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Energy Assessment of a Tannery to Improve Its Sustainability

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Abstract: The tanning industry is one of the highly polluting sectors, and it is only in the last few years that studies on the energy improvement of tanneries started to proliferate in the literature. Even though the energy cost of a tannery is only a small fraction of the total cost, many tanners became aware of the importance of improving energy efficiency and reducing the environmental footprint to keep the business afloat and be more competitive in the market. This paper presents a study on increasing the sustainability of a tannery located in the region of Catalonia, Spain. Several measures to increase its energy efficiency and reduce its primary energy consumption were proposed and analysed including, among others, the implementation of solar thermal collectors and photovoltaic panels. A cost analysis of the most promising solutions was carried out and discussed. The results show that the tannery should invest between EUR 2 to 2.5 M to obtain the highest energy savings, with an estimated payback period between 5 and 7 years. However, acceptable energy savings can be obtained with a lower investment cost of between EUR 1 to 1.5 M, with a shorter payback period of between 2 and 4 years.

Keywords: tanning industry; energy efficiency; renewable energy; sustainability; cost analysis

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1. Introduction

Recently, evidence of global warming [1] has caused increased concern about climate change. Most governments are aware of the great danger that the continuous increase in the planet's temperature represents for the future of their countries and have begun to reach agreements to implement measures to stop this increase and, if possible, reverse it [2]. One of the proposed solutions involves changing the current energy model, looking for new energy sources, and optimizing energy consumption [3].

In order to reverse the current situation of continuous temperature rise, the collaboration of the industrial sector, which consumes a large amount of energy, is essential [4]. Common consumer goods are manufactured thanks to this energy. Industry must continue to provide the products it now makes, but at a lower energy cost.

One of the industries that have traditionally been considered highly polluting is the tanning industry [5], a widespread industry in developing countries [6]. Nevertheless, recently, a very important effort has been made to improve the sustainability of companies in this sector, called tanneries. Some of the studies carried out and their results have been reflected in publications edited by various organizations, such as the European Union [7]. Most of the corrective actions implemented and recommended are on generated wastes (solid and liquid). The studies carried out have made it possible to greatly improve the processes, and both the emission of waste and the risk of toxicity for workers have been greatly minimized [8].

It is estimated that the energy cost of a tannery is approximately 3% of the total cost [9]. The low economic impact of energy expenditure has meant that in most cases no efforts were made to reduce or optimize it.

Some important actions have been carried out so far, especially by UNIDO, in developing countries. One of these actions was the replacement of fossil energy sources (with constant problems of regular supply) with much more sustainable energy (solar) in Bangladesh [10] and India [11]. Another important action carried out was related to energy savings through the relocation, modernization, and implementation of more sustainable energy technologies affecting tanneries in countries as diverse as Argentina, Bangladesh, Egypt, Ethiopia, Italy, Mexico, Sri Lanka, Tunisia, and Turkey [12]. The treatment of solid waste [13] and sewage sludge [14] to produce biogas has been tested. The European Union also contributed by financing projects that contribute to energy savings in tanneries [15]. Moreover, there have been academic studies on energy supply and optimization [16]. However, until a few years ago, the bibliography on the energy improvement of tanneries was scarce. This situation is changing. Energy efficiency is increasingly a requirement for tanneries, including those in the most developed countries. Many tanners have realized that the survival of their tanneries depends on being as energy efficient as possible. In the most developed countries, the problem is no longer the regularity of the energy supply, but rather the consumption of cleaner and renewable energies, and in a more efficient way, to help curb global warming.

The tanning industry is global. There are tanneries scattered all over the world. A number of issues related to energy efficiency common to many tanneries have been identified. Some examples are inefficient boilers or heat loss from hot surfaces (pipes) [17]. However, each tannery has its own characteristics, such as the number of employees, the infrastructure available, the legislation of their country, etc. This makes it necessary to carry out an individualized study of the energy issues affecting each particular tanner, to evaluate ways to optimize their energy efficiency [18–22]. This will bring the possibility of proposing different possible and reasonable solutions from the economic point of view to help improve said efficiency. Different considerations have been published on regulations related to energy efficiency levels and the calculation of the carbon footprint in tanneries [23–26]. The implementation of corrective actions at a global level would be the way that would allow the tanning industry to take effective measures in a short space of time against the climate change that we are suffering. Nevertheless, in the scientific literature, the energy efficiency in tanneries still remains a research gap. All the companies located in the south of Europe are in a similar situation (climate, energy sources, energy price, etc.) and there is no similar study of tanneries located in this area in the literature.

This paper presents a study on how to increase energy efficiency and reduce the primary energy consumption of a tannery located in Spain. In particular, this paper is based on a real case study of a tannery which does not reach the highest sustainability requirements of energy consumption established by the LWG protocol. Different solutions, such as the replacement of key components of the plant and the implementation of solar thermal collectors and photovoltaic panels, were proposed and analysed. A cost analysis of the most promising solutions was also carried out and discussed. The results of this paper and the recommendation given in the conclusion can be taken as a reference by tanneries and other industries with similar energy requirements (i.e., high use of thermal energy) which aim to increase their sustainability requirement by means of increasing their energy efficiency. The rest of the material is divided into several parts. Thus, in Section 2, the input data provided by the company as well as the methodology applied to evaluate the sustainability of the tannery are presented. Section 3 presents the results in terms of recommendations for energy savings, implementation of renewable energy sources, and target reductions of primary energy consumption. Section 4 presents a rough cost analysis of the most promising improvement solutions and a discussion of the main outputs. Finally, the main conclusions and limitations of the study are given in Section 5.

2. Methodology

2.1. Input Data

The data used to carry out the assessment and to evaluate the potential of improving the energy performance of tanneries were from a tannery located in the region of Catalonia, Spain. This tannery produces wet blue, crust, and leather. In the production process, the tannery uses hot water, hot air, and steam, which are produced using natural gas and electricity as the main energy sources; the tannery also uses gasoil (for pallet trucks mainly) and water. Table 1 shows a summary of the consumption and production of the tannery for the period between 2019 and 2020. Moreover, the tannery has two gas boilers with the characteristics presented in Table 2.

Table 1. Summary of energy consumption and leather production for 2019 and 2020.

Year	Month	Production		Water	Gas	Electricity
		(ft^2)	(m^2)	(m^3)	(kWh)	(kWh)
2019	January	7.04×10^5	6.54×10^4	2.05×10^2	1.96×10^6	4.71×10^5
	February	7.48×10^5	6.95×10^4	1.85×10^2	1.79×10^6	4.97×10^5
	March	6.61×10^5	6.15×10^4	1.73×10^2	1.51×10^6	5.14×10^5
	April	4.58×10^5	4.26×10^4	2.67×10^2	1.09×10^6	3.11×10^5
	May	5.88×10^5	5.46×10^4	7.88×10^2	1.05×10^6	4.88×10^5
	June	5.71×10^5	5.31×10^4	6.59×10^2	8.77×10^5	4.54×10^5
	July	1.01×10^6	9.38×10^4	2.60×10^2	1.02×10^6	5.90×10^5
	August	1.71×10^5	1.59×10^4	1.19×10^2	2.94×10^5	2.23×10^5
	September	7.65×10^5	7.11×10^4	6.20×10^1	9.79×10^5	5.01×10^5
	October	7.78×10^5	7.23×10^4	1.03×10^2	1.24×10^6	5.46×10^5
	November	7.70×10^5	7.16×10^4	3.20×10^2	1.64×10^6	4.88×10^5
	December	4.68×10^5	4.34×10^4	0.00×10^0	1.42×10^6	3.93×10^5
2020	January	6.80×10^5	6.32×10^4	1.85×10^2	1.93×10^6	4.52×10^5
	February	6.86×10^5	6.37×10^4	1.85×10^2	1.67×10^6	4.82×10^5
	March	2.56×10^5	2.37×10^4	2.43×10^2	7.53×10^5	2.91×10^5
	April	2.27×10^5	2.11×10^4	2.76×10^2	5.84×10^5	1.55×10^5
	May	3.59×10^5	3.34×10^4	8.15×10^2	6.86×10^5	2.81×10^5
	June	1.28×10^5	1.19×10^4	6.59×10^2	6.31×10^5	2.92×10^5
	July	3.17×10^5	2.95×10^4	1.24×10^2	6.95×10^5	3.39×10^5
	August	9.12×10^4	8.48×10^3	6.60×10^1	2.28×10^5	1.28×10^5
	September	3.64×10^5	3.38×10^4	1.53×10^2	7.67×10^5	2.92×10^5
	October	4.00×10^5	3.72×10^4	1.06×10^2	9.67×10^5	3.28×10^5
	November	4.78×10^5	4.44×10^4	n.a.	n.a.	n.a.
	December	n.a.	n.a.	n.a.	n.a.	n.a.

Note: n.a.—not available.

Table 2. Specifications of the installed gas boilers.

Parameter	RCB MINOR 2000	LOOS UL-S 7000
Year	2016	1993
Volume (L)	1994	12,300
T_{max} (°C)	179.1	183.0
Power (kW)	1345	4566

2.2. Leather Working Group (LWG) Audit Protocol and Reduction Targets for the Case Study

The leather working group (LWG) protocol is used to assess the environmental impact of tanneries and leather producers and provide suggested guidelines for improvement. According to the LWG leather manufacturer audit protocol responses report (issue 7.1.0) [26], different quality categories in different aspects (social audit, water usage, air and noise emissions, etc.) are assigned based on a scoring system as shown in Table 3.

Table 3. LWG protocol audit summary (adapted from [26]).

					Minimum Requirement (%)				
		Max. Score	**Potential Score**	**Actual Score**	**Gold**	**Silver**	**Bronze**	**Audited**	**%**
01	General facility details	**-**			-	-	-	-	
02	Subcontracted operations	**100**			85.0	75.0	65.0	50.0	
03	Social audit	**50**			0	0	0	0	
04	Operating permits	**100**			85.0	75.0	65.0	50.0	
05	Production data	**100**			85.0	75.0	65.0	25.0	
06	Traceability (incoming)	**50**			0.0	0.0	0.0	0.0	
07	Traceability (outgoing)	**60**			0.0	0.0	0.0	0.0	
08	EMS	**100**			85.0	75.0	65.0	50.0	
09	RSL, Compliance, CrVI	**150**			85.0	75.0	65.0	50.0	
10	Energy consumption	**100**			85.0	75.0	65.0	25.0	
11	Water usage	**100**			85.0	75.0	65.0	25.0	
12	Air & noise emissions	**100**			85.0	75.0	65.0	50.0	
13	Waste management	**150**			85.0	75.0	65.0	50.0	
14	Effluent treatment	**150**			85.0	75.0	65.0	50.0	
15	H&S, Emergency Plans	**150**			85.0	75.0	65.0	50.0	
16	Chemical Management	**150**			85.0	75.0	65.0	50.0	
17	Operations Management	**100**			85.0	75.0	65.0	50.0	
	Total	**1710**			**85.0**	**75.0**	**65.0**	**50.0**	

From the table, it is possible to observe that, in the section "Energy consumption", the tannery can be classified into different quality categories based on the percentage (%) of the maximum total score (100). In particular, the energy consumption of the tannery can be classified as:

- Audited: if the total score is 25% of the maximum (25 points).
- Bronze: if the total score is 65% of the maximum (65 points).
- Silver: if the total score is 75% of the maximum (75 points).
- Gold: if the total score is 85% of the maximum (85 points).

2.3. Calculation of the Score Associated with the Energy Consumption

According to the LWG protocol, the criteria used to evaluate the energy consumption of the tannery include all aspects of site operations including administration, engineering, space heating, fork trucks, and operation of the wastewater treatment. The score for the energy consumption evaluation may be based on 9 months' worth of data per 12-month period provided a monthly breakdown of both energy usage and production data for the full-year period is available at the time of the audit.

The purpose of this is to screen out the peak energy requirements encountered during the very hottest or very coldest parts of the year. The nine months' worth of data may be selected by the tannery being audited although the excluded three months must be three consecutive months. The month-by-month production and energy usage must be included in the audit report. An additional three months of energy data may be excluded due to the effects on trade of the COVID-19 pandemic.

To evaluate the energy consumption, the actual fuel energy values must be supplied by tanner being audited. Furthermore, the energy associated with wastewater treatment must be included. Those companies that do not operate their own wastewater treatment plant must indicate the energy usage of the plant that is responsible for the treatment of their effluent, the volume of effluent treated, and therefore an apportioned amount of energy associated with the treatment of the volume of effluent generated by the tannery.

To calculate the score, the data related to energy consumption from different sources and the production are filled in the table shown in Table 4.

Table 4. Form to be filled to calculate the energy consumption score (adapted from [26]).

Energy consumption **Energy consumption includes ALL aspects of site operations such as administration, engineering, space heating, fork trucks, operation of the waste water treatment plant, etc. (excluding dormitories provided actual values can be shown)**				
Energy				
Calculation		Enter data	Conversion	Automatic
Supplied energy and fuels		Annual usage	Factor	MJ
Electricity	kWhr	0	3.6	0
				0
Fuels	Units (m^3, ltr, kg)			0
Natural gas		0	0	0
LPG		0	0	0
Fuel Oil		0	0	0
Coal		0	0	0
Diesel		0	0	0
Petrol/Gasoline		0	0	0
Steam		0	0	0
Other		0	0	0
External WWTP energy				
Electricity		0	0	0
Sustainably sourced renewable energy				
Wood		0	0	0
Tallow		0	0	0
Biomass		0	0	0
Self generated renewable energy				
Wind Turbine		0	0	0
Solar panel		0	0	0
Geothermal well		0	0	0
Other		0	0	0
	Total Energy			0
	Total bought in Energy			0
	Total Renewables			0
	Internally generated renewables			0
	Total Renewable Percentage			0.0
Average Thickness	(b, c, d & f category tanners only)			0.0
Total less self generated renewable Energy (MJ)	0	Energy MJ/m^2		
	m^2			
A Raw to Wet Blue	0			
B Raw to Crust	0			
C Raw to Finished	0			
D Web Blue to Finished	0			
E Crust to Finished	0			
F Wet Blue to Crust	0			
		Aggregate Score (max 90)		
			Max	90.0
			Min	0

In particular, the categories to be filled are:

- Supplied energy and fuels (i.e., natural gas, electricity, and diesel).
- External (wastewater treatment plant) energy (electricity).
- Sustainably sourced renewable energy (wood, tallow, and biomass).
- Self-generated renewable energy (solar, geothermal, and wind).

Furthermore, the total production of leather (m^2) through different tanning processes (raw to wet blue, raw to crust, raw to finished, etc.) has to be filled in the form. The specific energy consumption per surface of leather produced with different processes (MJ/m^2) is calculated considering the sum of all energy supplied/used less the self-generated renewable energy. According to the LWG protocol, correction factors may be applied based on the process. From the specific energy consumption, the score is then calculated based on the equations shown in Table 5 or using the table shown in Table 6.

Table 5. Form to be filled in to calculate the score according to the specific consumption (adapted from [26]).

Energy Use/Unit Output The value will be calculated on the basis of nine months' worth of data provided month by month production and energy data for a full year has been supplied. In the event that demonstrable, quantifiable changes have been introduced that provide evidence supported by at least 6 months data of on-going long-term energy savings the value base of those 6 months will be used.			
	MJm^{-2} finished product	Score	SCORE Based on total energy
A	Raw hide to tanned	$\frac{(\text{recorded usage} - 37.4)}{-0.34}$	
B	Raw hide to crust	$\frac{(\text{recorded usage} - 2.12t - 116.4)}{-1.06}$	
C	Raw hide to finished leather	$\frac{(\text{recorded usage} - 4.24t - 182.4)}{-1.66}$	
D	Tanned hide finished leather	$\frac{(\text{recorded usage} - 4.24t - 123.2)}{-1.12}$	
E	Crust hide to finished leather	$\frac{(\text{recorded usage} - 66)}{-0.6}$	
F	Tanned hide to crust leather	$\frac{(\text{recorded usage} - 2.12t - 57.2)}{-0.52}$	
	Score	Average score if more than one production type (based on proportions of area produced)	Max 90

Table 6. Table to calculate the corresponding score according to the specific energy consumption (adapted from [26]).

(MJ/m^2)	**Energy Consumption**					
	A	**B**	**C**	**D**	**E**	**F**
Points	**Raw to Tanned**	**Raw to Crust**	**Raw to Finished**	**Tanned to Finished**	**Crust to Finished**	**Tanned to Crust**
0	37.4	116.4	182.4	123.2	66.0	57.2
5	35.7	111.1	174.1	117.6	63.0	54.6
10	34	105.8	165.8	112.0	60.0	52.0
15	32.3	100.5	157.5	106.4	57.0	49.4
20	30.6	95.2	149.2	100.8	54.0	46.8
25	28.9	89.9	140.9	95.2	51.0	44.2
30	27.2	84.6	132.6	89.6	48.0	41.6

Table 6. *Cont.*

(MJ/m²)	**Energy Consumption**					
	A	**B**	**C**	**D**	**E**	**F**
Points	**Raw to Tanned**	**Raw to Crust**	**Raw to Finished**	**Tanned to Finished**	**Crust to Finished**	**Tanned to Crust**
35	25.5	79.3	124.3	84.0	45.0	39.0
40	23.8	74.1	116.1	78.4	42.0	36.4
45	22.1	68.8	107.8	72.8	39.0	33.8
50	20.4	63.5	99.5	67.2	36.0	31.2
55	18.7	58.2	91.2	61.6	33.0	28.6
60	17	52.9	82.9	56.0	30.0	26.0
65	15.3	47.6	74.6	50.4	27.0	23.4
70	13.6	42.3	66.3	44.8	24.0	20.8
75	11.9	37.0	58.0	39.2	21.0	18.2
80	10.2	31.7	49.7	33.6	18.0	15.6
85	8.04	25.0	39.2	26.5	14.2	12.3
90	6.8	21.2	33.2	22.4	12.0	10.4

The table shown in Table 6 can give a maximum score of 90. The rest of the points (i.e., 10 points) are given by filling out the form shown in Table 7. In this case, the energy produced by technologies that can reduce greenhouse gas emissions (i.e., co-generation), sustainably sourced renewable energy (biomass, by-products), and renewables are considered.

Table 7. Form to calculate the points associated with the use of renewables and/or sustainably sourced renewable energy or efficient technologies (adapted from [26]).

	What Proportion of the Factory Total Energy Usage Comes from Sustainably Sourced Renewable Sources?			
	The scoring is designed to award the commissioning of sustainably sourced renewable energy generating capacity	%	Score (per %)	Overall score (% × score)
A	Greenhouse gas emissions reduction technologies (Combined Heat & Power/Co-generation)	0–100	0.05	
B	GHG releasing sustainably sourced renewable energy usage provided that the conversion has been undertaken on-site or by plant owned wholly by the tanner	0–5 5.1–100	0.2 0.042	
C	Zero Greenhouse Gas Emissions technologies (Solar panels, wind turbines, etc.) Energy from these sources is not included in the energy calculation and are given an additional reward via this question to promote GHG reduction technologies	0–100	0.1	
	TOTAL(Max score 10)			

3. Results

3.1. Preliminary Energy Analysis of the Tannery

In 2018, of the total energy used by the tannery, 72% came from natural gas, 27% from electricity, and 1% from gasoil. Natural gas was used to produce hot water, hot air, and steam for most steps in the production of wet blue, crust, and leather. The share of gasoil was really low; therefore, it was disregarded. Even though the amount of energy used in 2020 was considerably lower (due to a decrease in production), the share of each energy source was similar in the three years evaluated, with the share of natural gas being between 73% and 75%. Indeed, in the production plant, natural gas is mainly used to produce hot water, steam, and hot air needed for most of the tannery processes to produce wet blue (beam house and tanyard processes), crust (post-tanning processes), and finished leather (finishing process). Table 8 shows the specific energy consumption in the tannery. The energy consumption in 2019 was similar to 2018, while production decreased; therefore, the specific energy consumption was higher in 2019 than in 2018 (102.53 MJ/m^2 vs. 90.65 MJ/m^2, respectively). Although in 2020 the production was around half that of previous years, the specific energy consumption increased but at a lower rate than expected (up to 116.15 MJ/m^2). Even though these values are within the required range specified by the standard LWG (26.8 to 160.6 MJ/m^2), the lower value of this range shows that the assessed tannery has room to reduce its specific energy consumption.

Table 8. Total energy consumption, production, and specific energy consumption for the period 2018–2020.

Year	Energy Source	Energy Consumption (MJ)	Production (m^2)	Specific Energy Consumption (MJ/m^2)
2018	Natural gas	5.31×10^7		
	Electricity	1.97×10^7		
	Total	7.28×10^7	8.03×10^5	90.65
2019	Natural gas	5.36×10^7		
	Electricity	1.97×10^7		
	Total	7.33×10^7	7.15×10^5	102.53
2020	Natural gas	3.21×10^7		
	Electricity	1.09×10^7		
	Total	4.30×10^7	3.70×10^5	116.15

3.2. Basic Recommendations to Reduce the Tannery Energy Demand

The first step to reducing energy consumption is the reduction of the energy demand due to all the activities of the tannery (including administrative functions). The first option could be reducing the energy demand by improving the tanning process. However, recommendations on the process are beyond the scope of this energy assessment and a dedicated study must be conducted. Nevertheless, there are some basic recommendations that can help to reduce energy needs, thus reducing the final energy consumption.

3.2.1. Improvement of Thermal Insulation

The poor insulation of piping is one of the main causes of energy loss and its improvement represents one of the best low-cost actions that can lead to energy savings. Therefore, good insulation of piping is always recommended by different guidelines in the leather sector at the European level to achieve energy efficiency. The “Reference Document on Best Available Techniques for Energy Efficiency” [27] mentions that distribution pipes for steam and for water at a temperature above 30 °C must be tight and well insulated. Not only visible steam leakages must be corrected, but also the invisible parts of the system must be checked. Heat loss is determined by the diameter of the pipe and the thickness of the insulation. In terms of benefit, improving insulation allowed for a reduction in thermal energy consumption of 3% and 4%, respectively, in Société Moderne des Cuirs et Peaux and Tannerie du Nord Utique, two tanneries located in Tunisia [27]. An optimal insulation thickness, which relates energy consumption with economics, should be evaluated. However, the payback period for insulation is generally less than one year.

3.2.2. Water Monitoring and Control

The installation of a proper water consumption monitoring system could be helpful to control leakages and evaluate the consumption of single equipment/machines, allowing a detailed evaluation of the potential for a more efficient tanning process and a reduction in water consumption. Thermal energy consumption associated with an inefficient use of water can be reduced by also installing a system that can control and dose the water in drums. The installation of these systems in Société Moderne des Cuirs et Peaux and Tannerie allowed a water saving of 22%. The control of water consumption in drums through a water metering system installed in Tanneries Mégisseries du Maghreb (TMM) (Tunisia) allowed the achievement of water savings of 10%, thermal energy savings of 7%, and a cost reduction associated with water consumption of up to 14% [28].

3.2.3. Good Housekeeping and Maintenance

Good housekeeping and maintenance are always recommended in protocols and guidelines related to energy efficiency. It is important to keep a maintenance schedule and record of all inspections and maintenance activities. Process operators should carry out local good housekeeping measures and help address unscheduled maintenance tasks, such as:

- Cleaning fouled surfaces and pipes.
- Ensuring that adjustable equipment is optimised.
- Switching off equipment when not in use or not needed.
- Identifying and reporting leaks in broken equipment, fractured pipes, etc.
- Requesting timely replacement of worn bearings.

Training and educating the staff so that they may implement good maintenance and good housekeeping is therefore fundamental. In Atef El-Sayed Tannery (Egypt), the adoption of good housekeeping measures (regular maintenance programmes, regular cleaning and washing of equipment to control odour generation, better collection of splits from fleshing to reduce waste accumulation and unnecessary washing, using screens to prevent solids from entering wastewater channels, and activating the grounding system to all machines in the tannery to maintain health and safety for employees) led to 10% saving in water consumption and reduced the amount of wastewater [28].

3.3. Recommendations to Reduce the Energy Consumption

This section reports a series of advice that could help to achieve a reduction in the energy consumption of natural gas and electricity by replacing/updating the existing component used for thermal energy production.

3.3.1. New Steam Boiler

In the current situation, most of the thermal energy is generated in the plant by the combustion of natural gas, mainly using the 4.5 MW gas-fired boiler "LOOS UL-S 7000". From the technical data sheet, it is possible to observe that the year of manufacture is 1993. Old boilers are usually characterized by low energy efficiency, which is the first cause of the high consumption of natural gas. Furthermore, performance degradation related to usage and age must be considered. On the other hand, modern boilers can use the energy from the condensation of the water vapour from the fumes with higher efficiency. Although the real boiler efficiency was not measured, it could be estimated that, for an old gas boiler with more than 25 years, the efficiency could not be higher than 70% [29]. The replacement with a new boiler can achieve an efficiency of at least 85%, which can lead to substantial energy savings, as shown in Table 9.

Table 9. Natural gas annual consumption reduction due to the installation of a new gas boiler.

	Efficiency	Natural Gas Energy Consumption (kWh)	Reduction in Gas Consumption (%)
New gas boiler	0.85	1.23×10^7	17.6

3.3.2. Heat Pump (Also Including Geothermal Heat Pump)

Another option that could be considered to produce thermal energy in an efficient way could be the replacement of the gas boiler with a heat pump. In this case, the primary energy source to meet the thermal energy demand would change from natural gas to electricity. The heat source can be the ambient or the ground (ground source heat pump). The parameter that characterizes the efficiency of a heat pump is the coefficient of performance (COP). This parameter expresses the ratio between the thermal power generated and the electricity consumed. In general, commercially available industrial heat pumps have a COP of around 2.5 [30]. This means that, for 1 kWh of electrical energy consumed, 2.5 kWh of thermal energy is produced. The coefficient of performance can be increased by increasing the temperature of the heat source (evaporator). In this case, extracting heat from the ground could lead to an increase in the COP of the heat pump up to values around 4 [31].

Therefore, in the case of replacing the gas boiler with a heat pump, the gas consumption would be reduced to zero, while the electricity consumption would increase due to the fact that the heat pump needs electricity for its operation, as shown in Table 10.

Table 10. Estimated increase in annual electricity consumption due to the replacement of the gas boiler with a heat pump.

Equipment	COP	Electricity Consumption (kWh)	Increase in Electricity Consumption (%)
Air source heat pump (HP)	2.5	9.64×10^6	76.1
Geothermal source heat pump (GSHP)	4.0	6.86×10^6	25.0

As can be seen, the increase in electricity consumption is considerable in the case of a standard heat pump, while in the case of a geothermal heat pump, the increase is only 25%. That is why the COP value is a key factor in the viability of this solution. While from an energy and environmental point of view this option represents a clear improvement, from an economic point of view, the viability of the solution depends on external factors, such as the price of gas and electricity, which vary over time. This means that, for a given value of the COP, the solution may or may not be viable.

3.4. Recommendations to Integrate Self-Generated Renewable Energy

This section reports a series of advice that could help to achieve a reduction in the energy consumption of natural gas and electricity by integrating renewable energy sources that can generate thermal and electrical energy. Furthermore, the integration of renewable energy sources is one of the aspects considered in the LWG protocol to promote a sustainable tanning process. In this assessment, only the use of solar energy as a renewable source was considered. Indeed, solar systems represent the most widespread technologies in terms of renewable exploitation, and prices have decreased a lot in recent decades, becoming economically attractive.

However, in order to maximize the use of renewables, an on-site storage device should be considered to reduce the mismatch between energy production and demand.

3.4.1. Solar Thermal Collectors

The use of solar thermal collectors is the simplest method to take advantage of solar radiation and convert it into thermal energy. In particular, solar radiation can be used directly to heat up water or another working fluid and transfer thermal energy to water or air through a heat exchanger. The heat produced from solar thermal collectors can be used both to produce hot water used in most of the tanning process or to produce hot air used for the drying process. In the present case study, the heat transferred from the working fluid is directly transferred to the air. The only limitation related to the use of hot air is the storage due to its high specific volume. The annual yield of solar thermal collectors strictly depends on the location, their orientation, the type of solar collectors, and the installation. Nowadays, evacuated tubes solar collectors can reach efficiencies between 70 and 80% at temperatures up to 170 °C [32].

Savings in natural gas consumption depend to a large extent on the total installed area of thermal collectors, but also on the specific type and model of the collector. In this study, two types of solar collectors were considered: flat plate solar collectors and evacuated tube collectors. For each of the two types, a parametric study was carried out to estimate the production of thermal energy and the associated savings in the consumption of natural gas. In the case of using flat plate solar collectors, the estimates of the energy generated by the collectors, as well as the new annual consumption of natural gas and the reduction percentage with respect to the consumption of 2019 are shown in Table 11, for different values of the total installed surface.

Table 11. Parametric study on the reduction in the annual consumption of natural gas due to the installation of flat plate solar collectors.

Total Surface (m^2)	Energy Generated (kWh)	Natural Gas Consumption (kWh)	Reduction in Gas Consumption (%)
2500	2.00×10^6	1.20×10^7	19.2
5000	4.00×10^6	9.17×10^6	38.4
10,000	6.00×10^6	3.45×10^6	76.8

The results of the parametric study of the effects of using evacuated tube solar collectors on the annual consumption of natural gas and the percentage reduction compared to the consumption of 2019 are shown in Table 12.

Table 12. Parametric study on the reduction in the annual consumption of natural gas due to the installation of evacuated tube solar collectors.

Total Surface (m^2)	Energy Generated (kWh)	Natural Gas Consumption (kWh)	Reduction in Gas Consumption (%)
2500	2.39×10^6	1.15×10^7	23.0
5000	4.78×10^6	8.05×10^6	45.9
10,000	9.57×10^6	1.21×10^6	91.8

The results show that using the same surface area of solar collectors, a greater reduction in gas consumption is achieved in the case of evacuated tube collectors, thanks to a higher efficiency than that of flat plate collectors for the same operating conditions. However, evacuated tube solar collectors usually have a higher cost than flat plate collectors.

3.4.2. Photovoltaic Panels

The installation of photovoltaic panels (PVs) is the main solution to using solar energy to produce electricity. Although thermal energy is the main carrier in leather production, this solution helps to reduce the electricity taken from the grid while having both economic and environmental benefits. As in the case of solar thermal collectors, the electricity production depends on location, type of photovoltaic cells (i.e., monocrystalline or polycrystalline), and type of installation (with fixed or regulated position and tilt). Nowadays, the efficiency of PVs is estimated to be around 20%. Due to the price drop of the PVs in recent years, this solution has become economically attractive, with a payback period included between 1 and 4 years [33].

Therefore, the reduction in the electricity consumption of the plant, in this case, will also depend to a large extent on the total installed area of PV panels and, to a lesser extent, on the type of installation and PV cell. In this study, monocrystalline and polycrystalline PV cells with a fixed type of installation were considered in both cases. For each of the two cell types, a parametric study was carried out to estimate the production of electrical energy and the associated savings in electricity consumption. In the case of using monocrystalline cells, the estimates of the electricity generated by the panels, as well as the new annual electricity consumption, and the reduction percentage compared to the consumption of 2019 are shown in Table 13, for different values of the total installed surface.

Table 13. Parametric study on the reduction in annual electricity consumption due to the installation of monocrystalline PV panels.

Total Surface (m^2)	Electricity Generated (kWh)	Electricity Consumption (kWh)	Reduction in Electricity Consumption (%)
2500	9.85×10^5	4.49×10^6	18.0
5000	1.97×10^6	3.51×10^6	36.0
10,000	3.94×10^6	1.54×10^6	72.0

The results of the parametric study on the effects of installing PV panels with polycrystalline cells on annual electricity consumption, and the reduction percentage compared to the consumption of 2019 are shown in Table 14.

Table 14. Parametric study on the reduction in annual electricity consumption due to the installation of polycrystalline PV panels.

Total Surface (m^2)	Electricity Generated (kWh)	Electricity Consumption (kWh)	Reduction in Electricity Consumption (%)
2500	7.88×10^5	4.69×10^6	14.4
5000	1.58×10^6	3.90×10^6	28.8
10,000	3.15×10^6	2.32×10^6	57.6

In this case, using the same PV panel surface, a greater reduction in electricity consumption was achieved in the case of monocrystalline panels, thanks to a higher efficiency than that of polycrystalline panels for the same operating conditions. However, monocrystalline panels usually have a higher cost than polycrystalline ones.

3.5. Target of Reduction in Energy Consumption according to the LWG Protocol

To achieve a higher category, a substantial reduction in the actual energy consumption is needed. The reduction needed to reach a high-quality category can be estimated from the reference values used to calculate the score according to the protocol. The estimations below were made considering the production and energy consumption of 2019. Indeed, the values provided for 2020 were affected by the COVID-19 pandemic situation and some water leakages verified by the company.

Table 15 shows that to reach a higher quality category, the minimum reduction in the total energy consumption needed is estimated to be around 30% to fall into the bronze category, while to reach the highest quality category, more than 60% reduction in energy consumption is needed.

Table 15. Reduction needed to achieve different categories of the protocol.

Category	Minimum Requirement (%)	Maximum Energy Consumption Tot (MJ)	Energy Consumption of 2019 (MJ)	Reduction Needed (%)
Bronze	65	5.11×10^7	7.33×10^7	30.2
Silver	75	3.98×10^7	7.33×10^7	45.7
Gold	85	2.69×10^7	7.33×10^7	63.3

4. Cost Analysis of Different Improvement Solutions and Discussion

Considering the previously proposed solutions to reduce the total energy consumption and the implementation of renewable energy sources, the combination of all possible solutions was studied to determine the most attractive alternatives from both energy audit and cost perspectives. To do that, a preliminary analysis of the investment cost and savings associated with each improvement solution was carried out. The investment costs considered for each component are shown in Table 16.

Table 16. Summary of the components' investment costs.

Component	Size	Cost (EUR)	References
Gas boiler	4500 kW	2.65×10^5	[34]
Heat pump	4500 kW	4.36×10^6	[35]
Ground-source heat pump	4500 kW	8.03×10^6	[36]
Flat plate collectors	2500 m^2	4.00×10^5	[37,38]
Evacuated tube collectors	2500 m^2	6.00×10^5	[37,38]
Monocrystalline PV panels	2500 m^2	2.00×10^5	[39–41]
Polycrystalline PV panels	2500 m^2	1.80×10^5	[39–41]

The savings in the total energy consumption with respect to the current system were calculated with respect to the energy consumption data and energy prices during 2019. However, the estimation of the payback time may be strongly affected by future variations in the prices of electricity and natural gas with respect to the reference year 2019, even if the future production of the tannery and energy demand remain the same as in 2019. A detailed sensitivity analysis is however beyond the scope of this study and could be the subject of future work focusing on the most promising improvement solutions. A summary of the most promising solutions is shown in Figure 1, where the payback period is presented versus the initial investment. The colour of each bullet corresponds to the LWG category that could be achieved by the corresponding solution (green = audited; red = bronze; grey = silver; yellow = gold).

According to Figure 1, the solutions that allow the achievement of the gold categories are the ones that include the installation of efficient solar thermal collectors (10,000 m^2 of evacuated tubes collector). This is because thermal energy is the main primary energy demand of the tannery, with natural gas consumption representing around 75% of the total energy consumption. Therefore, having a high fraction of self-generated thermal energy leads to the highest savings in total energy consumption. However, this solution is the one with the highest investment cost and payback time. Moreover, by installing a large surface of solar thermal collectors, the gold category can be reached either with the existing or with a new boiler. The high fraction of thermal energy produced can significantly reduce natural gas consumption, making the efficiency of the gas boiler a less critical parameter.

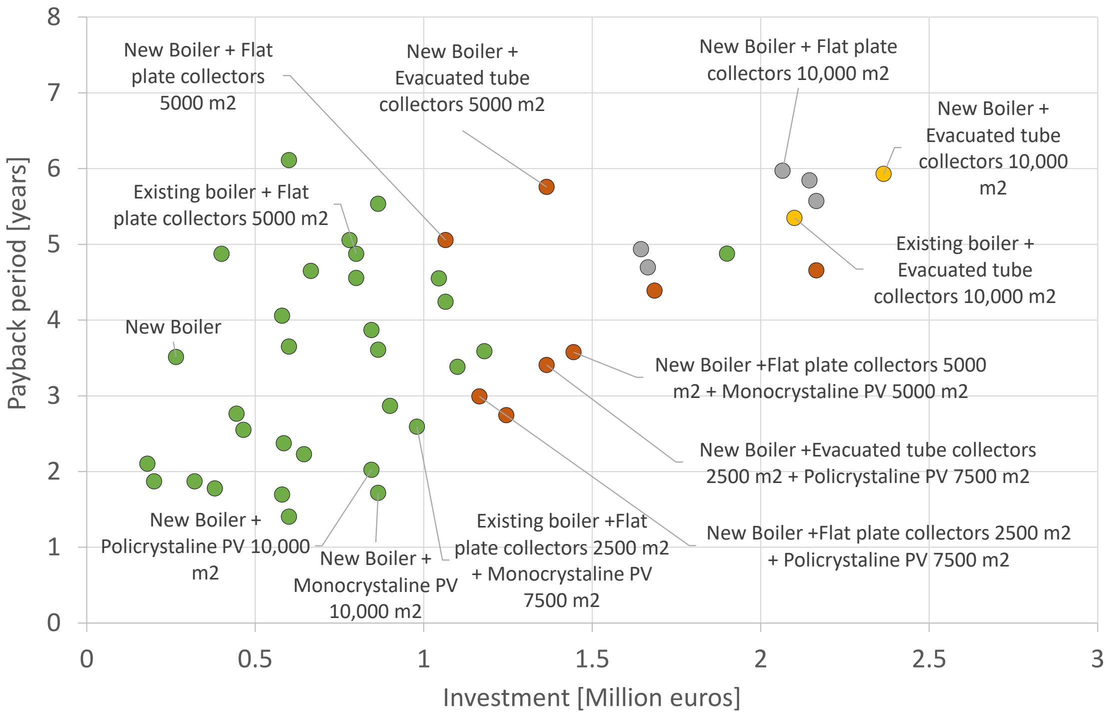

Figure 1. Summary of all proposed options, including payback period, initial investment, and LWG category.

Although the installation of PV panels has the lowest payback time, the implementation of this solution alone does not generate significant benefits in terms of primary energy savings, since the main energy demand of the tannery consists of thermal energy. Therefore, according to this preliminary study, the installation of only PV panels does not help to reach the highest categories according to the LWG protocol. However, if PV panels are installed together with solar thermal collectors, it is possible to achieve higher primary energy savings and reach higher quality categories established by the protocol (silver and bronze).

In summary, to reach the gold category, the company will have to undertake an investment in the order of EUR 2–2.5 M, obtaining a payback period of 5 to 7 years. To reach the silver category, the investment decreases to EUR 1.7 M, maintaining a payback period similar to the gold category. However, to reach the bronze category, the investment is around EUR 1–1.5 M and the payback period decreases to 2–4 years.

5. Conclusions

The study presented in this paper investigated different measures to increase energy efficiency and reduce the primary energy consumption of a tannery located in the region of Catalonia, Spain. In particular, the energy performance of the tannery was assessed based on the protocol and the benchmarks established by the Leather Working Group (LWG) on the environmental impact of tanneries. Nevertheless, the recommendations given in this paper can be adopted by similar industries with similar energy needs and high thermal energy requirements. The most promising options to increase the sustainability of the tannery were identified by considering the energy savings that can be achieved, the investment costs, and the payback period associated with each solution. The results showed that the energy consumption of the tannery can be considerably reduced by installing a total surface of 10,000 m^2 of solar thermal collectors along with replacing the current old boiler with a more efficient one. This would also make it possible to reach the highest category according to the LWG protocol, at the expense of investing between EUR 2 to 2.5 M, with a payback period of between 5 and 7 years. The limitations of this study consist of uncertainties in the estimations of the energy that can be produced by the solar collectors and the PV panels, the actual efficiency of the current gas boilers, the seasonal performance of the potential heat pump to be installed, as well as in the costs of energy and of all components considered in the improvement solutions. Therefore, future research could consist of a more detailed analysis of the most promising solutions identified in this study and a sensitivity analysis of the influence of uncertainties in the variables on the final results.

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