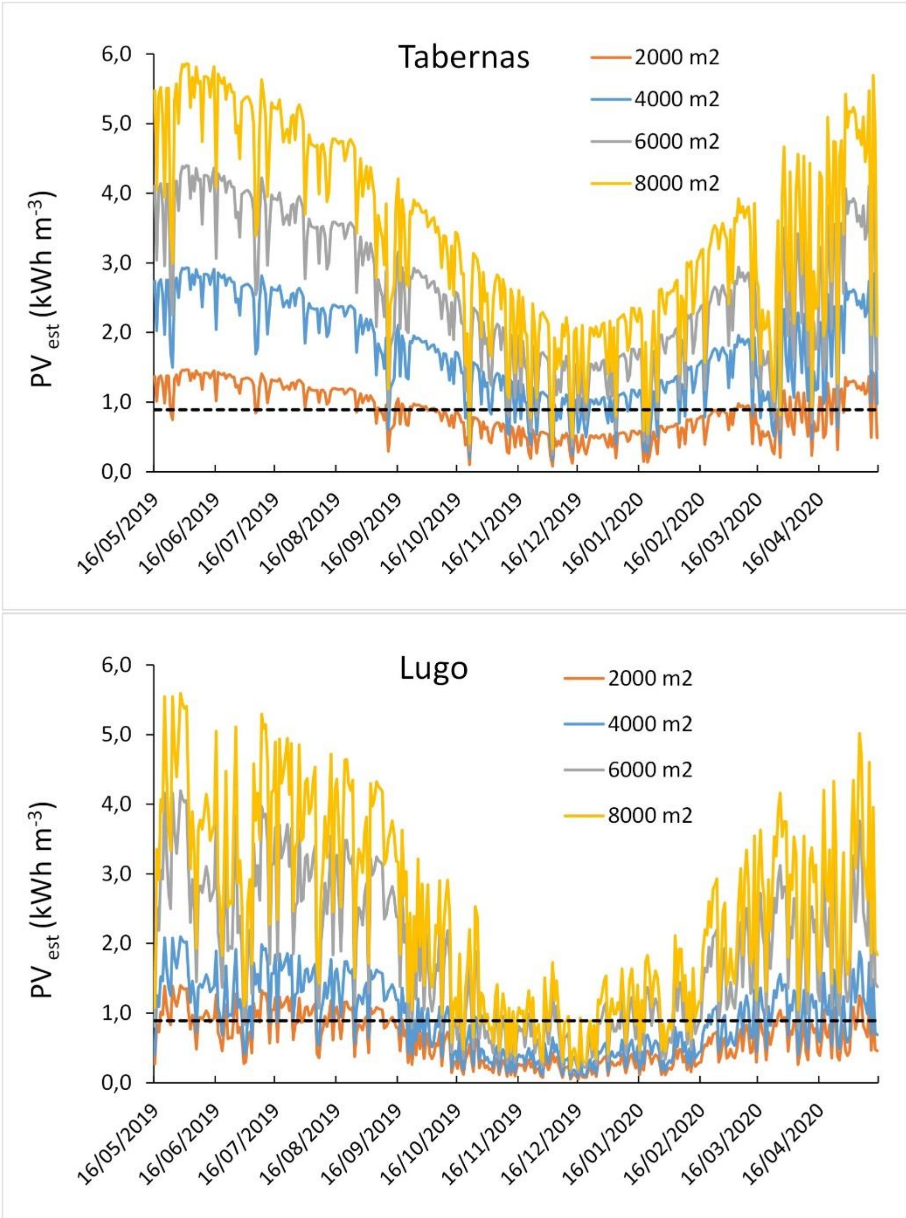

Figure 2. PV power for different areas; the energy consumption threshold (0.89 kwh/m^3) is included

As surface occupied by the PV facility increases, the number of days in which the energy consumption threshold is overcome also increases. The same as the case of power derived from biomass, the seasonal evolution, associated to climate characteristic, is evident. This evolution is more pronounced in Tabernas and has more daily fluctuations in Lugo.

In order to compare the PV powers (Figure 2) with the energy consumption threshold (0.89 kwh/m^3), we estimate the probability of not achieving that threshold at least one day, according to the surface

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occupied by PV panels (Figure 3). This probability can serve to assess the viability of the project when a PV facility supplies the energy needed by the activated sludge system. As observed, the decreasing slope is very pronounced for smaller surfaces, but later this slope strongly diminishes. This change in the slope is more abrupt in the case of Tabernas. In Figure 3, we have included the probabilities of not achieving the corresponding HRAP energy consumption threshold (0.06 kwh/m^3). These probabilities are 0.0546 for Tabernas case and 0.2077 for Lugo. In this situation, the behaviour of both systems could be considered similar, as the probabilities of not achieving the corresponding thresholds, according to the system considered (HRAP or activated sludge system with PV power) are the same. These intersection points are obtained for 6,030 m^2 in Tabernas and for 6,552 m^2 in Lugo. Thus, these surfaces of PV panels are needed to obtain the same probability than in the 40,000 m^2 HRAP system.

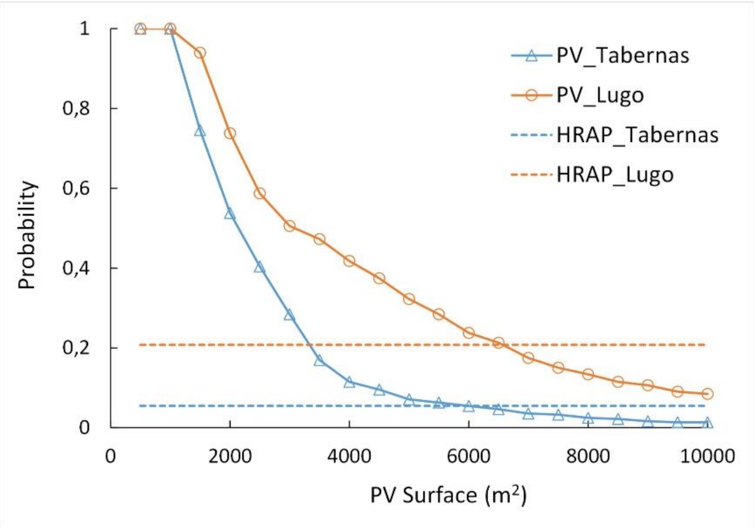

Figure 3. Probability of not meeting the energy consumption threshold at least one day

1.1.2. With storage

The former study does not consider the possibility of storing the energy surplus during those days in which the corresponding energy consumption threshold is exceeded. However, this possibility must be taken into account, as it is very difficult to reach the consumption threshold every day. Thus, in this section we study the self-sufficiency in both analysed systems assuming that the possible energy surplus of one day is available for subsequent days.

1.1.2.1. HRAP system

In the case of the HRAP system, the estimated power from biomass shown in Figure 1 (e) and f)) can be modified by storing the energy that overcomes 0.06 kwh/m^3 and by supplying this energy those days in which the power is lower than this threshold. By this storage system, the power intra-annual evolution no longer shows values below 0.06 kwh/m^3 (Figure 4).

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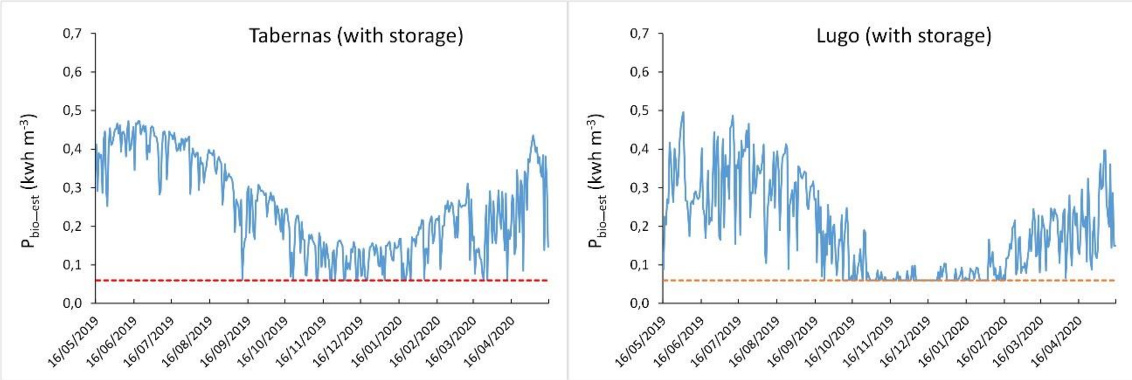

Figure 4. Temporal evolution of power from biomass using storage along with energy consumption (0.06 kwh/m³)

1.1.2.2. Activated sludge system with PV panels

Similar to the variability without storage represented in Figure 2, the PV power intra-annual variability in case of storage for different PV surfaces is shown in Figure 5. The graphs show that, as surface increases, the possibility that the threshold is achieved all days also increases. Indeed, for the surfaces represented, this achievement is accomplished from 4,000 m², in the case of Tabernas, and from 6,000 m², in the case of Lugo. The daily fluctuations are again much more pronounced in Lugo than in Tabernas.

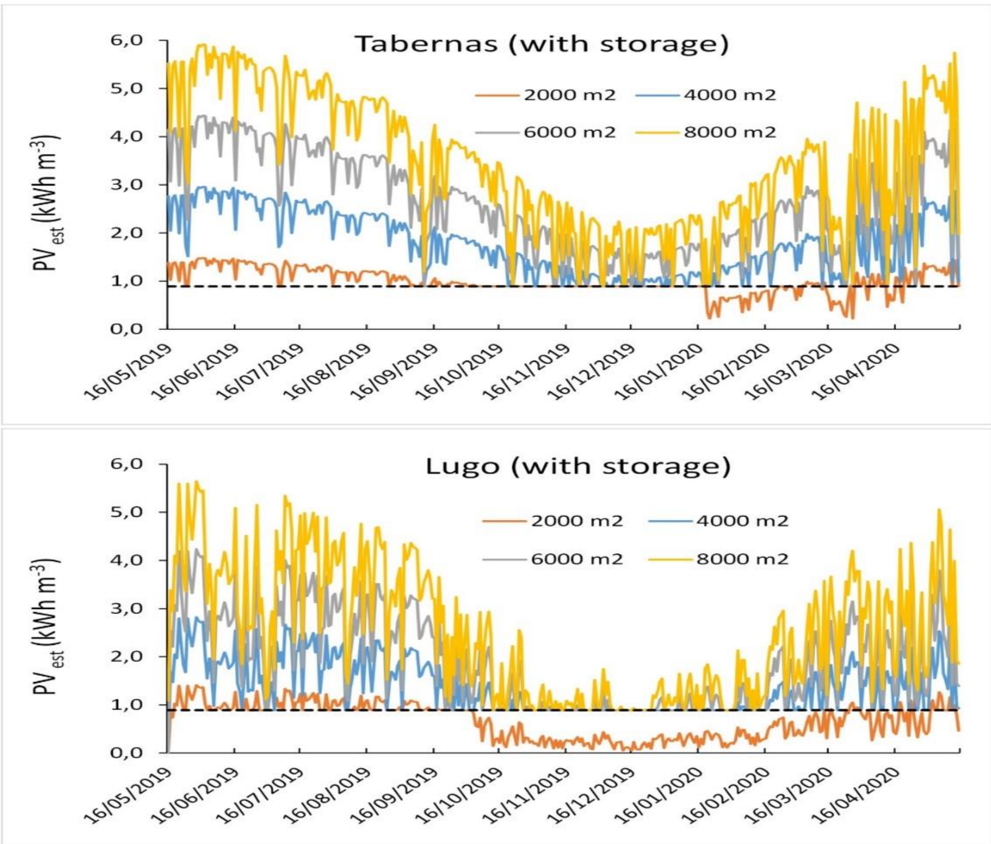

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Figure 5. PV power for different areas considering storage; the energy consumption threshold is included (0.89 kwh/m³)

Similarly to the case without storage (Figure 3), we can include storage and obtain the probability of not achieving the corresponding threshold at least one day according to the surface occupied by PV panels (Figure 6). This probability can serve again to assess the viability of the activated sludge system based on PV facility. In this case, the null probability is quickly reached (for 2,500 m² in Tabernas and for 3,500 m² in Lugo), unlike the case without storage where this null probability is never reached. That is, the storage allows us to ensure that the demand is always satisfied by using much less PV surface, making the project more viable. On the other hand, the probabilities of not achieving the corresponding threshold for one day in the HRAP system, when storage is considered, are 0 in both stations, as all values overcome this threshold (0.06 kwh/m³) (Figure 4). Thus, 2,500 m² in Tabernas and 3,500 m² in Lugo are, precisely, the surfaces needed to reach the same probability than in case of 40,000 m² HRAP system with storage. Therefore, thanks to storage, the surface needed has been greatly reduced in both locations.

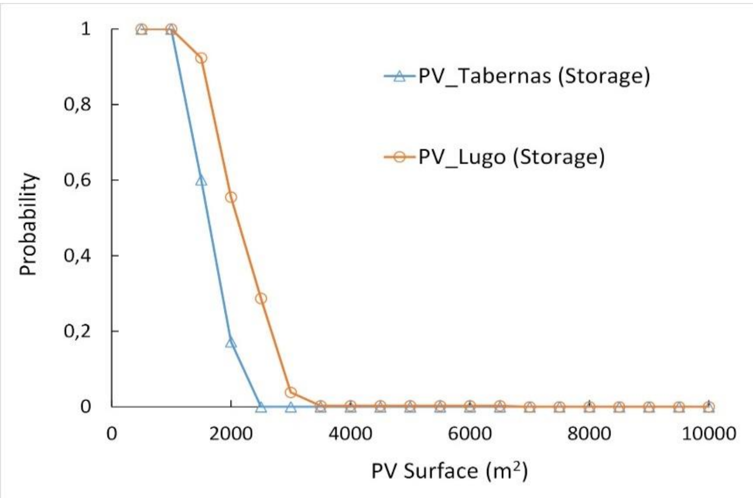

Figure 6. Probability of not meeting the energy consumption threshold considering storage

1.1.3. Storage vs. No storage

The project viability based on PV power has also been assessed by three recommended exceedance probabilities (P50, P90 and P99). In Figure 7, exceedance probabilities vs. the PV surface have been represented for both cases, with and without storage. Since the PV power increases with the surface used, the exceedance probabilities also increase as this surface increases.

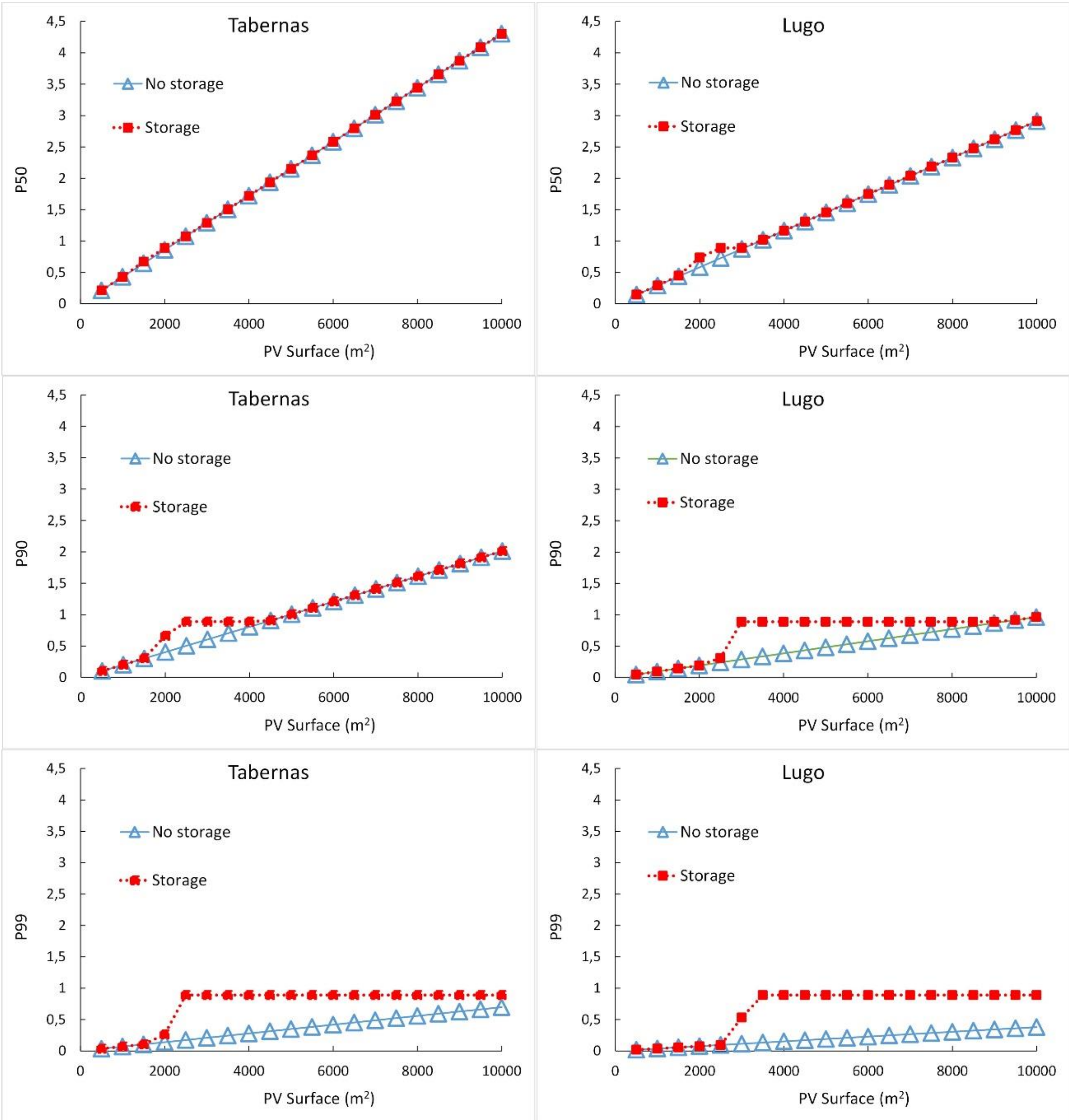

Figure 7. Exceedance probabilities according to the PV surface

As observed, the slopes are higher in Tabernas than in Lugo, as the power achieved by PV is clearly higher in Tabernas, with Mediterranean climate, than in Lugo, and this is more evident as the PV surface increases. Storage brings probabilities higher or equal than those obtained in absence of storage, as power is increased by storage. Besides, storage affects small PV power, so the lower percentiles increase with storage. Thus, there is a greater difference between both cases (storage and absence of storage) for higher exceedance probabilities, associated to lower percentiles. That is, the differences between P99s are higher than the differences between P50s.

These probabilities provide information about the system, but they do not allow us to qualify a project as viable or not viable, unlike the study based on the project self-sufficiency. To achieve self-sufficiency, the estimate of the size of a power facility is of great interest. Indeed, we have above estimated the PV facility surface required to satisfy the need of energy consumption in the activated sludge system (Figure 3 in absence of storage and Figure 6 with storage). According to the results, storage leads to a large diminishing in this surface: in absence of storage, the probability of not achieving the energy consumption threshold is always higher than zero in both stations, while this probability is zero for 2,500 m^2 at Tabernas and for 3,500 m^2 at Lugo, when storage is considered.

1.2. Opportunity cost analysis

In the previous sections, we have assessed space needs for self-sufficiency of projects. However, the EU Green Deal needs also to assess the opportunity cost of different energy sources, in special in terms of the availability and possible alternative uses of land or capital. Some green energy sources have great inconveniencies in terms of the needs of land and the loss of its alternative uses. Besides, the wastewater treatment systems proposed in the work need specific orographic conditions, such as non-steep slopes and they must not be installed in protected areas due to environmental reasons. Finally, other terrain uses must be considered, such as the profitability of a possible agriculture or livestock exploitation, which also implies benefits for farmers drawn from the diversification of income. In this sense, we need to take into account that the optimal social and private solutions may differ.

The EU Green Deal aims at reaching the target of climate neutrality. Then, we need to decarbonise the energy system, prioritise energy efficiency and develop a power sector based largely on renewable resources. But this objective will only be achieved by an opportunity cost analysis between alternative renewable energies. For instance, the extensive need for terrain in the HRAP projects limits their viability and conveniency as compared to AS+PV – the need for land is 40.000 m^2 versus less than 6.500 m^2. However, the prices of both systems also need to be compared. A von Thunen framework [35] is suitable for analysing economic decisions when distance from different uses of energy matters. Transport is costly and reduces the profitability of bioenergy production when the distance to the power plant increases. In this case, distance is zero, but we could compare the result obtained with the alternative supplies of energy from other possible locations, as well as the possible uses of the energy produced in these locations in other facilities or industries. Some studies compare the process which uses the combustion of biomass with that of biocrude extraction [36]. Besides, as previously mentioned, different possible uses of the surfaces could be assessed [37, 38]. These price comparisons are very specific of each location and moment and, so, they need to be done by each project.

Being aware of the circumstantial character of this price analysis, we have made an economic analysis comparing the costs associated to both analysed systems, HRAP and activated sludge system with PV facility. For HRAP case, two type of costs are considered: the capital cost and the terrain cost. The operation and maintenance cost (energy and flocculant consumption) is not included as the energy consumption is supplied by the algae itself. According to [28], the capital cost is 192.55 €/p.e. Since the system was designed to serve a population equivalent to 10,000 p.e. the total capital cost will be 1,925,500 €. The terrain cost is also different according to the site considered (71.9 €/m^2 at Lugo and 150.8 €/m^2 at Tabernas according to the Spanish Official Statistics, http://www.fomento.es/be2/). As regards to the activated sludge system with PV facility, according to [10], the AS construction costs are typically 70% higher than those of HRAPs, so the capital costs may be established in 6,418,333 €.

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On the other hand, the capital and operation cost of PV is 350 €/m² (an average estimation of the one offered in [39]). Additionally, we must add the terrain cost. Finally, we include the economic storage pack cost, that according to [40] we can estimate in 200 €/kwh of the battery energy storage systems. For the case of Lugo, the need of storage for 3,500 m² is of 94.7 kwh, while for Tabernas in 2,500 m², this need is of 81.1 kwh. The costs obtained for both systems are shown in Table V:

Table V. Economic costs

System	Station	Storage	Surface (m²)	Capital cost of HRAP or AS (€)	Capital and Operation cost of PV (€)	Storage pack cost (€)	Terrain cost (€)	Total cost (€)
HRAP	Lugo	No	40,000	1,925,500			2,876,000	4,801,500
	Tabernas	No	40,000	1,925,500			6,032,000	7,957,500
AS + PV	Lugo	No	6,552	6,418,333	2,293,200		471,089	9,182,622
		Yes	3,500	6,418,333	1,225,000	18,940	251,650	7,913,923
	Tabernas	No	6,030	6,418,333	2,110,500		909,324	9,438,157
		Yes	2,500	6,418,333	875,000	16,220	377,000	7,686,553

As we see, the total cost in the HRAP system is clearly lesser than in the AS+PV system in absence of storage. The difference is mainly due to the important capital cost of AS, although the difference in the terrain cost is, especially in Tabernas, very high, something that affects more the cost of the HRAP system. On the other hand, the presence of storage allows us to reduce significantly the costs of the PV facility. For example, in the case of Tabernas, although the HRAP system is less costly than the AS+PV system in a -15.7%, storage makes it more costly in a 3.5%. Indeed, storage provides a great advantage for using the AS+PV in locations where we have a lot of irradiance, as is the case with Tabernas. We can even consider the existence of a threshold of the irradiance needed so as to improve the costs of the AS+PV with relation to the HRAP.

Then, the previous considerations about disadvantages linked to large surface needs of HRAP system seem to be balanced out by the little requirement of capital linked to HRAP. As we show, this opportunity cost analysis is then essential for a better assessment of different energy sources.

5. Conclusions

Aiming at achieving the energy efficiency proposed by the EU Green Deal, this work compares the viability of wastewater treatment projects under outdoor conditions by high rate algal ponds and by activated sludge systems, complementing this last system by a PV facility. It introduces a viability analysis based on the capacity of project self-sufficiency, so that the energy consumption associated to the system is covered by the energy supplied by the system itself. This energy consumption is much smaller for HRAPs than for activated sludge systems, in which PV power is needed to supplement this energy. However, algal ponds systems require much larger surfaces.

In order to assess the mentioned viability, the probability of not achieving the energy consumption threshold for at least one day is studied, considering both absence of storage and full capacity of storage.

From these considerations, the following conclusions can be drawn out:

1) PV power, the same as power derived from biomass, follows a seasonal evolution associated to climate characteristic. In the stations of study, this evolution is more pronounced in Tabernas and has more daily fluctuations in Lugo.

2) If we pass from a HRAP system to an activated sludge system with PV power, we can achieve the self-sufficiency system by reducing greatly the occupied surface. In Tabernas, we reduce it from 40000 m^2 in HRAP up to 6030 m^2 or 2500 m^2 of PV surface – considering, or not considering, storage - and up to 6552 m^2 or 3500 m^2 in Lugo.

3) PV power exceedance probabilities increase with the PV surface, and the probability differences between situations with storage and without storage increase for higher exceedance probabilities. These probabilities do not allow to qualify a project as viable, or not viable, unlike the study based on the project self-sufficiency.

4) Entropy and radical uncertainty are reduced by using the flow-fund model. Governance within green energy industries and in the economy as a whole need to include the expectation of storage to avoid uncertainty. Storage allows us to reduce significantly the costs of the PV facility, so it provides a great advantage for using the AS+PV in locations where we have a lot of irradiance.

5) However, economic differences between surface prices should be compared, as well as the distance from different uses of energy. Here, we have compared the total cost of the HRAP system with that of AS+PV showing that the latter is higher due to the important capital costs associated to AS, in spite of the fact that surface needs lead to a significant increase in the cost of HRAP systems.

6) As we see, the opportunity cost analysis is essential for a better assessment and understanding of different energy sources.

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