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Sustainable Thermal Energy Generation at Universities by Using Loquat Seeds as Biofuel

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Received: 31 December 2019; Accepted: 6 March 2020; Published: 9 March 2020

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Abstract: Global energy consumption has increased the emission of greenhouse gases (GHG), these being the main cause of global warming. Within renewable energies, bioenergy has undergone a great development in recent years. This is due to its carbon neutral balance and the fact that bioenergy can be obtained from a range of biomass resources, including residues from forestry, agricultural or livestock industries, the rapid rotation of forest plantations, the development of energy crops, organic matter from urban solid waste, and other sources of organic waste from agro-food industries. Processing factories that use loquats to make products such as liqueurs and jams generate large amounts of waste mainly in the form of skin and stones or seeds. These wastes are disposed of and sent to landfills without making environmentally sustainable use of them. The University of Almeria Sports Centre is made up of indoor spaces in which different sports can be practiced: sports centre pavilion (central court and two lateral courts), rocodrome, fitness room, cycle inner room, and indoor swimming pool. At present, the indoor swimming pool of the University of Almeria (UAL) has two fuel oil boilers, with a nominal power of 267 kW. The main objective of this study is to propose an energetic analysis to determine, on the one hand, the energetic properties of the loquat seed and, on the other hand, to evaluate its suitability to be used as a solid biofuel to feed the boilers of the heated swimming pool of the University of Almeria (Spain), highlighting the significant energy and environmental savings obtained. Results show that the higher calorific value of loquat seed (17.205 MJ/kg), is like other industrial wastes such as wheat straw, or pistachio shell, which demonstrates the energy potential of this residual biomass. In addition, the change of the fuel oil boiler to a biomass (loquat seed) boiler in the UAL's indoor swimming pool means a reduction of 147,973.8 kg of CO_2 in emissions into the atmosphere and an annual saving of 35,739.5 €, which means a saving of 72.78% with respect to the previous fuel oil installation. A sensitivity analysis shows that fuel cost of base case is the variable with the most sensitivity changing the initial cost and net present value (NPV).

Keywords: loquat seed; sustainability; renewable energy; universities; biomass boiler

1. Introduction

Social and economic development, together with an increase in human welfare, has led to an increase in energy consumption. Energy services in societies become essential to satisfy the demands of light, heating, transport, communication, etc., as well as for the manufacture of goods. Fossil fuels have been the main source of energy since 1850, and since then there has been a growing demand worldwide [1]. This has led to a progressive increase in the levels of carbon dioxide in the atmosphere, reaching a record 415.70 ppm in May 2019 [2]. Such a concentration of CO_2 in the Earth's atmosphere had not been reached for more than three million years, when the global sea level was a few meters higher and Antarctica was partially covered with forests.

The provision of energy services to a world population in continuous growth has increased the emission of greenhouse gases (GHG), these being the main cause of global warming. In December 2015, the Paris Climate Change Conference, also known as COP21, was held in Paris. It established the world's first binding climate agreement, through which the 195 signatory countries establish a global action plan to keep global warming below 2 °C between 2020 and 2030, and below 1.5 °C if possible [3].

In order to tackle global warming, two types of strategies have been developed: those for mitigating climate change and those for adapting to it. Mitigation strategies aim to reduce greenhouse gas emissions in such a way that the point of no return is not reached, while adaptation strategies aim to reduce the consequences of an already apparent climate change and address its impact.

Climate change mitigation measures that can be taken to reduce pollutant emissions include increased energy efficiency, greater use of green energy within the global energy mix, electrification of industrial processes, promotion of more sustainable transport (electric mobility, cycling) or higher carbon taxes as well as a market for CO_2 emissions [4]. Therefore, it can be said that climate change is a global problem demanding a shift from the current energy model [5].

Measures to adapt to climate change that can be taken in order to reduce its effects include the construction of adapted housing and workplaces, reforestation, adaptation of crops to new agronomic variables, development of emergency plans to deal with possible natural disasters, or research into possible effects on human health [6].

Renewable energies have demonstrated their potential in mitigating climate change, but they also have other benefits. Such forms of energy favour local employment and thus contribute to economic and social development, facilitate access to energy, increase energy resilience, and reduce pollution in cities, and therefore the effects on human health [7]. The concept of renewable energy encompasses heterogeneous categories of technologies. Some renewable energy sources can provide electricity, others supply thermal or mechanical energy, and others can provide biofuels to meet various energy demands. Some renewable energy technologies can be adopted at the point of consumption (centralized) in rural and urban environments, while others are implemented mainly in large supply networks (decentralized). Although more and more technically advanced renewable energy technologies have been adopted on a medium scale, others are at a less advanced stage and have a more incipient commercial presence or supply specialised market niches.

Within renewable energies, bioenergy has undergone a great development in recent years. This is due to its carbon neutral balance and the fact that bioenergy can be obtained from a range of biomass resources, including residues from forestry, agricultural, or livestock industries, the rapid rotation of forest plantations, the development of energy crops, organic matter from urban solid waste, and other sources of organic waste from agro-food industries [8]. These residues can be burnt directly to produce electricity or heat or can be transformed by using physicochemical processes to generate gaseous, liquid or solid fuels. Bioenergy technologies are very diverse, and their degree of technical sophistication differs considerably. Some already marketed are small or large boilers, district heating systems, or the production of ethanol from sugar and starch. Bioenergy technologies have therefore applications in both, centralized and decentralized contexts, and their most widespread application is conventional use of biomass in industrialized countries for heating and power generation [9]. Bioenergy production is often constant or controllable. Bioenergy projects generally depend on locally and regionally available fuel, although recently there seem to be indications that solid biomass and liquid biofuels are increasingly present in international trade. Within centralized context and small-scale systems, biomass boilers are an emerging technology with numerous economic and environmental advantages [10].

Traditionally biomass boilers have been powered by pellets composed mainly of chips and sawdust from the wood industry [11]. Due to the increasing trend in the prices of biomass from the forest and wood industry, it has been necessary to investigate other sources of bioenergy, which allow lower costs while reducing the pressure on the agroforestry sector. Many investigations have shown the potential of certain fruit stones and nutshells in the generation of thermal energy at industrial and residential levels [12,13]. It is therefore necessary to find alternative biofuels as enacted by the European standard EN 14961-1.

Eriobotrya japonica, commonly called Japanese loquat, or simply loquat is a perennial fruit tree of the Rosaceae family, originating in south-eastern China, where it is known as "pi ba". It was introduced in Japan, where it was naturalized and has been cultivated for more than a thousand years. It was also naturalized in India, the Mediterranean Basin, Canary Islands, Pakistan, Argentina and many other areas. Today, Japanese loquat cultivation has spread throughout the world, both for its ornamental value and for its prized fruits. The loquat is cultivated mainly in China, Japan, India, Pakistan, Mediterranean countries (Spain, Portugal, Turkey, Italy, Greece, Israel), United States (California and Florida), Brazil, Venezuela, and Australia. According to data provided by the Food and Agriculture Organization (FAO), China, in addition to be its country of origin, is the world's largest producer. In the last ten years China has doubled its area of cultivation and production, reaching 118,270 ha. and 453,600 Tn per year [14]. Spain is the world's second largest producer and exporter of loquat with an annual production of around 30,000 tn. Andalusia has around 1,100 hectares of loquat spread between Granada (815 hectares) and Malaga (275 hectares) [15]. The consumption of this tropical fruit has gradually increased over the last two decades and a good performance of demand is forecast for the coming years. Figure 1 shows the loquat production in the main countries in the world.

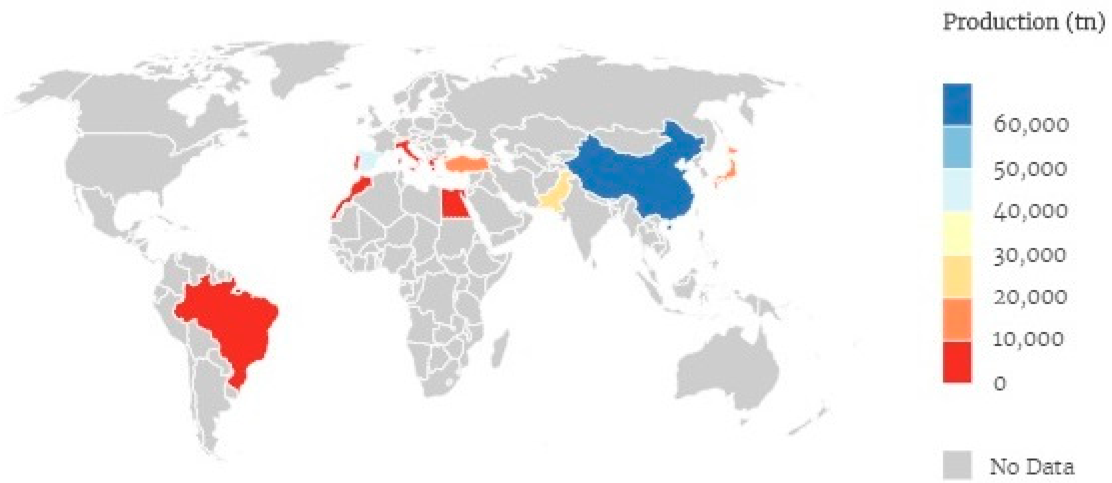

Figure 1. Loquat production in the main countries [16].

Processing factories that use loquats to make products such as liqueurs and jams generate large amounts of waste mainly in the form of skin and stones or seeds. Inside the loquat contains between 3 and 7 large brown seeds representing between 15% and 18% of the total weight of the fruit [17]. These wastes are disposed of and sent to landfills without making environmentally sustainable use of them.

The water in heated swimming pools needs an external supply of energy in order to maintain thermal comfort, as the natural tendency of the water will be to equalize the temperature of its environment. If the temperature of your environment is lower, the temperature of the water will decrease depending on the conditions of the environment such as: temperature of the air, of the walls and floor of the pool, etc. As a first consideration, we must bear in mind that the energy consumption of this type of installation can be higher than 700 MWh per year, depending on the climate of the place where it is located, the conditions and seasonality of the use, and the demand required by the systems included. Therefore, a small improvement in energy efficiency for proper operation translates into a big saving in global terms in CO_2 emissions to the atmosphere and the use of scarce energy resources. It should be noted that not only is the demand very high, but in most cases, there is a priori ignorance of the amount of energy that will demand a heated pool [18–20].

The main objective of this study is to determine, on the one hand, the energetic properties of the loquat seed and, on the other hand, to evaluate its suitability to be used as a solid biofuel to feed the boilers of the heated swimming pool of the University of Almeria (Spain), highlighting the significant energy, economical, and environmental savings obtained, contributing to reduce greenhouses gases.

2. Case Study

As a case study has been taken a university sport centre located in the University of Almería (UAL), Southern Spain (Figure 2).

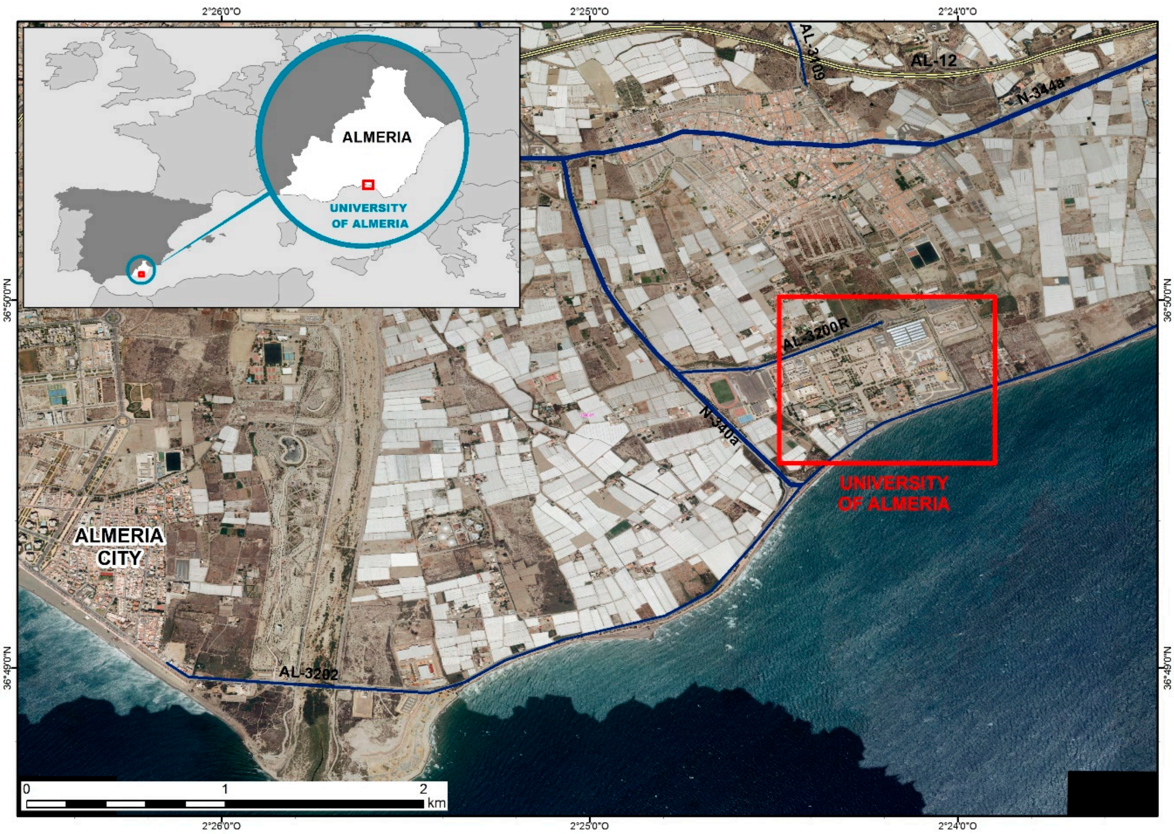

Figure 2. Location of University of Almeria.

The UAL Sports Centre is made up of indoor spaces in which different sports can be practised: sports centre pavilion (central court and two lateral courts), rocodrome, fitness room, cycle inner room and indoor swimming pool.

The water volume of the heated swimming pool is 494.15 m^3, has a compensation vessel of 30 m^3 and has an internal dimension of the water sheet of 12.5 × 25.10 m. Figure 3 shows the indoor swimming pool of the UAL Sports Centre.

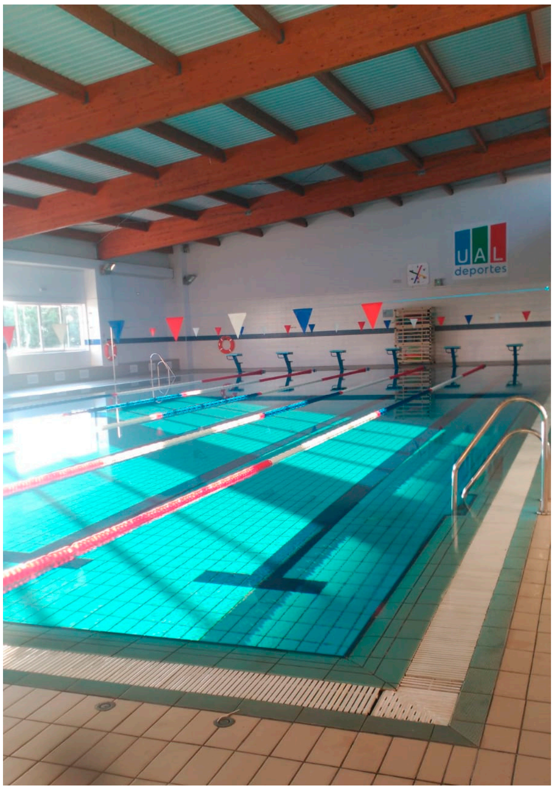

Figure 3. Indoor swimming pool of the University of Almeria.

Firstly, an energy audit of the installation was carried out to establish a technical basis for this study. In addition, all the necessary data was collected to study the possibility of replacing the existing boiler with a biomass boiler using loquat seed as biofuel.

2.1. Meteorological Data

Almeria has a Mediterranean climate, with mild winters, hot summers, and little rain. The average annual temperature is 17.9 °C and the average rainfall is 228 mm. Table 1 shows the most important meteorological data of Almeria.

Table 1. Meteorological conditions in Almeria.

Parameters	Values
Longitude	2°24′23.3″ W
Latitude	36°49′40.9″ N
Altitude	16 m
Average maximum annual temperature	23.1 °C
Average minimum annual temperature	14.3 °C
Average annual temperature	17.9 °C
Winter dry temperature	8 °C
Summer dry temperature	31 °C

2.2. Description of Existing Thermal Facilities

When planning the heating of an indoor swimming pool, some fundamental differences must be considered compared to a residential building heating system: firstly, there is a high level of evaporation on the premises, and secondly, the comfort conditions for bathers are different.

According to current regulations, the temperature and relative humidity of the room must be adequate to protect the health of the users (RITE, Complementary Technical Instruction) [21]. As for the temperature of the ambient air, the water temperature, and the environmental humidity, the following were taken as comfort conditions:

- Setpoint water temperature: 28 °C
- Maximum water temperature: 29 °C
- Air temperature: 29 °C
- Relative Humidity: 60%.
- Daily renewal of pool water: 2.5%.

At present, the indoor swimming pool of the University of Almeria has two fuel oil boilers, with a nominal power of 267 kW. One of them is a backup in case of failure.

The current installation has the following auxiliary elements:

- Two tanks of 2000 litres.
- Main hydraulic circuit of impulsion and return of steel pipe of 1′.
- Boiler room with dimensions of 40 m^2.
- Fuel oil tank of 3000 litres.
- The facility of the indoor swimming pool is presented in Figure 4.

Figure 4. Boiler room of the indoor swimming pool.

This installation has an annual consumption of 52,239 liters, as Table 2 shows.

Table 2. Annual consumption of the indoor swimming pool boiler for the year 2018.

Month	Fuel Consumption (L)
January	7582
February	8370
March	8110
April	6434
May	4473
June	2186
July	1018
September	671
October	3477
November	3926
December	5992
Total	52,239

In Spain, Royal Decree 742/2013 [22] classifies swimming pools with respect to public access and classifies them into public and private use swimming pools. In relation to the temperature of the air and of the bath water, heated or covered swimming pools are defined as those in which the enclosure where the glasses are located is closed, has a fixed structure, and the water is kept at a more or less hot temperature.

Figure 5 shows the operating diagram of the fuel oil boiler.

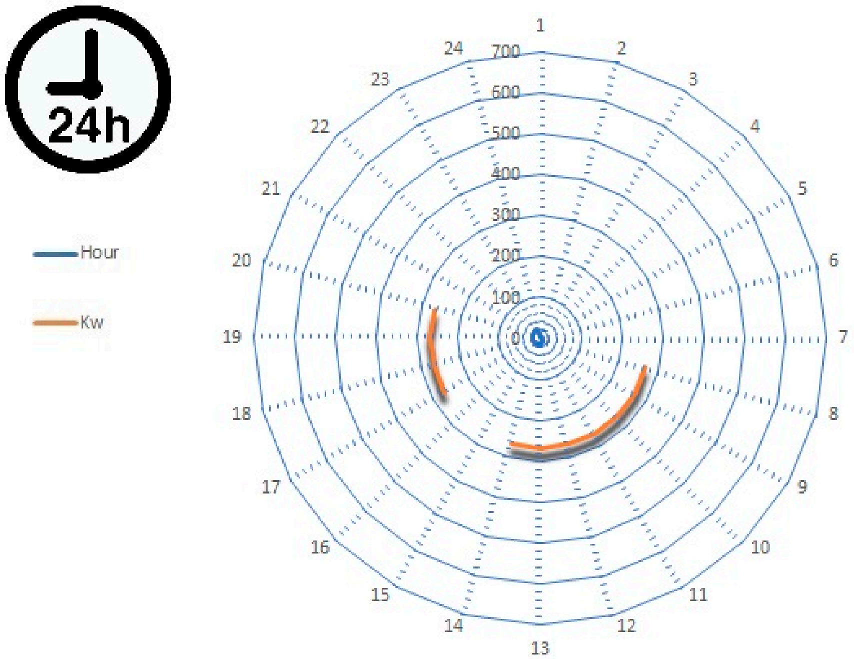

Figure 5. Operating diagram of the fuel boiler..

3. Materials and Methods

Regarding the use as biofuel of loquat seeds from agro-food industries, 2000 g of such seeds were collected for their subsequent energy and chemical composition analysis (Figure 6).

Figure 6. Eriobotrya japonica, commonly called Japanese loquat.

UNE-EN 14961-1 standard "Solid biofuels–Specifications and fuel classes—Part 1: General requirements", were used to assign the biomass quality parameters. This standard has been developed by the Spanish Association for Standardisation and Certification (AENOR).

Table 3 shows the standards and the measuring equipment used.

Table 3. Standards and the measuring equipment used in this study.

Parameter	Unit	Standards	Equipment	Standard Deviation (SD)
Higher heating value	MJ/kg	EN 14918	Calorimeter Parr 6300	0.02
Total sulphur	%	EN 15289	Analyzer LECO TruSpec S 630-100-700	0.002
Total hydrogen	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400	0.03
Total chlorine	mg/kg	EN 15289	Titrator Mettler Toledo G20	6.73
Total carbon	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400	0.12
Total nitrogen	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400	0.009
Ash	%	EN 14775	Muffle Furnace NABERTHERM LVT 15/11	0.02
Moisture	%	EN 14774-1	Drying Oven Memmert UFE 700	According to EN14774-1

3.1. Humidity

The moisture content of the biomass is the ratio of the mass of water contained per kilogram of dry matter. An excess of humidity in the biomass, leads to [23]:

- A large amount of volatile elements, which offer a loss in energy efficiency.
- A low calorific value, which would call into question the expectations regarding the replacement of other fuels.
- Ashes in large quantities. This can cause equipment cleaning problems.
- Boilers would suffer continuous problems, affecting the durability of their life.
- Have much more storage volume for biomass.

In order to avoid these problems, a solar greenhouse dryer system for loquat seed improvement as biofuel is proposed.

The solar greenhouse dryer built in this study was the feature on conventional greenhouse type tunnel with north-south facing (Figure 7). Figure 8 shows the dimensions of this greenhouse dryer.

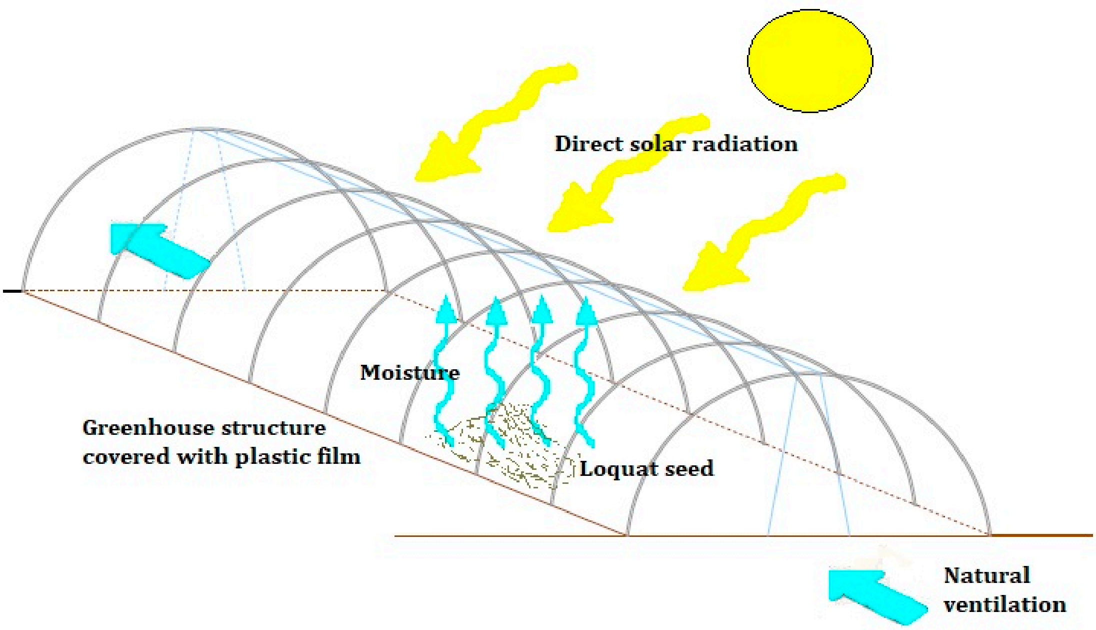

Figure 7. Scheme of the greenhouse dryer.

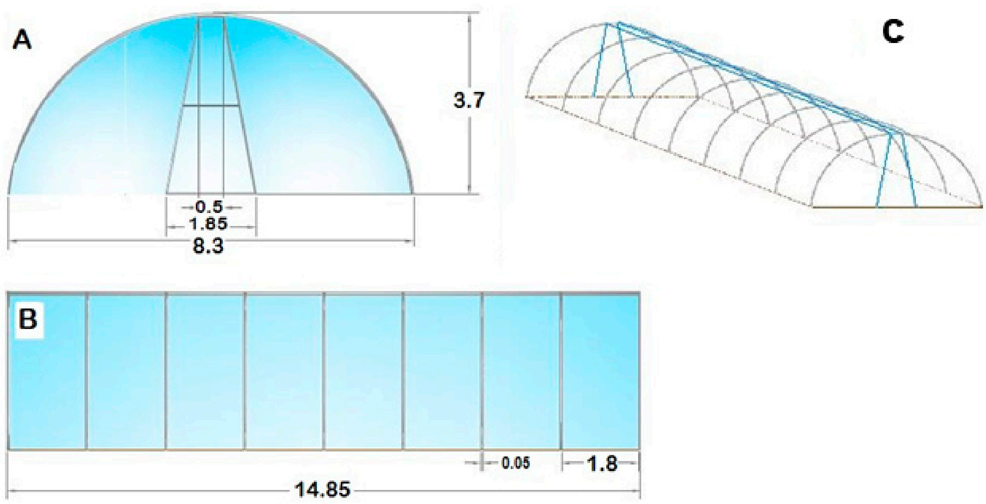

Figure 8. Dimensions of the greenhouse dryer proposed.

The drying of the loquat seeds in the solar dryer started on 1 October 2019 and was completed on the 17th of the following month. The moisture content was measured using Extech hygrometer M0210.

Before introducing the loquat seeds into the solar dryer to evaluate its operation, the air temperature and relative humidity levels were recorded during a week at different times of the day with an Extech RHT20 recorder, in order to know precisely their magnitude and the conditions under which the seeds would be exposed.

In order to show solar monthly resource and air temperature, Figure 9 is presented.

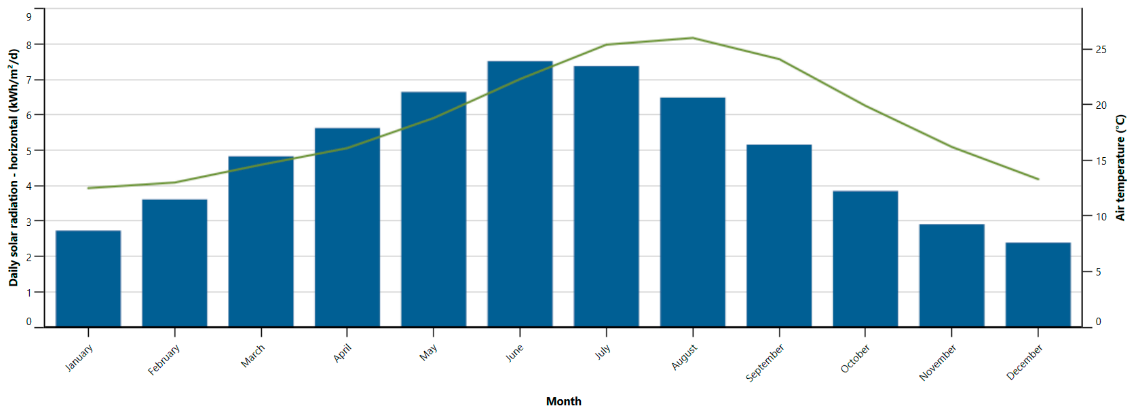

Figure 9. Relationship between monthly solar radiation and air temperature in Almeria.

As seen in Figure 9, in Almería the lowest solar radiation is January and December with 4 kWh/m^2/d, the months with the highest solar resource are July and August with more than 8 kWh/m^2/d.

3.2. Elemental Composition

The elemental analysis technique consists of determining the content of hydrogen, nitrogen, carbon and sulphur present in samples of an organic and inorganic nature, both solid and liquid. The UNE-EN 15104 standard has been consider in this analysis and the analyzer LECO TruSpec CHN 620-100-400 was used.

3.3. Ash Content

The determination of ashes will be based on UNE EN 14775 standard. Ashes are the residue of air incineration of coal and come from the inorganic compounds initially present in carbonaceous substances and associated mineral materials.

The ash content is expressed as the percentage ratio between the mass of the residue after incineration and the mass of the original sample.

The percentage of ash in biofuels is an important parameter to consider in boilers, since it can produce corrosion and accelerated erosion of the metal that makes up each of the elements of the boiler.

3.4. Chlorine and Sulfur Content

Titrator Mettler Toledo G20 was used to obtain the chlorine content and Analyzer LECO TruSpec S 630-100-700 to obtain sulfur content and the standard UNE EN 15289 was followed.

Riedl et al. [24] describe the corrosion mechanism in the presence of chlorine as "active oxidation" and assign to it the accelerated corrosion rate observed in boiler tubes. The authors describe the enrichment of alkaline metal chlorides on the surface of pipes by a condensation process. They also suggest that the chlorides react with SO_2 and SO_3 in the gases to form sulphates with the subsequent generation of chlorine gas.

An important study on this subject has been carried out in Denmark where accelerated corrosion tests were conducted on boilers that were using fuels such as straw and cereals with ash levels in the range of 5%–7%, chlorine levels between 0.3% and 0.5%, and sulfur content less than 0.2%, on a dry basis [25].

3.5. Higher Heating Value (HHV) and Lower Heating Value (LHV)

The higher heating value (HHV) is defined assuming that all elements of the combustion (fuel and air) are taken to 0 °C and the products (combustion gases) are also taken to 0 °C after the combustion, so the water vapor will be completely condensed.

In the calculation of the LHV, it is assumed that the water vapor contained in the flue gas does not condense and therefore there is no additional heat input due to the condensation of the water vapor. Only the heat of oxidation of the fuel is available. While determining the HHV experimentally in a calorimeter, the LHV is obtained by a calculation from the HHV [26–28].

$$\mathrm{LHV}\left(\frac{\mathrm{kJ}}{\mathrm{kg}}\right) = \mathrm{HHV}\left(\frac{\mathrm{kJ}}{\mathrm{kg}}\right) - 212.2 \times \mathrm{H}\,\% - 0.8 \times (\mathrm{O}\% + \mathrm{N}\%) \quad (1)$$

3.6. Biomass Combustion Technology

According to Wolf & Dong [29], three types of technologies for biomass combustion can be distinguished: fixed bed, fluidized bed (which can be either circulating or bubbling bed), and pulverized fuel. In our case study, considering the characteristics of the biofuel and the boiler output, fixed bed technology will be chosen for the direct combustion of the biomass once it has been dried.

Fixed-bed combustion includes furnaces with grates and feeders (stokers). The biomass is placed on a grate and moves slowly through the boiler. The required air is supplied through holes arranged along the grate. The combustible gases issued by the biomass are burned after the addition of a secondary air, usually in a combustion zone separated from the fuel bed. This technology is suitable for any type of biomass but limited to installations of up to 100 MW.

An important aspect of the grate furnace is that the combustion stages must be obtained by separating the primary and secondary combustion chambers, in order to avoid the mixing of secondary air currents and to separate the gasification and oxidation zones. The better the quality of the mixture between the combustion gases and the secondary combustion air, the less oxygen is needed to achieve complete combustion, thus achieving greater efficiency.

According to the direction of flow of the fuel and flue gases, there are three operating systems for grate-fired boilers:

1. Counter-stream flow (the flames are in the opposite position to the fuel).
2. Stream flow (the flames are in the same direction as the fuel).
3. Cross flow (the removal of the combustion gases in the middle of the furnace).

In our case study the stream flow system will be chosen. The flow in stream is applied for dry fuels or in systems where primary heated air is used. This system increases the residence time of the gases released by the fuel bed, allowing for a reduction in NO_x emissions, due to the improved contact of the combustion gases with the bed of carbonized material at the back of the grills [30].

3.7. Economic Analysis

The economic analysis has been performed at initial conditions of 267 kW as rated power, loquat properties compared to oil fuel. All these processes have been carried out with RETScreen software, which is a clean energy management software system for energy efficiency, renewable energy, and cogeneration project feasibility analysis, as well as ongoing energy performance analysis, developed by the Natural Resource of Canada office [31].

4. Results and Discussion

The physico-chemical parameters of loquat seed were analysed and compared with those of other sources of residual biomass in order to evaluate its usefulness as a solid biofuel. Afterwards, an energy, economic and environmental analysis of the installation was carried out.

4.1. Loquat Seed Values

To evaluate the quality parameters of loquat seed, 2000 g of samples from the loquat industry were analysed. Table 4 shows the mean value, the standard deviation, the maximum value, and the minimum value which determine the parametric distribution.

Table 4. Energy and chemical parameters obtained from loquat seed analysis (parameters calculated on a dry basis except for moisture).

Magnitude	Unit	Mean Value	Standard Deviation (SD)	Maximum Value	Minimum Value
Moisture	%	37.53	—	37.53	37.53
Ash content	%	2.37	0.060	2.43	2.31
HHV	MJ/kg	17.205	0.018	17.223	17.187
LHV	MJ/kg	16.007	0.090	16.097	15.917
Total carbon	%	44.03	0.006	44.036	44.024
Total hydrogen	%	5.47	0.011	5.481	5.459
Total nitrogen	%	0.63	0.037	0.667	0.593
Total sulfur	%	0.03	0.002	0.032	0.028
Total oxygen	%	46.57	2.651	49.221	43.919
Total chlorine	%	0.07	0.003	0.073	0.067

As can be seen from Table 4, one of the main disadvantages of loquat seed is its high moisture content, above 30%. This decreases the efficiency of combustion, since water needs to evaporate before heat is available, resulting in a lower heating value. Furthermore, from a technical point of view, the presence of a high moisture content produces corrosion in the equipment and generates the emission of tars that accumulate in the outlet pipes and can cause them to block. As a result, pre-drying processes must be implemented in order to obtain a moisture content below 10%.

Ash is the inorganic fraction of the biomass that remains once the fuel has been burned, mainly in the form of SiO_2 and CaO. The formation of ashes is linked to problems such as the formation of agglomerates on the walls of the grids and the formation of slag deposits which accelerate the corrosion of the installation and increase its maintenance costs. With respect to the ash content of the loquat seed, it is in the range of 2.31%–2.43%. If this value is compared with that of other standardized fuels, such as almond shell pellets (3.35%) or oak pellets (3.32%), it can be seen that in spite of its high value, it is below the ash content of other conventional fuels.

Table 5 compares the physicochemical parameters of several commercial biofuels and industrial wastes with those of loquat seed in order to evaluate the use of this by-product in the generation of thermal energy.

Table 5. Comparation between Loquat seed and other biofuels.

Parameters	Unit	Avocado Stone [32]	Olive Stone [33–35]	Pine Pellets [35,36]	Almond Shell [35,37,38]	Loquat Seed
Moisture	%	35.20	18.45	7.29	7.63	37.53
HHV	MJ/kg	19.145	17.884	20.030	18.200	17.205
LHV	MJ/kg	17.889	16.504	18.470	17.920	16.007
Ash content	%	2.86	0.77	0.33	0.55	2.37
Total carbon	%	48.01	46.55	47.70	49.27	44.03
Total hydrogen	%	5.755	6.33	6.12	6.06	5.47
Total nitrogen	%	0.447	1.810	1.274	0.120	0.63
Total sulphur	%	0.104	0.110	0.004	0.050	0.03
Total oxygen	%	42.80	45.20	52.30	44.49	46.57
Total chlorine	%	0.024	0.060	0.000	0.01	0.07
$\frac{HHV_{biomass}}{HHV_{loquat\ seed}}$	%	111.27	103.95	116.42	105.78	100.0

As shown in Table 5, the ash content of loquat seed is higher than that of other industrial waste but lower than the ash content of the mango stone. This suggests that the formation of ash deposits will be greater and therefore will need additional maintenance.

As for the higher calorific value of loquat seed (17.205 MJ/kg), it is observed that it is lower than that of other standardized solid biofuels such as almond shells or olive stones. However, if we compare it with other industrial wastes such as wheat straw (17.344 MJ/kg) or pistachio shell (17.348 MJ/kg) [31], it is shown to have similar values, showing the energy viability of this agro-industrial waste.

Another quality parameter to be considered in a biofuel is its chlorine and sulphur content. Sulphur, in addition to having a corrosive effect on the installation, is associated with the emission of greenhouse gases in the form of SO_x. Loquat seed has a 0.03% sulphur content that is lower than that of other commercially available biofuels such as almond shells (0.050%) or olive stones (0.110%), which means that SO_x emissions would be minimised if this biofuel were used.

Regarding the chlorine content, this has a significant effect on the corrosiveness of the plant due to the formation of chlorides, which have a dissociative catalytic effect on the steel pipes. Loquat seed has a low chlorine content (0.07%), like that of other standardized biofuels such as olive stone (0.06%) and lower than that of almond shells pellets (0.2%). In view of these results, corrosion problems would be minimized by using this solid biofuel.

However, in addition to its high calorific value, the main advantage of using loquat seed as biofuel is its carbon-neutral character. In fact, when the plant grows it fixes carbon from the atmosphere which is then released when it is burned, making the life cycle carbon neutral.

This residual biomass can be obtained from loquat processing industries in the surroundings, helping on the one hand to a better environmental management of these wastes and on the other hand to a reduction of greenhouse gas emissions.

4.2. Environmental Benefits

Biomass as an energy source has several advantages over other alternatives in the fight against climate change and local pollution. Biomass is a source of non-polluting energy. Plants emit CO_2 but also absorb CO_2 during their growth, so their total balance is zero (Figure 10).

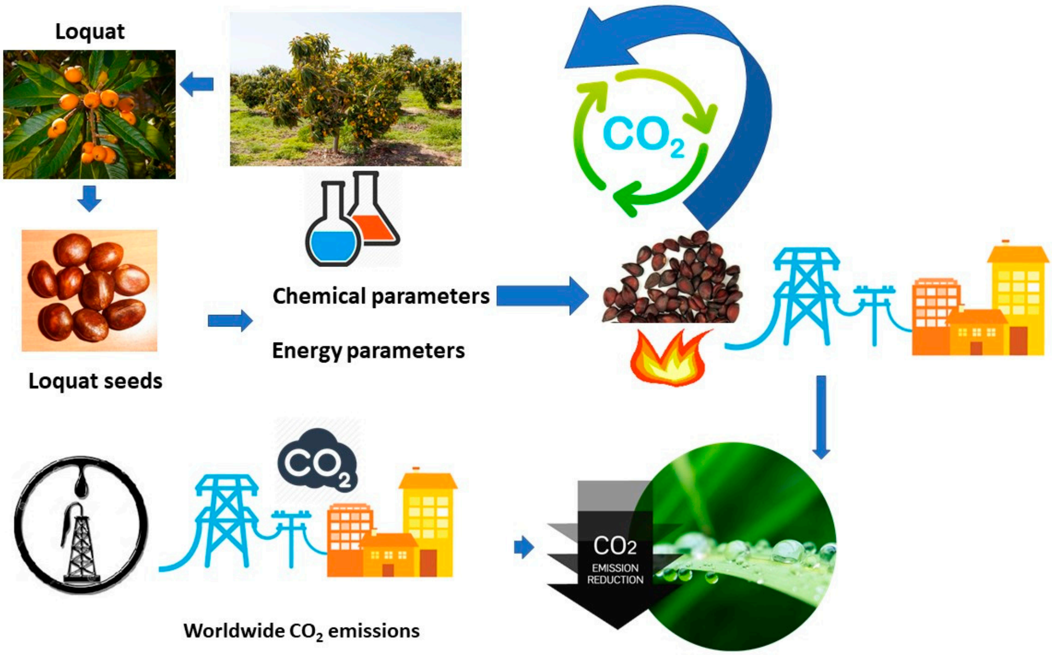

Figure 10. CO_2 cycle using loquat seed as biofuel.

Once the energy characteristics of the loquat seed are known, it is possible to calculate the CO_2 savings in the installations of the UAL indoor swimming pool, as well as the worldwide CO_2 savings in loquat producing countries.

Firstly, the potential energy obtained from the use of loquat seed as a biofuel is calculated using Equation (2). This potential energy is calculated considering the worldwide production of loquat for each country.

$$U_p = RH \times P_{loquat\ seed} \times HHV \times f_s \times F_c \quad (2)$$

where:

U_p denotes energy obtained from the loquat seed as biofuel (MWh);
RH is relative humidity (10%);
$P_{loquat\ seed}$: loquat seed production (kg);
HHV: higher heating value (17.205 MJ/kg);
f_s is the percentage of seed in a whole loquat (15%);
F_c factor conversion for units (0.000277778 Wh/J).

Figure 11 shows worldwide bioenergy potential using loquat seed as biofuel (MWh).

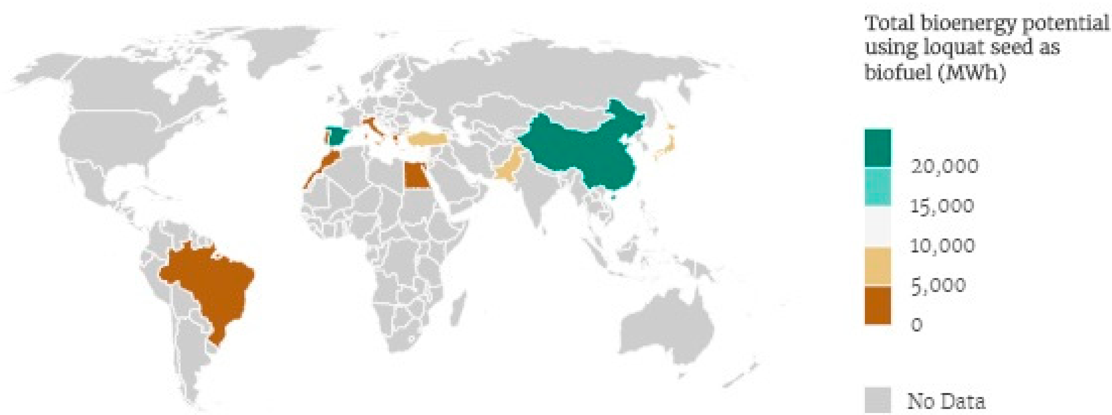

Figure 11. Worldwide bioenergy potential using loquat seed as biofuel (MWh).

The next step in the study will be to calculate the CO_2 reductions that would occur if loquat seeds were used as a biofuel instead of fuel oil.

As mentioned above, Biomass is a source of non-polluting energy, with zero CO_2 emissions. The CO_2 emission of fuel oil would be calculated as:

$$\mathrm{MCO_2}_{\ \mathrm{fuel\ oil}} = \mathrm{C}_{\mathrm{fuel\ oil}} \times \mathrm{F}_{\mathrm{fuel\ oil}} \quad (3)$$

where:

$MCO_2\ _{fuel\ oil}$: mass of carbon dioxide emitted (kg/year).
$C_{fuel\ oil}$: consumption of fuel oil per year (kWh/year).
$F_{fuel\ oil}$: carbon dioxide emission factor of fuel oil (kg/kWh).

Table 6 shows the CO_2 emission factor for biomass and fuel and the total CO_2 emission reduced annually using loquat seed as biofuel.

Table 6. CO_2 emission factor of Fuel oil and Loquat seed [39].

Boiler	CO_2 Emissions (kg/kWh)
Fuel oil	0.311
Loquat seed	0
Total CO_2 emission reduced annually (kg)	228,031.70

The change of the boiler to biomass in UAL indoor swimming pool means a reduction of 147,973.8 kg CO_2 in emissions into the atmosphere.

Figure 12 shows the worldwide CO_2 saving using loquat seed as biofuel (Tn).

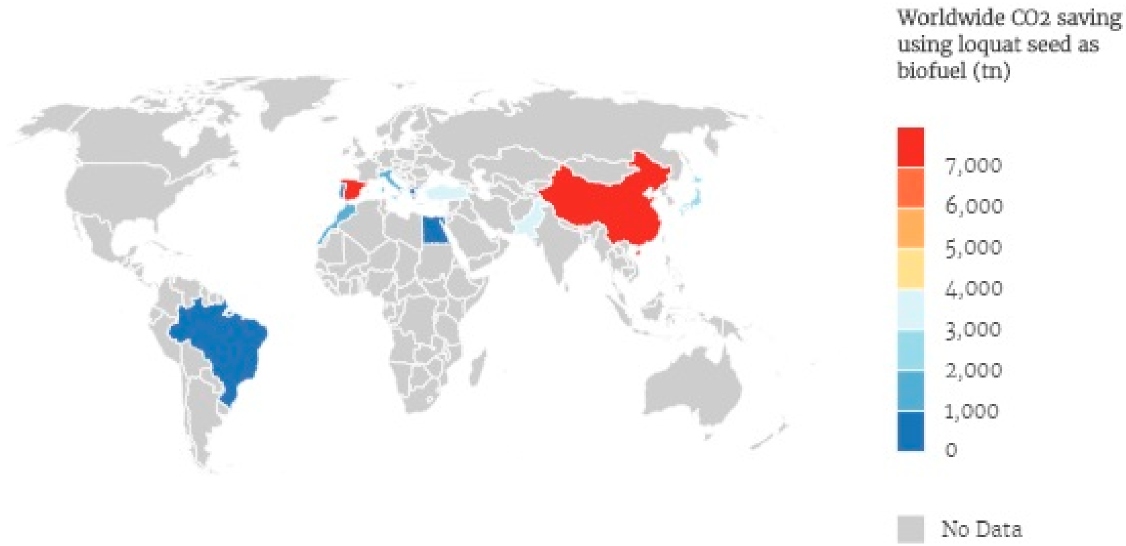

Figure 12. Worldwide CO_2 saving using loquat seed as biofuel (Tn).

The five main countries that would reduce their annual CO_2 emissions by using loquat seeds as biofuel are: China (51,184.92 Tn), Spain (10,617.54 Tn), Turkey (3454.98 Tn), Pakistan (3275.83 Tn), and Japan (2621.95 Tn). Further, the annual worldwide reduction of CO_2 emissions if loquat seed is used as biofuel would be 76,363.80 tn.

In a society committed to sustainable development, the use of biomass for heat and electricity production is an important source of renewable energy. Its increasing use as a substitute for fossil fuels can significantly reduce CO_2 emissions. However, in recent years discussion has focused on the sustainability of biomass, and the environmental implications of its use must be taken into account.

Particularly important is the particle size of the emissions that are produced, which have been identified as a relevant factor of the deterioration of air quality. Not so long ago, the existing legislation for emission control in combustion plants only took into account total particles with a diameter of less than 10 micrometers (PM_{10}). However, particles with a diameter of less than 5 micrometers (PM_5) and especially those with a diameter of less than 2.5 micrometers ($PM_{2.5}$) have the most harmful effect on health. Fine particles ($PM_{2.5}$) emitted during biomass combustion can be divided into three groups, based on their chemical composition and morphology: particles spherical organic carbon particles, sooty aggregate particles and inorganic ash particles. Because of their small size, these particles are able to reach the pulmonary alveoli and pass into the bloodstream. This is associated with an increased risk of respiratory and cardiovascular disease, especially when the environmental concentration of these particles exceeds 35.4 $\mu g/m^3$ [40–43].

This has led to a boost in research activity, both in the characterisation of emissions and in the development of control equipment, and in enacting legislation at national and European level.

For our case study, the R.D. 1073/2002 transposing the Directive 1999/30/EC on air quality, establishes in relation to PM_{10}, that the limit value of 50 μg/m^3 must not be exceeded in 24 h for more than 35 days, on the date of entry into force of 1 January 2005.

In the year 2015, new European legislation has been published (Directive (EU) 2015/2193 of the European Parliament) that involves air emissions from the combustion of solids, such as biomass, in equipment and installations with a rated thermal input of more than 1 MW and less than 5 MW, and that makes a big impact on particle emissions.

Conversely, the European Directive 2009/125/EC establishes a framework for setting ecodesign requirements for energy-related products. The national transposition of this regulation is the Royal Decree 187/2011 of 18 February.

The result of this directive is Regulation 2015/1189 of 28 April on solid fuel and wood biomass boilers of nominal output not exceeding 500 kW, which is mandatory from 1 January 2020. The environmental aspects considered important in this regulation are energy consumption and emissions generated by particulate matter (PM), organic gaseous compounds (OGC), carbon monoxide (CO), and nitrogen oxides (NO_x) in the use phase of this equipment. This regulation stipulates that seasonal particle emissions from heating may not exceed 40 mg/m^3 for automatically fed boilers and 60 mg/m^3 for manually fed ones.

In order to reduce the amount of particles emitted into the atmosphere due to the incomplete combustion of the biomass, modifications have been made to combustion equipment in recent years. In this way, for example, special emphasis has been placed on the modulation of the equipment to adapt to thermal demand, lambda probes have been used to ensure control of the most appropriate fuel-air ratio according to operating conditions and secondary and tertiary air has been introduced in different parts of the equipment.

However, the permitted emission limits are becoming increasingly restrictive, making it necessary to use of equipment that can be coupled to the stoves and boilers of biomass in order to reduce the emission of particles. In this way, research is being carried out into different technologies that can be adapted to the residential sector, such as the introduction of additives with the biomass, the use of catalytic filters or the use of electrostatic precipitators.

In low power installations (up to 1 MW) the most effective and profitable solution is the use of an electrostatic filter [44]. Its operation is based on electrically charging the particles in order to direct them out of the gas towards plates with an opposite charge, to which they adhere. Therefore, in our case study an electrostatic filter will be installed consisting of a metal rod that rotates inside the metal chimney tube, carrying a voltage of 24,000 volts, so that it ionizes the solid particles, which are attracted by the walls of the chimney tube, where they accumulate until they fall by gravity into the equipment. This technology has proven to achieve efficiencies of over 90% in $PM_{2.5}$ abatement [45].

4.3. Economical Benefits

The economic feasibility of the study of changing the fuel boiler for loquat seed as a biofuel is based on the following:

- Annual hours of operation.
- Annual consumption of fuel oil and biomass.
- LHV of fuel oil and biomass to be used.
- Current prices of fuel oil and biomass to be used.

Starting with a 267 kW boiler that will work approximately 6 h a day with an average of 297 days, the energy required is 475,800 kWh.

The high price of fossil fuels, which is also heavily taxed in many countries, is boosting the market for biomass boilers for heating generation. In order to calculate the economic benefit to be gained from the new biomass installation compared to the original fuel oil installation, the necessary fuel expenditure in both scenarios has been calculated to cover the annual energy demand. As shown in Table 7, the annual fuel oil consumption of the existing facility during 2018 was 52,239 litres, and considering a fuel price of 0.94 euros/litre, a total annual cost of 49,104.67 euros is obtained.

Table 7. Economic analysis of fuel oil installation and the Loquat seed boiler.

Parameter	Unit	Fuel oil Boiler	Biomass Boiler
Fuel		Fuel oil	Loquat seed
LHV	kWh/L	10.12	
LHV	kWh/kg		4.45
Price	€/L	0.94	
Price	€/kg		0.10
Boiler efficiency	%	90	80
Nominal power	kW	267	267
Operating hours	H	1782	1782
Thermal energy demand	kWh/year	475,800	475,800
Fuel consumption	L	52,239	
Biomass consumption	Kg		133,651.7
Annual cost	€	**49,104.67**	**13,365.17**
Annual saving	€		35,739.5
Annual saving	%		*72.78*
Total investment	€		***69,540.35***

The annual thermal demand of the installation (kWh/year) can be calculated as the product of the amount of fuel consumed by the lower heating value (LHV) of the same, but considering the efficiency of the boiler, this is:

$$\text{Annual thermal demand} = \text{Fuel quantity} \times \text{LHV} \times \text{Boiler efficiency} \quad (4)$$

Taking into account the necessary thermal demand of 475,800 kwh per year, with the new biomass boiler 133,651.7 kg of loquat seeds will be consumed, and taking as a reference price of this residual biomass a value of 0.1 €/kg already treated and transported, there would be an annual saving of 35,739.5 € which means a saving of 72.78% with respect to the previous fuel oil installation.

A sensitivity analysis has been carried out with a threshold of seven years, a range of 25% and the analysis is performed on equity payback, see Table 8.

Table 8. Sensitivity analysis based in equity payback.

		Fuel Cost- Proposed Case				
Initial Costs		**10,023.88**	**11,694.52**	**13,365.17**	15,035.82	16,706.46
€		−25.0%	−12.5%	0.0%	12.5%	25.0%
52,155	−25.0%	*0.3*	*0.3*	*0.3*	*0.5*	*0.5*
60,848	−12.5%	*> project*	*0.3*	*0.4*	*0.5*	*0.6*
69,540	0.0%	*> project*	*> project*	***0.4***	*0.6*	*0.6*
78,233	12.5%	*> project*	*> project*	*> project*	*0.6*	*0.6*
86,925	25.0%	*> project*	*> project*	*> project*	*> project*	*0.7*

Table 8 shows that fuel cost will increases in 0.4 in 7 years if costs do not increase, however, in the worst case the costs will increases in 0.7 times if fuel cost increase in 25%.

A risk analysis is performed on net present value (NPV) and 500 combinations. In Table 9 are presented the parameters and in Figure 13 is presented a tornado chart to identify the impact of NPV on these parameters.

Table 9. Parameters.

Parameter	Unit	Value	Range	Minimum	Maximum
Initial costs	€	69,540.35	25%	52,155	86,925
Fuel cost- proposed case	€	13,365.17	25%	10,024	16,706
Fuel cost- based case	€	49,104.67	25%	36,829	61,380.84
Debt ratio	%	70%	25%	52.50%	87.50%
Debt interest rate	%	7%	25%	5.25%	8.75%
Debt term	yr	15	25%	11	19

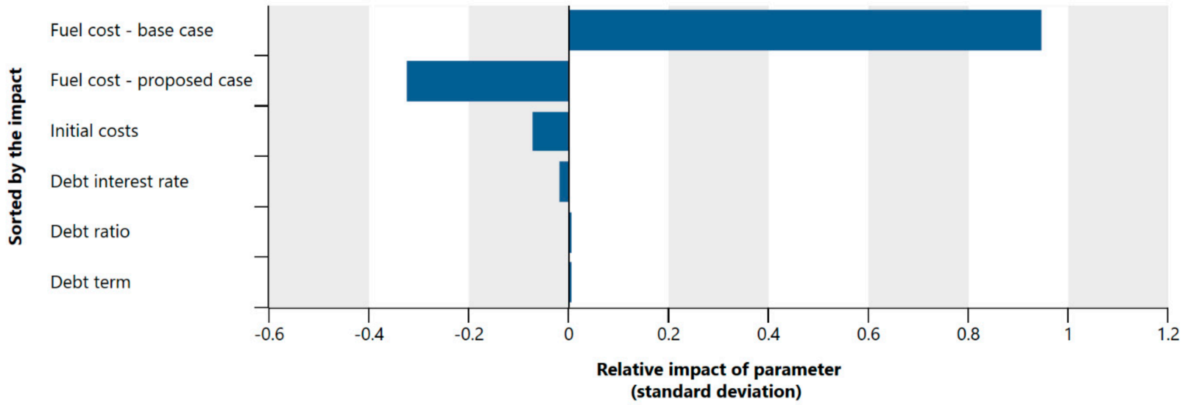

Figure 13. Impact – Net Present Value (NPV).

Figure 13 shows the economic impact of NPV on fuel cost of proposed case and base case, as it can be seen, the highest sensitivity variable is fuel cost-base case (fuel oil); debt interest rate, debt ratio and debt term have very small effects and can be ignored their uncertainty.

Financial viability presents the results provide to the decision-maker with various financial indicators for the proposed case, see Table 10.

Table 10. Financial viability.

Parameter	Unit	Value
Pre-tax-IRR-assets	%	20.6
Simple payback	yr	1.3
Net Present Value	€	162,013
Annual life cycle savings	€/yr	17,748
Benefit-Cost (B-C) ratio		25.1

The internal rate return (IRR) is 20.6%, which is higher than European central bank interest rate (0.25%), payback is 1.3 years, and B-C shows that investment has financial viability.

4.4. Biomass Storage

The Thermal Installations Regulation (2007) [46] in Spain describes a few essential requirements for solid biofuel storage systems (IT.1.3.4.1.4 Solid biofuel storage). In general, the storage site must be exclusively for this use, and this does not change the physical, chemical and mechanical characteristics of the biomass. It must also comply with a series of requirements to prevent the risk of self-combustion. The types of storage can be divided into prefabricated or built storage, either new construction or existing room, either above or below ground. In new buildings, the minimum storage capacity for biofuel will be sufficient to cover two weeks' consumption. The silo can be filled semi-automatically, with direct loading or with a pneumatic system, depending on the type of solid biofuel and size of the silo.

In the case of this study, the existing deposit room will be adapted as a silo, making some slopes of galvanized sheet and having an extraction system of about 2 m. This silo will have a floor area of 3.4 m^2 and a height of 2 m as defined in Figure 14. Therefore, a volume of 6.8 m^3 is available, which complies with the 15-day minimum fuel supply (6.18 m^3 of Loquat seeds required).

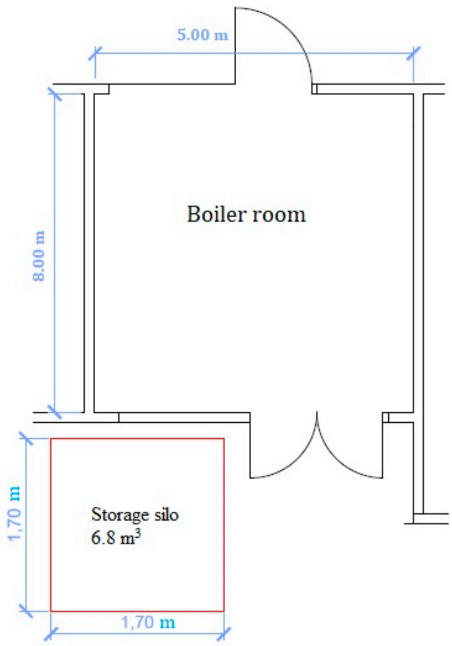

Figure 14. Location of storage silo.

4.5. Biomass Drying

An excess of humidity in the biomass, leads to a lot of problems. It is essential for biomass fuel to remain dry, or it will not burn efficiently.

The drying of the loquat seeds in the solar dryer started on 30 October 2019 and was completed on the 17th of the following month. The drying of loquat seeds with an initial moisture content of 35.20% was started and ended at 10% final moisture content after 12 days (Figure 15).

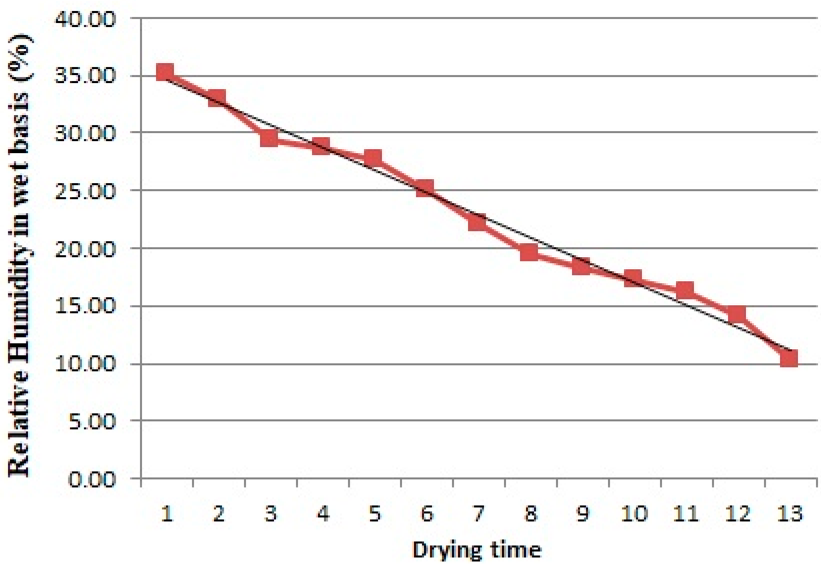

Figure 15. Evolution of the relative humidity in wet basis of the loquat seed in greenhouse dryer.

Figures 16 and 17 show the average temperature and relative humidity levels reached at different times of the day inside the greenhouse dryer.

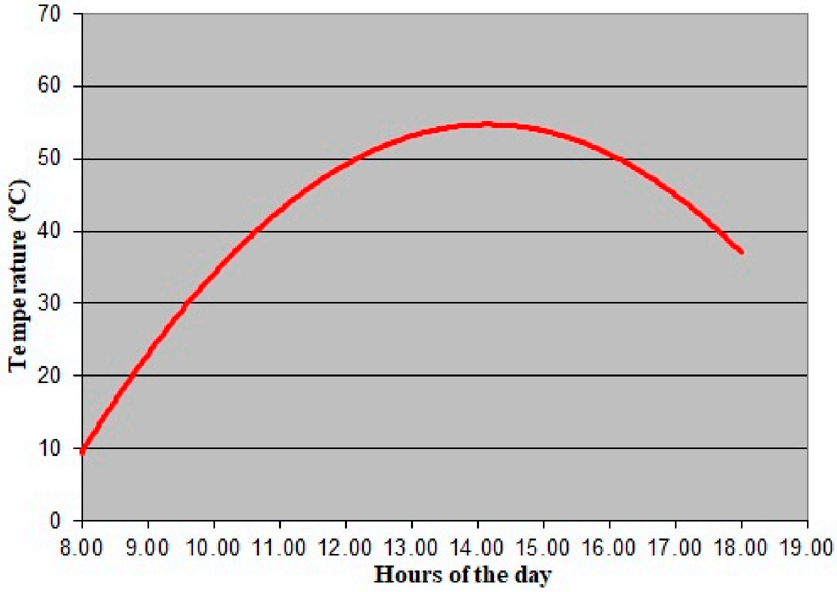

Figure 16. Average temperature variation during the day in the greenhouse dryer.

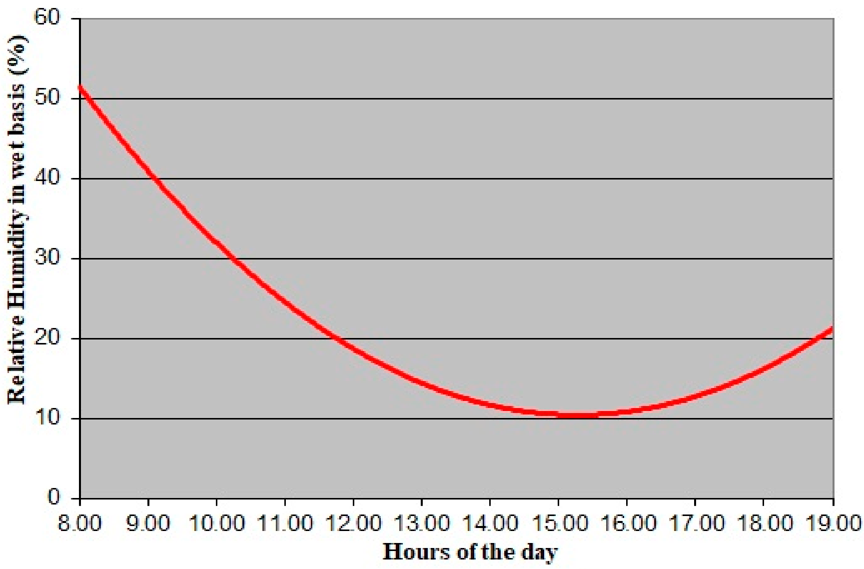

Figure 17. Average variation in relative humidity on a wet basis during the day in the greenhouse dryer.

5. Conclusions

As for the higher calorific value of loquat seed (17.205 MJ/kg), it is observed that it is lower than that of other standardized solid biofuels such as almond shells or olive stones. However, if we compare it with other industrial wastes such as wheat straw or pistachio shell, it is shown to have similar values, which demonstrates the energy potential of this residual biomass.

The use of loquat seed as an energy source has several advantages over other alternatives in the fight against climate change and local pollution that should be highlighted:

- It generates lower emissions than conventional fuel boilers, reduced sulphur and particle emissions and reduced emissions of pollutants such as CO, HC and NO_X. The change of fuel oil boiler to

biomass boiler in UAL indoor swimming pool means a reduction of 147,973.8 kg CO_2 in emissions into the atmosphere and an annual saving of 35,739.5 € which means a saving of 72.78% with respect to the previous fuel oil installation.
- Reduced maintenance and hazards from toxic and combustible gas leaks.
- Reduced agricultural and forestry by-products going to landfills.
- Biomass is an inexhaustible source of energy, provided it is used sustainably.
- It helps to prevent fires and reduce the risks of forest fires and pests.
- The implantation of energy crops on abandoned land prevents erosion and soil degradation, as well as the possible use of agricultural by-products, avoiding their burning on the ground.
- It helps to clean up the mountains and to use the by-products of the agro-industries.

The five main countries that would reduce their annual CO_2 emissions by using loquat seeds as biofuel are: China (51,184.92 tn), Spain (10,617.54 tn), Turkey (3454.98 tn), Pakistan (3275.83 tn), and Japan (2621.95 tn). In addition, the annual worldwide reduction of CO_2 emissions if loquat seed is used as biofuel would be 76,363.80 tn.

The sensitivity analysis showed that the variable most sensitive is the fuel cost of base case, and the variables with minimum impact in this analysis are debt interest rate, debt ratio and debt term that have very small effects and can be ignored their uncertainty.

Financial analysis determined that the project has viability, the IRR (20.6%) is higher than European central bank interest rate (0.25%), and the B-C ratio shows that benefits are 25.1 times higher than costs.

Author Contributions: Conceptualization, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M.; methodology, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M.; formal analysis, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M.; investigation, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M.; resources, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M.; writing—original draft preparation, M.-A.P.-M., F.M.-A., Q.H.-E. & A.-J.P.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This research has been supported by the Ministry of Science, Innovation and Universities at the University of Almeria under the programme "Proyectos de I+D de Generacion de Conocimiento" of the national programme for the generation of scientific and technological knowledge and strengthening of the R+D+I system with grant number PGC2018-098813- B-C33.

Conflicts of Interest: The authors declare no conflict of interest.

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