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Instituto de Estudios de Postgrado

TESIS DOCTORAL

EVALUACIÓN DE LA GENERACIÓN DE ENERGÍA RENOVABLE EN ZONAS URBANAS DE PAÍSES MEDITERRÁNEOS

GENERATION ASSESSMENT OF RENEWABLE ENERGY AT URBAN AREAS IN MEDITERRANEAN COUNTRIES

PROGRAMA DE DOCTORADO

INGENIERÍA AGRARIA, ALIMENTARIA, FORESTAL Y DE DESARROLLO RURAL SOSTENIBLE

DOCTORANDO: **MIGUEL ÁNGEL PEREA MORENO**

DIRECTOR: **PROF. DR. ALBERTO JESÚS PEREA MORENO**

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TITULO: *Generation assessment of renewable energy at urban areas in Mediterranean Countries*

AUTOR: *Miguel Ángel Perea Moreno*

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Campus de Rabanales
Ctra. Nacional IV, Km. 396 A
14071 Córdoba

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TÍTULO DE LA TESIS: GENERATION ASSESSMENT OF RENEWABLE ENERGY AT URBAN AREAS IN MEDITERRANEAN COUNTRIES

DOCTORANDO: MIGUEL ÁNGEL PEREA MORENO

INFORME RAZONADO DEL DIRECTOR DE LA TESIS

EL doctorando presenta y desarrolla un amplio análisis sobre la evaluación de la generación de energías renovables en zonas urbana de Países Mediterráneos. La metodología empleada es correcta, ya que en primer lugar se realiza un análisis bibliométrico a partir de bases de datos indexadas que sitúa a la investigación dentro del contexto de científico actual, y posteriormente se presentan interesantes investigaciones para poner de manifiesto el potencial de nuevas fuentes de energías renovables procedentes de la biomasa (residuos agroindustriales con especial presencia en Países Mediterráneos), así como su integración a nivel de distrito para la generación de energía térmica y eléctrica.

El resultado es original no sólo en un contexto energético y económico, sino también dentro del escenario actual de medidas para la mitigación del cambio climático, ya que la tesis también incorpora análisis mediomabientales sobre las posibles reducciones de CO_2 y otros gases de efecto invernadero que se obtendrían mediante la utilización de estas fuentes de energías renovables. La tesis ha dado lugar a cinco publicaciones en revistas indexadas de alto impacto:

- Perea-Moreno, M. A., Hernandez-Escobedo, Q., & Perea-Moreno, A. J. (2018). Renewable energy in urban areas: Worldwide research trends. *Energies, 11*(3), 577-593. doi: 10.3390/en11030577. **Open Access**

  Energy & Fuels
  Science citation index: JCR (2017) 2.676; Placed: 48/97 (Q2)

- Perea-Moreno, A. J., Perea-Moreno, M. Á., Hernandez-Escobedo, Q., & Manzano-Agugliaro, F. (2017). Towards forest sustainability in Mediterranean countries using biomass as fuel for heating. *Journal of Cleaner Production, 156,* 624-634. http://doi.org/10.1016/j.jclepro.2017.04.091.

  Green & Sustainable Science & Technology
  Science citation index: JCR (2017) 5.65; Placed: 6/33 (Q1)

- Perea-Moreno, A. J., Perea-Moreno, M. Á., Dorado, M. P., & Manzano-Agugliaro, F. (2018). Mango stone properties as biofuel and its potential for reducing CO_2 emissions. *Journal of Cleaner Production, 190*, 53-62. http://doi.org/10.1016/j.jclepro.2018.04.147.

  Green & Sustainable Science & Technology
  Science citation index: JCR (2017) 5.651; Placed: 6/33 (Q1)

- Perea-Moreno, M. A., Manzano-Agugliaro, F., Hernandez-Escobedo, Q., & Perea-Moreno, A. J. (2018). Peanut shell for energy: Properties and its potential to respect the environment. *Sustainability, 10*(9), 3254-3269. doi:10.3390/su10093254. **Open Access**

  Environmental Sciences
  Science citation index: JCR (2017) 2.075; Placed: 121/242 (Q2)

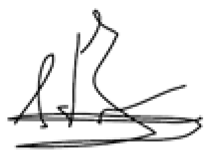
- Perea-Moreno, M. A., Manzano-Agugliaro, F., & Perea-Moreno, A. J. (2018). Sustainable energy based on sunflower seed husk boiler for residential buildings. *Sustainability, 10*(10), 3407-3427. doi:10.3390/su10103407. **Open Access.**

  Environmental Sciences
  Science citation index: JCR (2017) 2.075; Placed: 121/242 (Q2)

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 21 de noviembre de 2018

Firma del director



Fdo.: Prof. Dr. Alberto Jesús Perea Moreno

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A mis amigos los de toda la vida, muchos de ellos ya doctores, sin duda han sido un gran acicate para la realización de esta Tesis.

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Introduction, hypothesis and objectives, and structure of the thesis

«Renewable energy is not more expensive than fossil fuel when you factor in life-cycle costs»
Piyush Goyal (2009)

Chapter I. Introduction, hypothesis and objectives, and structure of the thesis

I-1. INTRODUCTION

The world's population continues to grow at a high rate, so that today's population is twice that of 1960, and is projected to increase further to 9 billion by 2050 (Herrera-Quintero et al., 2015). Forecasting models suggest that developing countries will undergo 99 per cent of this population increase, with population growth of 50 per cent in urban areas (Weinmaster, 2009). This situation has brought along that the percentage of the global energy used in the cities is increasing considerably.

In the early 1990s, cities consumed under half of the total energy produced, while they currently use two-thirds of the worldwide energy (International Renewable Energy Agency -IRENA, 2016). This means that the share of urban energy use in the global energy mix is growing at a higher rate than the global share of urban population (Figure I-1).

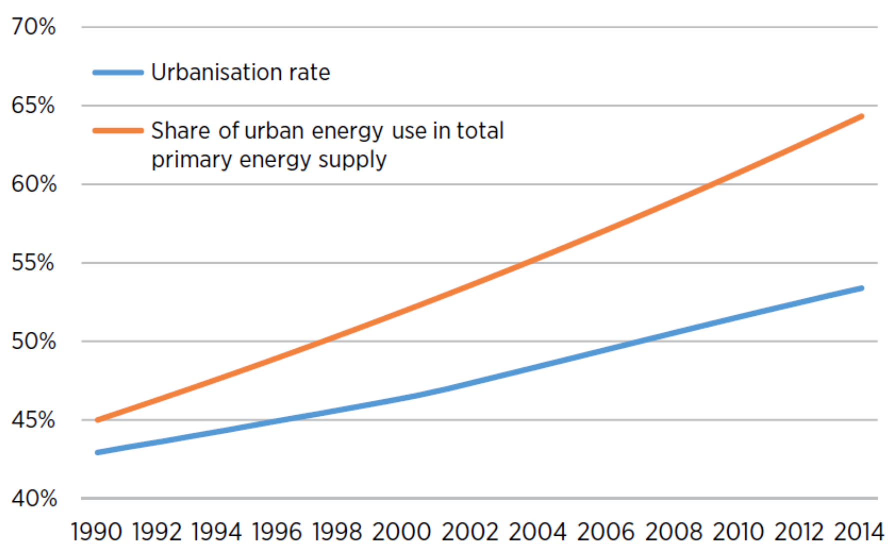

Figure I-1. Global urbanisation rate and share of urban energy use in total primary energy supply, 1990-2014 (IRENA, 2016).

In spite of the fact that cities continue to use fossil fuels as the main source of energy, energy sustainability is becoming a key political solution to mitigate the problems related to climate change (Perea-Moreno et al., 2016). This thesis aims to open new perspectives in the urban generation of renewable energy as a key element to achieve the transition to a low carbon economy, as well as suggesting solutions to make cities more sustainable.

Indeed, cities represent 70% of the total emissions of CO_2 caused by humans (Lu and Li, 2018), being one of the largest contributors to climate change. In addition, cities face the devastating effects of climate change. Approximately 70% of cities are coping already with the effects of climate change. Since 90% of all urban areas are coastal, the damage caused by rising sea levels is expected to increase, with some cities in developing countries being particularly vulnerable.

The increase in urban energy consumption has also led to an increase in urban air pollution. According to the World Health Organization (WHO), 90% of the inhabitants of urban areas are subject to environmental pollution levels that exceed the recommended limits. In addition, 65% of European citizens in large cities are exposed to high levels of noise (World Health Organization, 2017).

Energy efficiency is also postulated one of the key solutions to decrease the use of foreseen energy by 2030 (Capros et al., 2018). Although new buildings in cities are designed with state-of-the-art technologies that allow maximum energy savings, greater investment on energy efficiency in buildings is needed to meet the objectives of combating climate change and keep the average global temperature increase within 2 °C of preindustrial levels. Many international associations have promoted initiatives to boost the improvement of energy efficiency in buildings. This is in line with the Energy Efficiency Directive (EED-2012/27/EU) through which a common framework is established to promote energy efficiency within members states. At the same time, the Directive on Energy Efficiency in Buildings states that all newly constructed buildings should be listed as “Zero-Energy Buildings” (ZEB) by the end of 2020 and in the case of public buildings, by the end of 2018 (Ferrara et al., 2018; Zavadskas et al., 2017). This new concept refers to buildings with minimum levels of energy, whose origin is from renewable sources (Gao et al., 2018).

Renewable energy is a clean energy that reduces CO_2 emissions as well as atmospheric pollutants (Perea-Moreno et al., 2018a). It is cost-effective, which means it is competitively priced against non-renewable sources (Perea-Moreno et al., 2018b). It is environmentally sustainable and offers enhanced energy security due to its resistance to external shocks (Perea-Moreno et al., 2018c, 2018d). On the other hand, the renewable energy sector is growing, providing a large number of additional jobs and increased socio-economic opportunities in cities (Ma et al., 2018).

Figure I-2 shows that 20% of energy use for transport and buildings in cities came from renewable sources in 2013 (International Energy Agency, 2016).

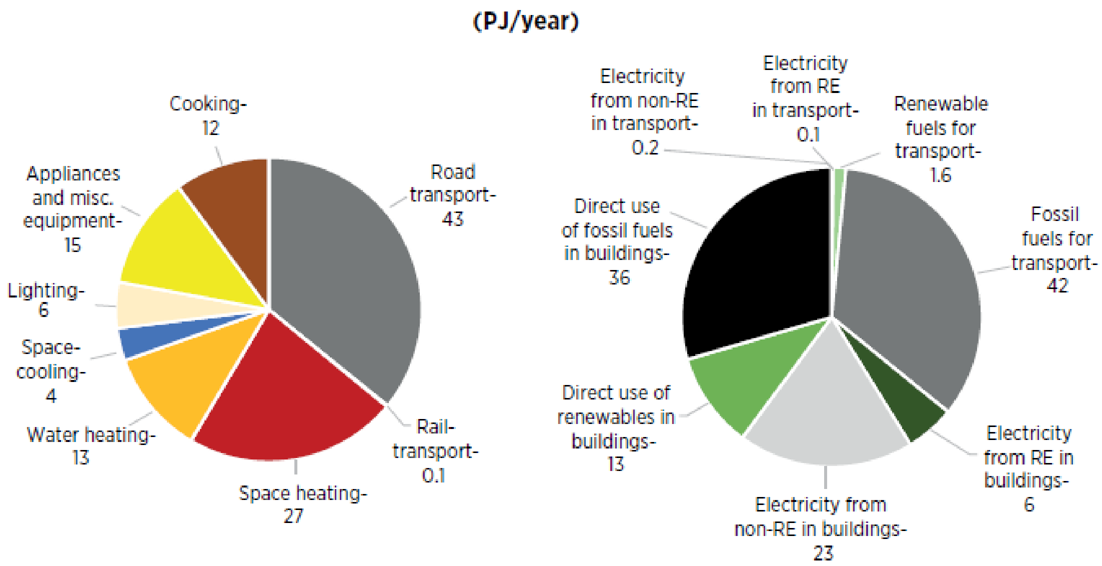

Figure I-2. Breakdown of urban energy use in buildings and transport by application and carrier (IEA, 2016).

As can be observed, the largest part of energy consumption in cities is used to heat or cool public and private buildings, as well as to meet transport needs.

I-1.1. Sustainable heating and its benefits

The renewable energy for heating comes either from decentralised equipments in buildings or from centralised generation and its further distribution.

Decentralised biomass boilers are an emerging technology in constant development (Wang et al., 2018). Biomass is a carbon neutral energy source, since the biomass during its growth absorbs CO_2 that is then released into the atmosphere during its combustion, with a zero-net balance of CO_2 emissions. In the same way solar thermal systems are widely used in the generation of hot water, and to some extent for home heating. Taking into account the available space on the roofs, the capacity of generation of thermal energy could be up to six times higher in the year 2030 (Perea-Moreno et al., 2017a).

However, large amounts of thermal energy are being wasted in power generation and in many manufacturing processes. Cogeneration is the most widely used technology to reuse lost heat, generating useful heat as well as electrical energy. Combined Heat and Power plants (CHP) simultaneously produce electricity and heat in the industry, trade or residence. The industry consumes all the heat and electricity it needs, and the excess electricity is fed into the grid and is consumed mostly in the local environment.

In conventional systems, industry produces the heat it needs in a boiler and the electricity is produced in a power plant far from the point of consumption, with the consequent consequences of losses in transport and distribution, and lower energy efficiency in electricity production (compared to cogeneration).

The main benefits of cogeneration are (Brown, 2017):

- Cogeneration is a key instrument for energy efficiency and the reduction of Greenhouse Gas Emissions (GHG), with significant economic savings.
- It is essential for competitiveness and the maintenance of industrial employment.
- It acts as an engine for investment, innovation, economic development and job creation.
- Cogeneration is essential for security of supply and reduction of energy dependency.

On the other hand, district heating and cooling networks are a highly effective way to integrate natural resources such as industrial and agricultural biomass, while increasing energy efficiency. Distributed energy systems consist of a network of underground insulated pipes, connected to a thermal or cold heat plant, through which hot or cold water is pumped to several buildings within a district (Figure I-3).

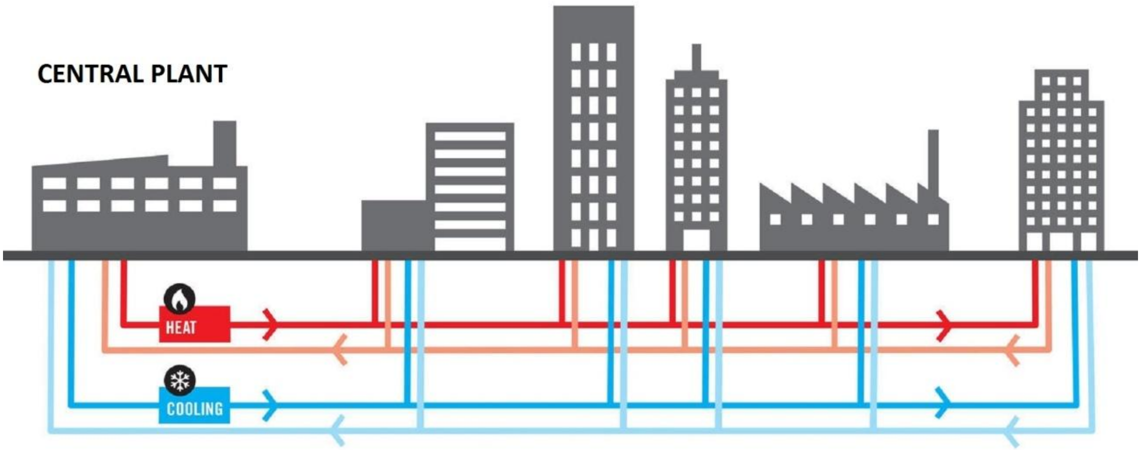

Figure I-3. District heating and cooling networks (Subterra Renewables, 2018).

The benefits of the use of district energy systems have been appointed by many authors (Lund et al., 2010; Stephen et al., 2016; Perea-Moreno et al., 20017b) and can be summarized as follows:

I-1.1.1. Reduction of greenhouse gasses emissions

The district's energy enables a transition to the abandonment of fossil fuels and, as a result, a 30-50% reduction in primary energy consumption (Lund et al., 2010). Since 1990, and thanks to use of a district heating system, Denmark has achieved reduce CO_2 emissions by 20%; likewise, district energy systems are becoming one of the key components of the climate action plans. Energy district represents a central strategy to achieve Paris manage to reduce CO_2 emissions by 75% by the year 2050; only the plants that convert waste into energy prevent 800,000 tons of CO_2 are emitted each year.

I-1.1.2. Reduction of air pollution

By reducing the use of fossil fuels, the district's energy systems can lead to a reduction in air pollution, both indoors and outdoors, as well as its health effects (Perea-Moreno et al., 2017b). In the city of Gothenburg, Sweden, district heating production doubled in the 1973-2010 period whereas CO_2 emissions halved, and the city's nitrogen oxide (NO_x) and sulphur dioxide (SO_2) emissions fell even more sharply.

I-1.1.3. Improvements in energy efficiency

Linking the heating and electricity sectors through district energy infrastructure, as well as the use of low-energy sources like residual heat or free cooling, can significantly increase the energy efficiency of both new and pre-existing constructions (Stephen et al., 2016). All buildings demand essential efficiency actions; nevertheless, in addition to improving the efficiency of buildings, being connected to a district energy system can be more cost-effective than doing a complete refurbishment, as it was proved in the city of Frankfurt, Germany, evaluating 12,000 buildings with historic facades. Similarly, in Rotterdam, the Netherlands, it has been shown that from a certain limit on the labeling of energy efficiency, the energy of the district is more cost-effective than buildings renovations.

I-1.1.4. Use of local and renewable resources

The district's energy system is a highly successful means of incorporating sustainable technologies into the heating and cooling sectors, thanks to the use of economies of scale and thermal energy storing. Urban energy also facilitates a greater share of the production of renewable energy through the balance.

Due to the wide availability of biomass worldwide mainly because it can be obtained as a by-product of many industrial and agricultural processes, biomass represents a growing renewable energy source with high growth potential (Li et al., 2017). One of the main characteristics of biomass that makes it suitable as an energy source is that through direct combustion it can be burned in waste conversion plants (figure I-4) to produce electricity (Manzano-Agugliaro, 2007) or in boilers to produce heat at industrial and residential levels (Casanova-Peláez et al., 2015). However, it must be borne in mind that direct combustion of biomass is not always feasible in existing facilities, and that in many cases it is necessary to carry out physical-chemical or biological treatments to adapt it to the quality of conventional fuels.Therefore, Biomass District Heating (BDH) is a very effective system for the integration of natural energy resources within urban environments, achieving on the one hand a 100% reduction in CO_2 emissions compared to fossil fuels, and on the other hand a increase in energy efficiency due to the lower cost of biofuels.

Figure I-4. Biomass conversion plant.

I-1.1.5. Resilence and energy access

District energy systems can increase resilience and enhance access to energy because of their potential to better manage electricity demand, minimize the risk of voltage drops, and adapt to stresses such as fuel price shocks (kuik et al., 2018). In Kuwait City conventional refrigeration systems accounted for 70% of peak-energy demand and consumed over half of the city's annual consumption. Switching to a district cooling system has been able to reduce both energy demands by 46% and annual consumption by 44%.

I-1.1.6. Green economy

District energy systems can help shift to a sustainable green economy by saving unnecessary or deferred costs of infrastructure investments for power generation and peak capacity; the creation of wealth and increase in energy efficiency through reduced expenditure on fossil fuels and the generation of tax revenues; as well as the increase in hiring for jobs created in the areas of system design, constructing, equipment fabrication, operation and maintenance (Andini et al., 2018).

In Bergen, Norway, electricity companies encouraged district heating because it lowered replenishment costs and, at the same time, brought in extra income. The city of St. Paul, USA, uses district energy fed by municipal wood waste. This not only in order to displace the 275,000 tons of coal that are used annually, but also to ensure that the $ 12 million USD that is spent on energy remain circulating in the local economy.

The potential of district energy systems to match energy efficiency improvements with the integration of renewable energies has made these technologies more relevant. However, there are still barriers in the markets for their use to spread, including a gap in knowledge of technological applications and their many advantages and savings, a lack of integration of technology infrastructure and land-use planning, as well as a lack of understanding and ability to structure projects that appeal for investment.

Information and accountancy issues involve the insufficient data on municipal air-conditioning systems, the absence of a common approach to recognizing energy savings and environmental returns, and the inexistence of consensual accounting methods for efficiency indicators, labels and building standards. Barriers range from interconnection regulations and limitations on network access, to high initial capital costs and energy pricing regimes or market structures that put district energy systems at a disadvantage compared to other technologies (Lygnerud and Werner, 2018).

However, despite the numerous advantages of district energy, its use is still quite limited, representing only a tenth of the total heat demand in the residential sector. This represents an important opportunity for policy makers to boost the use of renewable energies as a source of heat generation in cities, being conditioned its potential by the availability of renewable urban resources.

Bioenergy district heating networks have long been in operation in some cities. These heat networks (figure I-5) are characterized by a large central heat producing boiler, commonly known as a heat plant, and a set of underground pipes that distribute heat throughout the cities to different buildings or consumption centers (Bush et al., 2016).

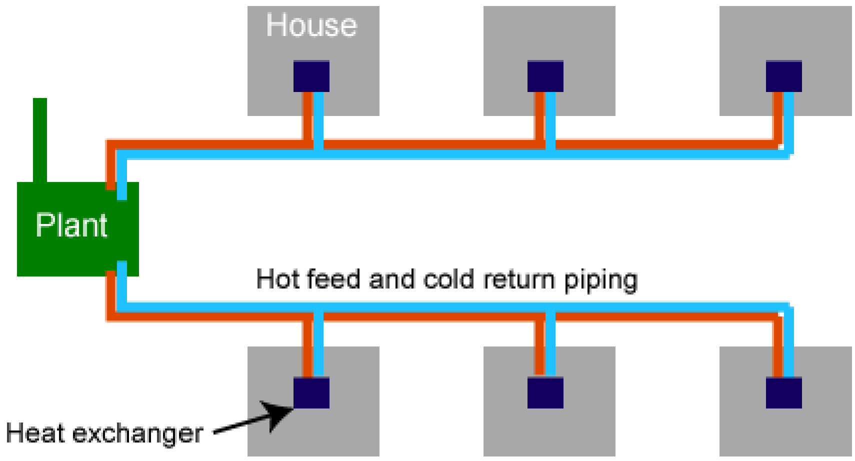

Figure I-5. Heat distribution network topology (Chisholm and Upham, 2010).

Biomass stands out among the main fuels used in district heating networks. A plant that produces heat from the biomass combustion, consisting of a high-power biomass boiler, which distributes the heat generated through a network of underground pipes, where it is delivered to the different consumption centers through a heat exchanger (figure I-6).

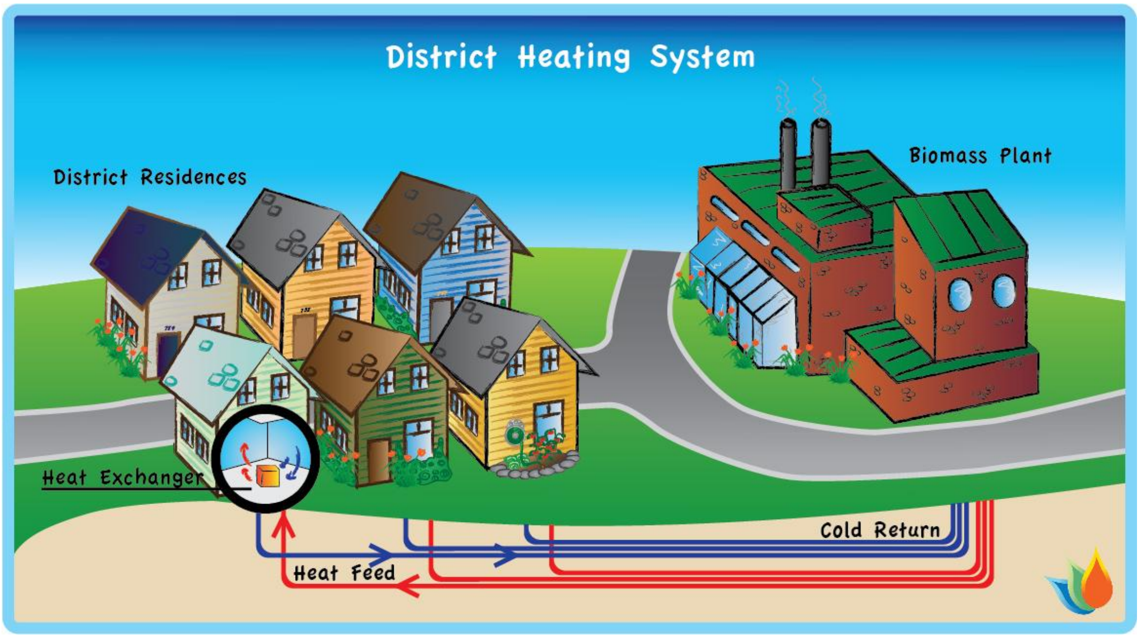

Figure I-6. Biomass District Heating (BDH) (University of Stratchclyde, 2014).

Biomass means all organic matter existing in the biosphere, whether of plant or animal origin, as well as those materials obtained through their natural or artificial transformation. Directive 2009/28/EC on the promotion of the use of energy from renewable sources, defines biomass as "the biodegradable fraction of products, disposals and residues of biological origin coming from agricultural activities (including substances of plant and animal origin), of forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste". In other words, biomass refers to a very wide concept ranging from residues from forestry, agricultural and livestock activities to the organic fraction of household and industrial wastes, including by-products from the agro-alimentary and wood transforming industries (Mehedintu et al., 2018; Muresan and Attia, 2017; Contescu et al., 2018).

Biofuels deriving from biomass include firewood, wood shavings, pellets, some fruit stones such as olives or avocados, as well as nutshells. Of these, cut and chopped firewood is the least processed, and is usually burned directly in domestic appliances such as stoves and boilers. The chips come from the crushing of biomass both agricultural and forest, being their size variable depending on the manufacturing process from which they derive or the transformation process to which they have undergone. Finally, pellets are the most elaborate biofuel, and consist of small cylinders of 6 to 12 mm in diameter and 10 to 30 mm in length that are obtained by pressing biofuels with binders. Pellets are used especially in fuels with a low energy/volume ratio (Li et al., 2018; Williams et al., 2018).

Fruit stones and seeds, as well as fruit husks, though used to a lesser extent than other standardized fuels such as fuelwood, wood chips and pellets, also represent an increasingly used solid biofuel. Indeed, in this Thesis it has been shown that mango stone, peanut shell and sunflower seed husk have a high energy potential, with a Higher Heating Value (HHV) similar to other commercialized biofuels (Perea-Moreno et al., 2018a, 2018c, 2018d). This fact together with the increasing worldwide production of these by-products, make them especially attractive for thermal energy generation, as well as to reduce CO_2 emissions.

Biomass is a resource that is therefore presented in a variety of different materials: wood, sawdust, straw, seed waste, manure, paper waste, household waste, wastewater, etc. The characteristics of some materials allow them to be used as fuels directly; however, others require a series of pretreatments, which require different technologies before they can be used. Figure I-7 shows a classification of the biomass energy extraction processes, ordered according to their complexity.

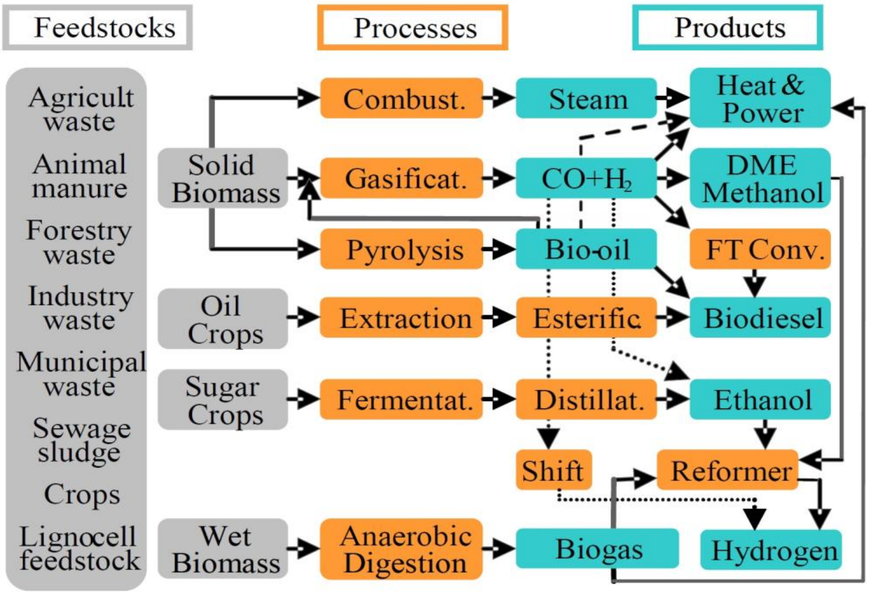

Figure I-7. Biomass conversion paths (IEA, 2007)

The immediate use of some of these processes is heat, usually used on site or at short distances, for chemical processes or heating, or to generate steam for power plants. In other processes the resulting product is a solid, liquid or gaseous fuel: charcoal, liquid fuels substitutes for gasoline used in transport, gas for power plants, using both gas and steam turbines.

Prior to the use of biomass in the different processes reflected in figure I-7, it is collected and subjected to various treatments, depending on the type of biomass and its use. Among the previous treatments are the collection of the biomass and its subsequent chipping, the homogenization or refining carried out by crushing, grinding and refining, the densification through the production of pellets and briquettes, and the final storage of the treated biomass.

As a result of the previous treatments, the biomass can be stored before its use in various formats. As has already been said, two of the most common formats are pellets, which come in the form of cylinders with diameters ranging from 8 mm to 12 mm and lengths in the range of 30 mm to 50 mm, and briquettes, also cylindrical, but with diameters ranging from 50 mm to 130 mm and lengths in the range of 50 mm to 300 mm.

I-1.2. Biomass Conversion Paths

The different paths for converting biomass into energy will now be briefly described:

I-1.2.1. Direct Combustion

Direct combustion is the oldest system for extracting energy from biomass. In the combustion process, organic matter (fuel) chemically reacts with oxygen (oxidizing) in an exothermic reaction (gives off heat to the medium), obtaining carbon dioxide (CO_2), water (H_2O) and, if the elements sulfur and nitrogen are part of the reagents, sulfur oxides (SO_x) and nitrogen (N_yO_z).

The main factors affecting the process are: physical, chemical and energy characteristics of the biomass (fuel), the percentage of oxygen and the temperature at which combustion takes place (between 600 ºC and 1300 ºC).

Among the physical characteristics of biomass, moisture content stands out due to its importance. It is recommended that the degree of humidity stays below 15% (dry biomass), since the evaporation of the water contained in the biomass consumes part of the energy released during combustion. If dry biomass is used, outputs of the order of 80% can be achieved, compared to the outputs achieved (60%) when wet biomass is used (humidity >50%). Likewise, granulometry (size) and density are characteristics that influence the duration of the combustion process and the equipment used in the treatment and the combustion itself.

With regard to the chemical characteristics, it should be noted that the sulphur content of the plant biomass is minimal, so that there are practically no emissions of sulphur oxides into the atmosphere (Bunn et al., 2018).

The energy properties of biomass are given by the so-called Higher Heating Value (HHV) or Gross Calorific Value (GCV), whose most frequent unit is kcal/kg, and which is defined as the amount of heat released by the complete combustion of one kilogram of fuel at constant pressure. However, the so-called Lower Heating Value (LHV) or Net Calorific Value (NCV) is most frequently used, as it reflects the net amount of heat released, once the heat absorbed in the evaporation of the water contained in the biomass has been discounted.

Through direct combustion of biomass, the chemical energy stored in it is transformed into heat energy. Direct combustion of biomass can be carried out in households for direct heating (chimneys, wood-burning stoves, etc.) or through the use of heating systems (boilers) (Perea-Moreno et al., 2018d). Likewise, the heat generated by burning biomass directly can be used in industrial plants for heating and producing steam, which can be used in the generation of electricity.

I-1.2.2. Thermochemical Processes

Biomass is transformed by subjecting it to different oxidation processes, under given pressure and temperature conditions, to obtain solid, liquid or gaseous fuels suitable for various applications. If the process is performed in partial absence of oxygen, this is called Gasification, however, if the process is performed without the presence of oxygen, it is called Pyrolysis.

I-1.2.2.1. Gasification

The term gasification includes the set of processes in which a solid fuel is partially oxidized to produce a gaseous fuel, containing among other components CO (carbon monoxide), CO_2 (carbon dioxide), H_2 (hydrogen), CH_4 (methane) and water vapour.

There are several types of gasifiers, which are usually classified into fixed bed gasifiers, which are further subdivided into upstream and downstream gasifiers, and fluidized bed gasifiers.

The percentages obtained for each of these components depend on the materials mosused (composition, moisture content, particle size and uniformity, etc.), the conditions under which the process is carried out (with air or pure oxygen, operating pressure, process temperature, etc.) and the type of gasifier. When low moisture biomass (less than 15%) is gasified with air (circulating a small volume of air through a large mass of combustion), the so-called gasogenic or poor gas (calorific value less than 5.5 MJ/m^3) is obtained. This gas, due to its nitrogen content and low energy density, is not usually stored, but it is often used directly in combustion equipment to generate electricity using gas turbines and power generators.

When dry biomass is gasified with oxygen, the so-called synthesis gas is obtained, with a calorific value higher than that of gasogenic, but lower than that of conventional fuels (propane, butane, etc.). This gas can be converted, by catalytic processes, into various products, obtaining liquid fuels of great demand, such as methanol (CH_3OH), as well as gaseous fuels.

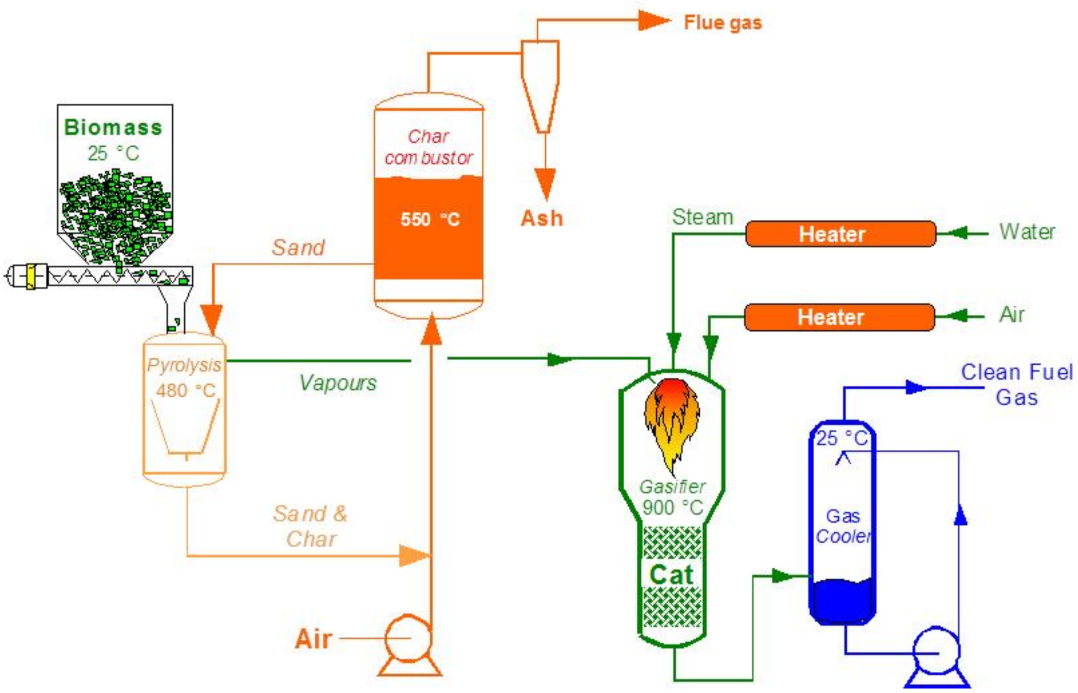

Figure I-8. Gasification process (Biomass Technology Group btg, 2018).

I-1.2.2.2. Pyrolysis

This is the simplest and oldest method of processing a fuel in order to obtain a better one. Conventional pyrolysis requires the heating of the original material in the total absence of oxygen. The process usually initiates at about 260 °C and is finished at about 450 °C or 550 °C (if vegetable waste is used); when Municipal Solid Waste (MSW) is used, the temperature is usually higher and can reach 1000 ºC (Sipra et al., 2018).

The characteristics of the used biomass (agricultural and forest residues, urban solid residues) and the operating conditions of the process (temperature, pressure, times, etc.) are the factors that will determine the composition and type of product obtained. The products obtained can be charcoal, liquid fuel and gas fuel.

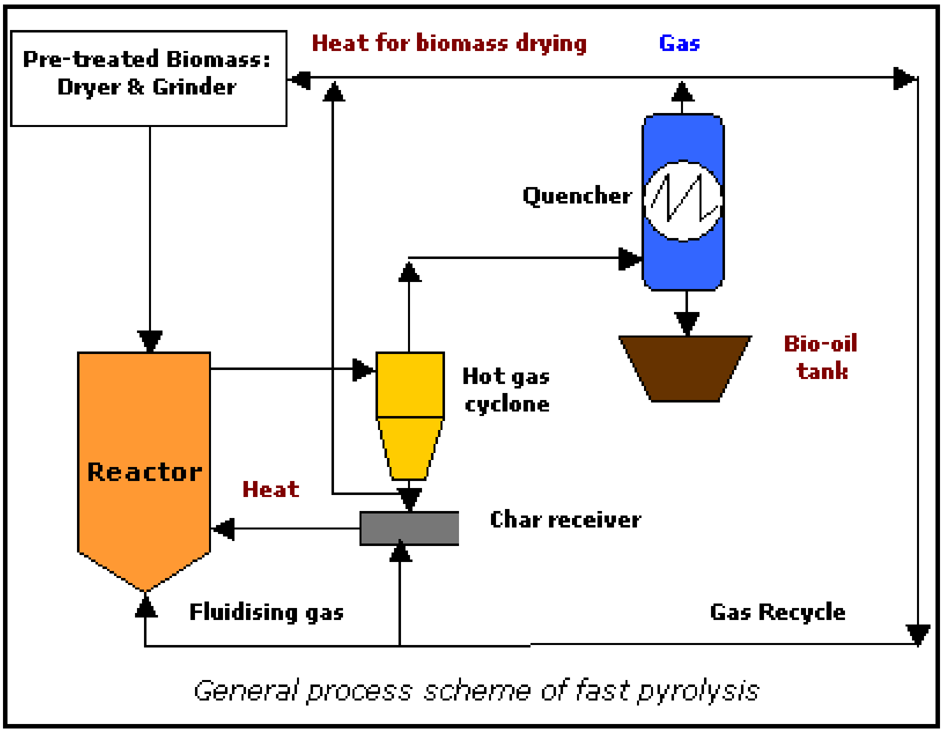

Figure I-9. Fast pyrolisis process (Combio, 2018).

The so-called fast pyrolysis (figure I-9) operates in short times and at high temperatures (800 ºC - 1000 ºC). This technique allows obtaining a small part of solid material (10%) and converts 60% into gas rich in hydrogen and carbon monoxide. This means that fast pyrolysis can compete with conventional gasification methods. This is probably the most suitable process for converting Municipal Solid Waste (MSW) into compounds of some interest.

I-1.2.3. Biological Processes

In these processes the wet biomass is degraded by the action of microorganisms, which contain the biomass or are incorporated into the process, obtaining products of high energy density. The two best known processes are anaerobic digestion and fermentation alcoholic.

I-1.2.3.1. Anaerobic Digestion

As its name indicates, anaerobic digestion, just like pyrolysis, takes place in the absence of air, but in this case the decomposition of the biomass is due to the action of bacteria and not to high temperatures.

The biomass materials that feed the process are often livestock waste (animal manure, dead animal waste, etc.), waste obtained from wastewater treatment plants (sludge) and waste from organic industries (sugar factories, litter bins, etc.) (Ahmad et al., 2018; Acosta et al., 2018). The resulting product is the so-called biogas, which mainly contains, carbon dioxide (CO_2) and methane (CH_4), together with sludge. The components solids from the sludge can be used in animal feed or as fertilizer for land.

The biogas production process is rather complex and takes place in three stages (figure I-10). In the first stage (hydrolysis), a population of bacteria breaks down organic matter into sugars. In the second stage (acetogenic), the sugars are transformed into organic acids. In the third stage (methanogenic), the previously obtained substances are transformed into methane (CH_4) and acid gases (SH_2, CO_2).

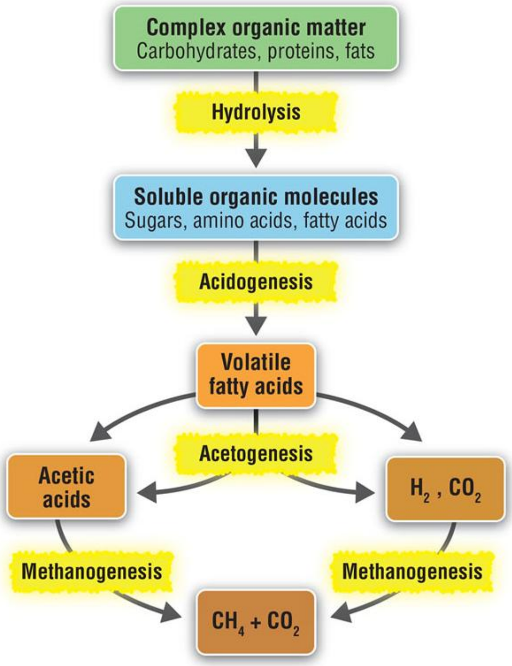

Figure I-10. Biological process of anaerobic digestion (BioCycle, 2016).

The key factors affecting the process are the type and composition of biomass, process temperature, acidity (determines biogas production and percentage of methane), solids content (not too liquid for microorganisms to feed on and not too thick for them to move around), and the retention time, which depends on the type of biomass, but is between 10 days and one month.

The devices where anaerobic digestion takes place are called digesters. These are classified into continuous and discontinuous digesters (the latter in disuse). In the latter, as the name suggests, the process is carried out in a discontinuous manner, that is, the digester is not filled with fresh biomass until the biomass that was introduced in a previous treatment has fermented (hydraulic residence time of 20 to 60 days), the gas produced has been collected, stored in so-called gasometers and the undigested solid matter has been removed. Hydraulic Residence Time (HRT) is the time that biomass stays in the digester.

The continuous digesters do not stop their activity at any time, and there is a wide range of typologies available for them (Lemieux et al., 2017). Among them it should be highlighted the complete mixing digesters (HRT between 15 and 25 days), which have mixing devices and heating systems; contact digesters (HRT between 4 and 8 days), which aim to improve the bacterial flora by using feedback systems; anaerobic filter digesters (HRT between 1 and 4 days), which retain the bacteria responsible for the process by using inert filters.

The most common applications of biogas are: heating, combustion of conventional steam boilers and as a fuel for internal combustion engines for electricity generation (Musthafa, 2018). In addition, digestion residues can be used for animal feed and soil fertilization.

I-1.2.3.2. *Alcoholic Fermentation*

The sugars (simple carbohydrates) contained in the plants can be transformed into alcohol by the intervention of specific microorganisms. Plants also contain starches and cellulose (complex carbohydrates), which can also be transformed into alcohols, although through a more complex process. The biofuels obtained from the process are basically methanol [$CH_3(OH)$], or methyl alcohol, and ethanol

[CH_3-$CH_2(OH)$], or ethyl alcohol. The latter is currently the one with the greatest development potential (Saville, et al., 2016).

By means of mechanical pre-treatment (the most common), the aim is to increase the contact surface of the biomass in the treatment. This includes crushing, grinding, etc. Complex carbohydrates are broken down by hydrolysis of microorganisms (enzymatic hydrolysis) or by chemical reagents (chemical hydrolysis). Through the alcoholic fermentation process, the sugars are transformed into hydrated ethanol, by the intervention of certain microorganisms. Finally, the ethanol is distilled in order to release it from water (figure I-11).

Ethanol can be used as eco-friendly fuel in gasoline and diesel engines (Chollacoop, et al., 2013). In the latter case, substantial engine modifications can be required, while modifications to petrol engines are sometimes not necessary.

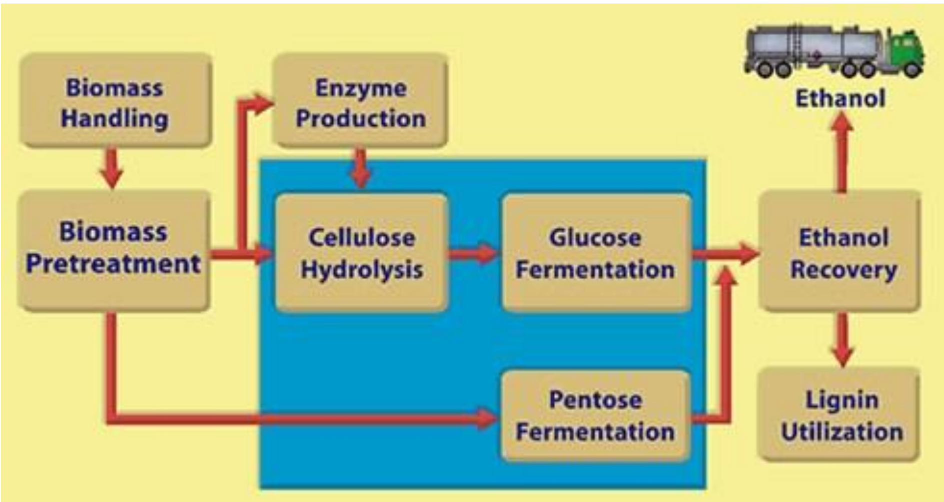

Figure I-11. Biological process of ethanol production (Cibele, 2011).

I-1.2.4. Other Processes

Within this group are the processes aimed at obtaining a biofuel. One of the most widely used biofuels in transport is biodiesel. The ASTM (American Society for Testing and Materials) defines biodiesel as "the long-chain monoalkyl ester of fatty acids derived from renewable resources, such as vegetable oils or animal fats, for use in diesel engines".

Biodiesel is a liquid fuel obtained from oil extracted from oilseeds or animal fat. Biodiesel can be used as a substitute for diesel fuel from automotive, if compression ignition engines are conditioned, or can be mixed with it in different proportions, as it has similar density characteristics and cetane number, as well as a higher flash point.

Any material containing triglycerides can be used for the production of biodiesel (conventional vegetable oils, alternative vegetable oils, used frying oils, genetically modified vegetable oils, animal fats, oils from algae, etc.) (Arumugam and Ponnusami, 2018; Jeon et al., 2018), however, the most widely used biomass for the manufacture of this fuel is made up of conventional vegetable oils: sunflower and rapeseed (Europe), soybean (United States), coconut (Philippines), etc (Gutierrez-Zapata et al., 2017; Khwanpruk and U-Tapao, 2018).

The industrial process of obtaining biodiesel with the greatest advantages is transesterification. The oilseeds are subjected to a chemical process (dragging of the oil with solvents), obtaining the oil and a cake (rich in proteins and particularly suitable for the production of animal feed). This oil is filtered, refined or degummed and subjected to the transesterification process which basically consists of the mixture of vegetable oil or fats with alcohol (usually methanol) and an alkali (caustic soda) (figure I-12).

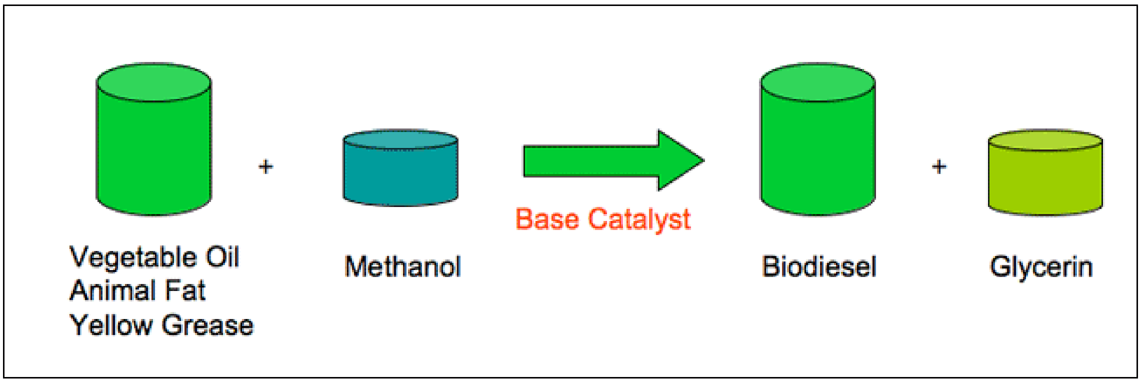

Figure I-12. Industrial process for obtaining biodiesel (Green Catalysts, 2015).

Vegetable oils are composed of triglyceride molecules, connected to glycerin through ester bonds. Triglyceride is converted consecutively into diglyceride, monoglyceride and glycerin in three continuous and reversible reactions (figure I-13). In the process, the glycerin is replaced by methanol (methyl alcohol) which is added to the process, obtaining linear molecules similar to those of the hydrocarbons present in the diesel. The use of catalysts allows the reaction to take place at temperatures and pressures lower than those required if the reaction is natural.

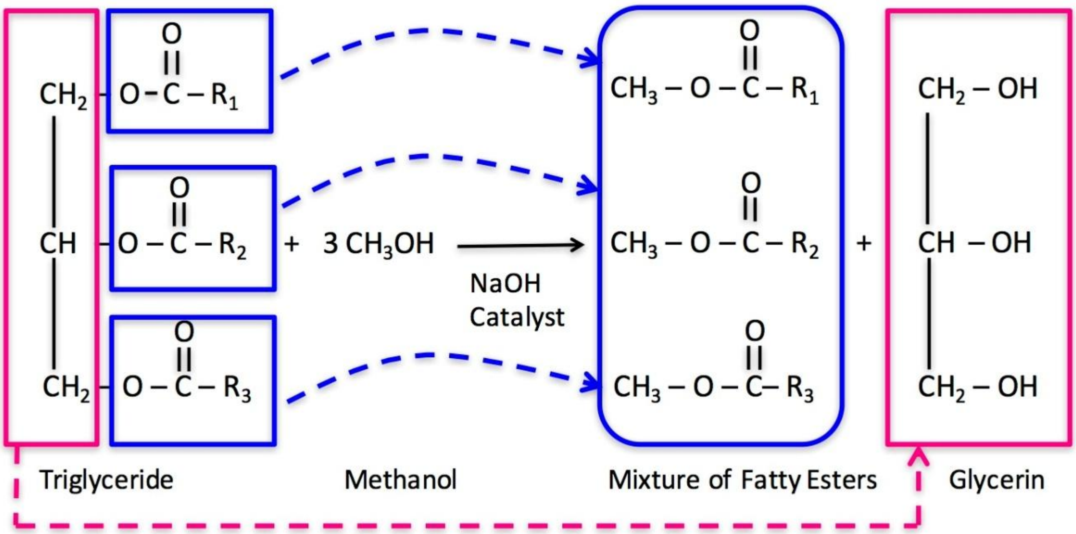

Figure I-13. Reactions of the transesterification process (Anshu et al., 2018).

During the last decade the biomass market has grown and consolidated, as research has shown its enormous potential (Ferreira et al., 2018). In this way, standards have appeared to certify the quality of this type of fuel, such as ISO 17225 for shavings and pellets, with specific standards for agrifood residues such as olive stone or nutshells (UNE-164003 and UNE-164004, respectively) (Karampinis et al., 20018; Mata-Sánchez et al., 2014).

Biomass is considered a carbon-neutral renewable source, since in its growth stage it takes CO_2 from the atmosphere through the photosynthetic process, which is then released when burning, so the carbon balance is null. Besides, it should be taking into account that the biomass market not only allow to obtain a renewable fuel, neutral in terms of CO_2 emissions and competitive in price regarding fossil fuels, but also play a key role in the improvement of forest management and in the socio-economic development of the urban areas (Lygnerud and Werner, 2018).

The transition to a low carbon energy system involves researching new forms of renewable energy that stayed useless during the fossil fuel era. Cities are the main producers of waste and disposals, and according to the available infrastructure, and the established regulatory framework, these wastes can be classified, decontaminated and reused, burned for thermal and electric energy production or taken to landfill. Currently most of the agroindustral and livestock wastes are discarded without making an eco-friendly use of them. Several studies have pointed out the huge potential of industrial biomass for residential-level heat generation (Perea-Moreno et al., 2016, 2017b, 2018a, 2018c, 2018d).

According to The World Bank, in 2012 1.3 billion tonnes of urban Municipal Solid Waste (MSW) were generated and this amount is expected to increase to 2.2 billion tonnes by 2025 (World Data Bank, 2018). These residues tend to accumulate in landfills where they end up decomposing by anaerobic digestion and releasing methane gas that contributes to increase climate change effects. However, this gas can be captured and reused for the generation of thermal and electrical energy in cogeneration plants. This biogas, which is also generated as a by-product of the agro-food industry, can be transformed into biomethane and distributed through the municipal gas network or even used as a transport fuel (O'Shea et al., 2017).

The industry not only consumes energy, but also produces it as a by-product of its processes. An example is the olive and sunflower oil, avocado or mango industry whose waste can be treated and reused as biodiesel or solid biofuel of high calorific value (Bartocci et al., 2018; Perea-Moreno et al., 2016, 2018a, 2018c, 2018d). Therefore, the burning of municipal solid waste can be used in district heating networks for thermal power generation, while improving waste management (Perea-Moreno et al., 2017b).

I-1.3. Sustainable Transport

Transport represents one third of the total energy currently used in cities and is expected to increase by 50% by 2030 (International Energy Agency, 2016). If this energy is supplied by means of fossil fuels, the consequences on pollution of cities and climate change will be devastating. Figure I-14 depicts the different options in which transport in cities can be powered by green energies:

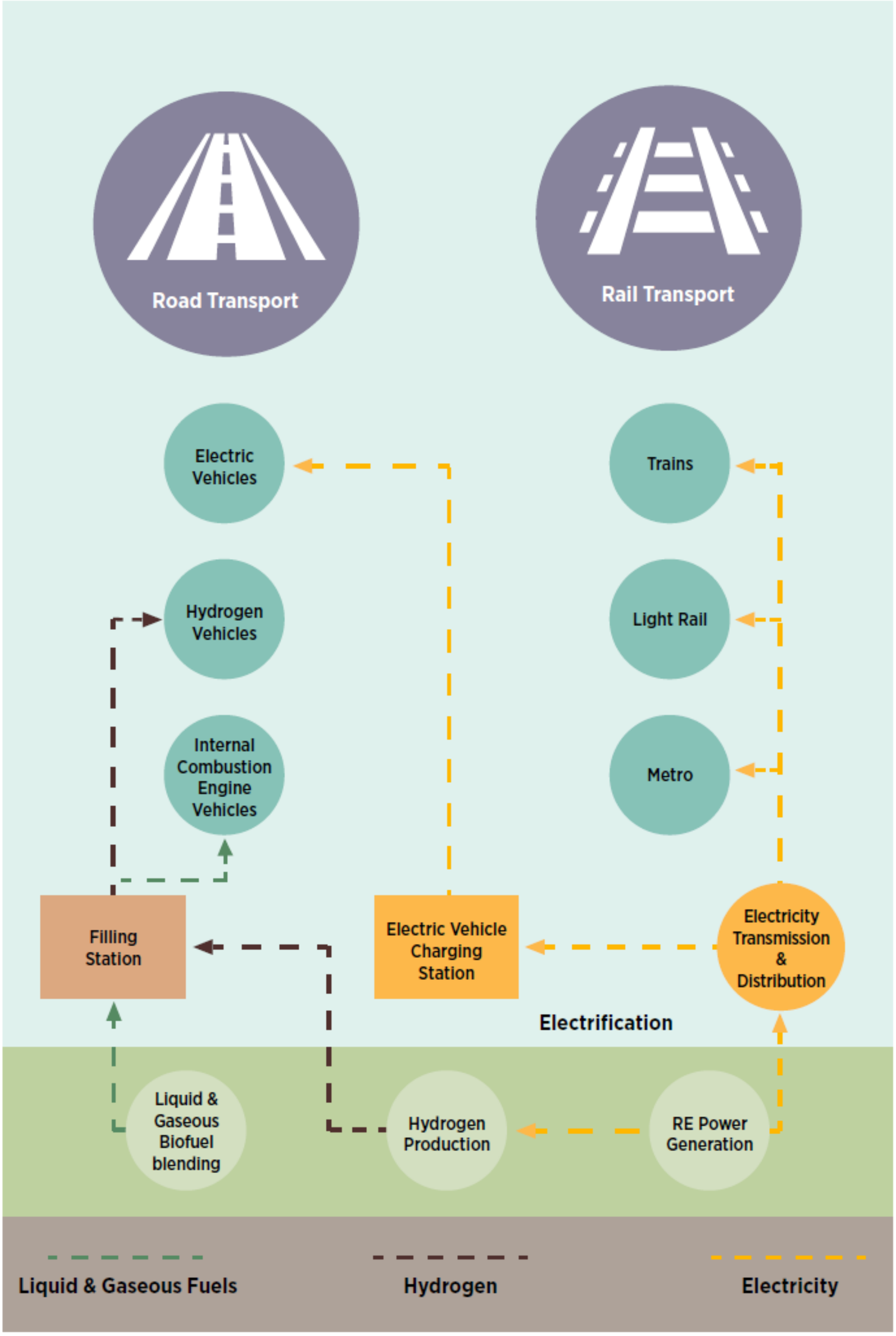

Figure I-14. Renewable energy options for road and rail transport in cities (IRENA, 2016).

In rail transport, green solutions are electric trains, light rail and subway systems. In road transport sustainable options are the use of electric vehicles, as well as the substitution of traditional fossil fuels for both liquid and gaseous biofuels and hydrogen.

With regard to other renewable energy sources used in urban areas, solar and wind energy are emerging technologies. Solar energy can also play an important role in making sustainable cities, as it is a highly efficient green technology in constant development. There is great potential for the generation of thermal and photovoltaic solar energy by taking advantage of the roofs of existing and new buildings (Perea-Moreno et al., 2017a), where photovoltaic panels and solar collectors can be installed at an increasingly competitive price, and with great reliability and low maintenance. Solar power generation capacity is expected to increase up to 147 GW by 2020, 337 GW by 2030 and 1,089 GW by 2050 (Philips and Smith, 2015).

Another sustainable technology that is being researched and successfully applied in some cities concerns small-scale wind power generation. It has been proven that mini wind turbines can operate with low wind regimes maintaining a high level of efficiency without the need to create new electrical installations, due to the fact that losses by transport and distribution of electrical grids are avoided (Waite and Modi, 2016). In addition to being reliable, this environmentally sustainable technology has a relatively low maintenance cost and minimal environmental impact. It is estimated that in China, an average household would need roughly one 1 KW wind turbine to meet its one-year energy demand; for a European household a 4 kW turbine would be sufficient to meet its annual energy demand, while an American household would need a 10 kW turbine to meet an average annual electricity consumption of 11,500 kWh (Liu et al., 2018).

Currently, the generation assessment of energy from renewable sources in urban areas is a field of great interest to the scientific community. The large-scale generation of low-carbon energy in cities is postulated as one of the key solutions for the development of sustainable cities, due to the fact that on the one hand it allows to satisfy the growing energy demand for them, and on the other hand it makes possible to reduce pollution issues in cities, as well as to contribute to climate change mitigation.

I-2. HYPOTHESIS AND OBJECTIVES

According to predictive models, the world's population is likely to exceed 11 billion by the end of the century. Most of this population will live in urban areas, so our planet faces major challenges in terms of sustainable energy supply. Despite its enormous potential to increase sustainability, the use of renewable energy in urban areas continues to be limited. The hypothesis is that urban contribution to renewable energy will be essential for the welfare of a growing urban population, by both, reducing greenhouse gasses emissions, and by increasing energy efficiency.

The general objective of this thesis is to investigate about the generation and use of renewable energy at urban areas in Mediterranean countries. The general objective can be divided into the following specific objectives **(O1, O2 and O3)**:

- To establish methodologies for the integration of renewable energy resources in small urban areas with high energy consumption, and to evaluate that this methodology could be successfully applied in the Mediterranean areas **(O1)**.
- To evaluate the use of new renewable energy sources, highlighting the potential of biomass and urban solid waste in urban renewable energy generation, as a key element to improve energy efficiency and sustainability of urban environments **(O2)**.
- Evaluation of methodologies for energy saving in public and private buildings **(O3).**

These objectives have been achieved and justified by publishing the following peer-reviewed articles:

- Perea-Moreno, M. A., Hernandez-Escobedo, Q., & Perea-Moreno, A. J. (2018). Renewable energy in urban areas: Worldwide research trends. *Energies, 11*(3), 577-593. doi: 10.3390/en11030577. Open Access. **(O1)**

  Energy & Fuels
  Science citation index: JCR (2017) 2.676
  Placed: 48/97 (Q2)

- Perea-Moreno, A. J., Perea-Moreno, M. Á., Hernandez-Escobedo, Q., & Manzano-Agugliaro, F. (2017). Towards forest sustainability in Mediterranean countries using biomass as fuel for heating. *Journal of Cleaner Production, 156,* 624-634. http://doi.org/10.1016/j.jclepro.2017.04.091. **(O1 and O3)**

  Green & Sustainable Science & Technology
  Science citation index: JCR (2017) 5.651
  Placed: 6/33 (Q1)

- Perea-Moreno, A. J., Perea-Moreno, M. Á., Dorado, M. P., & Manzano-Agugliaro, F. (2018). Mango stone properties as biofuel and its potential for reducing CO_2 emissions. *Journal of Cleaner Production, 190*, 53-62. https://doi.org/10.1016/j.jclepro.2018.04.147. **(O2)**

  Green & Sustainable Science & Technology
  Science citation index: JCR (2017) 5.651
  Placed: 6/33 (Q1)

- Perea-Moreno, M. A., Manzano-Agugliaro, F., Hernandez-Escobedo, Q., & Perea-Moreno, A. J. (2018). Peanut shell for energy: Properties and its potential to respect the environment. *Sustainability, 10*(9), 3254-3269. doi:10.3390/su10093254. Open Access. **(O2)**

  Environmental Sciences
  Science citation index: JCR (2017) 2.075
  Placed: 121/242 (Q2)

- Perea-Moreno, M. A., Manzano-Agugliaro, F., & Perea-Moreno, A. J. (2018). Sustainable energy based on sunflower seed husk boiler for residential buildings. *Sustainability, 10*(10), 3407-3427. doi:10.3390/su10103407. Open Access. **(O1 and O3)**

  Environmental Sciences
  Science citation index: JCR (2017) 2.075
  Placed: 121/242 (Q2)

I-3. STRUCTURE

This thesis consists of seven chapters, five of which are articles published in indexed journals: *Energies*- Chapter II, *Journal of Cleaner Production*- Chapters III and IV, *Sustainability*- Chapters V and VI.

The thesis is structured as follows:

- Chapter I: Introduction, hypothesis and objectives, and structure of the thesis.
- Chapter II: Renewable energy in urban areas: Worldwide research trends.
- Chapter III: Towards forest sustainability in Mediterranean countries using biomass as fuel for heating.
- Chapter IV: Mango stone properties as biofuel and its potential for reducing CO_2 emissions.
- Chapter V: Peanut shell for energy: Properties and its potential to respect de environment.
- Chapter VI: Sustainable energy based on sunflower seed susk boiler for residential buildings.
- Chapter VII: Summary and general conclusions.

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Chapter II.

Renewable energy in urban areas: Worldwide research trends

«Sustainable Urban Energy is the Future»

United Nations (2015)

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Chapter II. Renewable energy in urban areas: Worldwide research trends

Miguel-Angel Perea-Moreno [1], Quetzalcoatl Hernandez-Escobedo [2], and Alberto-Jesus Perea-Moreno [1]

[1] Departamento de Física Aplicada, Universidad de Córdoba, CEIA3, Campus de Rabanales
14071 Córdoba, Spain

[2] Faculty of Engineering, Campus Coatzacoalcos University of Veracruz, Mexico

II-1. ABSTRACT

This study aims to highlight the contribution made by different international institutions in the field of urban generation of renewable energy, as a key element to achieve sustainability. This has been possible through the use of the Scopus Elsevier database, and the application of bibliometric techniques through which the articles content published from 1977 to 2017 has been analysed. The results shown by Scopus (e.g., journal articles and conferences proceedings) have been taken into account for further analysis by using the following search pattern (TITLE-ABS-KEY ({Renewable energy} AND ({urban} OR ({cit*})). In order to carry out this study, key features of the publications have been taken into consideration, such as type of document, language, thematic area, type of publication, and keywords. As far as keywords are concerned, renewable energy, sustainability, sustainable development, urban areas, city, and energy efficiency, have been the most frequently used. The results found have been broken down both geographically and by institution, showing that China, the United States, the United Kingdom, Italy, Germany and India are the main research countries and Chinese Academy of Sciences, Ministry of Education China and Tsinghua University the major contributing institutes. With regard to the categories, Energy, Environmental Sciences, and Engineering are positioned as the most active categories. The scientific community agrees that the study of the renewable energy generation in cities is of vital importance to achieve more sustainable cities, and for the welfare of a growing urban population. Moreover, this is in line with the

energy policies adopted by most of developed countries in order to mitigate climate change effects.

Keywords: renewable energy; sustainable development; urban areas; city; bibliometric research

II-2. INTRODUCTION

Energy production and consumption have considerations that affect both sustainability and economy (Shen et al., 2018). Indeed, not only the depletion of fossil resources and generated greenhouse gasses emissions, as a consequence of a coal and oil based model, or the occupation of natural spaces for renewable models of centralized production should be taken into account, but also the increasing cost of energy (Perea-Moreno et al., 2016, 2017b). In the economic activity, this cost has an impact on the income statement, which may involve a variable amount in relation to the total costs of the activity, usually ranging from 5 to 40% of the costs necessary to produce or provide the services (Sorgato et al., 2018).

On the whole, energy efficiency is defined as the relationship between the production of goods or services and the energy expenditure required (De la Cruz-Lovera et al., 2017). Thus, through energy efficiency, the reduction in energy consumption is sought by maintaining the same uses of energy that is, without reducing the level of production or decreasing the level of comfort, ensuring supply, promoting sustainability and protecting the environment. This reduction involves the different sources of energy used, such as oil, coal, natural gas, etc. (Zhao and Zhou, 2017; Geller et al., 2006; Marchi and Zanoni, 2017).

The group of fossil fuels (coal, oil and natural gas) used worldwide as a source of energy represents a very high percentage of the primary energy used. This is leading to its depletion and resulting in the increase of prices (Harvey, 2018).

Because of the above, it can be said that the current energy system presents serious problems that are summarized in the depletion of fossil fuel reserves, negative consequences for the environment (climate change, greenhouse effect, acid rain, deforestation, etc.) and instability of the geopolitical system caused mainly by inequality in the distribution of energy consumption and reserves (Perea-Moreno and Hernandez-Escobedo, 2016; Bilgen, 2014; Filippín et al., 2018).

The alternative to these problems raised by the current global energy system should be the progressive implementation of measures that promote sustainable development (Lee et al., 2017; Hernandez-Escobedo, 2016; Perea-Moreno et al., 2017a). In the current economic model, three production sectors are of great importance for saving energy and reducing pollution and, therefore, for sustainable development: construction by improving building techniques (Alfaris et al., 2016); the energy producing sector with cogeneration systems (Teymoori and Amjady, 2018; Chitsaz et al., 2018; Ben Youssef et al., 2018), hybrid systems (wind-diesel) and alternative sources (Hossain et al., 2017; Sciubba et al., 2016); and the transport sector using unleaded gasoline, biofuels, catalytic filters and mixed and electric vehicles (Wu, 2018; Martínez-Lao et al., 2017; Cubito et al., 2017).

On the other hand, renewable energies cover only 15% of the world's energy sources, and fossil fuels will continue to satisfy a large part of the world's energy demand for the foreseeable future (Zheng et al., 2018). The energy sector is responsible for two thirds of global CO_2 emissions and one of the main drivers of climate change. Therefore, to limit this increase in emissions, strategic plans have been put in place such as the Strategic Framework for 2030 of the European Union, or the Clean Energy Plan of the United States in which countries involved are committed to reducing CO_2 emissions by 32% by 2030 (Maricic et al., 2018; Gurney et al., 2016).

There are twice as many inhabitants in the world compared to the year 1960, and the population is expected to continue growing to reach 9000 million by 2050 (Herrera-Quintero, 2015). According to predictive models, developing countries will experience 99% of this population growth, with a 50% population increase in urban areas. In accordance with the information given by the United Nations in relation to the environment program, in Latin America, which has a high degree of urbanization, 78% of its inhabitants resided in urban areas in 2007, and it is expected that this percentage will increase to 89% by 2050 (Neves et al., 2017). In less urbanized countries such as Asia and Africa, with 40% of the population living in cities, a high rate of increase in the urban population is also expected, reaching 62% by 2050. According to the United Nations forecasts, in 2050, the number of people who will live in cities will amount to 6000 million (Weinmaster, 2009). However, the increase in urbanization also means new opportunities for policy makers in developing countries to promote better urban conditions in terms of stricter efficiency standards in buildings, as well as to boost sustainable mobility in order to achieve a sustainable urban development (Deakin and Reid, 2018).

Although fossil fuels continue to be the main source of energy in cities, the use of sustainable energy as a policy solution to mitigate the serious pollution issues, is becoming more and more essential (Perea-Moreno et al., 2016). Upcoming technologies such as the use of cogeneration systems and biomass district heating in cities are characterized by energy savings and high energy efficiency. Research and development of renewable energy models in urban areas are becoming an imperative to achieve a sustainable energy system. Many cities have already expressed their commitment towards a 100% renewable model. It is expected that by the year 2025, cities such as Copenhagen and Munich will obtain 100% of their electricity from renewable sources, thus becoming neutral carbon cities (Thellufsen and Lund, 2016).

With regard to the main sources of renewable energy that are currently used in cities, biomass, solar and wind energy are the main technologies, which remain under-researched (Juaidi et al., 2016). Municipal Solid Waste (MSW) generated in urban areas is generally carried to dumps and buried, without making a sustainable use of it. Once decomposed by anaerobic digestion, they end up generating a methane-rich biogas that reaches the atmosphere and becomes carbon dioxide, one of the main drivers of global warming. This generated biogas can be used for thermal and electrical energy generation, avoiding in this form the negative consequences of its release into the atmosphere. The use of biomass (wastewater, agricultural and livestock waste, urban or industrial residues, remains of trees or crops, ...), for the generation of useful energy-electricity or heat-, is a source of energy production with a large potential, which contributes on the one hand to a more sustainable waste management, and on the other hand, to reduce the energy dependence on fossil fuels (Yi et al., 2018).

Moreover, solar energy applied in urban environments is an effective and environmentally friendly technology, since panels and photovoltaic (PV) equipment, as well as thermal solar collectors, can be placed on the roofs of buildings, where they function efficiently, without hindering normal activity and with low maintenance (Mohajeri, et al., 2018). It is estimated that the global capacity for concentrating solar energy production will reach 147 GW in 2020, 337 GW in 2030 and 1089 GW in 2050 (Philips and Smith, 2015).

Another growing research trend is related to small-scale wind energy generation. The installation of wind turbines in cities is a simple and eco-friendly technology; since a mini wind generator has a low maintenance cost, is very reliable and has a minimum environmental impact. It also works with low intensity winds, does not need the creation of new electrical infrastructures and has a high efficiency index, since it avoids the losses that occur in the transport and distribution electricity grids (Waite and Modi, 2016). A Chinese home, for example, would currently need a 1 kW turbine to generate all the energy needed for a year; a European house would not need more than 4 kW, and an American home would need roughly a 10 kW wind turbine to cover an average consumption of 11,500 kWh of annual electricity (Liu et al., 2018).

Nowadays, the use of green energy in urban areas represents a field of great interest to the scientific community. The large-scale urban generation of renewable energy is postulated as a solution for the development of sustainable energy, both, to meet the growing demand for energy in cities and, to reduce greenhouse gasses emissions (Laiola and Giungato, 2018). Research is needed to achieve more efficient, profitable and sustainable renewable sources. Then, the knowledge about the distribution of the worldwide scientific scene with regard to the urban generation and use of renewable energy in cities is of utmost interest (Curreli et al., 2016).

Because there are two widely used databases, Web of Science (WoS) and Scopus, the problem related to the statistical data provided from different sources arises, as regards their comparability and stability. The overlay among these databases and the effect due to the use of data coming from different sources for specific research fields in bibliometric indicators, have been studied. To solve this problem, and taking into account some studies involving citations, it has been limited the citation period from 1977 onwards, since Scopus citations are comparable to Web of Science citations in this period (the citation coverage from Scopus); it has been proved that each database covers approximately 90% of the references identified by the other (Bar-Ilan, 2010). Nevertheless, if the scope of WoS and Scopus journals is taken as an indicator, a comparative study shows that Scopus has a greater coverage of active academic journals (20,346 journals) compared to WoS (13,605 journals) (Mongeon and Paul-Hus, 2016), being the correspondences between the data obtained with both databases in relation to the quantity of documents and citations by country and range extremely high ($R^2 \approx 0.99$) (Archambault et al., 2009). The advantages of Scopus database are highlighted in diverse papers and, consequently, is frequently employed for many bibliometric analyses (Solomon, 2013; Rodrigues et al., 2016).

The ultimate purpose of this study is to establish the current situation as well as the research trends in the field of renewable energy in urban areas over the 1977–2017 period, in order to help the scientific world to have a greater understanding about the present and future situation, providing useful information to foresee future tendencies that might occur in research lines.

II-3. MATERIALS AND METHODS

Bibliometrics is the branch of bibliology that studies the scientific production contained in various types of documents through statistical methods. Bibliometrics is considered one of the key research tools widely extended to all scientific fields, being frequently used in the evaluation of the results of peer-reviewed research.

On the other hand, the Scopus database, which has a catalog of more than 20,000 publications coming from more than five thousand international publishers, has been chosen in this study, owing to the fact the scientific community agrees on its great usefulness as the largest source of data and citations on the referenced literature.

Through the use of this database, a thorough search of the subfields of the title, abstract, and authkey involving the topics of renewable energy and city has been accomplished. The search was limited between the years 1977 and 2017. The success of this methodology has also been proved by other studies (Gimenez and Manzano-Agugliaro, 2017; Salmeron-Manzano and Manzano-Agugliaro, 2017; Montoya et al., 2016; Manzano-Agugliaro, 2013).

The following search pattern has been used, in order to avoid distorting the results: (TITLE-ABS-KEY ({Renewable energy} AND ({urban} OR ({cit*})).

Several indices, as well as the statistical indicators in lot of interest areas can be established by combining the field results with the information collected. The publications found concerning renewable energy and urban areas or cities over the time frame from 1977 to 2017 were assessed based on different criteria such as kind of publication, language, scientific product features, distribution of publications by country and institution, categories of distribution topics, analysis of citations as well as the frequency of the key word appearance. For the analysis of citations, the influence of the h-index has been taken on board. This index, which was suggested in 2005 by Hirsch, is extensively used to evaluate the impact of an individual researcher. It is considered the most reliable way to measure the work scientific quality, evaluating the regularity of production and predicting the future result, since it takes into consideration both productivity and impact.

The h-index of a researcher is equivalent to the number of articles of that researcher whose number of citations is equal or greater than the number of articles published. That is, if the index h is 20, that means that the author has 20 articles with 20 or more citations each. Therefore, it can be concluded that the higher the h-index, the better the academic scientific quality of the researcher.

II-4. RESULTS AND DISCUSSION

II-4.1. Type of Publications and Languages of Publications

Considering several fields and types of documents, the search has shown a total of 46,172 documents. A further analysis of the different types of publications reveals that the great part of the research works are articles (30,764; 67%) and conference papers (8074; 17%). By contrast, there are a remarkably lower number of reviews (3933; 9%), being devoted the lowest percentage to book chapters and books. Figure II-1 shows a chart representation of the distribution according to the type of document during the period 1977–2017.

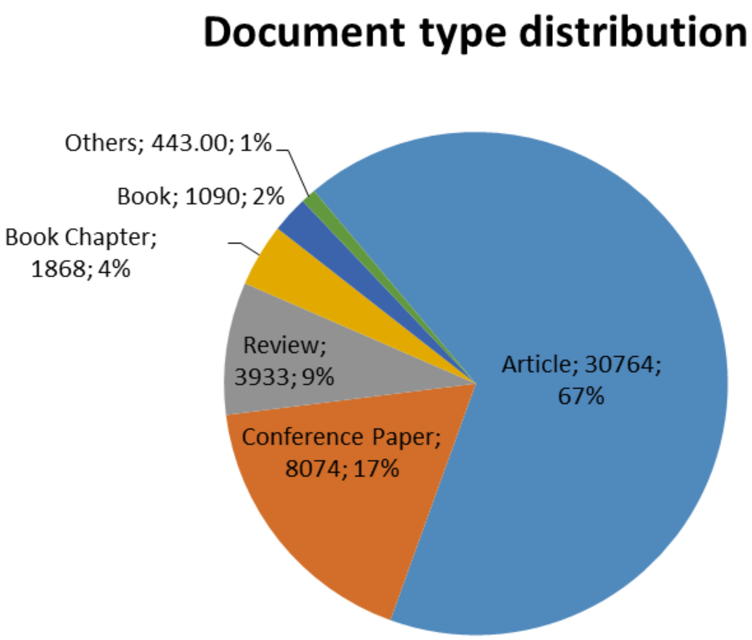


Figure II-1. Chart representation of document type distribution during period 1977–2017.

Due to the fact that the majority of the analysed publications are articles published in international journals, a great percentage (96.50%) of the works have been published in English, with a minute percentage (2.61%) being written in Chinese, German or Spanish language. Figure II-2 depicts the percentage of publications according to the language used in the document.

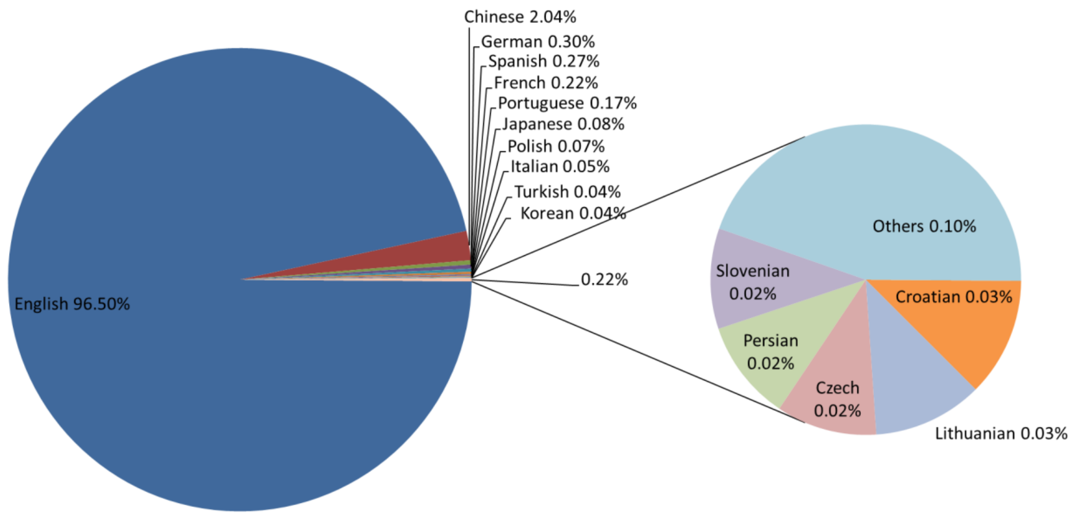
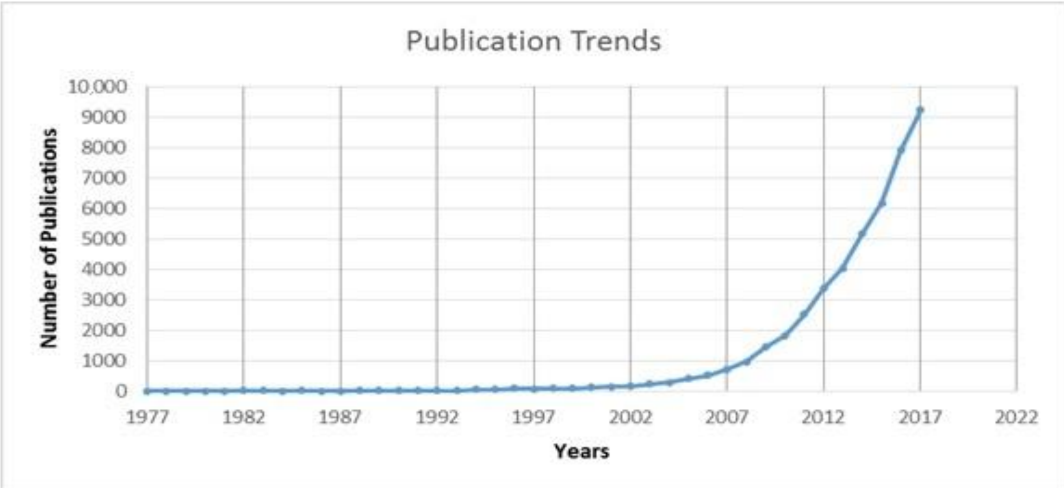


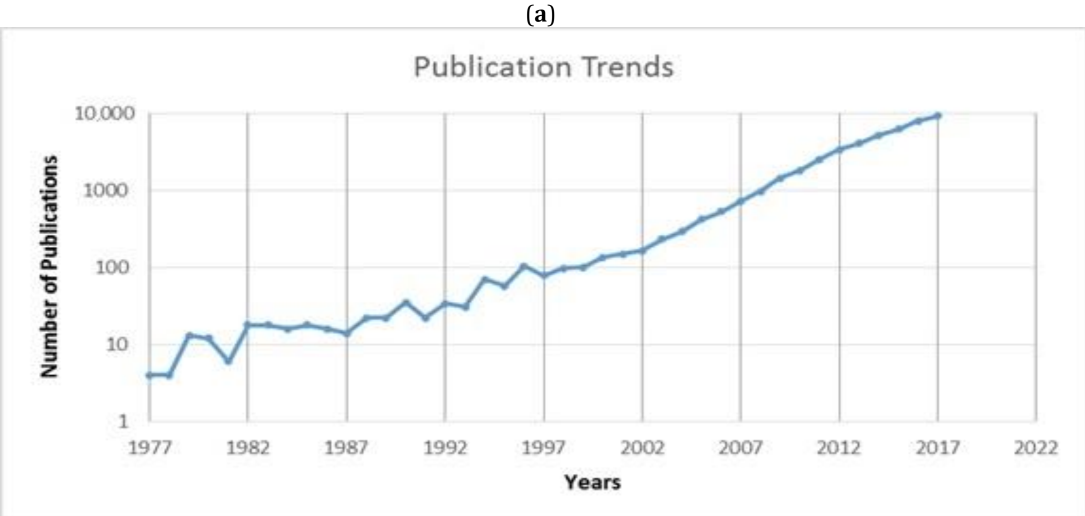
Figure II-2. Chart representation of publications based on the language used.

II-4.2. Characteristics of scientific output

Figure II-3a represents the evolution trend in the publications amount over the last four decades. As can be seen, scientific production in this area was scarce until the beginning of the 2000s, when it began to increase almost exponentially, going from barely 250 annual publications, to exceed 9000 in 2017. This important rise was motivated by a greater understanding of the environmental issue at the dawn of the 21st century, in which different governments and institutions established energy policies with the objective of encouraging renewable energies and energy efficiency, as a measure to mitigate the effects of climate change. In Figure II-3b, a logarithmic scale is used to represent the data, thus giving a clear view of the growth rate.



(**a**)



(**b**)

Figure II-3. (a) Trend in renewable energy in urban areas publications during the period of 1977–2017. (b) Trend in renewable energy in urban areas publications showing the data with a logarithmic scale along the *y*-axis.

II-4.3. Publication Distribution by Regions and Institutions

Figure II-4 shows a representative map of the publications distribution according to the country of origin. The quantity of publications is represented by colors ranging from turquoise that indicates the greatest number of publications, to gray that indicates the non-existence of publications. As can be observed, China is the top country in number of publications, followed by the United States and the United Kingdom. It also highlights the scientific production of other countries such as Italy, Germany, or India. These data lead us to the conclusion of the importance of urban generation of renewable energy in developed countries as a key element to achieve sustainable development. Governments all over the world, especially in industrialized countries, develop increasingly stringent energy policies, having as main objective reducing greenhouse gas emissions to mitigate climate change effects.

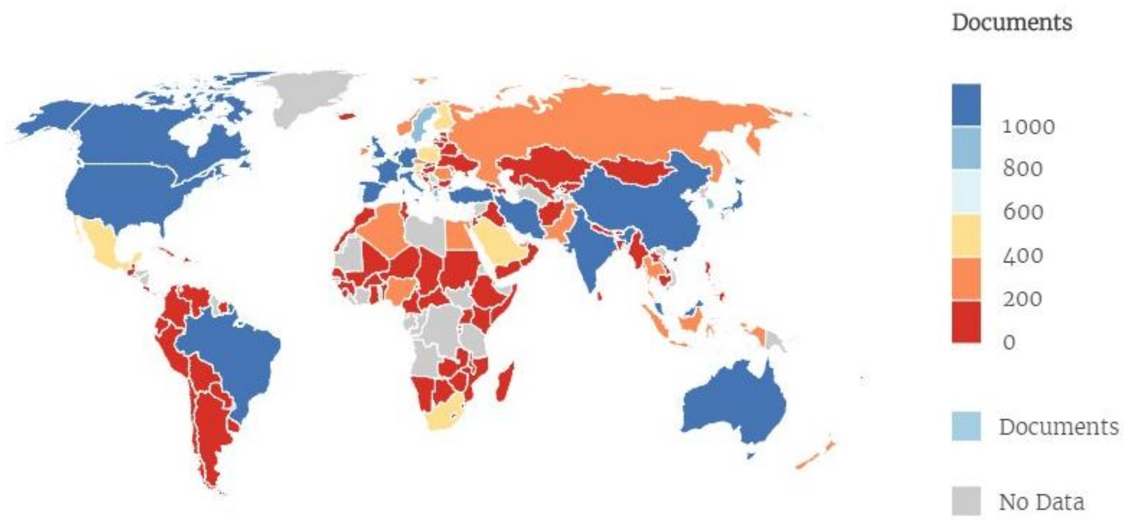


Figure II-4. Distribution of renewable energy in urban areas publications according to country.

In the case of China, in view of its overwhelming pollution issues and the possibility that their coastal cities being devastated by the rising sea level, Beijing was forced to launch a campaign in search of green solutions. The program "Made in China 2025", a central axis of the internal industrial policy of Beijing, foresees a considerable investment in research and development of clean energies, in order to meet climates aims. State banks invest tens of billion dollars each year in technologies such as solar and wind energies, as well as strategies for energy conservation such as high-speed rail and underground transport lines. China already enjoys a dominant position in many low carbon emission energy technologies. It produces two thirds of the solar panels and almost half of the wind turbines in the world. It has also rapidly expanded its fleet of nuclear reactors and is the undisputed world leader in hydropower energy (Liu et al., 2018).

One of the studied emerging technologies consists of the installation of floating photovoltaic solar panels. In a lake originated after the collapse of abandoned coal mines, China has built the largest worldwide floating solar project, capable of supplying light and air conditioning to a nearby city almost completely. The government plans to extend this project to ten more cities, which together could produce the same amount of energy as a normal-sized commercial nuclear reactor. This project is a sample of the contribution of China to the urban generation of renewable energy, as a key element to achieve its climate goals.

In addition to the reduction of air pollution in cities, energy security is another of the main drivers of renewable energy in urban areas. For example in the United States energy security is considered part of a national security issue, which plays a key role in ensuring the security of its own military operations. Energy security is also widely considered in terms of increasing the resilience of the electrical system.

Also, from an economic point of view, the implementation of renewables will generate value and employment at the local level. The renewable energy sector offers an alternative to increase wages, improve the trade balance, contribute to industrial and local development, and generate jobs. Analyses made show that countries with stable regulatory frameworks in renewable energies are the ones that benefit the most from the value generated by this sector at the local level.

Figure II-5 represents the total scientific production for the top 50 contributing countries. As can be seen, China and the United States are the countries with greater annual scientific contribution, more than 800 per year from 2014, followed by the United Kingdom with roughly 400 annual editions, and Italy close to 300 publications each year from 2014. As previously stated, all countries experienced an exponential increase in scientific publications amount over the first decade of the 21st century. Figure II-6 depicts the evolving trend of the main five countries over the last 17 years.

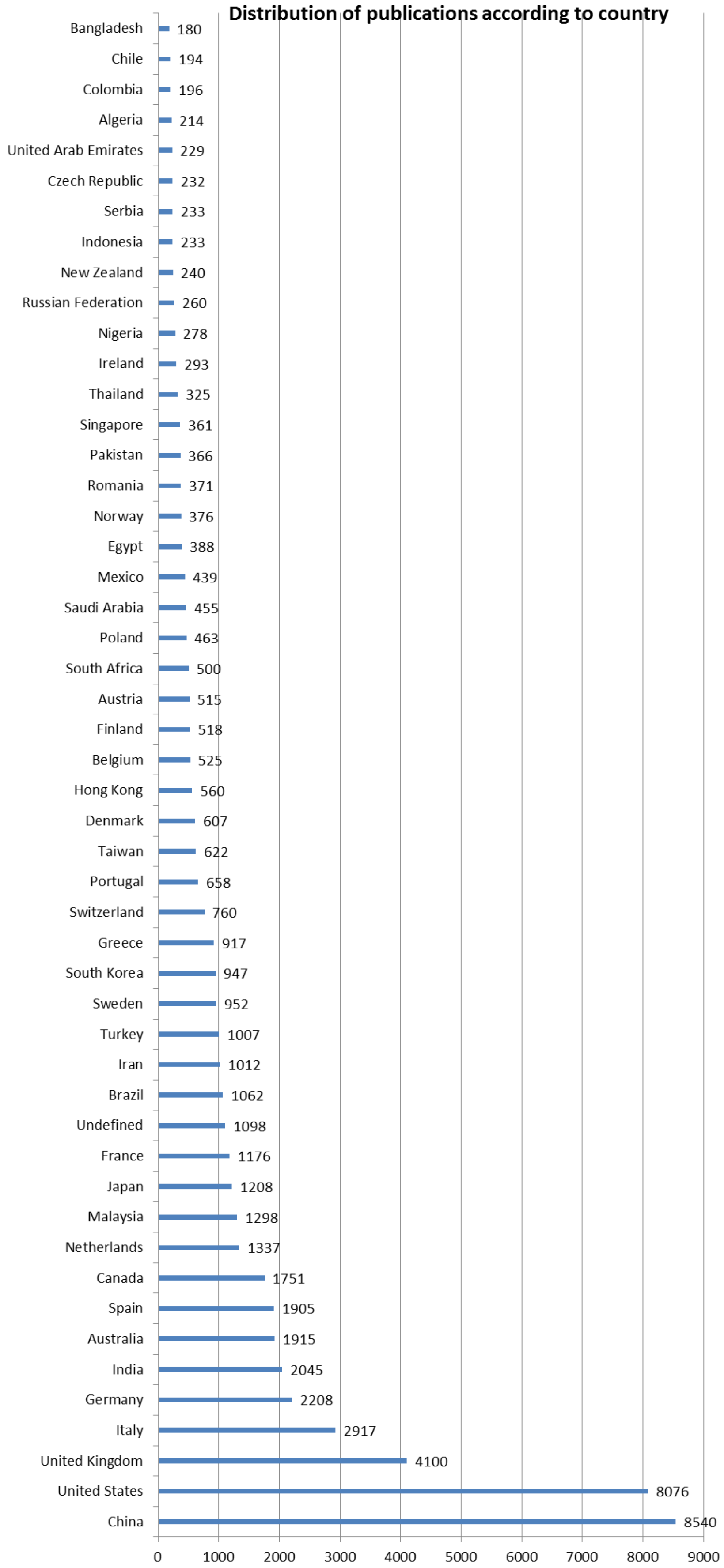


Figure II-5. Scientific production for the top 50 contributing countries.

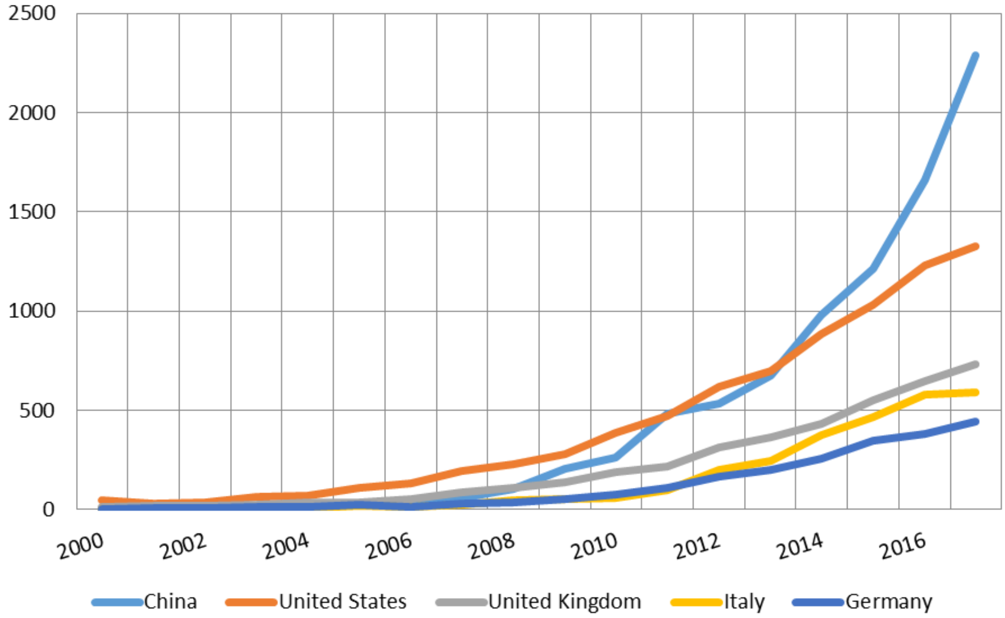


Figure II-6. Trends in publications on renewable energy in urban areas during the last 17 years for the top five countries.

The 10 institutions with the highest scientific output are sorted in Table II-1. In the first place is The Chinese Academy of Sciences, secondly the Ministry of Education of China, and thirdly the Tsinghua University. These institutions belong to China, the top productive country in this field, as has already been specified above. If publications are analysed according to their key words, it is observed that the term "Energy utilization" leads the research, occupying the first place in four of the top 10 institutions. If this analysis takes into account the three main keywords, it is observed that "Energy efficiency" appears in five of these institutions, followed by "Energy utilization" and "Sustainable development" in four of the 10 main institutions. Figure II-7 represents the research activity of the five main institutions in the last decade, in addition to the share of publications in this field on overall.

Table II-1. Ranking of the top 10 most productive international institutions.

Institution	Country	Items	Main Keywords Used		
			1	2	3
Chinese Academy of Sciences	China	1145	Carbon dioxide	Sustainable development	Biomass
Ministry of Education China	China	669	Energy utilization	Energy efficiency	Carbon dioxide
Tsinghua University	China	563	Energy utilization	Energy efficiency	Carbon dioxide

Harbin Institute of Technology	China	489	Hydrogen Production	Fermentation	Biomass
North China Electric Power University	China	380	Optimitation	Decision making	Sustainable development
National Renewable Energy Laboratory	USA	354	Fuels	Solar energy	Biomass
University of Malaya	Malasia	317	Energy utilization	Energy efficiency	Renewable Energies
Beijing Normal University	China	306	Sustainable development	Ecology	Decision making
Tongji University	China	283	Energy utilization	Anaerobic digestion	Energy efficiency
Delft University of Technology	Nederland	278	Energy efficiency	Sustainable development	Innovation

Figure II-8 depicts the collaborative network existing among countries that share the same co-author in the publications. The map was achieved using the VOSviewer software v.1.6.6., which generates a CSV file obtained through the SCOPUS database, with the key aspects of our search. It can be seen a remarkable scientific link in this field between China and the United States, likewise between the United States and Canada or between China and Australia. Traditionally the industrialized countries and those that speak the same language tend to have a greater exchange of information and works. However, due to the English language proficiency in the scientific field, there are already great interconnections with non-English speaking countries. It should also be noted that unlike other fields of research, renewable energy in urban areas is a subject where most countries maintain relationships with each other.

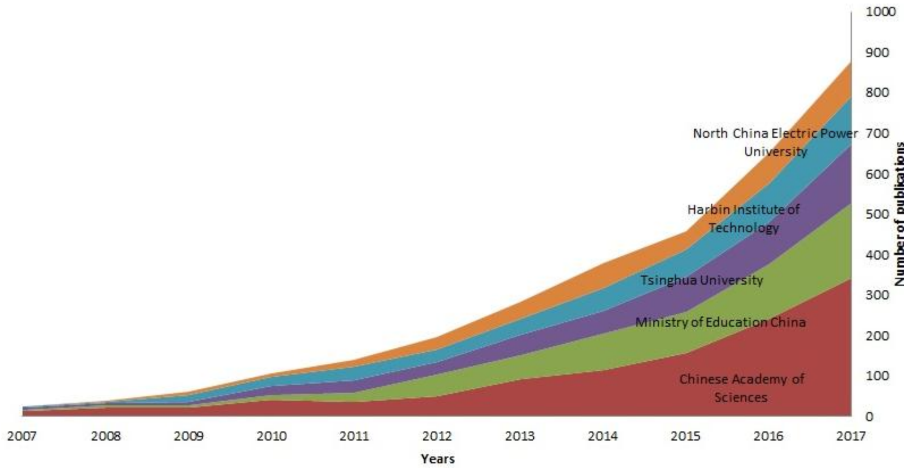


Figure II-7. Time evolution of the top five productive institutions over the period 2007–2017.

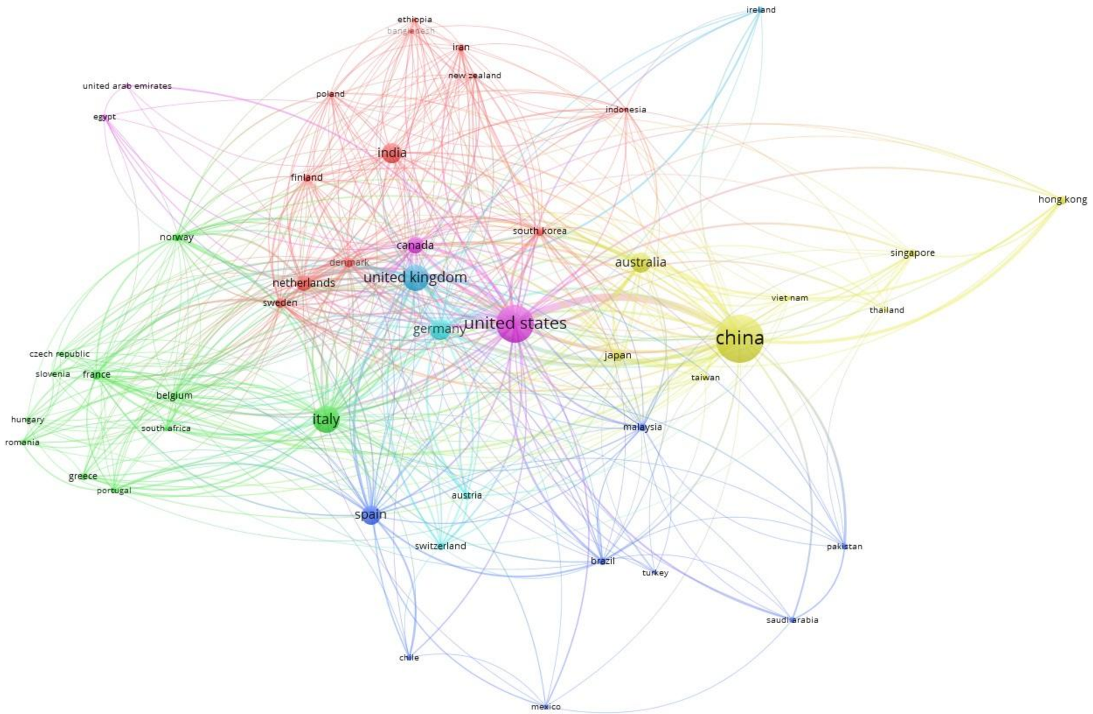


Figure II-8. Collaborative network between countries.

II-4.4. Distribution of Output in Subject Categories and Journals

The Scopus database generated the time evolution of the distribution of publications on renewable energy in urban areas, by subject area (Gimenez et al., 2018). Figure II-9 depicts the findings of the search classified by topic. The highest percentage corresponds to the subject of Energy (37.4%), followed by Environmental Science (34.7%) and Engineering (31.1%). The "Other" area includes the unspecified subject areas. Table II-2 lists the number of publications by subject area.

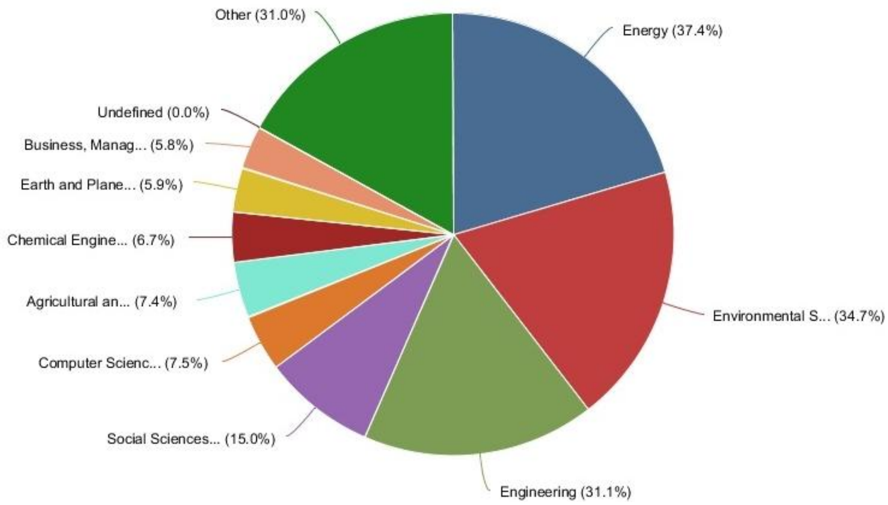


Figure II-9. Publication distribution by subject area, according to Scopus.

Table II-2. Number of publications by subject area.

Subject Area	Number of Publications
Energy	17,249
Environmental Science	16,041
Engineering	14,361
Social Sciences	6917
Computer Science	3469
Agricultural and Biological Sciences	3422
Chemical Engineering	3091
Earth and Planetary Sciences	2717
Business, Management and Accounting	2680
Chemistry	2457
Materials Science	2297
Economics, Econometrics and Finance	1783
Physics and Astronomy	1730
Biochemistry, Genetics and Molecular Biology	1343
Mathematics	1309
Medicine	833
Decision Sciences	668
Arts and Humanities	528
Immunology and Microbiology	512
Multidisciplinary	337
Psychology	190
Pharmacology, Toxicology and Pharmaceutics	168
Neuroscience	35
Veterinary	35
Nursing	31
Health Professions	28
Undefined	5
Dentistry	1

Table II-3 shows the top twelve journals that have published most of the works in this field. The data has been presented based on the h-index, since it is the criterion most frequently used to catalog a publication. First of all is the journal "Bioresource Technology" with a 216 h-index, followed by "Renewable and

Sustainable Energy Reviews" with a 176 h-index and thirdly "Energy Policy" with a 146 h-index.

To go beyond the analytical results representation, it is necessary to combine several techniques along with the use of new applications that provide a different approach in the presentation of the found results. With a view to evaluate the appearance of international Scopus newsletter in the investigation field that occupies us, besides the editorial production of the different countries and regions, it is necessary to consider the overlap existing between the main journals of the Energy, Environmental Science, and Engineering sectors.

Figure II-10 shows this overlap, through a map which is generated by taking into account the citations, co-citations and the bibliographic linkage of the approximately 30,000 publications (journals and congress proceedings) found in Scopus, which are used to generate a relational array that serves as the basis for the output presentation. In this chart the bibliometric indicators, as well as the shape of the clusters in which they are arranged, according to the utilization given by the authors, can be observed. The overlap mapping methodology is applied to situate subasemblies of publications within the general context of publications. The different clusters generated by the algorithm are represented in different colors. At the top of the map, a green cluster dedicated mainly to Environmental Sciences is represented. On the right-hand side it is observed two small clusters, one yellow dedicated to Biology and Ecology, and another reddish brown that deals with Hydrological Processess. These two groups blend with two bigger clusters, one purple dedicated to the Technology of Materials and Water Research, and elongated bright blue one dedicated to Electronics, Automatics, and Signal, Sound and Video Processing. On the left-hand side there is a small orange cluster dedicated to Neuroscience and Physiology and just below a pinkish group that deals with mutation research, biotechnology and bio-medical materials. It can easily observed that most of the journals stay on the right side of the map, coinciding with the areas of Environmental Science, Engineering, Computer Science and Energy.

Table II-3. International journal classification according to the impact factor of scientific publications.

Journals	Q	SJR	H-Index	JCR	Total Docs (2016)	Total Docs (3 Years)	Total Refs.	Total Cites (3 Years)	Cites/Doc (2 Years)	Country
Renewable and Sustainable Energy Reviews	Q1	3.051	176	8.050	1354	2716	125,280	25,093	8.78	The Netherlands
Applied Energy	Q1	3.058	125	7.182	1673	3494	84,348	26,677	7.58	United Kingdom
Energy Policy	Q1	2.197	146	4.140	595	2119	28,582	9362	4.40	United Kingdom
Energy and Buildings	Q1	2.093	123	4.067	962	2233	36,500	10,215	4.42	The Netherlands
Journal of Cleaner Production	Q1	1.615	116	5.715	2002	3104	96,466	15,164	5.35	The Netherlands
Renewable Energy	Q1	1.697	134	4.357	1208	2231	45,476	10,941	4.80	United Kingdom
Energy	Q1	1.999	134	4.520	1619	3642	66,714	18,256	4.95	United Kingdom
Energy Procedia	-	0.467	51	-	1414	7966	21,251	9115	1.02	United Kingdom
Sustainability	Q2	0.524	35	1.789	1342	1629	73,601	3159	1.96	Switzerland
Energy Conversion and Management	Q1	2.278	139	5.589	1021	2736	42,581	16,277	6.06	United Kingdom
Bioresource Technology	Q1	2.191	216	5.651	1655	5089	54,795	30,004	5.74	The Netherlands
Energies	Q1	0.691	48	2.262	672	1543	27,302	3810	2.23	Switzerland

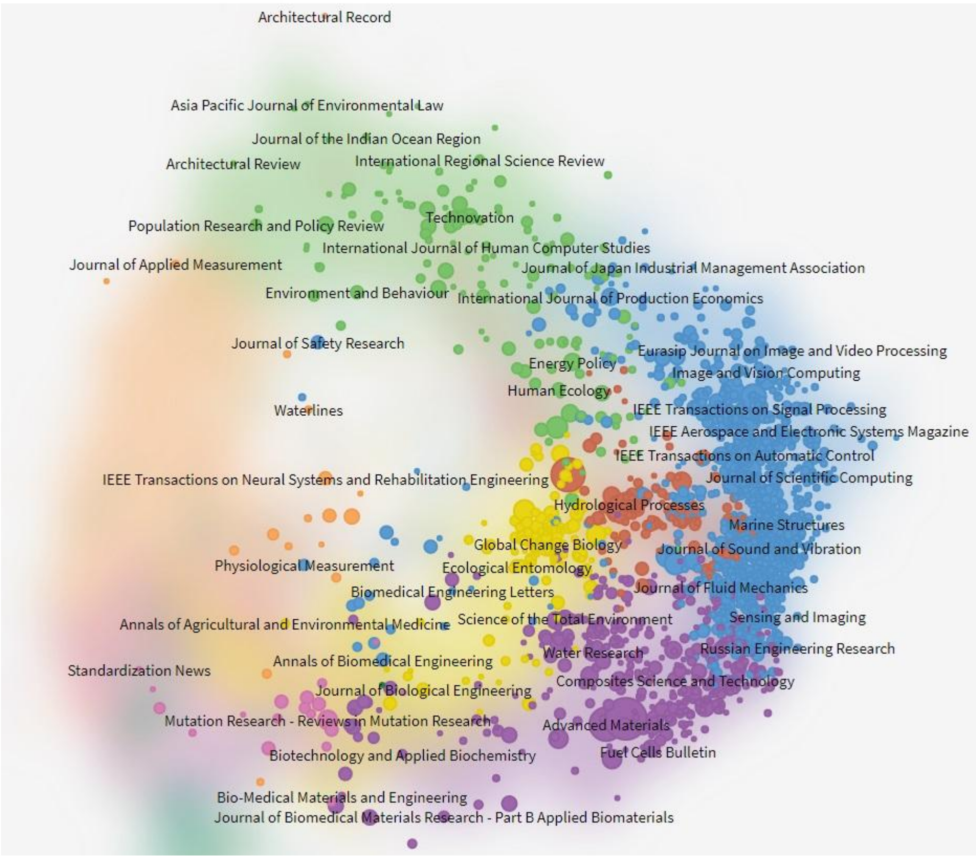


Figure II-10. Overlap in the scientific areas Energy, Environmental Science, and Engineering with node size according to the SJR-2016.

II-4.5. Analysis of Authors and Keywords

With regard to the most noteworthy authors in the field of renewable energy in urban areas, Figure II-11 and Table II-4 show the quantity of publications of the top five authors of this subject in the last decade. At a glance, it can be seen that Ren leads the classification with 95 publications since 2007. This researcher has a 55 h-index, with greatest part of his works being released by the Harbin Institute of Technology. He is followed by Huangof the University of Regina, with a total of 76 publications and a h-index of 50. Next are Sovacool, Zuo, and Chen with 64, 62 and 61 publications, respectively, in the 2007–2017 period. It is outstanding the growing trend of publications in recent years on urban generation of renewable energy. A proof of this is that the publications number during the last three years, accounted for more than 40 percent over the total publications in the last decade. It should be highlighted the year 2015 with a total of 60 publications among the five main authors.

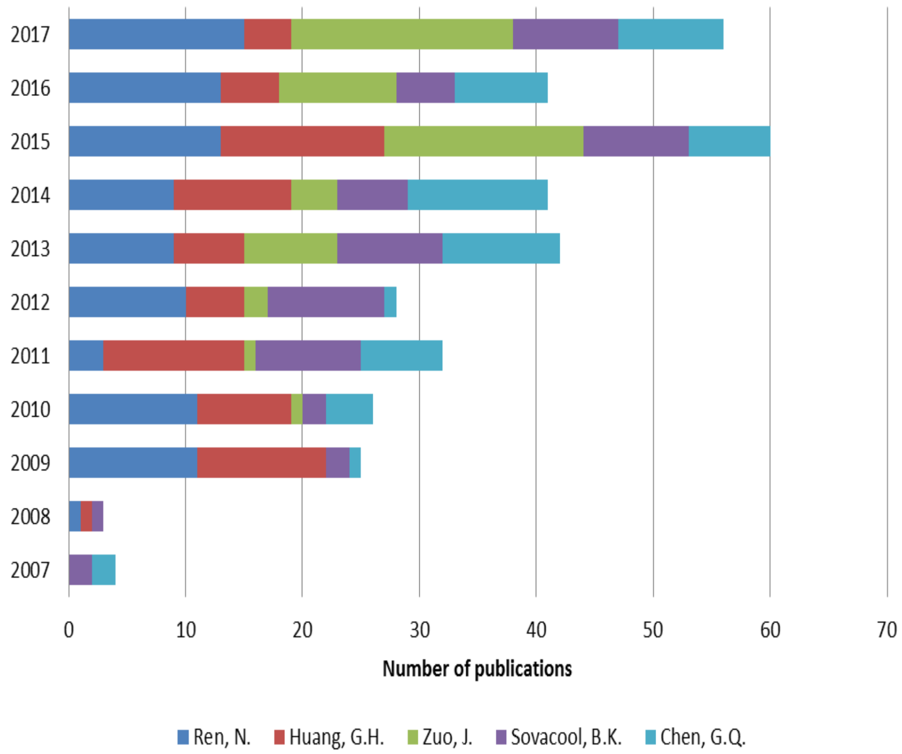


Figure II-11. Author distribution regarding the number of publications during the 2007–2017 period.

Table II-4. Publications number of the most relevant authors between 2007 and 2017.

Year	Ren, N.	Huang, G.H.	Zuo, J.	Sovacool, B.K.	Chen, G.Q.	TOTAL
2007	0	0	0	2	2	4
2008	1	1	0	1	0	3
2009	11	11	0	2	1	25
2010	11	8	1	2	4	26
2011	3	12	1	9	7	32
2012	10	5	2	10	1	28
2013	9	6	8	9	10	42
2014	9	10	4	6	12	41
2015	13	14	17	9	7	60
2016	13	5	10	5	8	41
2017	15	4	19	9	9	56
TOTAL	95	76	62	64	61	358

Figure II-12 shows the relationship between different co-authors and the main authors of publications on the subject. It can be observed a strong attachment among Asian authors, presumably due to both, the idiom and the proximity of their institutes.

On the other hand, the analysis of the keywords used in the quest is of vital importance to define the areas and themes that have been considered in the study. Based on the last 40 years, 173,925 items have been found. Thus, the key word "Energy Efficiency" appeared in 4069 items (2.34%), followed by "Sustainable Development" with 3998 appearances (2.30%) and in third place "Energy Utilization" with 3447 occurrences and a percentage of 1.98% over the total. Table II-5 lists the 40 most significant keywords in the last four decades.

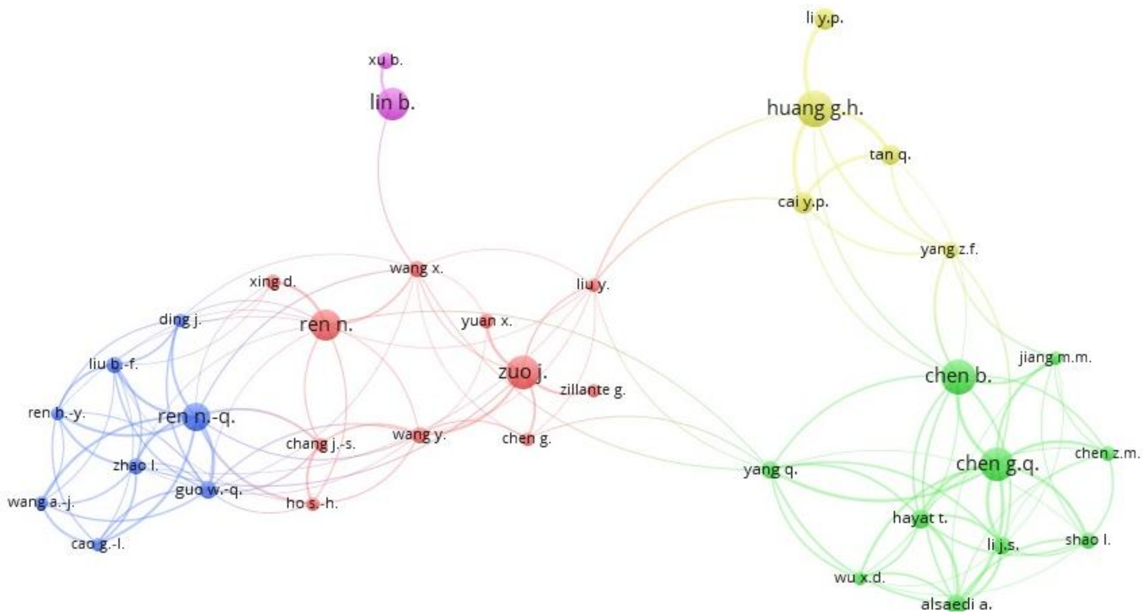


Figure II-12. Co-authorship network.

Table II-5. List of the 40 most used keywords.

Order	TERM	Items	%
1	Energy Efficiency	4069	2.34
2	Sustainable Development	3998	2.30
3	Energy Utilization	3447	1.98
4	Renewable Energy Resources	3243	1.86
5	Carbon Dioxide	2793	1.61
6	Climate Change	2600	1.49
7	Solar Energy	2434	1.40
8	Energy Conservation	2396	1.38
9	Biomass	2374	1.36
10	China	2335	1.34
11	Renewable Resource	2254	1.30
12	Energy Policy	2201	1.27
13	Optimization	2185	1.26
14	Buildings	2169	1.25
15	Sustainability	2161	1.24
16	Renewable Energies	2153	1.24
17	Environmental Impact	2147	1.23
18	Renewable Energy	2065	1.19
19	Economics	1977	1.14
20	Greenhouse Gases	1949	1.12
21	Wind Power	1924	1.11

22	Decision Making	1781	1.02
23	Carbon	1743	1.00
24	Costs	1586	0.91
25	Emission Control	1549	0.89
26	Heating	1507	0.87
27	Investments	1455	0.84
28	Energy Use	1441	0.83
29	Gas Emissions	1342	0.77
30	Solar Radiation	1337	0.77
31	Life Cycle	1324	0.76
32	Global Warming	1236	0.71
33	Biofuel	1230	0.71
34	United States	1220	0.70
35	Photovoltaic Cells	1214	0.70
36	Waste Management	1180	0.68
37	Biofuels	1165	0.67
38	Economic Analysis	1163	0.67
39	Housing	1138	0.65
40	Nonhuman	1125	0.65

The keyword analysis in scientific publications in the fields of science and engineering is highly recommended for the follow-through and search of research trends. However, to obtain the data that have been presented, it has been previously necessary to apply a search filter to the data supplied by Scopus. At this point, it should be pointed out the existence of different versions for the same keyword, depending on the writing made by each author. For instance, “Renewable energy”, may be written as “Green energy”, “Sustainable energy” or “Renewable power” thereby giving rise different expressions for the same concept. Indeed, in Table II-5, the first and third positions are occupied by the concepts of “Energy efficiency” and “Energy utilization”, which although they may share some aspects, their meaning is completely different. Finally, Figure II-13 represents a cloud of words which, at a glance, provides a clear overview of the most representative keywords.

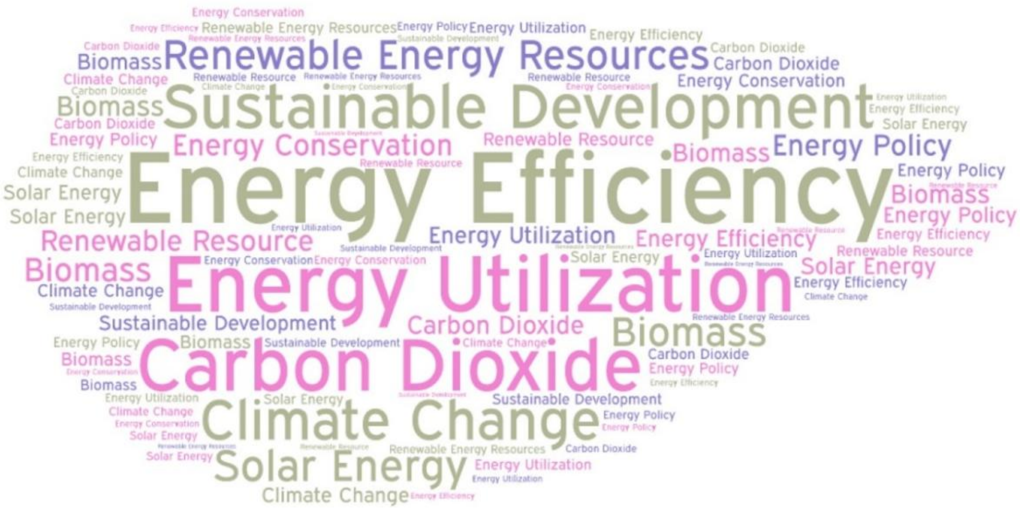


Figure II-12. Word cloud based on the main keywords related to renewable energy in urban areas worldwide research.

Figure II-14 represents a map with the most frequents words that our searching brought to light. They are split according to their field, shown by a color. It can be seen that, the bigger the circle, the more frequent is the used term. In the case study, “Energy efficiency”, “Sustainable development”, “Energy utilization”, “Carbon dioxide”, and “Renewable energy resources” are the most common words. Moreover, the lines that connect the different circles reveal the linkage between the keywords by means of papers and other publications.

The graph in Figure II-15 shows the tendency of use of these five technical terms in the publications of the last decade. As we can see, the take-off in the use of these terms took place at the end of 2005, probably due to the entry into force of the Kyoto protocol, and this rising tendency continues nowadays, where these topics seem to be of overwhelming interest to the international scientific society.

As can be noticed, there is a clear inclination towards the use of the term energy efficiency, whose synergy with renewable energies is considered a key dynamic duo to achieve sustainable development. The relation between energy efficiency and energy utilization must be highlighted. In fact, energy efficiency is the set of actions that reduce energy consumption to produce the same. Therefore, it is an inverse relationship between production and consumption, in such a way that energy efficiency (EE) improves either if production is maintained with less energy utilization, or the production increases with the same energy utilization. That is, EE = Production/Energy utilization.

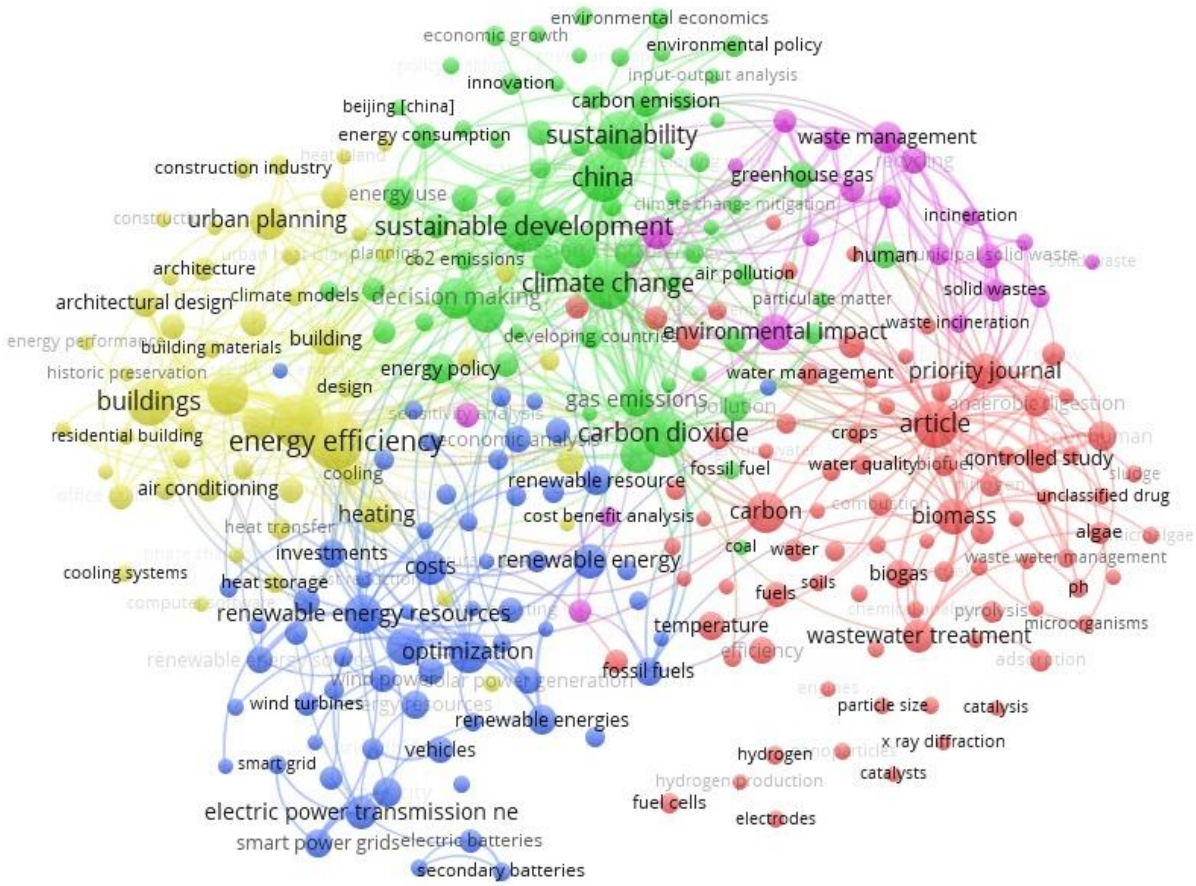


Figure II-13. Co-occurrence-keywords.

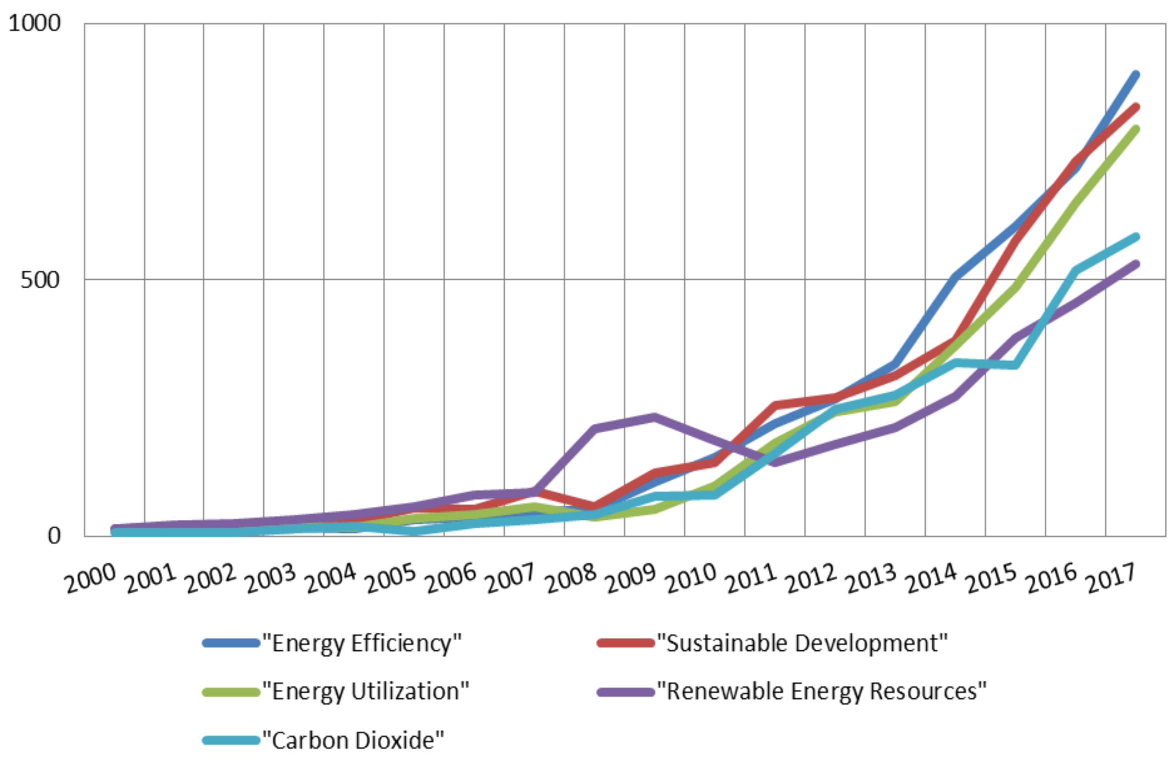


Figure II-14. Trend of the five most used terms in the period 2000–2017.

II-5. DISCUSSION AND CONCLUSIONS

A broad scope of data concerning to the international input to the scientific knowledge of urban generation of renewable energy during the period 1977–2017 has been traced. The data found in more than ten categories have been collected, yielding a total of 46,172 publications. The categories Energy, Environmental Sciences and Engineering stand out, which experienced an exponential growth.

It is pinpointed 2017 as the richest year in scientific production with 9242 publications in all, being the magazine *Journal of Cleaner Production* the one that accumulated the largest number of publications on the matter. As far as the authors are concerned, Ren, Huang, Zuo, Sovacool, and Chen concentrate the greatest part of the works in the analysed period.

The works have been mostly released in international journals (76%) and congresses (17%), with English being the language used in more than 96.5% of the papers. Regarding the main institutions that have published most of the works in this field, stand out the Chinese Academy of Sciences, Ministry of Education of China, The University of Tsinghua and The Harbin Institute of Technology, which account for half of publications over the last decade. All these institutions (7 of the top ten) are located in China, which demonstrates the great awareness in this country about renewable energy in urban areas.

In mainland Europe, the United Kingdom, Italy, Germany, Spain, Netherlands and France highlight as the main research countries in this field, with the United Kingdom representing 23.06% of the total number of publications in European countries.

Table II-6 shows information obtained from both, the World Bank and Scopus database (World Bank Open Data, 2018). China is the country with more documents published, however is important to see that Netherlands has the most number of researchers in Research and Development (R&D) per million people. Considering this, the ratio between these variables shows that Netherlands is the leader with 3.40 documents published per million people spending 2.0% of Gross Domestic Product (GDP) in R&D, however Germany is the country with the highest

GDP in R&D with 2.9%. China only has 0.50 documents per million people and spend 2.1% of GDP, but is necessary to consider its population.

Table II-6. Research information by country.

Country	Documents	Researchers in R&D (per Million People)	Ratio R&D/Documents	Research and Development Expenditure (% of GDP)
China	8540	4232	0.50	2.1
United States	8076	1177	0.15	2.8
United Kingdom	4100	4471	1.09	1.7
Italy	2917	2018	0.69	1.3
Germany	2208	4431	2.01	2.9
India	2045	216	0.11	0.6
Australia	1915	2655	1.39	2.2
Spain	1905	4531	2.38	1.2
Canada	1751	4519	2.58	1.6
Netherlands	1337	4548	3.40	2.0

Focusing on the keywords study, found publications reveal a considerable dispersion in the utilization of the keywords group. In fact, many compound words are employed, which increase the number of unique terms. In addition, the same term can be typed differently according to the author, giving rise to a broader fictitious range.

The terms most frequently used are "energy efficiency", "sustainable development", "energy utilization", "carbon dioxide", and "renewable energy resources". There is a clear trend towards the use of the term energy efficiency, which refers to the increase of productivity with the same energy utilization, and whose synergy with renewable energy is considered a key dynamic duo to achieve a sustainable development.

The analysed data comes to the conclusion that the international contribution to the scientific knowledge of renewable energies in urban areas is outstanding, producing a vast quantity of publications in congresses and high-impact journals. The important boom in renewable energy throughout the world, and especially in industrialized countries, as a key element to mitigate the climate change effects, has also boosted the research in this field. However, it is also necessary to promote research and use of renewable energy in urban areas of developing countries, where there will be a significant increase in urban population in the coming decades, as in the case of Latin American countries. Therefore, policy makers in these countries should promote better urban conditions in terms of stricter efficiency standards in buildings, as well as to boost sustainable mobility in order to achieve a sustainable urban development. Analyses made show that countries with stable regulatory frameworks in renewable energies are the ones that benefit the most from the value generated by this sector at the local level.

Abbreviations

EE	Energy Efficiency
GDP	Gross Domestic Product
JCR	Journal Citation Report
kWh	Kilowatts hours
MSW	Municipal Solid Waste
PV	Photovoltaic
R&D	Research and Development
SJR	Scientific Journal Ranking
WoS	Web of Science

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Chapter III.

Towards forest sustainability in Mediterranean countries using biomass as fuel for heating

«Renewable energy could reduce emissions but also create jobs and improve public health»

Paul Polman (2014)

Perea-Moreno, A. J., Perea-Moreno, M. Á., Hernandez-Escobedo, Q., & Manzano-Agugliaro, F. (2017). Towards forest sustainability in Mediterranean countries using biomass as fuel for heating. Journal of Cleaner Production, 156, 624-634.
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Chapter III. Towards forest sustainability in Mediterranean countries using biomass as fuel for heating

Perea-Moreno, Alberto-Jesús [1], Perea-Moreno, Miguel-Ángel [1], Hernandez-Escobedo, Quetzalcoatl [2], Manzano-Agugliaro, Francisco [3,4]

[1] Department of Applied Physics, University of Cordoba, CEIA3, Campus de Rabanales, 14071 Córdoba, Spain.

[2] Faculty of Engineering Campus Coatzacoalcos, University of Veracruz Av. Universidad km. 7.5 Santa Isabel 56535, Coatzacoalcos Veracruz Mexico.

[3] Dpt. Engineering, University of Almeria, CEIA3, 04120Almeria, Spain.

[4] CIAMBITAL (Research Center on Agricultural and Food Biotechnology), University of Almeria, 04120Almeria, Spain.

III-1. ABSTRACT

The increasing fossil fuels price is a direct result of a growth in worldwide demand of energy and has become a major concern of many countries. The special conditions of Mediterranean countries, with high dependency on energy imports and energy used mainly from fossil fuels, make these countries users of high carbon energy. On the other hand, the mild environmental conditions which do not need high energy demands in heating, together with the progressive abandonment of forest exploitation as fuel source, have provoked environmental problems, such as increased risk of forest fires. In view of the above arguments, the Mediterranean forest use becomes essential in order to reduce the risk fire as well as the dependence on energy imports of fossil fuels, and lower CO_2 emissions. Nowadays, Biomass District Heating (BDH) is widely used in the North of Europe. The main objective of this work is to establish a methodology for renewable energy resources integration at small urban areas in Mediterranean countries till now with high-energy consumption, and to asses that this methodology could be applied in Mediterranean areas successfully, and the determination of forest needs. For this purpose, a case study is shown, so a BDH network to cover the energy demand in a small urban area in the south of Spain was studied. The study was done in three phases: energy demand survey, BDH calculations, and assessment of

technology for both, savings costs and CO_2 emissions. In this case, BDH system offers 100% of CO_2 savings and 68.22% of fuel cost savings versus fossil fuels. Using BDH, CO_2 emissions to the atmosphere have been reduced by 35 tonnes, which is the equivalent of the annual CO_2 sequestration of 700 adult trees approximately. As main conclusion of this work, if used, the available forest biomass, it could be saved more than 68% of the current energy demand in the case study. For this small rural settlement of 3000 inhabitants, 4 ha of forest was found as forest biomass needs every year, this means a total of 40 ha as sustainable energy model based on Mediterranean pine forest. The finds of this work can be used as policy solution that has to be study in the whole Mediterranean areas with forest resources, in order to have more sustainable environment.

Keywords: biomass, district heating, small urban areas, renewable energy policy, sustainability

III-2. RESUMEN

El aumento del precio de los combustibles fósiles es el resultado directo del crecimiento de la demanda mundial de energía y se ha convertido en una de las principales preocupaciones de muchos países. Las condiciones especiales de los Países Mediterráneos, con una gran dependencia de las importaciones de energía y un consumo de energía procedente principalmente de combustibles fósiles, hacen que estos países sean consumidores de energía con alto contenido de carbono. Por otro lado, las condiciones ambientales suaves que no requieren altas demandas de energía en calefacción, junto con el abandono progresivo de la explotación forestal como fuente de combustible, han provocado problemas ambientales, como el aumento del riesgo de incendios forestales. A la vista de los argumentos anteriores, el uso del bosque Mediterráneo se hace imprescindible para reducir el riesgo de incendios, así como la dependencia de las importaciones energéticas de combustibles fósiles y la reducción de las emisiones de CO2. Hoy en día, los Sistemas de Calefacción Urbana de Biomasa (SCUB) son ampliamente utilizados en el Norte de Europa. El objetivo principal de este trabajo es establecer una metodología para la integración de los recursos energéticos renovables en las pequeñas zonas urbanas de los Países Mediterráneos hasta ahora con un alto consumo energético, y evaluar que esta metodología podría aplicarse con éxito en las zonas Mediterráneas, así como la determinación de las necesidades forestales. Para ello, se presenta un caso de estudio, en el que se diseña y analiza una red de calefacción urbana de biomasa para cubrir la demanda energética de una pequeña zona urbana del sur de España. El estudio se realizó en tres fases: encuesta de demanda energética, cálculos del SCUB y evaluación de la tecnología tanto para el ahorro de costes como para las emisiones de CO2. En este caso, el sistema SCUB ofrece el 100% de ahorro de CO2 y el 68.22% de ahorro de combustible en comparación con los combustibles fósiles. Con el uso del SCUB, las emisiones de CO2 a la atmósfera se han reducido en 35 toneladas, lo que equivale a la captura anual de CO2 de 700 árboles adultos aproximadamente. Como conclusión principal de este trabajo, si se utiliza la biomasa forestal disponible, se podría ahorrar más del 68% de la demanda energética actual en el caso de estudio. Para este pequeño asentamiento rural de 3,000 habitantes, se determinó 4 ha de bosque como las necesidades de biomasa forestal cada año, lo que supone un total de 40 ha como modelo energético sostenible basado en el bosque de pino mediterráneo. Los hallazgos de este trabajo pueden ser utilizados como una solución política que debe ser estudiada en todas las áreas Mediterráneas con recursos forestales, con el fin de tener un medio ambiente más sostenible.

Palabras clave: biomasa, calefacción urbana, pequeñas zonas urbanas, política de energías renovables, sostenibilidad.

Chapter IV.
Mango stone properties as biofuel and its potential for reducing CO_2 emissions

«Climate change is a problem caused by humans, one which can be solved by humans»
L'Oceanogràfic, Valencia (Spain) (2018)

Perea-Moreno, A. J., Perea-Moreno, M. Á., Dorado, M. P., & Manzano-Agugliaro, F. (2018). Mango stone properties as biofuel and its potential for reducing CO_2 emissions. Journal of Cleaner Production, 190, 53-62. http://doi.org/10.1016/j.jclepro.2018.04.147.
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Chapter IV. Mango stone properties as biofuel and its potential for reducing CO_2 emissions

Perea-Moreno, Alberto-Jesús [1], Perea-Moreno, Miguel-Ángel [1], Dorado, María-Pilar [2], Manzano-Agugliaro, Francisco [3,4]

[1] Dpt. Applied Physics, Ed Albert Einstein, Campus de Rabanales, University of Cordoba, CeiA3, 14071, Cordoba, Spain

[2] Dpt. Physical Chemistry and Applied Thermodynamics, Ed Leonardo da Vinci, Campus de Rabanales, University of Cordoba, CeiA3, 14071, Cordoba, Spain

[3] Dpt. Engineering, University of Almeria, CeiA3, 04120 Almeria, Spain.

[4] CIAIMBITAL (Research Center on Agricultural and Food Biotechnology), University of Almeria, 04120, Almeria, Spain.

IV-1. ABSTRACT

Mango (*Mangifera indica* L.) is one of the most widely cultivated fruits in the tropics as well as other coastal subtropical climate areas, existing around 160 varieties of mangoes in the world, grown in more than 90 countries. Its consumption has greatly increased worldwide over the last decades. The world production of these fruits has been rising in recent years, with a production of more than 46 million tons in 2016, 23% above the production in 2009. India is the largest producer in the world by a very wide margin - more than 28% of the total produced worldwide in 2016. Next, China, Thailand and Indonesia produced 3.61, 2.25 and 1.83 million tons in that same year, respectively. Potential high energy content of the residual biomass produced in the mango sector is barely known. Mango stone weight accounts for 30 – 45% of the total fruit weight which completely goes off as waste. Hence, the aim of this work is to outline mango stone energy qualities and to assess these parameters to establish its suitability as a solid biofuel for thermal energy production. With a view to achieving this goal, the following analysed parameters were considered: moisture (59.70%), higher heating value (18.05 MJ/kg), lower heating value (1727 MJ/kg), elemental composition (48.26% C, 44.92% O, 3.48% H, 1.041% N, 0.086% S, 0.070% CL), ash content (2.14%), or oil content (3%). These results were compared to other biomass sources, such as olive pit and avocado stone, as well as almond shell, obtaining intermediate but similar readings. Finally, the most accurate model to estimate higher heating value of mango stone has been determined, considering the predictive models of HHV for the biomass submitted by other scientific research studies. As main conclusions, the findings of this work pave the way for using mango stone as biofuel in domestic or industrial heating facilities. On the other hand, this biofuel has proven to be useful in reducing greenhouse gas emissions in producing countries. In relative terms, it has proved to be particularly significant in a large part of Central Africa (Sudan, Nigeria, Tanzania, Kenya or Congo) and Madagascar, being able to reduce above 0.02 ‰ of their CO_2 emissions.

Keywords: Mango stone, Biomass, Elemental composition, Higher heating value, greenhouse gasses emission, CO_2.

IV-2. RESUMEN

El mango (Mangifera indica L.) es una de las frutas más cultivadas en los trópicos, así como en otras áreas costeras subtropicales, existiendo alrededor de 160 variedades de mangos en el mundo, cultivadas en más de 90 países. Su consumo ha aumentado considerablemente en todo el mundo en las últimas décadas. La producción mundial de estas frutas ha ido en aumento en los últimos años, con una producción de más de 46 millones de toneladas en 2016, un 23% por encima de la producción de 2009. La India es el mayor productor del mundo por un margen muy amplio, más del 28% del total producido en el mundo en 2016. Luego, China, Tailandia e Indonesia produjeron 3.61, 2.25 y 1.83 millones de toneladas en ese mismo año, respectivamente. El alto potencial energético de la biomasa residual producida en la industrial del mango es poco conocido. El peso de los huesos de mango representa entre el 30 y el 45% del peso total de la fruta, que se elimina por completo como residuo. Por tanto, el objetivo de este trabajo es poner de manifiesto las cualidades energéticas del hueso del mango y evaluar sus parámetros para establecer su idoneidad como biocombustible sólido para la producción de energía térmica. Para alcanzar este objetivo, se analizaron los siguientes parámetros: humedad (59.70%), poder calorífico superior (18.05 MJ/kg), poder calorífico inferior (17.27 MJ/kg), composición elemental (48.26% C, 44.92% O, 3.48% H, 1.041% N, 0.086% S, 0.070% CL), contenido de cenizas

(2.14%), o contenido en grasas (3%). Estos resultados se compararon con los de otras fuentes de biomasa, como el hueso de aceituna y el hueso de aguacate, así como la cáscara de almendra, obteniendo valores intermedios pero similares. Finalmente, se ha determinado el modelo más preciso para estimar el Poder Calorífico Superior (PCS) del hueso del mango, considerando los modelos predictivos del PCS para la biomasa presentados por otros estudios de investigación científica. Como conclusiones principales, los resultados de este trabajo allanan el camino para el uso del hueso del mango como biocombustible en instalaciones de calefacción domésticas o industriales. Por otro lado, este biocombustible ha demostrado ser útil para reducir las emisiones de gases de efecto invernadero en los países productores. En términos relativos, ha demostrado ser particularmente efectivo en gran parte de África Central (Sudán, Nigeria, Tanzania, Kenia o Congo) y Madagascar, pudiendo reducir por encima de 0.02 $‰_0$ sus emisiones de CO_2.

Palabras clave: hueso de mango, biomasa, composición elemental, poder calorífico superior, emisión de gases de efecto invernadero, CO_2.

Chapter V.

Peanut shell for energy: Properties and its potential to respect de environment.

« As human beings, we are vulnerable to confusing the unprecedented with the improbable. In our everyday experience, if something has never happened before, we are generally safe in assuming it is not going to happen in the future, but the exceptions can kill you and climate change is one of those exceptions »

Al Gore (2008)

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Chapter V. Peanut shell for energy: Properties and its potential to respect the environment

Miguel-Angel Perea-Moreno [1], Francisco Manzano-Agugliaro [2], Quetzalcoatl Hernandez-Escobedo [3] and Alberto-Jesus Perea-Moreno [1]

[1] Departamento de Física Aplicada, ceiA3, Campus de Rabanales, Universidad de Córdoba, 14071 Córdoba, Spain

[2] Department of Engineering, ceiA3, University of Almeria, 04120 Almeria, Spain

[3] Faculty of Engineering, Campus Coatzacoalcos, University of Veracruz, Coatzacoalcos, Veracruz 96535, Mexico

V-1. ABSTRACT

The peanut (*Arachys hypogaea*) is a plant of the Fabaceae family (legumes), as are chickpeas, lentils, beans, and peas. It is originally from South America and is used mainly for culinary purposes, in confectionery products, or as a nut as well as for the production of biscuits, breads, sweets, cereals, and salads. Also, due to its high percentage of fat, peanuts are used for industrialized products such as oils, flours, inks, creams, lipsticks, etc. According to the Food and Agriculture Organization (FAO) statistical yearbook in 2016, the production of peanuts was 43,982,066 t, produced in 27,660,802 hectares. Peanuts are grown mainly in Asia, with a global production rate of 65.3%, followed by Africa with 26.2%, the Americas with 8.4%, and Oceania with 0.1%. The peanut industry is one of the main generators of agroindustrial waste (shells). This residual biomass (25%–30% of the total weight) has a high energy content that is worth exploring. The main objectives of this study are, firstly, to evaluate the energy parameters of peanut shells as a possible solid biofuel applied as an energy source in residential and industrial heating installations. Secondly, different models are analysed to estimate the higher heating value (HHV) for biomass proposed by different scientists and to determine which most accurately fits the determination of this value for peanut shells. Thirdly, we evaluate the reduction in global CO_2 emissions that would result from the use of peanut shells as biofuel. The obtained HHV of peanut shells (18.547 MJ/kg) is higher than other biomass sources evaluated, such as olive stones

(17.884 MJ/kg) or almond shells (18.200 MJ/kg), and similar to other sources of biomass used at present for home and industrial heating applications. Different prediction models of the HHV value proposed by scientists for different types of biomass have been analysed and the one that best fits the calculation for the peanut shell has been determined. The CO_2 reduction that would result from the use of peanut shells as an energy source has been evaluated in all production countries, obtaining values above 0.5 ‰ of their total emissions.

Keywords: peanut shell, biomass, CO_2, higher heating value, waste, greenhouse gasses emission

V-2. INTRODUCTION

Emissions of pollutants into the atmosphere are the cause of the deterioration of air quality and the cause of numerous health, economic, and environmental problems. Large cities and some industrial areas concentrate levels of air pollution, with vehicle traffic being the main culprit (Nie et al., 2018; Zhang et al., 2018).

Carbon dioxide (CO_2) is one of the most abundant compounds in the atmosphere, being the most important of the so-called "greenhouse gases". It plays an important role in the vital processes of plants, animals, and humans and, in appropriate quantities, contributes to keeping the earth's temperature within the limits of life (Jung and Koo, 2018; Lee et al., 2017). However, since the Industrial Revolution, there has been a continuous increase in the amount of CO_2 emitted into the atmosphere due to the intensive use of fossil fuels (Cho and Na, 2017). They have affected the natural greenhouse effect and are causing unprecedented climate change which, for many, is the greatest threat to the environment. Over the last 100 years, the global average temperature has increased by 0.76 °C. Eleven of the 12 hottest years since 1850 were concentrated between 1995 and 2006 (O´reilly et al., 2003; Garrabou et al., 2009).

According to experts' forecasts, if no action is taken to limit greenhouse gas emissions, the average global temperature could rise by between 1.8 and 4 °C before the end of the 21st century (Wilby et al., 2002).

In Europe, the fight against climate change is a key priority of the sustainable development strategy, which explains why it has long been at the forefront of international efforts to combat climate change by committing itself to making Europe a highly energy-efficient, low-carbon economy (Reckien et al., 2018; D´Agostino and Parker, 2018; De la Cruz-Lovera et al., 2017).

The main element of environmental policy in Europe is the Kyoto Protocol and the policies resulting from it (Yama and Abe, 2018). One of the main strategies associated with these policies is the introduction of the Emissions Trading Scheme (ETS) created in 2005 (Nava et al., 2018). This mechanism is one of the cornerstones of the European energy system, in which a price is set for carbon dioxide and which allows CO_2 emission rights to be traded in order to promote their efficient reduction (Newberry et al., 2018; European Commission, 2016).

Another policy related to the Kyoto Protocol has been support for renewable energy sources, which has allowed for an increase in this sector (Gallo et al., 2018; Ali, 2017). This growth in renewable energy generation and the increased use of gas in the electricity sector has reduced the amounts of greenhouse gases in electricity production (Perea-Moreno et al., 2018). However, this progress towards reducing CO_2 emissions is insufficient to meet the targets set by European climate change policies.

In 2008, the European Commission approved the Climate and Energy Package, known as the 20-20-20 Plan, which contains binding legislation for Member States to ensure compliance with the climate and energy targets for 2020, including the following (Perea-Moreno et al., 2017):

- Reduce 20% of the emissions of greenhouse gases (GHG) that were recorded in 1990 (well above the Kyoto target of 8%).
- Achieve that renewable sources constitute 20% of total energy consumption.
- Improve energy efficiency by 20%.

In addition, this package of measures includes a commitment to increase the rate of greenhouse gas reduction from 20% to 30%.

The EU also aims to improve its energy efficiency by 20% by the same deadline. Moreover, the EU has offered to increase its GHG emission reduction figure by 2020 from 20% to 30% if other major economies contribute fairly to the international reduction effort (Pleßmann and Blechinger, 2017).

Biomass is the totality of organic matter, of plant or animal origin, and the materials that come from its natural or artificial transformation (Perea-Moreno et al., 2016a). Directive 2009/28/EC encourages the use of renewable sources for the production of energy and proposes a definition of biomass which includes not only substances of plant and animal origin but also any type of biological waste from agricultural, industrial, and municipal activities (Viana et al., 2018).

A range of thermal, physical, or biological processes can convert biomass into energy through several types of biofuels (Agugliaro, 2007; Casanova-Peláez et al., 2015; Perea-Moreno et al., 2016b; Manzano-Agugliaro et al., 2012). Biomass can be classified according to its origin as wood, energy crops, agricultural waste, food residues, and industrial waste (Al-Hamamre et al., 2017). Agricultural waste provides around 33% of total biofuels use, accounting for 39%, 29%, and 13% of biofuel use in Asia, Latin America, and Africa, respectively, and 41% and 51% of biofuel usage in India and China, respectively (Yevich and Logan, 2003).

The peanut (*Arachys hypogaea*) is a plant of the Fabaceae family (legumes), as are chickpeas, lentils, beans, and peas and is originally from South America. The first intentional peanut introduction into Europe was not reported, but American exotic plants were often harvested and first introduced into Europe from the first voyage of Columbus (Hammons et al., 2016).

Its use is mainly for culinary purposes, in confectionery products, or as a nut and is also used to produce biscuits, breads, sweets, cereals, and salads. Peanut butter is by far the largest product made from peanut in the United States, but it is rarely consumed outside that country (McArthur et al., 1982). Also, due to its high percentage of fat, peanuts are used for industrialized products, such as oils, flours, inks, creams, lipsticks, etc. Regarding biofuels, the nut has been successfully used to produce biodiesel (Ramos et al., 2009).

The production of peanuts according to the Food and Agriculture Organization (FAO) statistical yearbook in 2016 was 43,982,066 t, produced in 27,660,802 hectares (FAOSTAT, 2016). Peanuts are grown mainly in Asia, with a global production rate of 65.3%, followed by Africa with 26.2%, the Americas with 8.4%, and Oceania with 0.1% (Figure V-1).

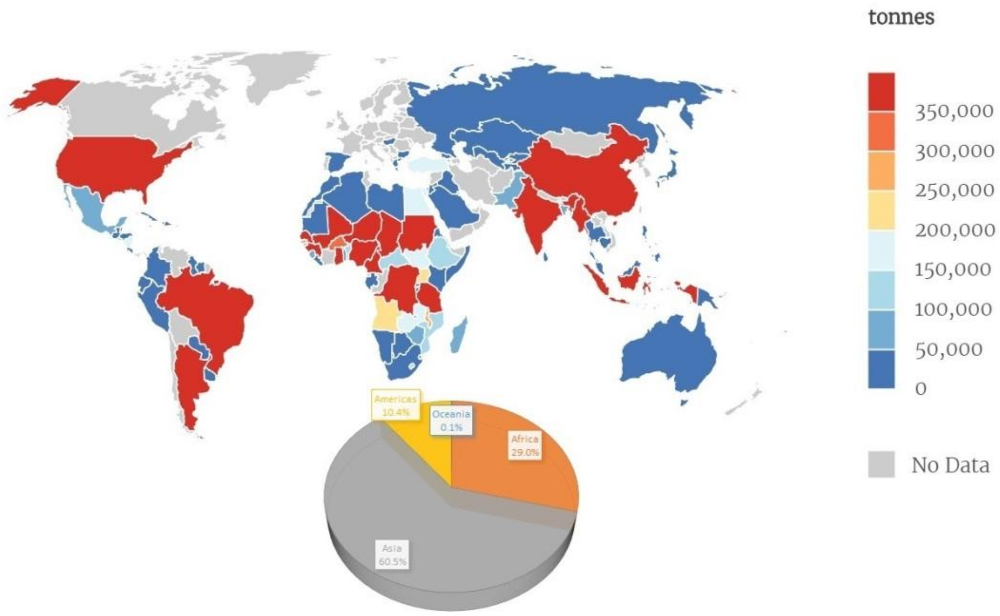

Figure V-1. Worldwide peanut production (year 2016).

The list of the five largest producing countries is headed by China with a production of 33,309,998 t, followed by India with 6,857,000 t, Nigeria with 3,028,571, the United States with 2,578,500 t, and Sudan with 1,826,000 t (FAOSTAT, 2016). However, the peanut yield is as high as 3000 kg ha^{-1} in the United States, while the average in tropical Africa is 800 kg ha^{-1} (Olayinka and Etejere, 2015). Therefore, there is still much potential for an increase in world production if the appropriate agronomic techniques were used in countries with such poor yields.

Figure V-2 shows the evolution of world peanut production over a 20-year period.

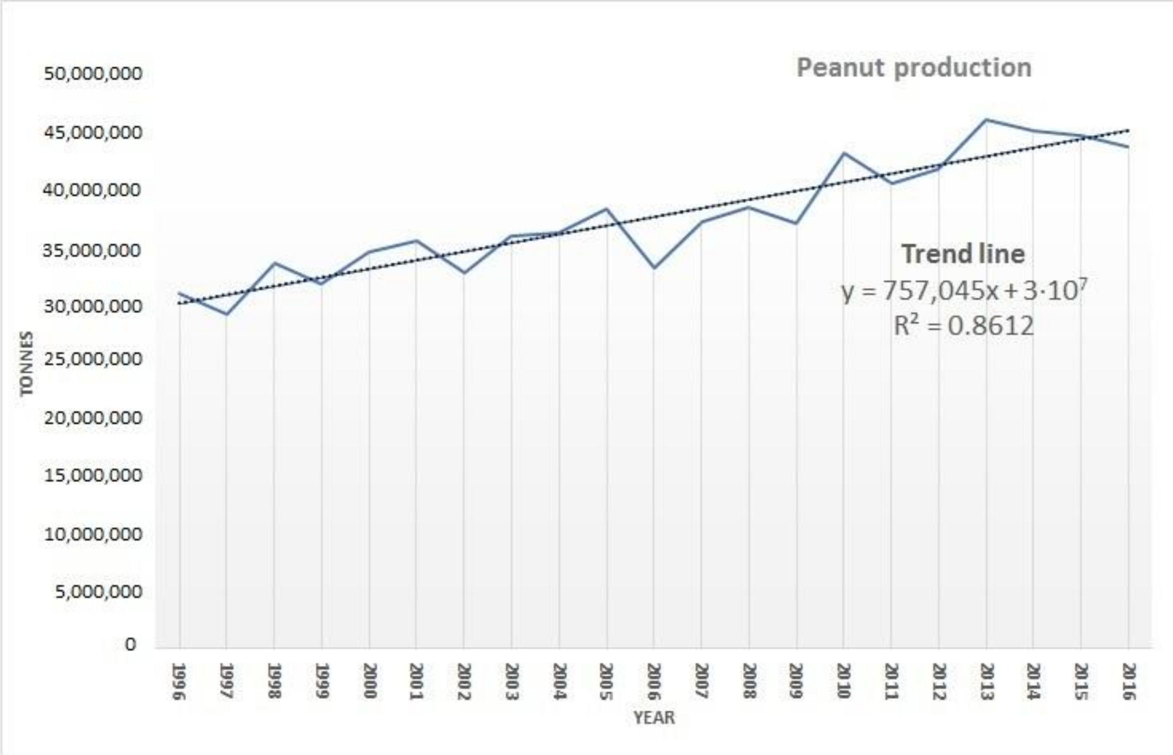

Figure V-2. World peanut production during a 20-year period (FAOSTAT, 2016).

The peanut industry is one of the main generators of agroindustrial waste (shells). This residual biomass has a high energy content that is worth exploring (Zhao et al., 2012).

The peanut shell is the main residue of the peanut industry and represents between 25% and 30% of the total weight of the legume, being eliminated as residues in the final stage of the processing of the peanut, either for oil production or for direct consumption without shell. Annually, there is a world production of this waste of around 11,000,000 t from the peanut industry that is still unexplored.

Therefore, there is a large amount of waste from the peanut industry that is being disposed of that can be used as biomass for energy purposes.

In Mediterranean countries, there are many boilers that are currently being used with fossil fuels and if they were adapted for use with other types of biomass, such as peanut shells, this would achieve large reductions in CO_2 emissions to the atmosphere and, therefore, greater environmental sustainability (Rinaldi et al., 2018).

The main objectives of this study are, firstly, to evaluate the energy parameters of peanut shells as a possible solid biofuel applied as an energy source in residential and industrial heating installations. Secondly, different models are analysed to estimate the Higher Heating Value (HHV) for biomass proposed by different scientists and to determine which most accurately fits the determination of this value for peanut shells. Thirdly, we evaluate the reduction in global CO_2 emissions that would result from the use of peanut shells as biofuel.

V-3. MATERIALS AND METHODS

V-3.1. Peanut Shells from Industrial Processing Samples for the Study

In order to study the energy potential of peanut shells, 3000 g of peanut shell residue samples was taken from various Andalusian industries (Figure V-3).

Figure V-3. Peanut shells from industrial processing.

V-3.2. Quality Parameters for Peanut Shell

The standard UNE-EN 14961-1 "Solid biofuels—Fuel specifications and classes—Part 1: General requirements", established by the Spanish Association for Standardization and Certification (AENOR), were applied to determine the quality parameters for peanut shells. These standards, units, and parameters are shown in Table V-1.

Table V-1. Biomass quality parameter standards and measurement equipment used.

Parameter	Unit	Standards	Measurement Equipment
Moisture	%	EN 14774-1	Drying Oven Memmert UFE 700
Ash	%	EN 14775	Muffle Furnace NABERTHERM LVT 15/11
Higher heating value	MJ/kg	EN 14918	Calorimeter Parr 6300
Lower heating value	MJ/kg	EN 14918	Calorimeter Parr 6300
Total carbon	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400
Total hydrogen	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400
Total nitrogen	%	EN 15104	Analyzer LECO TruSpec CHN 620-100-400
Total sulphur	%	EN 15289	Analyzer LECO TruSpec CHN 620-100-400
Total chlorine	mg/kg	EN 15289	Titrator Mettler Toledo G20
Volatile matter	%	EN 15148	Muffle Furnace NABERTHERM LVT 15/11
Fixed carbon	%	EN 15148	Muffle Furnace NABERTHERM LVT 15/11

V-3.2.1. Physical Parameters

Moisture is defined as the total amount of water contained in the total mass of a biomass sample. Moisture may exist on the outside surface of the biomass or be embedded within it (Sebastián Nogués, 2010).

V-3.2.2. Chemical Parameters

The chemical properties mainly concern the composition of the constituent elements of biomass (nitrogen, hydrogen, carbon, oxygen, and sulphur). The ash content (inorganic elements) and behaviour are also often of interest.

Elemental Analysis

Elemental analysis allows us to establish the percentage by weight of the main elements with the greatest presence in the molecule structure of the organic material: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulphur (S). From the knowledge of these constituents, the oxidation reactions can be established, so that, for example, the precise air for combustion (stoichiometric air) can be determined. There are also certain empirical formulations which, based on the percentage by weight of each element, allow us to obtain an approximation of its energy content (calorific value) (Perea-Moreno et al., 2016a).

Immediate Analysis

Immediate analysis provides the moisture, ash, volatile material, and fixed carbon content of the biomass, expressed as percentages by weight. Basically, this analysis serves to identify the fraction of the biomass in which its chemical energy (fixed carbon and volatile compounds) and inert fraction (ash and moisture) are stored.

Volatile matter is the portion of fuel that is released in the form of gases and vapours (hydrocarbons) when the biomass is thermally decomposed (Mata-Sánchez et al., 2013).

Fixed carbon and ashes are the fractions that remain once the volatile matter has been released. Fixed carbon, in combustion processes, continues to burn slowly after the volatiles are released.

Ashes are the inorganic residues that remain after the combustion of fixed carbon and vary in their composition and participation percentages according to the biomass source and collection methods used (Mata-Sanchez et al., 20013).

V-3.2.3. Energy Parameters

The calorific value is the chemical energy of the fuel that can be transformed directly into thermal energy by a thermochemical oxidation (combustion) process. This property is usually expressed in units of energy per units of mass (generally kJ/kg, MJ/kg, or lime/kg). Its value is terminated experimentally by a device called a calorimetric pump (Perea-Moreno et al., 2016a).

There are two ways of expressing the calorific value of a fuel. If, after combustion, the water formed in the combustion gases (from moisture or hydrogen oxidation) is found in liquid form, the Higher Heating Value (HHV) is obtained. If it remains in the form of steam, the Lower Heating Value (LHV) is obtained. They can be expressed per unit of wet fuel or dry fuel (Perea-Moreno et al., 2016a).

V-4. RESULTS AND DISCUSSION

The energetic properties of peanut shells were analysed from their main statistical descriptors. In addition, these properties were compared with those of other biomass waste.

V-4.1. Peanut Shell Quality Parameters

Samples of peanut shells obtained from the peanut industry were analysed in order to evaluate and determine the quality parameters.

The first step in the application of a fuel is to determine its chemical composition. The chemical composition of a fuel determines its properties, quality, applications, and environmental problems that can cause its combustion.

Table V-2 shows the average, median, standard deviation, and minimum and maximum values of the various parameters.

Table V-2. Quality parameters data of peanut shell samples.

Parameter	Unit	Standard Value	Standard Deviation (SD)	Maximum Value	Minimum Value
Moisture **	%	5.79	---	5.79	5.79
Ash content *	%	4.26	0.15	4.41	4.11
HHV *	MJ/kg	18.547	0.025	18.572	18.522
LHV *	MJ/kg	17.111	0.011	17.122	17.100
Total carbon *	%	46.42	0.007	46.427	46.413
Total hydrogen *	%	6.61	0.016	6.626	6.594
Total nitrogen *	%	0.50	0.012	0.512	0.488
Total sulphur *	%	0.54	0.01	0.55	0.53
Total oxygen *	%	41.77	2.453	44.223	39.317
Total chlorine *	%	0.07	0.001	0.071	0.069
Volatile matter *	%	84.90	1.09	85.99	83.81
Fixed carbon *	%	13.40			

* dry bases ** wet bases

It is important to know the percentage of N, S and Cl that each type of biomass has to study the environmental impact caused by its combustion, percentage of ash that causes problems of thermal efficiency in boilers, as well as the quantities of C, H, and O in order to estimate the calorific value of the biomass in question.

Peanut shells contribute to environmental conservation because their emissions into the atmosphere are lower than those of solid fuels because of their low sulphur (0.54%), nitrogen (0.50%), and chlorine (0.07%) content. Table V-3 shows a comparison of the parameters obtained from peanut shells and other biofuels used in boilers, such as olive stones, pine pellets, almond shells, or avocado stones.

The biggest advantage is the neutral CO_2 balance by closing the carbon cycle that the plants began to grow. Therefore, it can be said that emissions from biomass are not pollutants, since their composition is basically part of the CO_2 captured by the plant from which the biomass originates and water vapour.

The accumulation of ash deposits inside biomass boilers causes problems of thermal efficiency and can obstruct the ducts through which the combustion gases circulate. The ashes generated after biomass combustion are particularly problematic due to their low melting points and the high concentrations of alkaline metals they contain, which encourage corrosion of the pipes and walls of the boiler.

The average ash content in the peanut shell is 4.26%, which when compared to other biomass, such as olive stones (0.77%), avocado stones (2.86%), oak pellets (3.32%), and almond shells (0.55%), it can be observed that although it is a high value, it is within the average ash values produced by other biofuels used in boilers.

Despite all the advantages of biomass as a fuel, it also causes significant technical problems in boilers. It is very important to consider the Cl content of the biomass, since ashes with a low melting point are generated, which at 700–800 °C, begin to soften and have corrosive properties, so the impact of the deposition of these ashes on the system must be taken into account. If there is a large amount of ash deposition, this can lead to a failure which can lead to a boiler stoppage. In this case, costly manual cleaning of the heat transfer surfaces will be necessary.

If we analyse the values of chlorine for peanut shells, we can see that these values are much lower than those obtained for almond shells, pine pellets, or avocado pits, so its use as a biofuel would improve the problems of corrosion in the hips.

Table V-3. Comparison of peanut shell with other biomass materials.

Parameters	**Unit**	**Avocado Stone (Perea-Moreno, et al., 2016a)**	**Olive Stone (Mata-Sánchez et al., 2013; García et al., 2014; García et al., 2017)**	**Pine Pellets (García et al., 2017; Aranz et al., 2015)**	**Peanut Shell**	**Almond Shell (García et al., 2017; Gómez et al., 2016; González et al., 2005)**
Moisture	%	35.20	18.45	7.29	5.79	7.63
HHV	MJ/kg	19.145	17.884	20.030	18.547	18.200
LHV	MJ/kg	17.889	16.504	18.470	16.994	17.920
Ash content	%	2.86	0.77	0.33	4.26	0.55
Total carbon	%	48.01	46.55	47.70	46.42	49.27
Total hydrogen	%	5.755	6.33	6.12	6.61	6.06
Total nitrogen	%	0.447	1.810	1.274	0.50	0.120
Total sulphur	%	0.104	0.110	0.004	0.54	0.050
Total oxygen	%	42.80	45.20	52.30	41.77	44.49
Total chlorine	%	0.024	0.060	0.000	0.07	0.01
$\frac{HHV_{biomass}}{HHV_{peanut\ shell}}$	%	103.22	96.43	110.05	100	98.13

Thermal applications with heat and hot water production are the most common in the biomass sector, although they can also be used for electricity production. Biomass can feed an air-conditioning system (heat and cold) in the same way as if it were powered by gas, diesel, or electricity.

Thermal production can be carried out by means of:

- Stoves, usually of pellets or wood, that create a single room and usually act simultaneously as decorative elements.

- Low power boilers for single-family homes or small buildings.
- Boilers designed for a block or building of flats, which act as central heating.
- Thermal power stations that heat several buildings or installations (district heating) or a group of houses.

Normally, residual biomass has a high moisture content (over 100% on a dry basis), so it requires prior conditioning for subsequent use for energy purposes. The peanut shell has a very low moisture content (5.79%), which is a great advantage since it is not necessary to dry it for energy purposes.

The values of HHV and LHV in peanut shells vary between 18.572 and 18.522 MJ/kg and 17.122 and 17.100 MJ/kg, respectively. The variations are very slight when applying the standard deviation, and they are similar values to the ones that have been obtained by other authors: 18.920 MJ/kg (Abe et al., 2007) or 19.2 MJ/kg (Singh et al., 2015). It should be noted that the calorific value of peanut shells is similar or even higher than that of other biofuels. For example, the HHV of peanut shells (18.47 MJ/kg) is higher than olive stones (17.885 MJ/kg) or almond shells (18.200 MJ/kg). Table V-3 shows this comparison and the HHV biomass/HHV peanut shell ratio, which shows that there are no variations above 10%.

Many of the resources covered by the term solid biofuels for the production of heat and/or electricity are characterized by their high moisture content. The fact that biofuels always have a certain moisture content is due to two causes. On the one hand, it should be borne in mind that water is the vehicle for transporting nutrients in plant matter, i.e., water is an inherent component of this. On the other hand, the resources considered here are characterized as all plant matter by their hygroscopicity, that is, by their capacity to absorb and lose moisture according to the environmental conditions of the surrounding environment in order to maintain the hygrometric balance. The water content can reach values even higher than 60% of the total weight of the biofuel, increasing the costs associated with its handling (transport, storage, and feeding in the plant) and making it difficult to carry out all the operations necessary for its energy transformation (milling, densification, combustion, etc.).

In the case of peanut shells, its moisture content is very low, which means that no drying treatment would be necessary, making it an ideal biofuel for use in the production of heat in household or industrial boilers.

V-4.2. Predictive Models for Estimating the HHV of Peanut Shell

The biomass HHV can be calculated theoretically from correlation equations that relate the elemental composition of biomass and other chemical elements. Table V-4 shows 16 correlation equations of relevant authors in this field that have been used to calculate the HHV value of different biomasses from the experimental values of their elemental composition, sulphur, ash, fixed carbon, and volatile matter.

Table V-4. Evaluated HHV correlation equations.

No.	Name of the Authors and Reference	Correlation Equation (MJ/kg)
(1)	(Jenkins and Ebeling, 1985)	HHV = −0.763 + 0.301 C + 0.525 H + 0.064 O
(2)	(Sheng and Azevedo, 2005)	HHV = −1.3675 + 0.3137 C + 0.7009 H + 0.0318 O
(3)	(Yin, 2011)	HHV = 0.2949 C + 0.8250 H
(4)	(Graboski and Bain, 1979)	HHV = 0.328 C + 1.4306 H – 0.0237 N + 0.0929 S – (1 – Ash/100)·(40.11 H/C) + 0.3466
(5)	(Callejón-Ferre et al., 2011)	HHV = −3.440 + 0.517 (C + N) − 0.433 (H + N)
(6)	(Channiwala and Parikh, 2002)	HHV = 0.3491 C + 1.1783 H + 0.1005 S – 0.1034 O – 0.0151 N – 0.0211 Ash
(7)	(Sheng and Azevedo, 2005)	HHV = 19.914 – 0.2324 Ash
(8)	(Brigwater et al., 1996)	HHV = 0.341 C + 1.323 H + 0.068 S − 0.0153 Ash – 0.1194 (O − N)
(9)	(Tillman, 1978)	HHV = – 1.6701+0.4373 C
(10)	(Annamalai et al., 1987)	HHV = 0.3516 C + 1.16225 H – 0.1109 O + 0.0628 N + 0.10465 S
(11)	(Demirbas, 2004)	HHV = – 0.459+0.4084 C
(12)	(Callejón-Ferre et al., 2011)	HHV = −3.147 + 0.468 C
(13)	(Jenkins and Ebeling, 1985)	HHV = 1.209 + 0.379 C
(14)	(Jimenez and Gonzales, 1991)	HHV = −10.81408 + 0.3133 (VM + FC)
(15)	(Demirbas, 1997)	HHV = 0.312 FC + 0.1534 VM
(16)	(Cordero et al., 2001)	HHV = 0.3543 FC + 0.1708 VM
(17)	(Jenkins and Ebeling, 1985)	HHV = −0.049 + 0.332 C + 0.851 H − 0.036 O
(18)	(Jenkins and Ebeling, 1985)	HHV = 3.210 + 0.3333 C
(19)	(Jenkins and Ebeling, 1985)	HHV = 0.007 + 0.311 C+0.752H + 0.006 O

(20)	(Demirbas, 2004)	HHV = 0.4182 (C + H) − 3.4085

It should be borne in mind that the formulas analysed correspond to the HHV prediction for different types of biomass, in which the number of samples or the analysis methodology used must be taken into account. Therefore, it should be noted that despite the different origins of the formulas proposed by the different authors, the prediction results of HHV from peanut shells are very similar.

If we observe Table V-5, the best prediction result of the HHV value for peanut shell has been achieved with Equation (12) with a deviation of 0.165%, followed by Equation (11), proposed by Demirbas et al. (2004), with a deviation of 0.259%. In third place is Equation (9), proposed by Tillman (1978), with a deviation of 0.444%, and fourthly, Equation (18). In addition, it should be noted that Equations (9), (11), (12), and (18) require only one parameter for their calculation, assuming that HHV is a linear function of its the carbon content, and then the algebraic equation has the form HHV= a + b·C, where C is the carbon content (%). This has proven to be the most optimal formula for the calculation of HHV, with an expected error of less than 1% in absolute value. It should be noted that carbon and oxygen almost always account for about 90% of the biomass weight and that the correlation between carbon and oxygen is also high (Singh et al., 2015), so the results are logical. Therefore, the main advantage of this equation is that, using the data from an elemental component of biomass such as carbon, more sophisticated laboratory equipment is not needed, which is not always available everywhere.

Table V-5. Results of the different higher heating value (HHV) prediction models.

Equation Number	Correlation Value (MJ/kg)	Difference	% Deviation
(1)	19.353	−0.806	4.345
(2)	19.156	−0.609	3.282
(3)	19.143	−0.596	3.211
(4)	19.599	−1.052	5.671
(5)	17.739	0.808	4.356
(6)	19.632	−1.085	5.848
(7)	18.924	−0.377	2.033
(8)	19.618	−1.071	−5.775
(9)	18.629	−0.082	0.444
(10)	19.459	−0.912	4.919
(11)	18.499	0.048	0.259
(12)	18.578	−0.031	0.165
(13)	18.802	−0.255	1.376
(14)	19.983	−1.436	7.744
(15)	17.204	1.343	7.239
(16)	19.249	−0.702	3.782
(17)	19.484	−0.937	5.051
(18)	18.682	−0.135	0.727
(19)	19.665	−1.118	6.028
(20)	18.763	−0.216	1.166

V-4.3. Potential of Peanut Shell for Reducing CO_2 Emissions

Carbon dioxide emissions into the atmosphere are a major environmental concern. Considered one of the reasons for climate change, an alternative to fossil fuels is making its way: biomass.

The burning of fossil fuels is one of the main reasons for global warming. The search for energy sources to replace coal or oil is necessary to maintain sustainable economic development. This section shows the benefits of using peanut shells as a biofuel to reduce CO_2 emissions.

Once the different energy parameters of the peanut shell are known, its energy potency can be calculated from the world production of peanuts using Equation (21):

$$E_c = RH \times P_c \times HHV \times f_s \times U_c \tag{21}$$

where:

- E_c is the potential of energy production using the peanut shell as biofuel in each country (MWh),
- RH is relative humidity (10%),
- P_c is the peanut shell production in each country (kg),
- HHV is the higher heating value (18.547 MJ/kg),
- f_s is the factor of shell in a whole peanut (30%),
- U_c is the unit conversion (0.000277778 Wh/J).

Figure V-4 shows the global energy produced using peanut shells as biofuel. The largest production of energy from peanut shells is found in China (25,579.75 MWh), followed by India (11,440.42 MWh), Nigeria (5253.69 MWh), the United States (3637.60 MWh), and Sudan (2891.79 MWh).

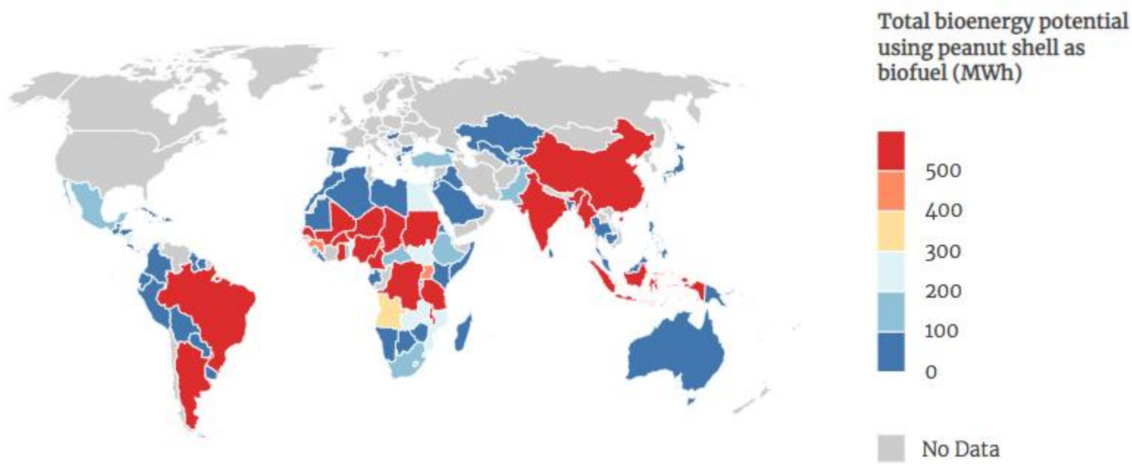

Figure V-4. Total bioenergy potential using peanut shell as biofuel.

In many industrialized countries, biomass accounts for more than 50% of national energy consumption. There, the consumption of energy biomass is often much lower due to the predominant contribution of "fossil fuels". This situation reached a turning point in the 1970s with the first oil crisis, which allowed us to glimpse the unsustainability of a model based on the almost exclusive use of fossil resources. Since then, there has been a growing interest in energy saving and efficiency as well as in the consumption of local renewable resources, including biomass, with the dual objective of reducing energy dependence and CO_2 emissions. Therefore, in order to limit this increase in emissions, strategic plans such as the European Union's Strategic Framework for 2030 or the United States' Clean Energy Plan have been implemented, in which the United States undertakes to reduce CO_2 emissions by 32% by 2030 (World Data Bank, 2018).

Energy competitiveness needs to be complemented by other measures to tackle climate change, i.e., to curb the increase in greenhouse gas emissions without damaging economic growth:

- Efficiency improvement.
- Limitation of inefficient coal-fired power stations.
- Decrease in methane emissions from oil and gas.
- Reform of fossil fuel subsidies.
- Increase in renewable energies, without their use leading to a loss of competition with respect to other countries where there are no measures to reduce greenhouse gas emissions.

In this work, the CO_2 reduction that would result from the use of peanut shells as an energy source has been evaluated using the method explained in Figure V-5. For this purpose, the total emissions values for 2014 (last updated) provided by the World Data Bank (http://databank.worldbank.org/data/home.aspx) (World Data Bank, 2018) and data of world peanut production from the same year (2014) provided by FAO (FAOSTAT, 2016) have been taken as a reference. It has also been taken into account that if the energy that can be produced from peanut shells were produced from conventional energy sources, these would generate 0.357 t of CO_2.

Therefore, the global CO_2 savings would be equivalent to if the energy produced by the peanut shell were produced by conventional sources. It is logical that the greatest savings in CO_2 emissions would occur in those countries with the highest production of peanuts, since they would be the largest producers of energy with this biofuel. The top 10 countries are: China (18.22 kt), India (4.08 kt), Nigeria

(1.88 kt), Myanmar (0.83 kt), Argentina (0.64 kt), Chad (0.44 kt), Senegal (0.37 kt), United Republic of Tanzania (0.90 kt), and the United States (1.30 kt).

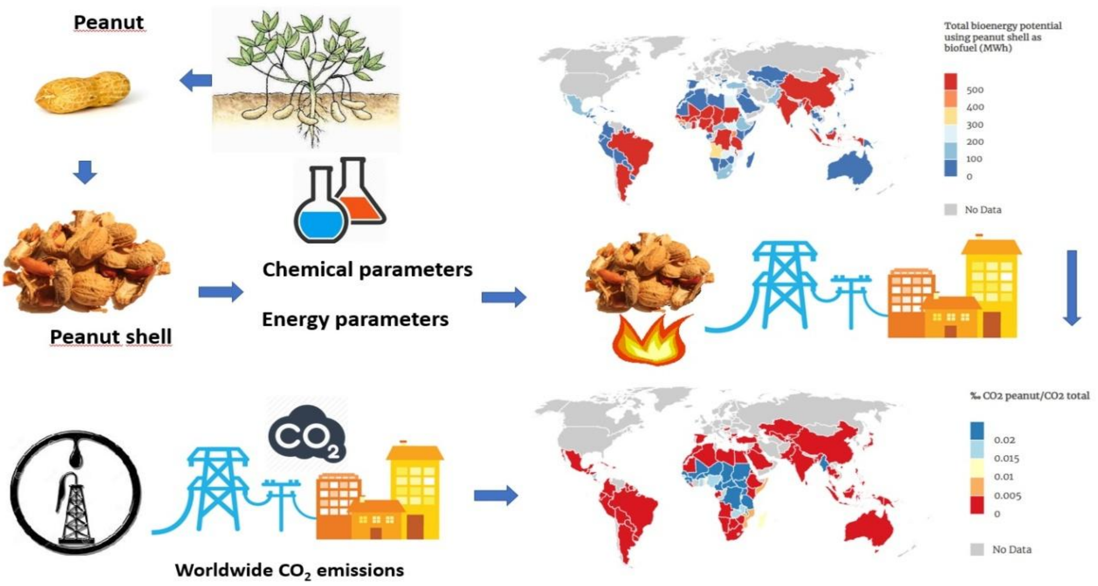

Figure V-5. Methodology for reducing CO_2 emissions by using peanut shell.

Figure V-6 shows a comparison between the savings in CO_2 emissions and the total emissions produced in each country per thousand. If we analyse this figure, we can see that the 10 countries with the greatest savings in CO_2 emissions in relation to their total emissions are: Chad (0.60‰), Central African Republic (0.22‰), Mali (0.20‰), Malawi (0.17‰), Niger (0.10‰), Gambia (0.09‰), Guinea-Bissau (0.08‰), United Republic of Tanzania (0.07‰), Sudan (0.07‰), and Guinea (0.07‰).

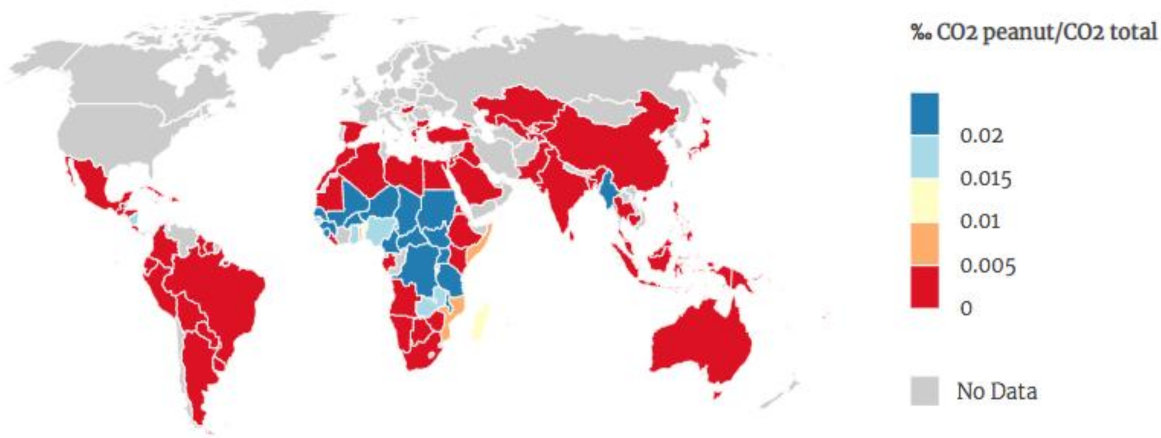

Figure V-6. Potential of peanut shell for reducing CO_2 emissions compared to total CO_2 emissions for peanut producer countries.

V-5. CONCLUSIONS

Biomass residues are a potentially huge source of energy-producing materials. This study has evaluated the energy parameters of peanut shells as a possible solid biofuel applied as an energy source in industrial and residential heating installations and the reduction in global CO_2 emissions that would result from the use of them.

The HHV is a major property of biomass fuels. The HHV of peanut shells obtained (18.547 MJ/kg) is higher than other biomass sources such as almond shells (18.200 MJ/kg) or olive stones (17.885 MJ/kg) and similar to other sources of biomass presently used for industrial and home heating applications. Different prediction models of the HHV value proposed by scientists for different types of biomass have been analysed and the one that best fits the calculation for the peanut shell has been determined. Therefore, of the mathematical equations analysed for the estimation of HHV, the best performers were linear equations which were based only on total carbon content, which have shown a deviation below 1%, specifically, $HHV = -3.147 + 0.468\ C$.

The possibilities for applications of the use of renewable energy sources such as biomass to replace fossil fuel combustion as a primary energy source is vital in all countries of the world. Peanuts are grown mainly in Asia, with a global production rate of 65.3%, followed by Africa with 26.2%, the Americas with 8.4%, and Oceania with 0.1%. The CO_2 reduction that would result from the use of peanut shells as an energy source has been evaluated and the 10 countries with the highest CO_2 savings are: China (18.22 kt), India (4.08 kt), Nigeria (1.88 kt), Myanmar (0.83 kt), Argentina (0.64 kt), Chad (0.44 kt), Senegal (0.37 kt), United Republic of Tanzania (0.90 kt) and the United States (1.30 kt). If we compare between the savings in CO_2 emissions and the total emissions produced in each country per thousand, the 10 countries with the greatest savings in CO_2 emissions in relation to their total emissions are: Chad (0.60‰), Central African Republic (0.22‰), Mali (0.20‰), Malawi (0.17‰), Niger (0.10‰), Gambia (0.09‰), Guinea-Bissau (0.08‰), United Republic of Tanzania (0.07‰), Sudan (0.07‰), and Guinea (0.07‰).

Finally, the moisture content of peanut shell is very low, which means that no drying treatment would be necessary, making it an ideal biofuel for use in the production of heat in household or industrial boilers. In addition, the combustion technologies are available commercially worldwide. As biomass is the only renewable carbon-based fuel, its use is playing an increasingly important role in climate protection.

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Chapter VI.

Sustainable energy based on sunflower seed husk boiler for residential buildings

«Nearly Zero-Energy Buidings (NEZB) should not be the buildings of the future, but of the present»
European Union (2013)

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Chapter VI. Sustainable energy based on sunflower seed husk boiler for residential buildings

Miguel-Angel Perea-Moreno [1], Francisco Manzano-Agugliaro [2] and Alberto-Jesus Perea-Moreno [1]

[1] Departamento de Física Aplicada, Universidad de Córdoba, ceiA3, Campus de Rabanales, 14071 Córdoba, Spain, g12pemoa@uco.es

[2] Department of Engineering, University of Almeria, ceiA3, 04120 Almeria, Spain, fmanzano@ual.es

VI-ABSTRACT

Buildings account for one third of the world's energy consumption, 70% of which is devoted to heating and cooling. To increase the share of renewables in the energy consumption of buildings, it is necessary to research and promote new sources of green energy. World production of sunflower (*Helianthus annuus*) was 47.34 million tons in 2016, with a harvested area of 26.20 million hectares, and the main producing countries being Ukraine, the Russian Federation, and Argentina, which produce about half of world production of sunflower seed. The sunflower husk, which represents a percentage by weight of 45%–60% of the seed depending on the sunflower variety, is widely used for the production of feed, however, its energy use is very scarce. The objectives of this study were to analyse the energy properties of sunflower husk as a solid biofuel and to carry out an energy, environmental, economic and operational analysis of a thermal installation fed with this by-product of the sunflower oil industry. The results show that this agro-industrial waste has a Higher Heating Value (HHV) of 17.844 MJ/kg, similar to that of other solid biofuels currently used. In addition, replacing a 430 kW fuel oil boiler with a biomass boiler of the same capacity fed by this biofuel can avoid the emission of 254.09 tons of CO_2 per year, as well as obtain an annual energy saving of 75.47%. If we consider the production of sunflower seeds in each country and the sunflower husk were used as biofuel, this would result in a CO_2 saving of more than 10 per thousand of the total emissions emitted. The results of this work contribute to the standardization of this by-product as a solid biofuel for thermal

energy generation due to its potential to reduce CO_2 emissions and increase energy efficiency.

Keywords: sunflower seed husk, biomass boiler, renewable energy, CO_2, higher heating value, energy efficiency, sustainable energy

VI-1. INTRODUCTION

According to data provided by the International Energy Agency, buildings consume over a third of the worldwide energy produced, and represent a major source of carbon dioxide-related emissions (International Energy Agency, 2018). Indeed, it is expected that, if no measures are adopted to enhance the sector's energy efficiency, energy consumption will increase up to more than 50% by 2050. Buildings in the European Union account for 40% of total primary energy consumption and 36% of total CO_2 emissions. A large part of the energy demand of buildings (up to 70%) is for heating and cooling, 75% of which is met by fossil fuels and only 18% by renewable sources (International Energy Agency, 2018). To promote energy saving measures and reduce the power consumption to heat and cool European buildings, the European Commission launched a strategy of engagement to cut down the huge quantity of energy used in heating and cooling. This is in line with the Energy Efficiency Directive (EED-2012/27/EU) through which a common framework is established to promote energy efficiency within members states (De la Cruz-Lovera et al., 2017; Pritchard and Kelly, 2017).

Furthermore, almost zero energy consumption will be a legal requirement in the construction of buildings by the end of 2018. Nearly Zero-Energy Buildings (NZEB) should not be the buildings of the future, but of the present. In this regard, the European directive 2010/31/EU determines that from 31 December 2018 all new public buildings will be NZEB, and in 2020 the rest will be NZEB (Ferrara et al., 2018; Zavadskas et al., 2017). A NZEB is a very highly energy-efficient building, so the nearly null or minimal quantity of requested energy must be largely satisfied by clean energy sources, whether produced on site or in the surrounding environment (Gao et al., 2018).

The European Union has as one of its major objectives to promote energy saving and energy efficiency measures, so that compared to the 1990 levels, the European Union's commitments to achieve this are to reduce Greenhouse Gas (GHG) emissions by 20%, to save 20% of energy consumption through greater energy efficiency, to cover in each country 10% of transport needs must by biofuels, and to promote renewable energies so that they account for 20% of the energy mix (European Commission, 2007).

To increase the share of renewables in the energy mix, as well as energy efficiency, new innovative sources of renewable energy should be researched and promoted. Biomass is a high-energy, clean source with a high degree of sustainable growth due to its carbon neutral status and high availability worldwide, as it can be obtained from a wide variety of agro-industrial and livestock waste. It accounts for between 9% and 14% of total primary energy consumption in industrialized countries, while in developing countries bioenergy accounts for approximately a fifth to a third of total consumption (Perea-Moreno et al., 2016, 2018a, 2018b). However, despite its potential as environmentally friendly energy source, biomass is largely discarded without making any energy use of it.

In the meantime, the transformation towards energy sustainability needs measures (García, 2017) such as the promotion of efficiency (Van Der Schoor and Scholtens, 2015), the provision of energy services (Bouzarovski and Petrova, 2015), cooperation for energy development (de Santoli, et al., 2015), or the incorporation into legislation of the most innovative technologies and procedures for efficiency (Alonso et al., 2005). Among these measures, it should not be forgotten to help finance efficiency improvements (de Santoli et al., 2015). This means for governments to invest in a more sustainable and productive economy over the long term (Fais et al., 2016), however, for households, it is necessary to have short-term results to assume the costs of the required investments (Kammen and Sunter, 2016). Then, the key is to encourage energy efficiency and savings of households (Manzano-Agugliaro et al., 2015), and within these highlights the residential use of energy, which must take into account both the combination of obtaining energy with an efficient and clean technology (Montoya et al., 2017) and maintenance operations of the same (AlFaris et al., 2016).

Biomass is the set of organic matter, of vegetable or animal origin, and the materials that come from their natural or artificial transformation. Directive 2009/28/EC on the promotion of the use of energy from renewable sources, defines biomass as "the biodegradable fraction of products, disposals and residues of biological origin coming from agricultural activities (including substances of plant and animal origin), of forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste". That is, biomass is a very broad concept that includes from the waste coming from the forestry, agricultural and livestock activities up to the organic fraction of domestic and industrial waste, including the by-products of the agri-food and wood processing industries (Mehedintu et al., 2018; Muresan and Attia, 2017; Contescu et al., 2018).

Biomass, from an environmental point of view, could be seen as a straightforward alternative to fossil fuels, especially coal, as it burns or gasifies in a similar way to coal and, similar to coal, produces greenhouse gas emissions, mainly CO_2. Nevertheless, there are important differences. The biomass of the plant as it grows captures carbon dioxide out of the atmosphere through photosynthesis process (Bouzarovski and Petrova, 2015). Therefore, throughout the cycle of growth, harvest and combustion, there is a net balance between the addition and subtraction of CO_2 into the atmosphere. However, the major distinction between biomass and coal is that biomass does not contain sulphides and therefore biomass gas power plants do not require treatment to remove sulphur dioxide before releasing emissions into the atmosphere.

The main fuels obtained from biomass are firewood, wood chips, pellets, olive stone and fruit shells. Firewood cut and chopped, ready for use in domestic combustion appliances such as stoves or chimneys, is the least elaborate of them, and they have traditionally been used in single-family homes. Chips are the product resulting from the crushing of biomass of woody origin, both agricultural and forestry, and have a variable size depending on the degree of crushing to which they have been subjected. The pellets are the most elaborated product, and they are small cylinders of 6–12 mm in diameter and 10–30 mm in length made with sawdust, splinters or other compressed waste that can be used as fuel (Li et al., 2018; Williams et al., 2018).

Fruit stones and seeds as well as fruit husks, although used in smaller quantities than firewood, wood chips and pellets, also are a fuel that is increasingly used. In recent years, as the exploitation of the immense potential available and a market for biomass has been consolidated, increasing the agents involved and the volumes commercialized, efforts have been increased to standardize and certify the quality of this type of fuels, mainly chips and pellets (ISO 17225 standards), having even studios recent (BIOMASUD) and specific standards intended for biomass waste such as olive stone and fruit shells (standards UNE-164003 and UNE-164004, respectively) (Karampinis et al., 20018; Mata-Sánchez et al., 2014).

The sunflower (*Helianthus annuus*) is a large herbaceous crop of the Asteraceae family, widely cultivated worldwide due to its relatively short growth cycle, high resistance to drought and adaptation to different soil conditions. The top producers' countries of sunflower and sunflower derivatives are the Russian Federation, Ukraine and Argentina, which produce roughly half of the world's sunflower seed production. Figure VI-1 shows world production of sunflower.

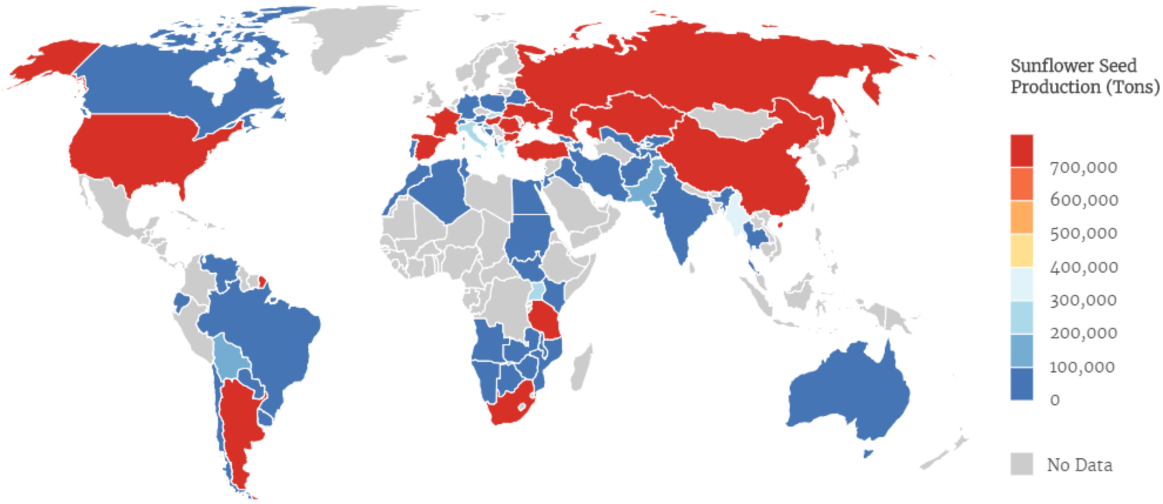

Figure VI-1. Worldwide sunflower production (2016).

Sunflower is currently planted in six continents (Figure VI-1), with the cultivated world surface of 26.2 million hectares with a total production of 47.34 million tons. In other words, the world average yield of this oleaginous species is 18,067 hg/ha. On the European continent, 18.07 million hectares (70% of the world surface) are harvested, of which 16.31 million are in the Eastern Countries. In Spain, the area sown with sunflower is stabilized at 700,000 hectares (4% of the European continent), being the eighth country in terms of sunflower seed production (FAOSTAT, 2016). Figure VI-2 depicts the trend in the world's sunflower production over the course of 20 years.

Sunflower husk represents a weight percentage of 45%–60% of the seed depending on the sunflower variety, and is separated from the kernel in the grinding process, to obtain a better pressing of the seed and a higher oil yield. Therefore, sunflower seed husk is a by-product of the sunflower oil industry, which, although widely used for the production of animal feed, its energy use is very scarce (Cubitto and Gentili, 2015). The high energy content of this biomass-by-product makes it optimal for use as a heating fuel. However, currently, a large share of it is disposed of and sent to landfills without eco-friendly use. It should be borne in mind that, because of its carbon-neutral potential, this by-product can help mitigate the effects of climate change.

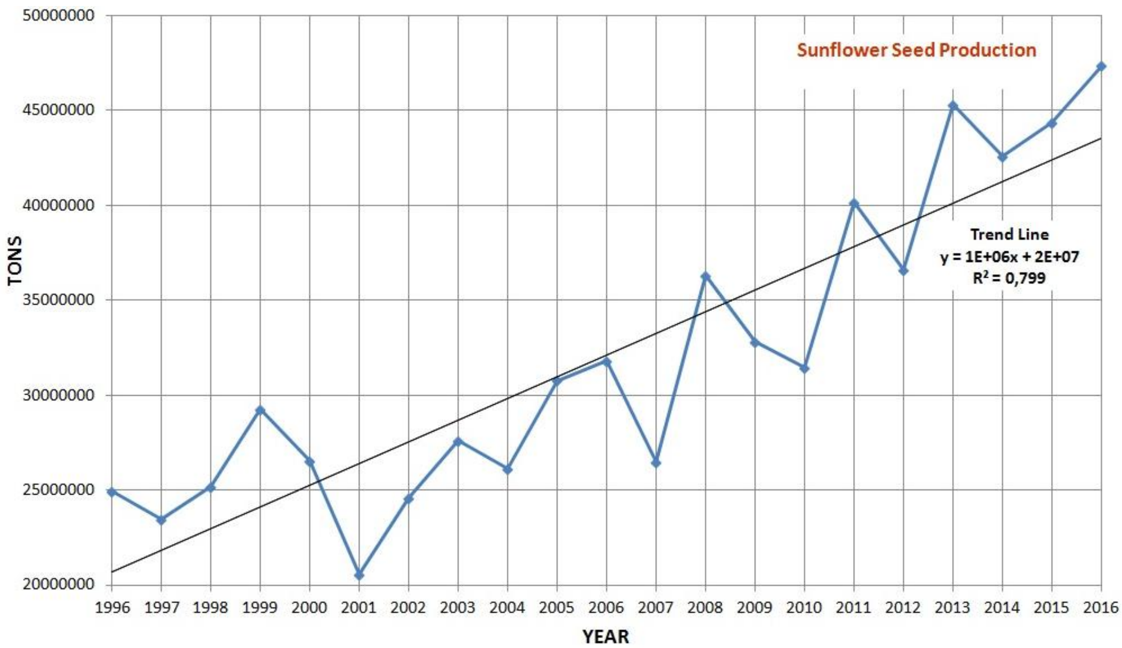

Figure VI-2. Trend production of worldwide sunflower seed over a 20-year period (FAOSTAT, 2016).

The objectives of this study were to evaluate the properties and suitability of the sunflower husk as a solid biofuel to produce heat and to evaluate the viability of a thermal installation that uses this fuel, from an energy, environmental, economic and operational point of view.

This paper presents the results on energy efficiency and economic viability, obtained from a heat generation system fed by sunflower seed husks, which would serve to cover part of the thermal energy demand in buildings of the residential sector. To meet the proposed objectives, we analysed the energy properties of sunflower husk as a solid biofuel. To evaluate the viability of a thermal installation that uses this fuel, a five-storey, sixty-room hotel located in the south of Spain was chosen, with a thermal installation consisting of a 430 kW fuel oil boiler.

VI-2. MATERIALS AND METHODS

VI-2.1. Materials

First, an energy audit of the building was carried out to check the real situation regarding the energy management of the installations, and served as a technical basis for the feasibility study.

Once the installation was executed, to obtain the data related to its operation, each of the components of the system was introduced in the hotel's preventive maintenance plan, assigning a specific time to each of the maintenance tasks. The daily time devoted to the maintenance work of the biomass boiler and its complementary facilities, as well as the one devoted to the location and repair of faults, was timed. In addition, the data related to the overall performance of the installation was monitored by using the remote management system of the boiler, monitoring the operating parameters and automatically recording the operating status and the value of its control parameters. The data acquisition procedure was enhanced with the data obtained from the historical archive of the hotel's maintenance service.

To validate the results obtained during the analysed period, the values have been contrasted by means of a second energy audit. The data collection methodology is described in Figure VI-3.

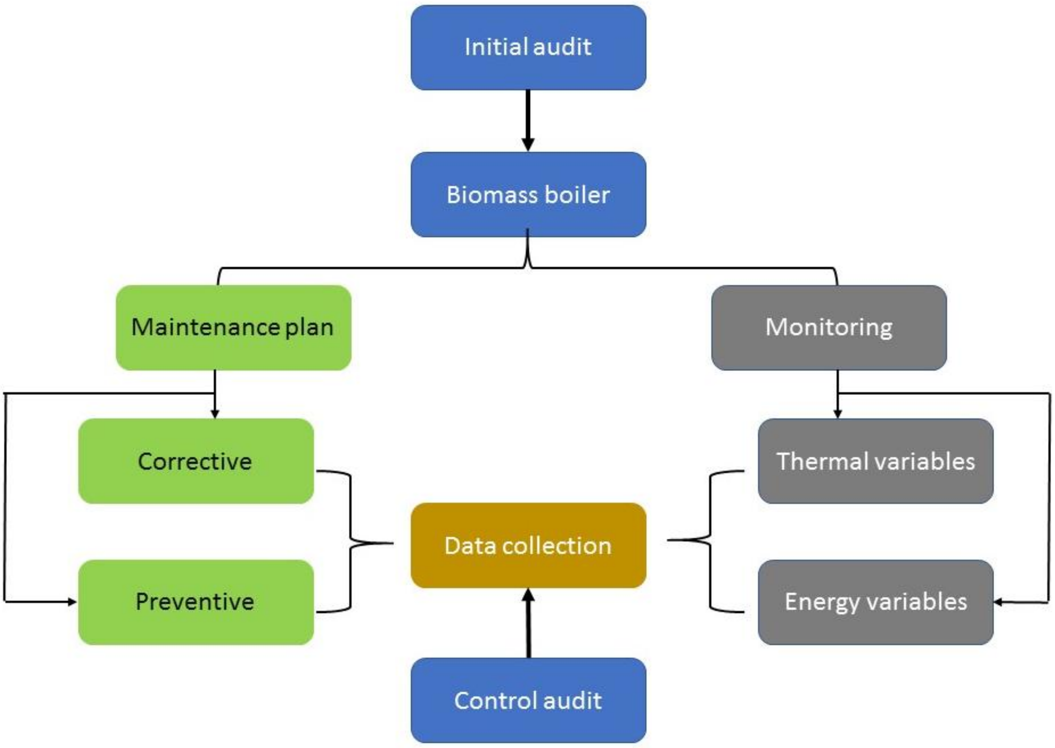

Figure VI-3. Methodological scheme for data collection.

As far as fuel analysis is concerned, 2000 g of sunflower seed husks were gathered for subsequent analysis coming from sunflower oil industries in the area (Figure VI-4).

Figure VI-4. Sunflower oil by-product.

VI-2.2. Determination of Quality Parameters and Equipment

The quality parameters were set by the UNE-EN 14961-1 standard "Solid biofuels–Specifications and fuel classes—Part 1: General requirements", developed by the Spanish Association for Standardisation and Certification (AENOR). Table

VI-1 shows the standards and the measuring equipment used. The samples were characterized by their dry weight content.

Table VI-1. Biomass quality parameter standards and measurement equipment used. Measurement error is expressed as the average standard deviation of analysed sunflower husks.

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

VI-2.2.1. Physical Parameters: Humidity

To determine the moisture percentage of the sample, it was dried at 105 ± 2 °C using an oven (MEMMERT UFE 700) and performing 3–5 full air exchanges per hour. The mass loss of the sample indicates the percentage of humidity, but considering the increase in mass of the trays produced by the heat expansion effect.

The moisture content of a solid biofuel is a key factor in its energy efficiency, because it is necessary to evaporate the water it contains before the heat is released. Therefore, the higher the moisture content of the fuel, the poorer its combustion power will be. Most heat transfers require fuels with a moisture content below 30%, achieving optimum yields at 10% humidity. With low moisture content, the combustion is complete, reducing both the emission of tars that tend to accumulate in the exhaust fumes and the problems of corrosion and clogging in the chimneys (Sebastián Nogués, 2010).

VI-2.2.2. Chemical Parameters: Elemental Composition

Carbon (C), Hydrogen (H) and Nitrogen (N) determine the elemental composition of the biomass. For the calculation of the total content of carbon, hydrogen and nitrogen, the UNE-EN 15104:2011 standard was applied and the LECO TruSpec CHN 620-100-400 analyser, which works in accordance with the Dumas combustion method, was used as measuring equipment.

To calculate the elemental composition of the biomass, a certain mass of the sample was burned in atmosphere containing oxygen or a mixture of a carrier gas and oxygen in such a way that ashes and combustion gases (carbon dioxide, water vapour, elemental nitrogen and/or nitrogen oxides, sulphur oxides and hydrogen halides) were obtained. The mass fractions of carbon dioxide, water vapour and nitrogen in the gas stream were determined quantitatively by using instrumental techniques. A drift correction with pattern EDTA was necessary before entering the sample quantity (0.1–0.25 grams) into the LECO Tru Spec CHN 620-100-400 analyser for combustion at 950 °C to quantify the proportion of carbon, hydrogen and nitrogen in the instrumentation.

A proper ultimate analysis of the biomass, i.e., the precise determination of the percentage mass contents of carbon, hydrogen and oxygen, was necessary to determine the quality of the biofuel and its Higher Heating Value (HHV). It also served to evaluate its possible environmental impact, as nitrogen is mostly converted into N_2 gas and NO_x, the latter being one of the gases that contributes to the greenhouse effect. The carbon content would also allow CO_2 emissions to be assessed (Perea-Moreno et al., 2016).

VI-2.2.3. Chemical Parameters: Sulphur and Chlorine Content

As reflected in Table VI-1, the determination of the chlorine and sulphur content was carried out in accordance with the UNE-EN 15289 standard, which sets out various techniques for its quantification. In our case, we opted for a procedure similar to the one used to determine calorific value according to the UNE-EN 14918 standard, but using digestion in a calorimetric pump. In this case, by means of potentiometry (TITRATOR METTLER TOLEDO G20), the existing chlorine in the washing water generated during combustion was quantified by using silver nitrate.

For sulphur, a procedure similar to that used for the determination of the elemental chemical composition (C, H, and N) was followed using in this case a LECO TruSpec S 630-100-700 elemental analyser where the sample was combusted at 1350 °C and the gaseous combustion products formed were quantified (Perea-Moreno et al., 2016).

VI-2.2.4. Chemical Parameters: Non-Combustible Inorganic Fraction (Ashes)

Ashes are considered the inorganic and non-flammable part of biomass that is formed as a result of its content in minerals such as potassium, chlorine, sodium and phosphorus. The ash content is an indicative parameter of biofuel quality, where the higher the ash content, the worse the fuel quality. This is because this by-product of combustion can cause clogging and corrosion problems in various elements of the thermal installation due to the formation of sulphur oxide and molten potassium ash (Mata-Sánchez et al., 2013).

To calculate the ash content, the remaining residual mass was quantified after the sample was burned in a muffle furnace (NABERTHERM LVT 15/11) under strictly controlled weight, time and temperature conditions.

VI-2.2.5. Chemical Parameters: Total oxygen

The UNE-EN 15296 standard "Solid biofuels–Conversion of analytical results from one base to another" was used to indirectly determine the oxygen content as the percentage left after subtracting the percentage of the other elements plus the ashes (Mata-Sánchez et al., 2013).

VI-2.2.6. Energy Parameters: HHV and LHV

The calorific value of a fuel is the amount of energy released in the combustion reaction, referred to the unit of fuel mass (e.g., J/Kg), i.e., the amount of heat delivered by 1 kg, or 1 m^3 of fuel when completely oxidised.

The calorific value is defined as the total amount of energy that can be released by the bonding of the fuel to the oxidant, and is calculated by subtracting the energy used to form additional molecules in the gases generated during combustion from the energy that keeps the atoms together in the fuel molecules.

The magnitude of the calorific value can vary according to how it is measured. Depending on the method of measurement, the expressions Higher Heating Value (HHV) and Lower Heating Value (LHV) are used. HHV, also known as Gross Heating Value (GHV), is the total amount of heat emitted in the complete combustion of 1 kg of fuel when the water vapour produced by the combustion is condensed and the heat emitted in this phase change is therefore accounted for. The LHV, or Net Heating Value (NHV), is the overall quantity of thermal output from the complete burning of 1 kg of fuel, excluding the latent heat portion of the combustion water vapour, as there is no phase-shift and it is released as steam (Perea-Moreno et al., 2016).

The UNE-EN 14918 standard establishes the procedure for the determination of the HHV of a solid biofuel at a steady volume and 25 °C, by the use of a calorimetric pump (PARR 6300) gauged by the combustion of benzoic acid. The ultimate result is HHV at constant volume with the water from the combustion remaining liquid. The UNE-EN 14918 standard was also used to determine the LHV from the HHV by deducting the energy losses associated with the evaporation of water and the formation of other gases. For our case study, the moisture-free LHV (dry basis) was calculated from the constant volume HHV and the elemental chemical composition by using the following equation:

$$LHV_{db}\left(\frac{kJ}{kg}\right) = HHV_{db}\left(\frac{kJ}{kg}\right) - 212.2 \times H_{db}\% - 0.8 \times (O_{db}\% + N_{db}\%) \quad (1)$$

$H_{db}\%$, $O_{db}\%$, and $N_{db}\%$ represent the elemental hydrogen, oxygen and nitrogen contents of biofuel (dry basis), respectively.

VI-2.3. Boiler

The biomass boiler, which was installed for space heating and sanitary hot water, works in conjunction with existing boilers, maintaining the previous boiler in reserve mode to automatically start up redundantly in the case of failure. It is the Oliva-430 model of the manufacturer Hergom Industries, has a power of 430 kW, and complies with the UNE-EN 303/5 standard (heating boilers–special boilers for solid fuels) (Hergom industries, 2018). The operation of the Oliva 430 boiler is fully automatic and is equipped with an adjustable electronic panel. It is made of a steel body that guarantees maximum heat transmission of the combustion products to the water, thus achieving high performance. The high-capacity fuel tank guarantees long-lasting autonomous operation. The generated ashes are deposited in the bottom of the chamber, being very easy to remove.

The operating pressure of the system is 6 bar and the power can be regulated according to demand, as the burner is electronically adjusted by means of Proportional, Integral and Derivative (PID) controller. In addition, the boiler has automatic ignition control, an automatic cleaning system as well as an automatic ash collection system by means of a worm screw. The boiler replaced, which used fuel oil as fuel, had a nominal power similar to the installed.

A worm screw is used to transport the fuel from the storage silo to the boiler, in whose combustion chamber the fuel is introduced by gravity and the transfer of energy in the form of heat to the water of the primary circuit occurs. The operating diagram of the boiler is shown in Figure VI-5.

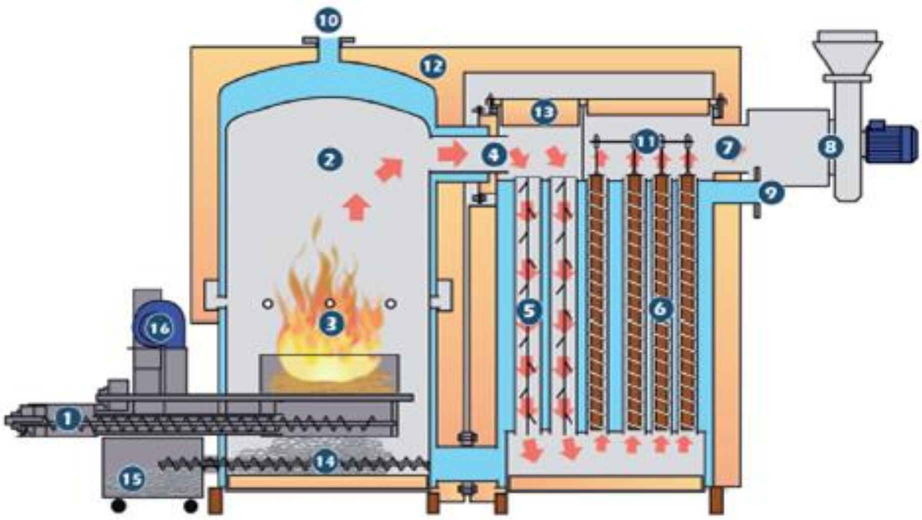

Figure VI-5. Operating diagram of a biomass boiler: 1, Fuel supply system, 2, Combustion chamber, 3, Secondary air, 4, Smoke passage, 5, Second smoke passage, 6, Third smoke passage, 7, Smoke exhaust, 8, Fume extractor, 9, Water outlet, 10, Water return, 11, Automatic cleaning system, 12, High performance thermal insulation, 13, Insulation of doors in ceramic fiber, 14, Automatic ash collection, 15, Ashtray drawer, 16, Combustion air fan.

In addition, the boiler has a remote management system, connected to a Programmable Logic Controller (PLC) that is integrated into the boiler itself that allows to regulate its operation, monitor and at the same time control all the operating variables of the installation, obtaining information in real time of temperatures, pressures, consumption and possible breakdowns that may occur. To achieve greater efficiency by regulating the thermal demand, an inertia tank of 2000 L was provided, which acts as a heat deposit that avoids multiple burner starts, optimizing burner performance and extending the life of the installation.

The working temperature was regulated at 84 °C and the operating hours were set uninterrupted. Figure VI-6 is the operating diagram of the biomass thermal power plant.

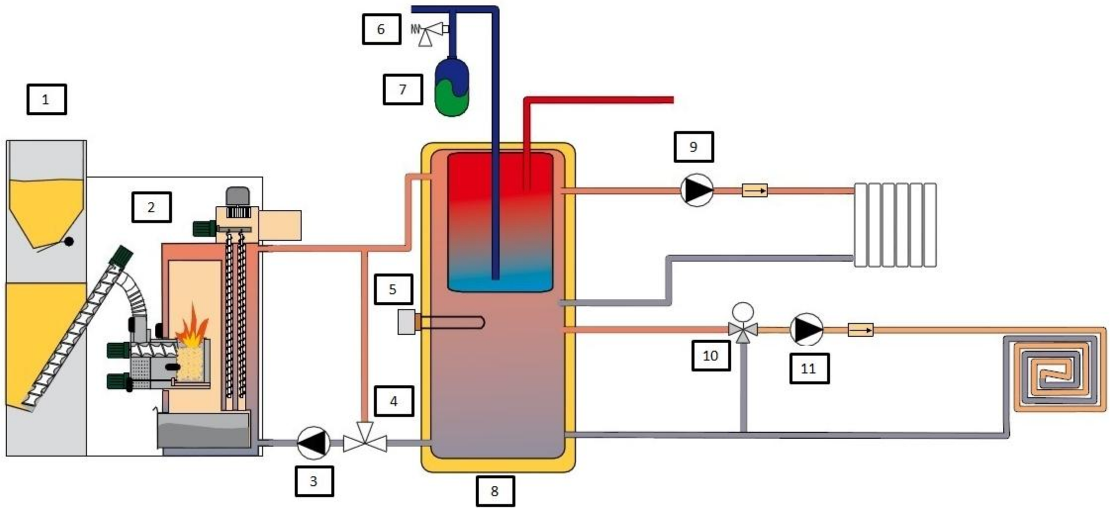

Figure VI-6. Operating diagram of the biomass thermal power plant: 1, Storage silo, 2, Biomass boiler, 3, Circulating pump, 4, Anticondensate return valve, 5, External temperature probe, 6, Safety valve for domestic hot water, 7, Expansion tank for domestic hot water, 8, Inertia tank, 9, Drive pump for heating radiators, 10, Mixing valve, 11, Drive pump for underfloor heating.

VI-2.4. Biofuels

In Spain, the types of biomass that can be used are conditioned by the availability of the market, the most common being the olive bone, the pruning of the olive grove and fruit trees to make chips, the wood cuttings coming from industries, the husk of nuts, forest residues, vine concentrates and "pellets" (Alakoski et al., 2016).

For the start-up of the installation, the economic cost per kilowatt hour relative to the use of different fuels has been evaluated, considering the costs derived from transport to the point of supply, and comparing them with the costs of non-renewable fuels (fuel oil and natural gas), considering the market prices (March 2018) for a consumption equivalent to that expected annually in the hotel.

Figure VI-7 shows the final costs of different fuels expressed in euro cents per kWh unit of heat energy produced, showing how renewable fuels are more economical. In particular, the sunflower husk is 43% cheaper than elaborate chip, 64% than the "pellet", 71% than natural gas and 75% than fuel oil, assuming that the efficiency of solid fuel boilers is 10% lower than the other boilers (IDAE, 2018).

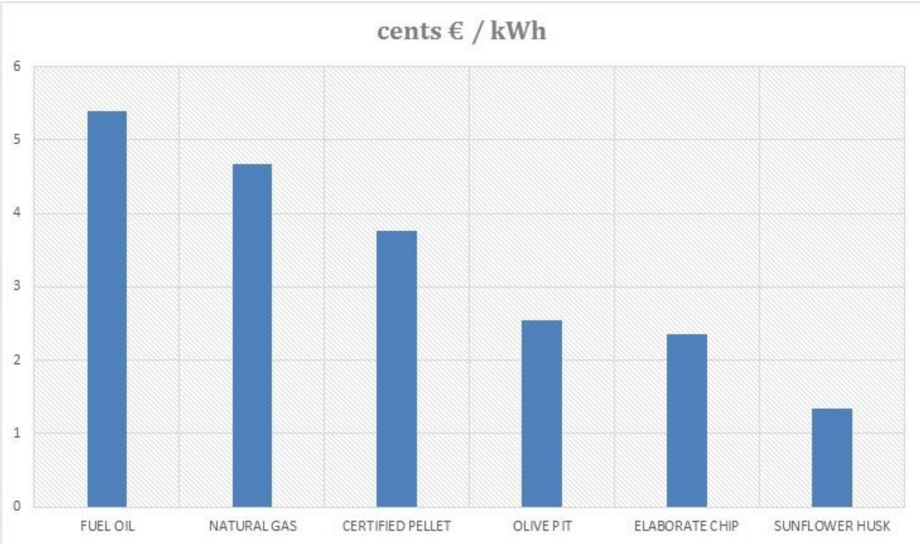

Figure VI-7. Cost per kW/h of thermal energy produced by different fuels (IDAE,2018).

However, the cost of fossil fuels is taxed at a high rate. In particular, heating oil increases the final price by up to 32.3%. On the other hand, biomass derived from agri-food resources has important subsidies derived from the European Union's agrarian policy. These facts alter the real price of commercialization of both types of fuels in such a way that, from a purely economic perspective, it even equals them.

In the medium to long term, the trend of increasing production costs of hydrocarbons and their derivatives, clearly upwards, will increase the price difference with respect to biofuels, whose cost tends to stabilize as the industries dedicated to the transformation of by-products.

Among the different types of existing biomass, it was decided to use crushed sunflower husk as fuel, whose physical characteristics are specified in Table VI-2.

Table VI-2. Physical parameters of sunflower husk.

Parameter	Unit	Standard Value	Standard Deviation (SD)	Maximum Value	Minimum Value
Moisture	%	8.4	---	8.4	8.4
Length	mm	10.346	0.153	10.5	10.193
Width	mm	5.384	0.278	5.662	5.106
Thickness	mm	2.985	0.235	3.22	2.75
Husk Thickness	mm	0.346	0.049	0.395	0.297
True density ρ_t	kg/m^3	644.4	28.3	672,7	616.1
Perceived density ρ_b	kg/m^3	95	1	94	96
Porosity ε	%	85.26			

The axial dimensions of the grains were determined from samples of 10 randomly selected seeds. The length (L), width (W) and thickness (T) of the seeds and husk thickness were obtained using a 0.001 mm resolution outside micrometer (DP-1HS, Digimatic Mini-Processor, Mitutoyo, Japan).

The true density (ρ_t), defined as the ratio of the mass of the sample to its true volume, was determined by using pycnometry, for each test, the 10 grain husk was used and xylene was used as the liquid to be displaced. The apparent density (ρ_b), the ratio of the mass of a grain sample to its total volume, was calculated using a standardized weight-hectolitre scale. Physical properties are reported as averages of ten repetitions.

Bed porosity (ε), defined as the fraction of space in bulk seed that is not occupied by grains, was calculated using Equation (2) (Figuereido et al., 2011).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \cdot 100 \quad (2)$$

The difference between the true density of 644.4 ± 28.3 kg/m^3 and the apparent density of 95 ± 1 kg/m^3 shows the main problem with this waste, large volumes of light weight. Residual biomass, in general, presents low energy density and it is essential to increase density to reduce problems and logistic costs for its use. Densification, which consists of compacting small pieces of biomass (wood sawdust, stubble, rice residues, coffee, sugar cane, etc.) into pieces of similar shape and size, becomes necessary for the use of this biofuel. The products formed (pellets and briquettes) have a constant density and moisture content, which makes the calorific value more homogeneous and improves the combustion efficiency of the equipment. With compaction, the density can be reduced up to 10 times. If the density is higher, the energy/volume ratio is also higher.

As already mentioned, this biofuel is obtained from the grinding process of the sunflower seeds in the mills, and it is considered a by-product of the oil sunflower extractor industries. Its size and low moisture content (usually below 10%) ensures the proper performance of the installation, thus proper combustion of all particles.

The high availability of this type of fuel means that it can be used throughout the year, as world sunflower production is around 47.34 million tons, of which 72% corresponds to Europe, with Spain being the eighth largest producer country within the European continent (FAO, 2018). Therefore, sunflower husks are a renewable biomass resource, although limited to the production of the basic industry from which they are derived.

VI-3. RESULTS AND DISCUSSION

Energy properties of the sunflower seed husk were analysed and compared with other biomass residues and the energy, environmental, economic and operational balance of the biomass thermal installation was calculated.

VI-3.1. Sunflower Seed Husk Quality Parameters

To quantify and assess the quality parameters, samples of sunflower husk from the sunflower oil industry were analysed. Table VI-3 lists the mean, median, standard deviation, and maximum and minimum values that define the parameters distribution.

Table VI-3. Quality parameters for sunflower seed husks resulting from the analysis of 2000 g samples. All parameters are referred to as dry basis, excluding humidity which is referred to as wet basis.

Parameter	Unit	Standard Value	Standard Deviation (SD)	Maximum Value	Minimum Value
Moisture	%	8.4	---	8.4	8.4
Ash content	%	2.1	0.12	2.22	1.98
HHV	MJ/kg	17.844	0.028	17.8.72	17.816
LHV	MJ/kg	16.507	0.015	16.522	16.492
Total carbon	%	44.23	0.008	44.238	44.222
Total hydrogen	%	6.12	0.015	6.135	6.105
Total nitrogen	%	0.41	0.061	0.471	0.349
Total sulphur	%	0.24	0.003	0.243	0.237
Total oxygen	%	48.92	2.641	51.561	46.279
Total chlorine	%	0.08	0.003	0.083	0.077

One of the most interesting properties of sunflower husks as biofuel is their low moisture content, below 10%. This means that no lengthy pre-drying processes will be required, as is the case with other wood biofuels, and that energy losses due to water evaporation during combustion are therefore minimal.

As the ash content of the sunflower husk is within the range of 1.98%–2.22%, in comparison with the ash concentration of other solid biofuels currently used such as almond shell pellets (3.35%), olive pellets (4.79%) and oak pellets (3.32%), it is observed that, despite having a high ash content, its value is below those of other standardized fuels.

The physicochemical parameters obtained from the analysis were compared with those of other standardized solid biofuels currently in use to establish the suitability of this waste by-product for the generation of thermal energy. Table VI-4 compares the quality parameters of various biofuels (pine pellets, olive stone, and almond shell) with those of the sunflower husk.

Table VI-4. Comparison of sunflower husk with other solid fuels.

Parameters	Unit	Pine Pellets (García et al., 2017; Arranz et al., 2015)	Olive Stone (Mata-Sánchez et al., 2013; Arranz et al., 2015; García et al., 2014)	Almond Shell (Arranz et al., 2015; Gómez et al., 2016; González et al., 2005)	Sunflower Husk
Moisture	%	7.29	18.45	7.63	8.4
HHV	MJ/kg	20.030	17.884	18.200	17.844
LHV	MJ/kg	18.470	16.504	17.920	16.507
Ash content	%	0.33	0.77	0.55	2.1
Total carbon	%	47.70	46.55	49.27	44.23
Total hydrogen	%	6.12	6.33	6.06	6.12
Total nitrogen	%	1.274	1.810	0.120	0.41
Total sulphur	%	0.004	0.110	0.050	0.24
Total oxygen	%	52.30	45.20	44.49	48.92
Total chlorine	%	0.000	0.060	0.01	0.08
$\frac{\text{HHV}_{biomass}}{\text{HHV}_{sunflower\ husk}}$	%	111.0	100.0	102.0	100.0

In view of the data obtained, it could be concluded that the ash percentage is clearly greater compared to some of the most widely used biofuels, which means that plant produces more residuum, and therefore corrosion problems and maintenance cost may increase.

Ash constitutes the inorganic constituent fraction of biomass and is produced as a consequence of its content in potassium, chlorine, phosphorus, silica and calcium. The inorganic elements that contain biomass might adopt three forms: uniformly spread in the biofuel, as independent granules of inorganic matter, or as impurities provided by the fuel in its collection, transport and subsequent treatment process. The chemical make-up of the ashes is mainly SiO_2 and CaO, and to a lesser extent the oxides of magnesium, aluminium, potassium and phosphorus.

In practice, ash-related issues in the burners and boilers of biomass combustion systems are linked to:

- The partially melted ashes tend to form agglomerates on the grid walls as well as to form slag deposits on the installation.
- Ash deposits formation at moderate temperature zones or exchangers in convection heat boilers.
- Rapid corrosion and abrasion of the metal body of the installation at its most critical points.
- Ash aerosol emission.
- Removal of ash waste from boilers.

Overall, it can be concluded that the efficiency of the plant is strongly dependent on the properties of the fuel (ash content, elemental composition and calorific value) as well as on the design and reliability of the installation.

As far as calorific value is concerned, the values of HHV and LHV are roughly similar to those of olive stone and a little inferior to those of almond shells, which demonstrates the high energy potential of this residual biomass. The last row of Table 4 shows a comparison of the HHV in per cent, ranging from 0.2% to 11%.

With regard to chlorine and sulphur, their proportion varies according to the biofuel chosen, and, once it is consumed, they are generally transformed into sulphur and chlorine oxides. These combustion by-products increase the corrosion problems of the installation, while also emitting greenhouse gases into the atmosphere as SO_x. In the case of sunflower husk, the sulphur content is 0.24%, which is double that of olive stones and five times higher than that of almond shells, indicating that SO_x emissions are higher than those of other solid biofuels, but lower than those of fossil fuels.

The chlorine content, which depends on the soil composition, has a significant effect on the corrosiveness of the installation. Chlorine has been shown in many scientific investigations to have a dissociative catalytic effect on steel pipe materials in heat exchangers, also at low temperatures (100–150 °C). This problem is greater in fuels with a molar ratio of Cl:S higher than 2, because the absence of sulphides leads to the chlorides formation, resulting in a catalytic effect on corrosion. The sunflower husk has an average chlorine content of 0.08%, which is below that of other biofuels such as almond shell (0.20%), wood material (0.1%) and cereal residues (0.4%), which implies that corrosion problems could be diminished if this biofuel is used.

VI-3.2. Energy Balance

The energy balance of the biomass installation has been made based on the historical demand of the last five years, both hot water for heating and domestic hot water. The energy demand that the biomass boiler must meet annually has been estimated and it has been assumed that the performance of the biomass heating system is 10% lower than the previous diesel boiler. In Table VI-5, the parameters are detailed.

Table VI-5. Annual energy balance of the biomass installation.

Parameters	Quantity
Thermal demand	814,726.7 kWh
Useful power	430 kW
Operating time	1900 h
Temperature	84 °C
Performance	80%

The calculations of the thermal demand considered that the use of hot water for heating is carried out in the months of October–April, while the boiler is only used to produce domestic hot water in the remaining months. According to the calorific value (LHV) of sunflower seed husk, 223 tonnes of this by-product are needed to meet the annual thermal demand of the installation.

VI-3.3. Environmental Balance

The main advantage of biomass as an energy source is its renewable nature, since it uses organic waste from agricultural activities or garbage from cities as its primary source. Whether in the form of unprocessed waste, pellets, biogas or biodiesel, biomass is unlimited, as living beings can never stop producing waste. The use of biomass energy to generate thermal and electrical energy—due to the burning of the same or its derived fuels—is considered as a neutral emission activity. This is because it takes advantage of the carbon that was initially in the plants and therefore was part of the natural CO_2 cycle. Then, once these fuels are burned, the CO_2 produced returns to the forests or sources of vegetation and is used in photosynthesis, being the carbon neutral balance throughout the cycle. In addition, the use of biomass boilers generates lower emissions than conventional fuel boilers, reducing emissions of sulphur and particles and pollutants such as CO, HC and NO_x.

Other advantages associated with the biomass use are its contribution to the reduction of forest fire and pest risks, the cleanliness of forests, the use of by-products from industries and the generation of local employment.

However, the greatest advantage of using biomass as an energy source is its contribution to mitigating the effects of climate change. Biomass emits CO_2, but in the same proportion that the plant absorbed during its growth process, so this CO_2 is considered zero. In addition, the emission of other greenhouse gases (NO_x and SO_x) is significantly lower compared to fossil fuels. To carry out an environmental analysis, assessing possible reductions in greenhouse gases emissions regarding to the suggested scenario, an estimated installation level of direct greenhouse gases emissions linked to the existing fuel oil boiler was worked out, in accordance with Well to tank Report, v 4.0, submitted by the Joint Research Institute (Edwards et al., 2013). Table VI-6 presents the emission coefficients considered in this work.

Table VI-6. Emission coefficients for fuel oil boilers by kg/kWh (SiReNa, 2018; Edwards et al., 2013).

Boiler Type	NO_2	SO_2	CO_2
Fuel oil	0.540	0.540	0.311
Biomass district heating	0.283	0.0036	0

Assuming that the plant retains more CO_2 in the growing cycle than it releases when it is burned, the emissions of this gas are zero (Batuhtin et al., 2016). As can be seen in Table VI-7, the biomass thermal installation for the case study would produce annual reductions of 254.09 tonnes of carbon dioxide (CO_2), 438.24 tonnes of sulphur dioxide (SO_2), and 209.97 tonnes of nitrous oxide (N_2O) emissions, compared to the conventional fuel oil installation.

Table VI-7. Annual environmental benefits from gases reductions.

Emission Factor	NO_2 (kg/kWh)	SO_2 (kg/kWh)	CO_2 (kg/kWh)
Fuel oil boiler	0.540	0.540	0.311
Biomass boiler	0.283	0.0036	0
Total emissions reduced annually (tonnes)	209.97	438.24	254.09

During the first year, carbon dioxide emissions to the atmosphere would be lowered by 254.09 tons, corresponding to the annual CO_2 sequestration of roughly 5092 adult trees (Gehrig et al., 2015).

It is interesting to carry out a worldwide study of the energy potential of sunflower husks as biofuel, and its effect on reducing CO_2 emissions. First, after determining the calorific value of the sunflower husk and knowing the annual production of each country (FAOSTAT, 2018), it is possible to calculate the energy production that can be generated by the combustion of this biomass using Equation (3):

$$E_c = P_c \times f_s \times LHV \times U_c \quad (3)$$

where E_c is the energy expressed in MWh that could be generated using all the sunflower husks produced in a selected country, P_c is the production of sunflower seeds from a specific country (kg), taking data for the year 2016, f_s is the factor of husk in a whole sunflower seed (45%), LHV is the previously determined Lower Heating Value (16.507 MJ/kg), and U_c is the conversion unit (0.000277778 Wh/J).

In the case of Spain, sunflower seed production was 755,050 t in 2016, which means the possibility of generating 1557.952 GWh or 133.960 ktoe (kilo tons of oil equivalent), with 1 toe being 11.63 MWh. Therefore, considering that the world production of sunflower seed was 47.34 million tons in the same year, the total bioenergy that could be produced with this biomass is estimated at 97.69 TWh or 8.40 Mtoe.

If the potential for power generation of each country is worked out using Equation (3), the world map in Figure VI-8, which relates energy production to the different sunflower seed producing countries is obtained. As can be seen on the

European continent, countries such as the Russian Federation, Ukraine, Romania and, to a lesser extent, Spain, stand out for their energy potential. In Asia, China concentrates the largest energy production capacity, while, in the Americas, the United States and Argentina are particularly noteworthy.

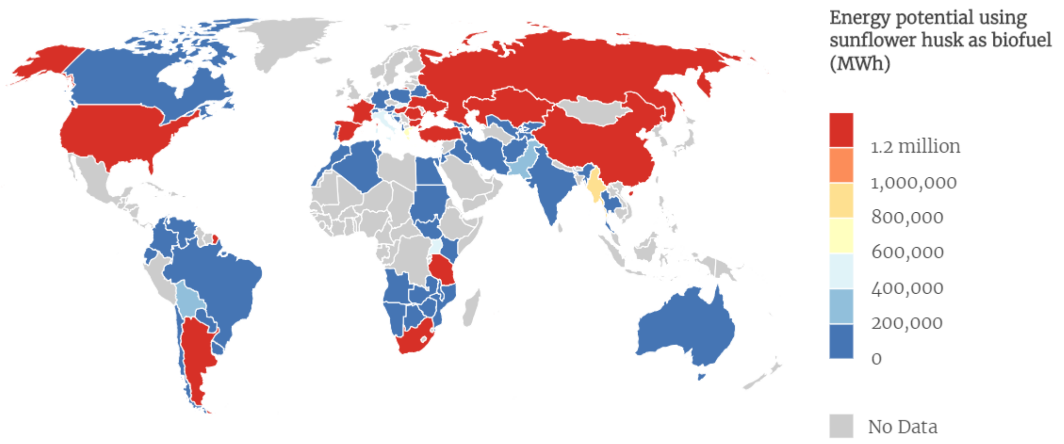

Figure VI-8. Energy potential distribution by country using sunflower husk as biofuel.

To evaluate the potential of the sunflower husk in CO_2 reduction, it is necessary to consider the related fossil fuel CO_2 emissions data provided by the world data bank, which converts the emissions of other greenhouse gases into CO_2 equivalent. Therefore, if the equivalent energy of using sunflower husks as fuel came from fossil fuels, 0.357 tons of CO_2 would be released into the atmosphere for every MWh generated.

As expected, the main countries producing sunflower seeds are those that would have the greatest potential for energy production and therefore also the greatest potential in reducing CO_2 emissions. The ten main countries are: Ukraine (10 million tonnes), Russia (8.11 million tonnes), Argentina (2.21 million tonnes), China (1.9 million tonnes), Romania (1.49 million tonnes), Bulgaria (1.38 million tonnes), Turkey (1.23 million tonnes), Hungary (1.13 million tonnes) and the United States (0.88 million tonnes).

However, if we compare the total CO_2 emissions generated by each country (world data bank) with the CO_2 emissions savings associated with the use of the sunflower husk as fuel (Figure VI-9), we observe that a large part of Central Africa (Tanzania, Uganda, and South Sudan) and Eastern Europe (Ukraine, Hungary, Romania and Bulgaria) would obtain emissions savings greater than ten per thousand.

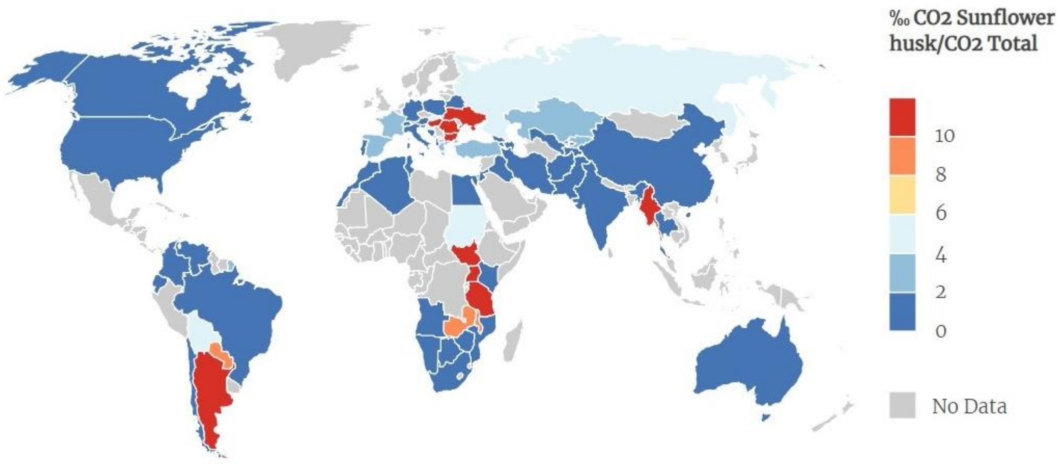

Figure VI-9. Possible reduction of CO_2 emissions in relation to the total CO_2 emitted in sunflower seed producing countries.

VI-3.4. Economical Balance

The market for decentralised biomass boilers is largely conditioned by regional fossil fuel prices, and is increasing, especially in countries where high taxes are levied on fossil fuels. The economic balance was carried out by means of a comparative study between the old fuel-oil installation and the new biomass-based installation, calculating the annual cost necessary to meet the thermal energy demand of the building with each of the fuels. Table VI-8 shows both the annual fuel oil consumption of the former installation and the actual cost of heating, considering 0.91 €/L as the value of the fuel oil. As can be seen, the total annual cost with fuel oil was 81,700 €.

Table VI-8. Comparative analysis between the installations of fuel oil and the new biomass boiler.

	Fuel Oil Consumption (L)	Annual Economic Cost Fuel Oil Installation (€)	Biomass Consumption (kg)	Annual Economic Cost Biomass (€)
Total	89,780.22	81,700.00	222,615.80	20,035.42

Parameter	Unit	Conventional Boiler	Biomass Boiler
Fuel		Fuel oil	Sunflower husk
LHV	kWh/L	10.12	
LHV	kWh/kg		4.59
Price	€/L	0.91	
Price	€/kg		0.09
Boiler efficiency	%	90	80
Nominal power	kW	430	430
Operating hours	h	1900	1900
Thermal energy demand	kWh/year	817,000	817,000
Fuel consumption	L	89,780.22	
Biomass consumption	kg		222,615.8
Annual cost	€	81,700	20,035.42
Annual saving	€		61,664.58
Annual saving	%		*75.47*

The amount of fuel required in both scenarios (fuel oil boiler and biomass boiler) can easily be calculated by dividing the annual thermal energy demand of the installation by the lower heating value of the fuel, but taking into account the boiler efficiency. That is to say,

$$Fuel\ quantity = \frac{Annual\ thermal\ demand}{LHV\ X\ Boiler\ efficiency} \qquad (4)$$

With the new biomass boiler, 22,2615.80 kg of sunflower husks were consumed, and considering a price of this by-product already treated of 0.09 €/kg, the annual cost associated with the new biomass installation is 20,035.42 €, which translates into an economic saving of 61,664.58 € for a 430 kW installation. This represents a cost saving of 75.47% of the present yearly expenditure.

These calculations were made for an operating time of 1900 h per year, considering that the use of hot water for heating is made in the months from October to April, while only the boiler is used to produce sanitary hot water in the remaining months. However, it must be borne in mind that, due to the existence of an inertial tank, the number of operating hours could be reduced.

The investment was 193,000 €, and considering the annual savings of 61,664.58 € produced, a return period of 3.13 years is obtained, which is lower than that obtained in other types of installations based on solar collection. Therefore, during the first ten years of operation, the total savings obtained with the use of this biofuel would be greater than 400,000 €. On the other hand, the purchase value of an equivalent amount of CO_2 avoided in the emissions rights market (reference August 2018), would mean an additional saving of 4,800 €/year (European Commission, 2018).

The 223 tons of sunflower husks can be easily obtained from the sunflower oil industries in the area, which sell their surplus waste once their energy demands from the manufacturing processes have been met, contributing on the one hand to a better use and environmental management of this agro-industrial by-product, and on the other hand to an enhancement of the local economy.

VI-3.5. Operating Balance

The security and continuity in the supply of any thermal power plant is essential to guarantee an acceptable quality of the installation. In the case of residential buildings, they become critical facilities in terms of the aforementioned factors, making it essential to carry out a detailed study on their reliability, availability and maintainability.

For this, a survival function is implemented, defined as the probability that the moment of a failure is later than a specified time, and that mathematically corresponds to the expression:

$$R(t) = P_r(T > t) \quad (5)$$

where $R(t)$ is the survival function, t is time, T is a random variable that denotes the moment of failure, and P_r is the probability. For the analysis of reliability in time-bound processes, the concept of failure rate has been used, which is defined as follows:

$$I(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T \leq t + \Delta t \mid T \geq t)}{\Delta t} \quad (6)$$

The failure rate over time is defined as the failure probability of the equipment that remains in good condition during time t, and is represented by $\lambda(t)$, according to Equation (7):

$$\lambda(t) = f(t)/R(t) \quad (7)$$

The failure rate is of particular interest, since its inverse represents the mean time between failures (MTBF), at least when $\lambda(t)$ remains constant in time. Its mathematical expression is as follows:

$$\text{MTBF} = 1/\lambda(t) \quad (8)$$

To analyse the reliability of the biomass installation over time, that is, the probability that the installation is in an operational state throughout its useful life, the trend of the failure rate as a function of the number of accumulated hours of operation is plotted in Figure VI-10.

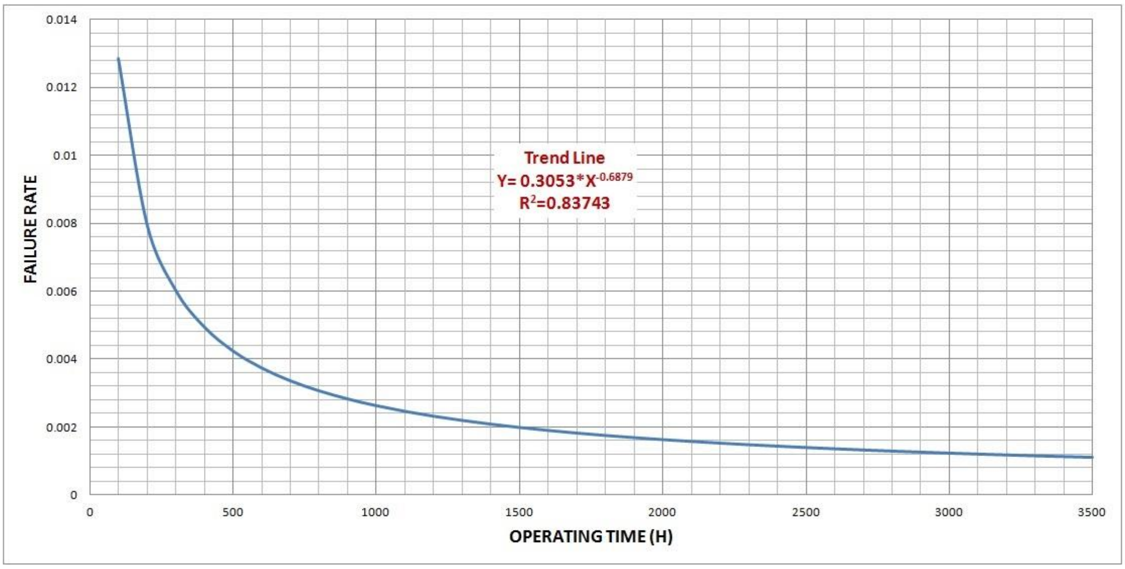

Figure VI-10. Ratio of failure rate to operating time

It can be observed how the failure rate is high during the first 500 h of operation, which implies that redundant complementary measures must be available to ensure the continuity of supply. However, after 1000 operation hours, the system stabilizes and evolves constantly over time.

It has been proven that the technology applied to biomass boilers has a lower reliability than natural gas and diesel boilers, especially in the first stage of operation, mainly due to the calibration and start-up processes of the installation.

On the other hand, the preventive maintenance tasks of the biomass installation have increased by 100% with regard to similar thermal energy production installations using diesel and/or natural gas, due to cleaning, regulation and emptying operations of the ashtray, which implies an average additional task of 45 min/day.

VI-4. CONCLUSIONS

The energy model of the last 150 years is unsustainable for environmental, economic and social reasons. Its transformation involves the widespread of renewable energies, efficiency and energy saving. This paper highlights the benefits of using biomass as fuel to reduce the energy consumed by buildings to meet heating demands. In concrete, it is performed an energy, environmental, economic and operational balance of a thermal installation powered by sunflower husk. For this purpose, an analysis of this residual biomass is first carried out to determine its calorific value as well as its elemental chemical analysis. The higher calorific value (17.844 MJ/kg) is similar to that of other commercially available solid biofuels, which demonstrates its potential for thermal energy generation. However, due to its low volume/energy ratio, it is necessary to pellet this biofuel to reduce transport costs.

The analysed scenario shows that, if a 430 kW boiler of fuel oil is replaced by a boiler of the same power fed by sunflower husk, 209.97 tons of NO_2, 438.24 tons of SO_2 and 254.09 tons of CO_2 could be stopped emitting annually. In addition, the annual saving would be 75% regarding the former fuel oil installation, obtaining a return period of 3.13 years of the necessary investment.

The environmental benefit of this biomass is due to its carbon neutral condition. When comparing the possible CO_2 savings of a country using this biofuel, in relation to the total CO_2 emitted, it is observed how a large part of Central Africa (Tanzania, Uganda, and South Sudan) and Eastern Europe (Ukraine, Hungary, Romania and Bulgaria) would obtain savings higher than 10 per thousand, considering the total sunflower seed production of these countries.

The findings of this work help improve the energy sustainability of residential buildings while highlighting the environmental and economic benefits of the sunflower husk as a fuel, which has thus far been scarcely used. Therefore, in helping to achieve sustainable energy development, the use of local resources such as biomass for heating systems must be facilitated. As has been demonstrated, these systems make it possible to move towards a low-carbon economy, fulfilling the long-term global objective of sustainability but also that of households in the short term, as their economic viability has been seen, including maintenance costs.

As future work, it is expected to apply this methodology in other public buildings such as universities and colleges, in addition to exploring other renewable sources such as biofuel.

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Chapter VII.
Summary, resumen and general conclusions

«Renewable energy is an essential part of our strategy of decarbonization, decentralization, as well as digitalization of energy»
Isabelle Kocher (2012)

Chapter VII. Summary, resumen and general conclusions

VII-1. SUMMARY

By the end of the century, the world's population is expected to reach over 11 billion people, most of whom will live in urban areas. This means that our planet faces a major challenge in terms of providing sustainable energy. Renewable energies have shown enormous potential for increasing sustainability, yet their use within cities remains scarce. This outlook highlights the urban contribution to renewable energies, which will be critical for the welfare of a rapidly growing urban population.

The European Union is one of the major drivers of renewable energy and energy efficiency measures, setting the following targets for 2020:

- 20% reduction in greenhouse gas emissions (relative to 1990 levels)
- 20% share of renewable energy in the EU energy mix
- 20% improvement in energy efficiency.

In addition, in the coming years, one of the major challenges for the construction sector in all European countries will be to meet the objectives set by the Energy Efficiency of Buildings Directive (2010/31/EC) for the implementation in 2020 of the so-called almost zero energy consumption buildings, called nZEB (Nearly Zero Energy Buildings).

For these reasons, the use of large-scale renewable energy in urban environments is a major future sustainable energy alternative, both to meet the increasing energy demand of cities and to reduce greenhouse gasses emissions. As technology continues to advance, renewable energies will become more efficient, user-friendly, cost-effective, accessible and sustainable. Chapter II provides a bibliometric approach to research into renewable energy in urban areas, highlighting the upcoming technologies, main researchers, institutions, journals and areas of interest.

Among the emerging renewable energy technologies applied in urban environments, the application of biomass for heating stands out. Like most renewable energy sources, biomass energy comes originally from the Sun. It could be summed up by saying that biomass is the solar energy converted by vegetation, through the process of photosynthesis, into organic matter (stored chemical energy).

From an environmental point of view, biomass could be considered as an eco-friendly alternative to fossil fuels. Biomass, just like coal, when burned or gasified produces atmospheric emissions, mainly in the form of carbon dioxide. However, it is considered a carbon neutral source because the biomass of the plant as it grows absorbs carbon dioxide from the atmosphere during the photosynthesis process, which is then released through combustion. Therefore, during the whole cycle of growth, harvesting and combustion there is a net balance between the addition and subtraction of carbon dioxide into the atmosphere. In addition, biomass does not contain sulfides, so power plants that use biogas do not need to implement processes to remove sulfur dioxide before releasing emissions into the atmosphere.

From the point of view of energy use, biomass can be classified into two categories, waste biomass and biomass from energy crops. In turn, biomass waste can be divided into four categories: municipal waste, agricultural waste, livestock waste and forestry waste.

There are different ways of transforming the chemical energy of biomass into another type of energy. The most common and simple way is to burn it directly in a furnace or boiler and use the heat generated as a heating medium. In co-generation plants, the steam generated in the process can also be used to drive a turbine that, coupled to an electrical generator, produces electricity.

A second technique consists of using thermo-chemical conversion processes (carbonization, gasification and pyrolysis) through which gas or liquid fuels can be obtained, which can be used in a combustion process and produce heat or electricity. Another technique uses physico-chemical processes (transesterification) to obtain liquid fuels that can be used, after combustion, to produce heat or generate electricity. There are also biochemical conversion techniques (alcoholic fermentation, anaerobic digestion, aerobic decomposition) that can be used to obtain gaseous and liquid fuels to generate heat and electricity.

There is a large market for solid biofuels that has been growing and consolidating over the years. Solid biomass for heating includes wood chips, pellets and briquettes, the quality of which is regulated by ISO 17225. However, due to the high price of wood biomass, other sources of biomass such as agro-industrial and livestock waste must be taken into account.

The transition to a low carbon energy system involves researching new forms of renewable energy that stayed useless during the fossil fuel era. Cities are the main producers of waste and disposals, and according to the available infrastructure, and the established regulatory framework, these waste can be classified, decontaminated and reused, burned for thermal and electric energy production or taken to landfill. Currently most of the agroindustral and livestock wastes are discarded without making an eco-friendly use of them.

In this Thesis is pointed out the huge potential of agro-industrial biomass for residential-level heat generation. Indeed, it has been proved that the stones of some fruits as well as the nutshell have a high calorific value and a chemical composition that makes them attractive for use in residential heating.

Chapters IV and V analyse the chemical composition (elemental analysis and immediate analysis) and calorific value of two agro-industrial by-products such as mango stone and peanut shell, comparing them with those of other standardised solid biofuels. In addition, an assessment is made of the worldwide reduction in CO_2 emissions that would be obtained if these by-products were used as substitutes for fossil fuels for thermal energy generation. In the case of the mango stone, whose Higher Heating Value (HHV) obtained is 18.05 MJ/kg, it has been shown that a large part of Central Africa (Sudan, Nigeria, Tanzania, Kenya and Kongo) and Madagascar would obtain relative reductions in their CO_2 emissions above 0.02‰ if the mango stone were used as fuel. With regard to peanut shells, the HHV obtained is 18.54 MJ/kg. If the total production of the main peanut-producing countries were used for thermal energy generation, a reduction in CO_2

emissions would be obtained with respect to total emissions as follows: Chad (0.60‰), Central African Republic (0.22‰), Mali (0.20‰), Malawi (0.17‰), Niger (0.10‰), Gambia (0.09‰), Guinea-Bissau (0.08‰), United Republic of Tanzania (0.07‰), Sudan (0.07‰), and Guinea (0.07‰).

Furthermore, the integration of renewable biomassical resources in the energy policies of cities will contribute on the one hand to better waste management and on the other hand to increase the share of renewables as well as energy efficiency. District energy systems are a growing technology in many cities that enable these objectives to be achieved. The large-scale integration of district energy systems in cities translates into multiple benefits, because in addition to providing urban areas with the thermal and electrical energy they need, it allows greater use of renewable sources from the surrounding environment and therefore less dependence on fossil fuels. It also promotes the local economy, making energy consumption more affordable and improving urban air quality by reducing greenhouse gas emissions.

BDH systems are the most efficient solutions to heat several buildings from a single centralized thermal power plant. The BDH system works with a main boiler room and from there a set of thermally insulated pipes is installed for both flow and return of water to each building that is connected. The hot water flows from the thermal plant to each building, and the cold water returns to the boiler room, where it is continuously reheated, and the process is restarted.

District heating systems can be matched to existing installations and conventional technologies and fuels, resulting in hybrid systems that improve installation yield and energy efficiency.

Chapter III presents a case study of district heating for a small settlement of 3000 inhabitants. Among the benefits obtained we can highlight an economic saving of 68% in fuel compared to fossil fuels, and from an environmental point of view a 100% saving in CO_2 emissions which means avoiding the emission each month of 35.27 tonnes of CO_2, as well as 50.5 tonnes of SO_2 and 25.7 tonnes of NO_2.

However, it must be borne in mind that the implementation of district heating systems is not always feasible due to technical as well as economic considerations, so in these cases the solution would be the installation of decentralized systems for the production of thermal energy such as biomass boilers. Chapter VI analyzes a case study for a hotel, where an old 430 KW fuel oil boiler is replaced by a new biomass boiler of the same power fed by sunflower husk, carrying out an energy, environmental, economic and operational analysis of the installation.

In conclusion, this thesis proposes lines of research for the use of new energy sources from biomass and to achieve their integration at district level, which will allow, on the one hand, a better management of these resources and, on the other hand, an increase in both, the share of renewables in the energy mix, and the energy efficiency of power systems.

VII-2. RESUMEN

Se espera que la población mundial alcance los 11.000 millones de personas a finales de siglo, la mayoría de las cuales vivirán en zonas urbanas. Esto significa que nuestro planeta se enfrenta a un gran reto en términos de suministro de energía sostenible. Las energías renovables han mostrado un enorme potencial para aumentar la sostenibilidad, pero su uso dentro de las ciudades sigue siendo escaso. Esta perspectiva pone de relieve la contribución urbana a las energías renovables, que será fundamental para el bienestar de una población urbana en rápido crecimiento.

La Unión Europea es uno de los principales impulsores de las energías renovables y de las medidas de eficiencia energética, y establece los siguientes objetivos para 2020:

- Reducción del 20% de las emisiones de gases de efecto invernadero (en relación con los niveles de 1990).

- Cuota del 20% de energías renovables en la combinación energética de la UE.

- Mejora de la eficiencia energética en un 20%.

Además, en los próximos años, uno de los principales retos para el sector de la construcción en todos los países europeos será cumplir los objetivos fijados por la Directiva de Eficiencia Energética de los Edificios (2010/31/CE) para la implantación en 2020 de los denominados edificios de consumo energético casi nulo, denominados nZEB (Nearly Zero Energy Buildings).

Por estas razones, el uso de energías renovables a gran escala en entornos urbanos es una de las principales alternativas energéticas sostenibles del futuro, tanto para satisfacer la creciente demanda energética de las ciudades como para reducir las emisiones de gases de efecto invernadero. A medida que la tecnología siga avanzando, las energías renovables serán más eficientes, fáciles de usar, rentables, accesibles y sostenibles. En el capítulo II se presenta un enfoque bibliométrico de la investigación sobre energías renovables en las zonas urbanas, en el que se destacan las nuevas tecnologías, los principales investigadores, las instituciones, las revistas y los ámbitos de interés.

Entre las tecnologías emergentes de energías renovables aplicadas en entornos urbanos destaca la aplicación de la biomasa para calefacción. Como la mayoría de las fuentes de energía renovables, la energía de la biomasa proviene originalmente del Sol. Se podría resumir diciendo que la biomasa es la energía solar convertida por la vegetación, mediante el proceso de fotosíntesis, en materia orgánica (energía química almacenada).

Desde un punto de vista medioambiental, la biomasa podría considerarse una alternativa ecológica a los combustibles fósiles. La biomasa, al igual que el carbón, cuando se quema o gasifica produce emisiones atmosféricas, principalmente en forma de dióxido de carbono. Sin embargo, se considera una fuente neutra en carbono porque la biomasa de la planta a medida que crece absorbe dióxido de carbono de la atmósfera durante el proceso de fotosíntesis, que luego se libera a través de la combustión. Por lo tanto, durante todo el ciclo de crecimiento, cosecha y combustión existe un equilibrio neto entre la adición y la sustracción de dióxido de carbono a la atmósfera. Además, la biomasa no contiene sulfuros, por lo que las centrales eléctricas que utilizan biogás no necesitan implementar procesos para eliminar el dióxido de azufre antes de liberar emisiones a la atmósfera.

Desde el punto de vista del uso energético, la biomasa puede clasificarse en dos categorías: biomasa residual y biomasa procedente de cultivos energéticos. A su vez, los residuos de biomasa pueden dividirse en cuatro categorías: residuos municipales, residuos agrícolas, residuos ganaderos y residuos forestales.

Existen diferentes formas de transformar la energía química de la biomasa en otro tipo de energía. La forma más común y sencilla es quemarlo directamente en un horno o caldera y utilizar el calor generado como medio de calentamiento. En las plantas de cogeneración, el vapor generado en el proceso también puede utilizarse para accionar una turbina que, acoplada a un generador eléctrico, produce electricidad.

Una segunda técnica consiste en utilizar procesos de conversión termoquímica (carbonización, gasificación y pirólisis) a través de los cuales se pueden obtener combustibles gaseosos o líquidos, que pueden ser utilizados en un proceso de combustión y producir calor o electricidad. Otra técnica utiliza procesos físico-químicos (transesterificación) para obtener combustibles líquidos que pueden ser utilizados, después de la combustión, para producir calor o generar electricidad. También existen técnicas de conversión bioquímica (fermentación alcohólica, digestión anaeróbica, descomposición aeróbica) que pueden utilizarse para obtener combustibles gaseosos y líquidos para generar calor y electricidad.

Existe un gran mercado de biocombustibles sólidos que ha ido creciendo y consolidándose a lo largo de los años. La biomasa sólida para calefacción incluye astillas, pellets y briquetas, cuya calidad está regulada por la norma ISO 17225. Sin embargo, debido al alto precio de la biomasa de madera, deben tenerse en cuenta otras fuentes de biomasa, como los residuos agroindustriales y ganaderos.

La transición a un sistema energético bajo en carbono implica la investigación de nuevas formas de energía renovable que permanecieron inutilizadas durante la era de los combustibles fósiles. Las ciudades son las principales productoras de residuos, y de acuerdo con la infraestructura disponible y el marco regulatorio establecido, estos residuos pueden ser clasificados, descontaminados y reutilizados, quemados para la producción de energía térmica y eléctrica o llevados a vertedero. En la actualidad, la mayoría de los residuos agroindustriales y ganaderos se descartan sin hacer un uso respetuoso con el medio ambiente.

En esta Tesis se señala el enorme potencial de la biomasa agroindustrial para la generación de calor a nivel residencial. De hecho, se ha demostrado que los huesos de algunas frutas, así como la cáscara de los frutos secos, tienen un alto poder calorífico y una composición química que las hace atractivas para su uso en la calefacción residencial.

En los capítulos IV y V se analiza la composición química (análisis elemental y análisis inmediato) y el poder calorífico de dos subproductos agroindustriales como el mango y la cáscara de cacahuete, comparándolos con los de otros biocombustibles sólidos estandarizados. Además, se evalúa la reducción mundial de las emisiones de CO_2 que se obtendrían si estos subproductos se utilizaran como sustitutos de los combustibles fósiles para la generación de energía térmica. En el caso del hueso del mango, cuyo Poder Calorífico Superior (PCS) obtenido es de 18.05 MJ/kg, se ha demostrado que en gran parte de África Central (Sudán, Nigeria, Tanzania, Kenia y Kongo) y Madagascar se obtendrían reducciones relativas en sus emisiones de CO_2 por encima de 0.02‰ si el hueso de mango se utilizara como combustible. En cuanto a las cáscaras de maní, el PCS obtenido es de 18.54 MJ/kg. Si la producción total de los principales países productores de maní se utilizara para la generación de energía térmica, se obtendría una reducción de las emisiones de CO_2 con respecto a las emisiones totales de la siguiente manera: Chad (0,60‰), República Centroafricana (0,22‰), Malí (0,20‰), Malawi (0,17‰), Níger (0,10‰), Gambia (0,09‰), Guinea-Bissau (0,08‰), República Unida de Tanzanía (0,07‰), Sudán (0,07‰) y Guinea (0,07‰).

Además, la integración de los recursos renovables de la biomasa en las políticas energéticas de las ciudades contribuirá, por una parte, a una mejor gestión de los residuos y, por otra, a aumentar la cuota de las energías renovables y la eficiencia energética. Los sistemas energéticos de los distritos son una tecnología creciente en muchas ciudades que permite alcanzar estos objetivos. La integración a gran escala de los sistemas energéticos de los distritos en las ciudades se traduce en múltiples beneficios, ya que además de proporcionar a las zonas urbanas la energía térmica y eléctrica que necesitan, permite un mayor uso de las fuentes renovables del entorno circundante y, por tanto, una menor dependencia de los combustibles fósiles. También promueve la economía local, haciendo que el consumo de energía sea más asequible y mejorando la calidad del aire urbano mediante la reducción de las emisiones de gases de efecto invernadero.

Los Sistemas de Calefacción de Distrito (SCD) también conocidos como Sistemas de Calefacción Urbana (SCU), son las soluciones más eficientes para calentar varios edificios desde una sola central térmica centralizada. El sistema SCD funciona con una sala de calderas principal y desde allí se instala un conjunto de tuberías aisladas térmicamente tanto para el flujo como para el retorno de agua a cada edificio conectado. El agua caliente fluye de la central térmica a cada edificio, y el agua fría vuelve a la sala de calderas, donde se recalienta continuamente y se reinicia el proceso.

Los sistemas de calefacción urbana pueden adaptarse a las instalaciones existentes y a las tecnologías y combustibles convencionales, lo que da lugar a sistemas híbridos que mejoran el rendimiento de la instalación y la eficiencia energética.

En el capítulo III se presenta un caso de estudio sobre la calefacción urbana en un pequeño asentamiento de 3.000 habitantes. Entre los beneficios obtenidos podemos destacar un ahorro económico del 68% en combustible respecto a los combustibles fósiles, y desde el punto de vista medioambiental un ahorro del 100% en las emisiones de CO_2, lo que supone evitar la emisión mensual de 35.27 toneladas de CO_2, así como de 50.5 toneladas de SO_2 y 25.7 toneladas de NO_2.

Sin embargo, hay que tener en cuenta que la implantación de sistemas de calefacción urbana no siempre es factible por razones técnicas y económicas, por lo que en estos casos la solución sería la instalación de sistemas descentralizados para la producción de energía térmica como las calderas de biomasa. En el capítulo VI se analiza un caso de estudio para un hotel, donde se sustituye una antigua caldera de fueloil de 430 KW por una nueva caldera de biomasa de la misma potencia alimentada con cascara de pipa de girasol, realizando un análisis energético, medioambiental, económico y operativo de la instalación.

En conclusión, esta Tesis propone líneas de investigación para el uso de nuevas fuentes de energía procedentes de la biomasa y para lograr su integración a nivel de distrito, lo que permitirá, por un lado, una mejor gestión de estos recursos y, por otro, un aumento tanto de la participación de las renovables en el mix energético como de la eficiencia energética de los sistemas de energía.

VII-3. GENERAL CONCLUSIONS

a) Nowadays, the use of green energy in urban areas represents a field of great interest to the scientific community. The large-scale urban generation of renewable energy is postulated as a solution for the development of sustainable energy, both, to meet the growing demand for energy in cities and, to reduce greenhouse gasses emissions. This thesis proposes new methodologies for the integration of renewable energy resources in urban areas, while highlighting the potential of more efficient, profitable and sustainable renewable sources. (Chapters II to VI).

b) Research is needed to achieve more efficient, profitable and sustainable renewable sources, therefore the knowledge about the distribution of the worldwide scientific scene with regard to the urban generation and use of renewable energy in cities is of utmost interest. The main research country in this field is China, with the Chinese Academy of Sciences, Chinese Ministry of Education, Tsinghua University and the Harbin Institute of Technology as the main research institutions in the country. In mainland Europe, the United Kingdom, Italy, Germany, Spain, Netherlands and France highlight as the main research countries in this field, with the United Kingdom representing 23.06% of the total number of publications in European countries. (Chapter II).

c) The increase in the urban population together with the high price of fossil fuels makes renewable energies a key element in the energy transition to a low-carbon economy. Clean energies will reduce dependence on fossil fuels, also reducing greenhouse gas emissions and thus improving environmental pollution in urban areas. (Chapters II to VI).

d) The integration of renewable energy resources at district level allows, on the one hand, better management of these resources and, on the other hand, an increase in both, the share of renewables in the energy mix, and the energy efficiency of power systems. (Chapters III and VI).

e) The integration of district energy systems into city networks translates into notable benefits such as an affordable energy supply system, increased use of renewable energy sources, less dependence on energy imports and fuels fossils, and greater control over energy supply. On the other hand, it promotes the economic development of the locality and the quality of the air will be enhanced, due to a reduction in CO_2 emissions. These systems can be integrated on a large scale for urban heating and cooling applications. (Chapter III).

f) Heating and cooling account for 70% of the energy consumption of buildings and represent a significant share of the world's final energy consumption. Currently, most of this energy comes from fossil fuels (gas, diesel, coal, etc.), causing significant emissions of greenhouse gases. In district heating systems and decentralised biomass boiler, energy resources that would otherwise be wasted can be used to meet the demands related to space heating, domestic hot water and other applications. (Chapters III and VI).

g) The Mediterranean countries in general and all Europeans in particular have a high external dependence of the energy used. Biomass district heating (BDH) in Mediterranean countries can signify a chance for rural settlements to conform with European directives. As long as biomass resources are available and close to the settlement, disposal and transportation costs of forest biomass, persist low warranting the sustainability energy and contributing to greenhouse gas emission reductions. (Chapter III).

h) In the proposed case study of this Thesis, a BDH system for a small settlement of 3000 inhabitants gets 68% of fuel cost savings versus fossil fuels. BDH reduces operating and maintenance expenses related to traditional boilers, while the consumer gets more efficient energy services by the district heating network, so BDH networks are suitable for the use of biomass currently. BDH offers 100% of CO_2 savings, and emissions to the atmosphere have been reduced in 35 tonnes, which is the equivalent of the annual CO_2 sequestration of 700 adult trees. (Chapter III).

i) At residential level, if a 430 kW fuel-oil boiler is replaced by a biomass boiler of the same power fed by sunflower seed husk, an annual economic saving of 75% could be obtained while avoiding the annual emission of 209.97 tons of NO_2, 438.24 tons of SO_2 and 254.09 tons of CO_2. (Chapter VI).

j) In order to comply with the Paris agreement and to ensure that 20% of the energy consumed in the countries of the European Union comes from renewable sources, it is necessary to research new renewable energy sources. Biomass is a renewable energy source with a high potential for development, due to its wide availability worldwide and that can be obtained from many residues of agricultural and industrial applications. It is estimated that in developed countries biomass contributes between 9% and 14% of the total energy supplied, while in developing countries this percentage is between one fifth and one third. Biomass is therefore an important source of energy for developing countries, but most of this energy is not traded. (Chapters III to VI).

k) Mango stone, peanut shell and sunflower husk have potentially attractive energy attributes that must be taken on board when considering the use of biomass in heating facilities. The higher heating value obtained HHV (18.05 MJ/kg, 18.54 MJ/kg and 17.84 MJ/kg respectively) is greater than that of other biomass sources evaluated by previous studies and is in line with those of other sources of biomass used at present for home and industrial heating applications. These industrial by-products offer optimum qualities for thermal power generation, using biomass combustion boilers at residential and industrial level. (Chapters IV, V and VI).

l) The CO_2 benefit of using mango stone, peanut shell and sunflower husk comes from the assumption that carbon emitted by biomass is carbon neutral. Regarding to greenhouse gasses emissions, it was observed that in case of mango stone a large part of Central Africa (Sudan, Nigeria, Tanzania, Kenya or

Congo) and Madagascar would have significant savings in their CO_2 emissions in relative terms, they can avoid emitting values above 0.02 ‰ of their total emissions if mango stone is used as biofuel. As far as the peanut shell is concerned, if we compare the possible CO_2 savings of the main producing countries using this biofuel in relation to the total CO_2 emitted, the following reductions would be obtained in terms of per thousand: Chad (0.60‰), Central African Republic (0.22‰), Mali (0.20‰), Malawi (0.17‰), Niger (0.10‰), Gambia (0.09‰), Guinea-Bissau (0.08‰), United Republic of Tanzania (0.07‰), Sudan (0.07‰), and Guinea (0.07‰). With regard to sunflower husk it is observed how a large part of Central Africa (Tanzania, Uganda, and South Sudan) and Eastern Europe (Ukraine, Hungary, Romania and Bulgaria) would obtain CO_2 savings higher than 10 per thousand, considering the total sunflower seed production of these countries. (Chapters IV, V and VI).

m) The findings of this thesis allow the use of new sources of bioenergy from agro-industrial waste and its integration at urban level, which will allow better environmental management of these by-products, an improvement in the local economy and an increase both in the use of renewable energy and in the energy efficiency of public and private buildings. (Chapters II to VI).