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TESIS DOCTORAL

EVALUACIÓN DE MEDIDAS DE AHORRO ENERGÉTICO Y SU CONTRIBUCIÓN A LA SOSTENIBILIDAD ENERGÉTICA Y AMBIENTAL

EVALUATION OF ENERGY SAVING MEASURES AND THEIR CONTRIBUTION TO ENERGY AND ENVIRONMENTAL SUSTAINABILITY

PROGRAMA DE DOCTORADO

INGENIERÍA AGRARIA, ALIMENTARIA, FORESTAL Y DE DESARROLLO RURAL SOSTENIBLE

DOCTORANDA: CARMEN DE LA CRUZ LOVERA

DIRECTOR: PROF. DR. ALBERTO JESÚS PEREA MORENO

Córdoba, Julio de 2019

TITULO: *EVALUATION OF ENERGY SAVING MEASURES AND THEIR CONTRIBUTION TO ENERGY AND ENVIRONMENTAL SUSTAINABILITY*

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TÍTULO DE LA TESIS: EVALUACIÓN DE MEDIDAS DE AHORRO ENERGÉTICO Y SU CONTRIBUCIÓN A LA SOSTENIBILIDAD ENERGÉTICA Y AMBIENTAL

DOCTORANDA: CARMEN DE LA CRUZ LOVERA

INFORME RAZONADO DEL DIRECTOR DE LA TESIS

La doctoranda presenta y desarrolla un amplio análisis sobre el consumo energético en edificios de uso público, para poder plantear posibles acciones energéticamente eficientes y sostenibles mediante soluciones innovadoras, aplicables tanto a edificios existentes como de nueva construcción. 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 en donde se analiza el consumo energético en edificios de uso público y se realizan propuestas de medidas de eficiencia energética y de medidas para el ahorro energético extrapolables a otros edificios. También, cabe destacar los resultados de las investigaciones llevadas a cabo en esta tesis presentan un análisis sobre las posibles reducciones de CO_2 y otros gases de efecto invernadero que se obtendrían mediante la utilización de fuentes de energías renovables, dentro del escenario actual de medidas para la mitigación del cambio climático.

Tanto la metodología como el trabajo de investigación, las conclusiones y los resultados obtenidos son satisfactorios.

La tesis ha dado lugar a tres publicaciones en revistas indexadas de alto impacto:

- de la Cruz-Lovera, C., Perea-Moreno, A. J., de la Cruz-Fernández, J. L., Alvarez-Bermejo, J. A., & Manzano-Agugliaro, F. (2017). Worldwide research on energy efficiency and sustainability in public buildings. *Sustainability*, *9*(8), 1294-1314. doi:10.3390/su9081294

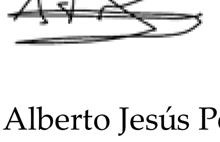
- De la Cruz-Lovera, C., Manzano-Agugliaro, F., Salmerón-Manzano, E., de la Cruz-Fernández, J.-L., & Perea-Moreno, A.-J. (2019). Date seeds (phoenix dactylifera L.) valorization for boilers in the mediterranean climate. *Sustainability*, *11*(3), 711-725. doi:10.3390/su11030711

- de la Cruz-Lovera, C., Perea-Moreno, A. J., de la Cruz-Fernández, J. L., G Montoya, F., Alcayde, A., & Manzano-Agugliaro, F. (2019). Analysis of Research Topics and Scientific Collaborations in Energy Saving Using Bibliometric Techniques and Community Detection. *Energies*, *12*(10), 2030-2053. doi: https://doi.org/10.3390/en12102030

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

Córdoba, 24 de junio de 2019

Firma del director



Fdo.: Prof. Dr. Alberto Jesús Perea Moreno
Departamento de Física Aplicada. Universidad de Córdoba

Agradecimientos

A mis padres, por su apoyo incondicional en todo momento. Con sus palabras, me han ayudado a crecer como persona y a luchar por lo que quiero. En particular a mi padre por ser el aliento que me animaba a seguir en los momentos más difíciles.

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

I-1. Introduction.

I-1.1. Climate change.

There are 7700 million people on this planet today, twice the population of 60 years ago, and although the forecasts seemed reassuring, largely due to declining fertility rates, the world's population is unlikely to stop growing in this century [1]. The United Nations (UN) predicts that world population will grow to 9.8 billion by 2050 and to 11.2 billion by 2100, with a strong impact on population structure, size, and distribution that will have profound consequences for environmental sustainability.

To promote development globally, one of the greatest challenges is the fight against climate change. Climate is shared across the globe, and no corner of the planet is spared the effects of climate change. We are becoming increasingly aware of the global energy and environmental problem, and this is manifested through global warming through the greenhouse effect.

The Intergovernmental Panel on Climate Change, in its fifth assessment report, completed in 2014, shows that most of the warming observed during the second half of the 20th century has been caused by human activities and that global warming is now a reality. The level of confidence increases to 95%, 5% more than the previous report published in 2007 [2].

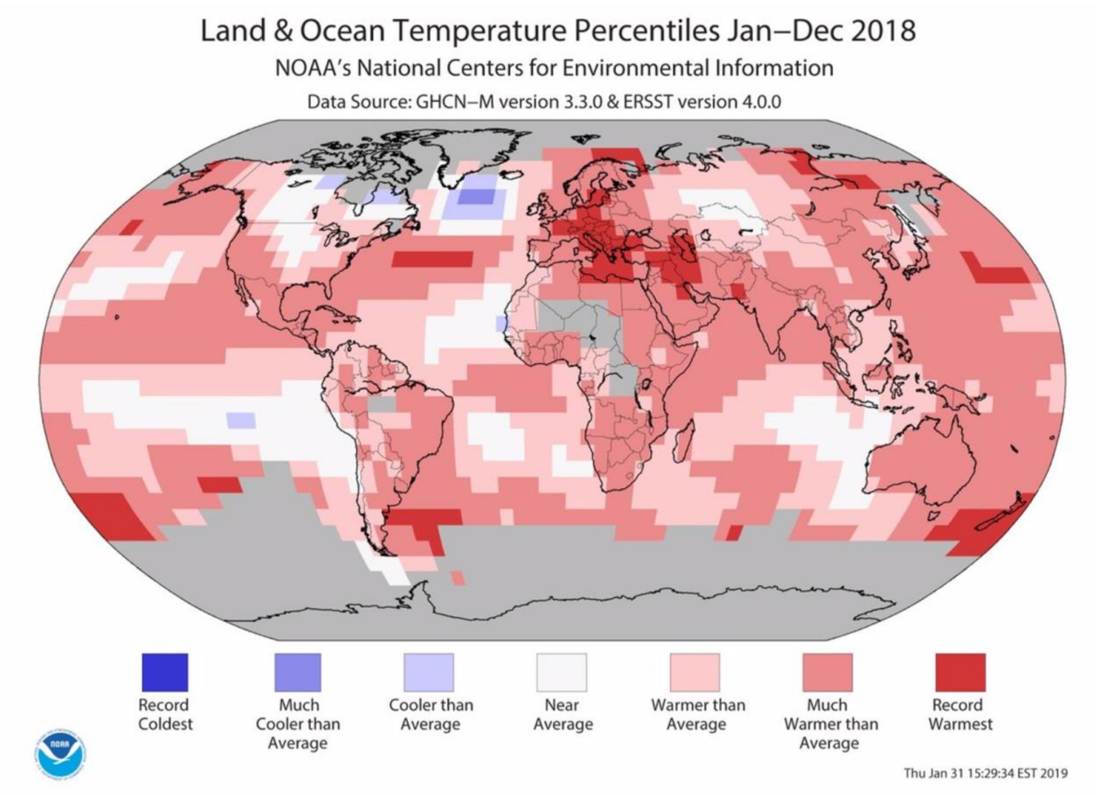

Figure I-1. Land and ocean temperature percentiles January-December 2018 [3].

According to the World Meteorological Organization (WMO), the last five years have been the hottest since registration, confirming that global warming can no longer be talked about as a future situation. The global temperature in 2018 was the fourth warmest since 1880, when records began. Extensive parts of the northern hemisphere have seen a spate of heat waves - in Europe, Asia, North America and Africa - as a result of a high-pressure system that has created what experts call a "heat dome".

Thus, 2018 is placed only behind the years 2016 (the warmest), 2015 and 2017. This shocking fact should activate us to look for energy efficient solutions from an environmental point of view. However, we must recognize that policies have been implemented and continue to be implemented to alleviate this situation.

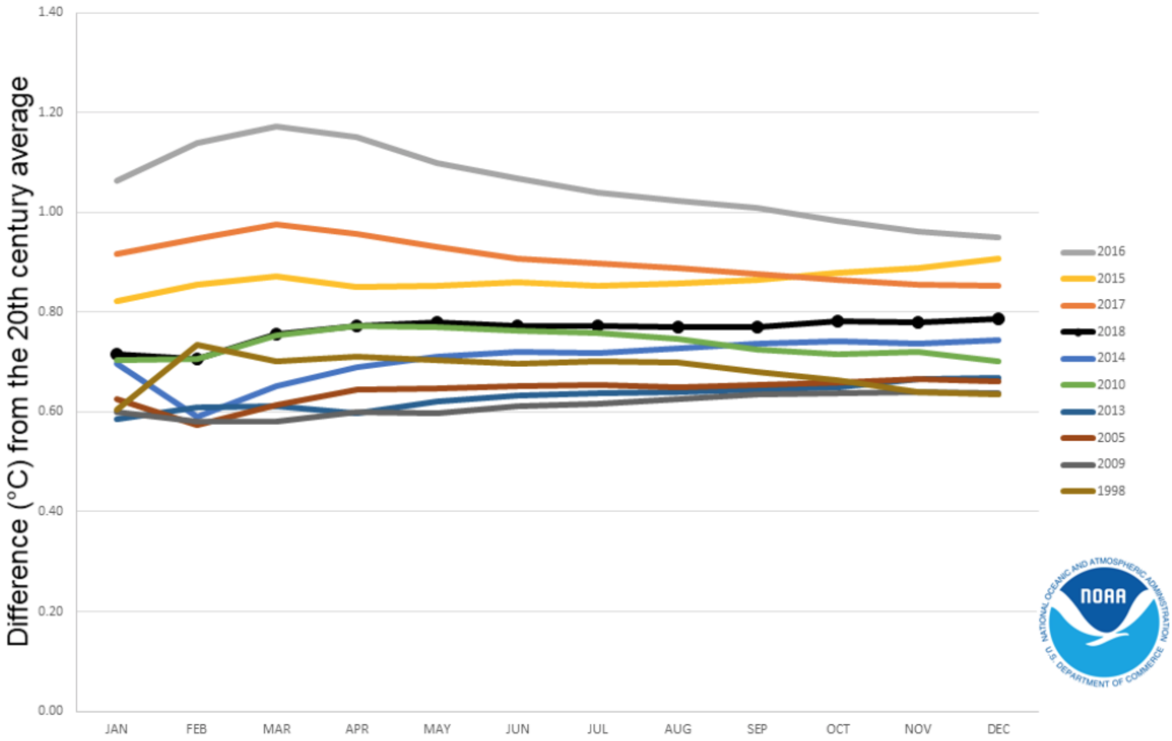

Figure I-2. Year to Date Global Temperatures for 2018 and the other nine warmest years on record (NOAA) [4].

It was in 2007 when the world finally became aware of the problem of climate change, directly accusing the human being as the main culprit of this problem. The Intergovernmental Panel of Experts on Climate Change (IPCC) confirmed that this process existed and that action had to be taken to remedy it.

But, at the global level, the different measures that had been taken until then were totally insufficient, and finally in December 2015, thanks to the work of researchers and the citizen's movement, 195 countries were able to sign the Paris Agreement: the first binding agreement on climate, at the Climate Conference (COP21).

This agreement allows all humanity to assume as its own the only great problem that is climate change and has been not only the driver of a spark of hope for humanity but also a source of generation of opportunities for business. This agreement has traveled around the world of energy with the support of all energy management professionals from all countries, establishing among other measures an international action plan that puts the limit of global warming well below 2º C [5].

Another major commitment is the Covenant of Mayors for Climate and Energy, which adds up to 7494 cities, one of the driving forces behind all the change that is taking place [6]. The signatories of the Covenant commit themselves to adopt measures that are in line with reducing the effects of climate change. They are required to prepare, in the first two years of their accession, an Action Plan for Climate and Sustainable Energy with the objectives of cutting CO_2 emissions by at least 40% by 2030 and increasing resilience to climate change [7].

Cities are home to more than half the world's population. These represent 70% of global CO_2 emissions caused by humans [8], therefore, cities are one of the great promoters of climate change. The change of the big cities is essential to get closer and closer to our objective of reducing the impact of this devastating phenomenon. Measures such as limiting the use of private transport or eliminating the use of certain fuels in the near future are the gateway to a real transformation. Thus, the role of the EU as a cohesive force in these policies is very important because it obliges governments to transpose into their laws the good practices agreed upon as a whole.

I-1.2. Sustainable development.

An important part of the environmental impact of any community is associated with the use of energy resources, as these continuously degrade the environment. That is why a community that yearns for sustainable development is limited to using only energy resources that do not cause environmental impact. In spite of having numerous ways of producing energy, all of them generate in one way or another some impact on the environment. It can be said that there is a linear correlation between energy efficiency and environmental impact, since the lower the use of resources, the lower the pollution [9].

Important conclusions can be drawn from the well-known definition of sustainable development defined by the Brundtland Commission. It is understood that until then, when it came to development issues, only economic and social variables were taken into account. It is at this point that environmental considerations begin to gain strength, as reflection began on the continued use of finite fossil fuels and how these did not help to achieve any kind of sustainability. As a result, it was agreed that there was a need to strike a balance between the socio-economic growth conditions of present generations and the imperative of preserving environmental resources for future generations.

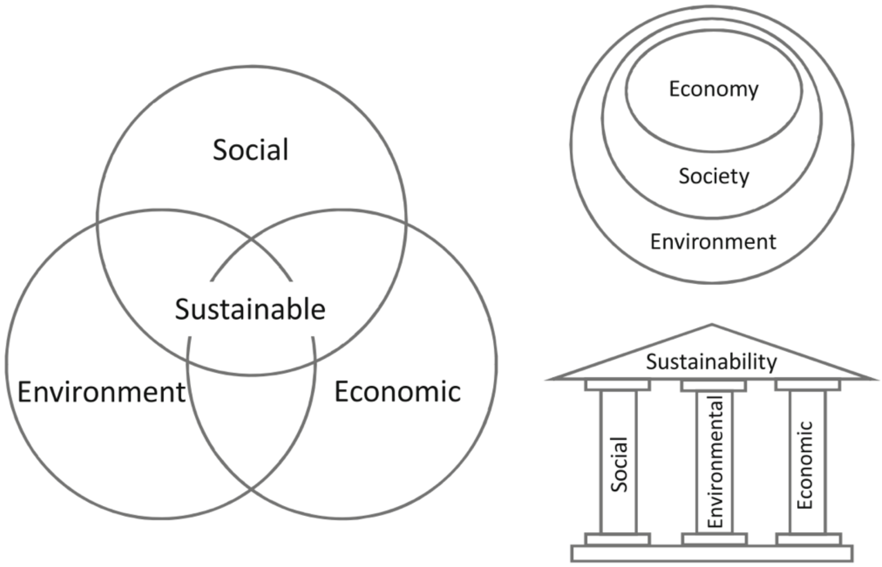

Figure I-3. The three pillar of sustainability development [10].

Sustainability is, therefore, the meeting point of social, environmental and economic development [11].

In a world of increasing problems related to sustainable development, education in this area is seen as the ideal way to create a new awareness of and behaviour towards the environment. Education for sustainable development must be an integrated, interdisciplinary and values-oriented education that contributes to the formation of new values based on the knowledge of sustainable development about worldview and environmental ethics [12].

I-1.3. Energy and population.

Our society has been based for more than a century on a voracious and ever-increasing consumption of energy [13]. As the world's population increases and living conditions improve, the need for energy increases. In addition, there is a linear correlation between an individual's quality of life and the amount of energy he or she consumes. Thus, it could be said that globally, the distribution of energy consumption is revealed as profoundly unequal. Energy consumption in developed countries is estimated to be 80 times higher than in sub-Saharan Africa. Less than a quarter of the world's population, living in the industrialized world, consumes 3/4 of the total energy available [14].

In contrast, the United States, with less than 5% of the world's population, consumes more than 20% of total energy consumption. Another example illustrates this: 92 % of the world's population does not own a car; while in the USA and the EU there is one car for every 1.8 and 2.8 inhabitants respectively, in Africa only 1 for 110, and in China 1 for 1375.

These figures show the strong parallel between increased wealth and increased energy consumption, while, on the contrary, the impact of policies to reduce energy demand is still very limited. For this reason, some authors argue that the decline in energy demand will not be as easy as initially envisaged and that current approaches will be insufficient to achieve the necessary transformation [15].

According to the IEA, energy demand will grow by 30% by 2040, the equivalent of bringing China and India back into global demand. This dizzying pace leads one to believe that the world will not be able to comply with the pacts established in the Paris Agreement. Therefore, in order to evolve towards a more sustainable energy model, energy saving and efficiency must be promoted in all those actions that demand energy consumption, otherwise the energy supply on which the global economy depends will be put at risk [16].

In order to counteract the effects of human intervention on the planet, various international institutions have recently proposed different objectives. These include the European Council of 8 and 9 March 2007: a 20% reduction in primary energy consumption, a 20% binding reduction in greenhouse gas emissions and the presence of 20% renewable energy by 2020, commonly known as the "20 20 20" target [17].

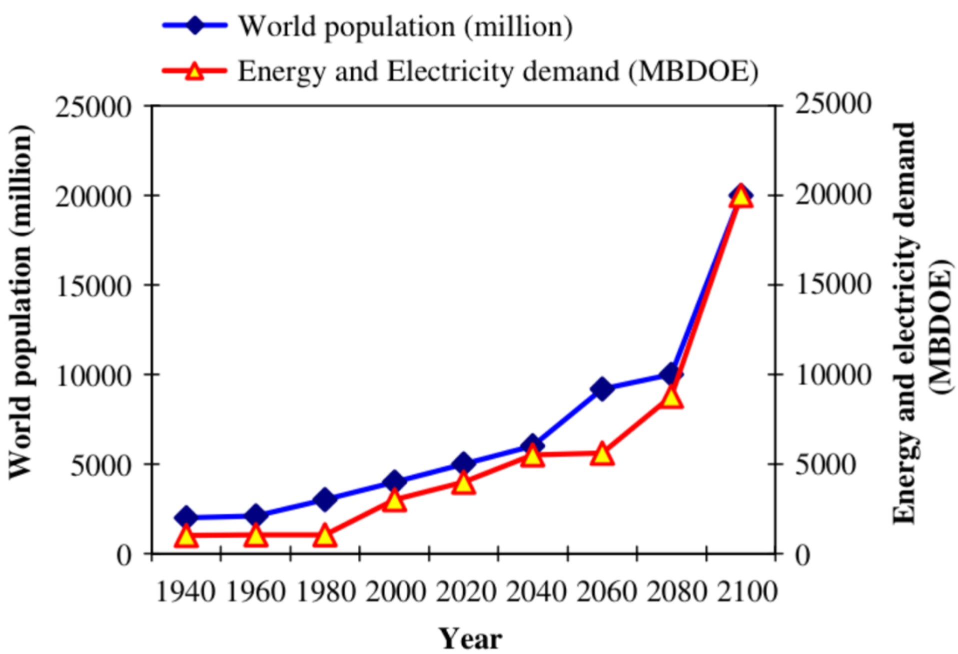

Figure I-4. World population and estimated energy demand. Million of barrels per day of oil equivalent (MBDOE) [18].

I-1.4. Energy efficiency in buildings.

The evaluation of energy efficiency is an area that has has attracted much attention during the early years of the 21st century, given its social, economic and environmental repercussions. [19].

Energy efficiency is defined as that which seeks to offer more services with the same energy input, or the same services for less energy consumption according to the International Energy Agency (IEA). Energy efficiency arises from the quotient between the useful energy or used by a system and the total energy consumed.

In Europe, the building sector is the number one consumer of energy, followed by industry and transport, which causes it to be the cause of producing more CO_2, one of the so-called "greenhouse gases". In addition, it consumes around 16% of fresh water and 25% of the wood in the forests [20], affecting the environment.

Specifically, the building sector accounts for 36% of global energy end-use and 39% of carbon dioxide (CO_2) emissions (Figure I-5) [21] In the last 7 years, global final energy consumption in buildings has grown by about 5%, as increases in energy efficiency were outpaced by continued strong growth in building sector activity and demand for energy services.

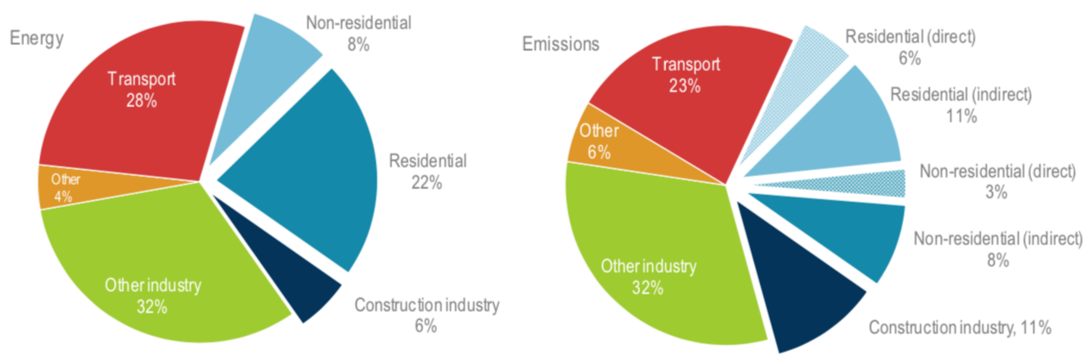

Figure I-5. Global share of buildings and construction final energy and emissions [22].

Therefore, energy efficiency in buildings consists of achieving the reduction of energy consumption without forgetting the comfort conditions of its inhabitants.

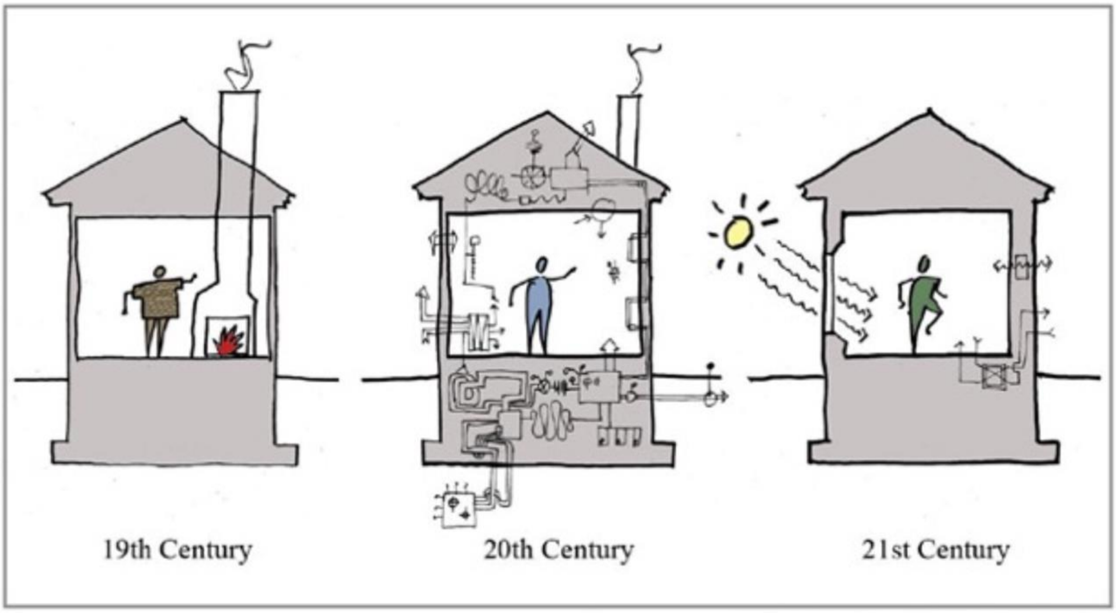

Figure I-6. Passive house [23].

The design, construction and operation of buildings has evolved over the centuries, but having thermal installations in buildings that consume polluting energy has not been the best option.

In general, economic performance has always been pursued in the shortest possible time and other agents such as energy maintenance of the building have not been taken into account.

In the 20th century mechanical installations and the use of polluting energies invaded architecture to guarantee the comfort of users without considering the negative impact on the environment, but in the 21st century it is architecture and its relationship with the environment that should be imposed, this being the fundamental line on which the concept of Passive house is based. In order to build in this way, it is necessary to previously study the climatic conditions of the site and to take advantage of renewable energies.

A passive house is a house with a very low energy consumption that offers comfort temperatures throughout the winter, due to its constructive design, which is managed with 10 times less thermal energy than the same house conventionally designed [24]. However, much remains to be done to reduce energy consumption considerably and reach the idyllic situation represented by Figure I-6 in the 21st century.

Fortunately, the obligatory technical regulations are becoming stricter and stricter when it comes to energy efficiency.

In 2010 it was decided at European level to approve the Directive 2010/31/EU on the energy performance of buildings and in 2012 the Energy Efficiency Directive 2012/27/EU, both recently amended by the Directive (EU) 2018/844.

The Directive on the energy performance of buildings has been a major step forward, forcing governments and large companies to establish improvement plans, such as the requirement from 31 December 2018 that all new publicly-owned buildings in the EU must be a building with almost no energy consumption, and from 31 December 2020, all public and private buildings must be nearly zero energy building (nZEB) [25].

Article 2 of Directive 2010/31/EU defines an nZEB as a building with a very high level of energy efficiency (...). The almost zero or very low amount of energy required should, to a large extent, be covered by energy from renewable sources, including energy from renewable sources produced on site or in the environment [26].

The main characteristic of low-consumption buildings is that their energy demand must be equal to their energy generated, i.e. they must be able to produce the same energy or more than the energy they are going to consume over an entire year. In addition, it is necessary that the energy produced be in situ or in the nearest environment, and by means of renewable energies. It must be evaluated whether the building uses the best practices in the market to reduce its impact on energy consumption and whether the project has also defined the best use of renewable energy resources available in the area.

However, the difficulty lies in establishing a single European standard that promulgates the indicators required for this type of building. It is clear that Europe is very diverse, and it includes countries from different climatic zones that cannot be judged under the same criteria. For this reason, the EU has established a general definition, leaving each state free to give a definition of an nZEB according to local and regional climatic conditions. It was therefore decided that it should be the technical building code of each state that dictates which buildings are considered to have almost no energy consumption and which are not. The EU does not dictate laws but guidelines that the different technical codes of the different states have to adapt to their directives and to their own legislation. Several studies highlight that the Member States of the European Union have made a great effort to integrate the nZEBs concept into the National and International Codes. This issue has received enormous attention in recent years, but the European Union, specially most Southern European countries, are still far from reaching a common notion of nZEBs and even further from putting into practice building systems that involve a building with almost zero energy consumption and construction routines, particularly at retrofitting existing buildings levels [27, 28].

Thus, in Spain, a modification of the technical building code was approved last September 2018, where the Basic Energy Saving Document DB HE 2018 establishes the limit values for a building to be catalogued as nZEB. These values are based on a series of global indicators: non-renewable primary energy consumption and energy demand for heating and cooling, which have already been introduced in the current CTE [29].

Despite the difficulties in driving the renovation of the public buildings stock towards near zero consumption levels, numerous projects are being carried out under the EPBD Directive with satisfactory results [30].

For the optimal design of an NZEB building it is necessary to apply the main bioclimatic criteria, with the aim of considerably reducing the energy demand of the building [31].

The transition to an almost zero-consumption building stock depends to a large extent on the consideration of passive and design aspects in both new and existing buildings. These architectural criteria are, for example, orientation, compactness, insulation, solar protection, natural ventilation or controlled ventilation [32].

Each of these aspects will be analysed and supported by the most suitable techniques and materials to achieve the final objective: to reduce energy demand. Once this objective has been achieved, it will be necessary to complement it with the active part of the building: the installations that must cover the existing demand of the building in the most efficient and sustainable way possible. Moreover, the energy consumption of the installations must come mostly from renewable energy sources generated in situ: solar panels, geothermal, photovoltaic, mini-wind, etc.

To check that a building meets the requirements to become nZEB, the different possible actions to be carried out on a building are evaluated energetically and comparatives are established. The main indicator of the energy efficiency of the new DB-HE as said before is the Non-Renewable Primary Energy Consumption, and it is set with quite severe limits. If this consumption is to be surpassed, it must be done through renewable energies up to the limit set by other efficiency indicator, Total Primary Energy Consumption. However, this limit does not only fix the renewable contribution, but also a minimum efficiency in the demand and in the efficiency of the systems, so that, if efficiency is improved in terms of demand it is possible to reduce the renewable contribution. It is understood that it is better not to consume energy than to consume renewable energy.

The name of nZEB should not be confused with receiving an energy rating A. Both distinctions, although related, refer to different things. The current energy certification system is based on the efficiency of a building compared to pre-determined standards based on the built plant of similar characteristic buildings. That is to say the building is good regular or bad based on what already exists built and that is not the purpose of an nZEB building. On the other hand, the final rating is based on CO_2 emissions is not the consumption of non-renewable primary energy. Nor does it contemplate a minimum contribution of renewable energies, a fundamental aspect for a building with almost zero energy consumption. In other words, a nZEB will undoubtedly have an energy rating of A, but a building with an energy rating of A may well not be a nZEB.

Similarly, a building with a green seal may not be considered a nZEB, as each seal (BREEAM LEED, GREEN...) has a different method for determining energy efficiency. Not everyone evaluates the same parameters and the comparison standards are different.

The only comparable qualification is the Passivhaus certificate. This, unlike the previous ones, is equivalent to the nZEB certificate, because the methodology is the one that best fits the normative conditions to be a building of almost zero energy consumption. However, there are certain differences. Passivhaus also considers the consumption of household appliances, does not differentiate climatic zones and requires certain requirements to the systems. Therefore, a Passivhaus building can be considered an NZEB, but an nZEB building will not always meet Passivhaus standards as these are more demanding.

Before the concept of nZEB was defined, the European Directive (2002/91/EC) on the Energy Performance of Buildings—EPBD [33], as subsequently amended by Directive 2010/31/EU, laid down the requirements for the energy certification of buildings, which has been implemented into national law by the EU Member States on 4 January 2006.

The energy performance certificate is a document that reflects how energy-efficient a building is. It is calculated following a series of guidelines that are indicated in the EPBD [34]. From the Directive on, all buildings must have an energy certification that classifies them on the basis of their energy rating. This rating is expressed by a letter that will vary from the letter (A) for the most efficient dwellings to the letter (G) for the least efficient ones.

In new buildings the scale comprises, in order of highest to lowest efficiency, the ratings or classes A, B, C, D and E, extending to the ratings F and G for existing buildings.

According to this classification, a building or dwelling with the highest energy efficiency category (class A) is considered to consume up to 90% less energy than a building or dwelling with the lowest level (class G) [35].

The current regulations do not specify a minimum energy rating for buildings, but since 2007, compliance with a series of minimum requirements in the Technical Building Code on aspects related to energy saving and thermal insulation have resulted in new buildings generally obtaining energy ratings between A and C.

The main energy indicator will be given by two main parameters:
- Yearly CO_2 emissions, expressed in kg per m_2 of useful floor area of the building.
- Yearly primary energy, in kWh per m_2 of usable floor area of the building.

I-1.5. Renewable energies. Biomass.

Although it is not possible to present a definition of renewable energy, it is possible to mention two common characteristics: they are clean energies, since they do not produce polluting emissions into the atmosphere [36], and on the other hand, they are renewable, that is, they regenerate periodically and through natural cycles, without exhausting resources [37].

Although they cause negative effects on the environment, these are much smaller than conventional energies such as fossil fuels (oil, gas and coal) or nuclear energy. Renewable energies have the additional advantage of being able to complement each other, favouring their integration, reducing dependence on external supplies and allowing energy to be transported to isolated places where there is no conventional grid supply [38].

Biomass is a booming source of renewable energy with high growth potential over the coming decades, as it can be obtained from waste, turning waste into a resource and, at the same time, collaborating with recycling [39]. Biomass is, therefore, a type of renewable energy that comes from organic matter, where the idea is to use this matter as an energy source [40].

Depending on where appropriate, biomass can be divided into vegetable or animal biomass and energy crops. Vegetable biomass includes agricultural surpluses, consisting of agricultural products not used by humans, and residual biomass, which includes forestry and agricultural residues, livestock residues, industrial residues and urban residues.

Energy crops are plantations made for the sole purpose of being used as an energy source (heat) or as a raw material for obtaining fuels (biofuels). They are characterised, on the one hand, by their high production per unit area and year and, on the other, by the few requirements that their cultivation demands [41].

In general, biomass has lower combustion features if we compare to fossil fuels, due to its scarce energy density and high humidity level, as well as the impossibility of storing it for a long time because it deteriorates. However, its potential is high enough to justify the study and development of technologies that allow an efficient use of it as an energy.

Although it is not yet widely used in industrialized countries, biomass is the main source of energy in developing countries [42].

There are several types of biomass depending on the state in which it is found: Biomass (solid), biofuel (liquid) and biogas (gaseous). Currently, solid biomass is the one with the highest rate of use as it requires little treatment of the fuel and a lower production cost [43]. Direct combustion is the oldest system of extracting energy from biomass, organic matter reacts chemically with oxygen and gives heat to the medium [44]. The fundamental factors affecting the reaction are the characteristics of the biomass, the percentage of oxygen and the temperature at which the combustion takes place.

Biomass favours the recycling of waste, contributing to a greater cleanliness of the forests and thus reducing the risk of fire. However, it requires a lot of space for the different processes and in certain areas, it is necessary to improve the technology [45].

Biomass appears in different forms: wood, sawdust, straw, seed residues, manure, paper residues, being the most widely accepted pellets, wood chips, firewood or olive seeds [46]. Some materials can be used directly as fuels, others, on the contrary, require a series of processes before they can be used. Since 2012, in Spain there has been a clear trend of growth in both the production and consumption of biomass, becoming the third in the world in the certification of pellets, only behind Germany and Italy. Thus, Spain is a country with high availability of biomass, which can ensure the supply of consumption [47].

In the last years, however, new waste products are emerging, such as fruit stones, which are perfectly valid as biofuels according to numerous studies. [35,48,49]. In fact, in this Thesis the properties associated with date bone are analysed to evaluate its suitability as a new biofuel, obtaining that this waste product has a high calorific power that gives it optimum properties as a source of thermal energy comparable to other biofuels on the market.

I-2. Hypothesis and objectives.

World population will grow from 7700 million people today to 9800 million by 2050. This increase will have an impact on population structure and distribution that will have important implications for environmental sustainability. As a result, the number of countries incorporating energy efficiency strategies in their public buildings is increasing, due, among many other factors, to the existing increase in energy needs, evident climate change or the scarcity of current resources. The hypothesis is that it will be necessary to reduce dependence on fossil fuels and implement energy efficiency measures to bring us closer to an optimal, clean, sustainable and competitive energy system that contributes to the fight against climate change and atmospheric health.

With this in mind, the main objective of this thesis is to provide useful information on energy consumption in public buildings, in order to propose possible energy efficient and sustainable actions through innovative solutions, applicable to both existing and new buildings. The main objective can be divided into the following specific objectives (O1, O2, O3 and O4):

- O1: Bibliometric study on sustainability and energy saving
- O2: Analysis of energy consumption in public buildings
- O3: Analysis of energy efficiency measures
- O4: Proposals for energy saving measures in public buildings

These objectives have been achieved in chapters II, III IV and V, being chapter II, III and IV published articles in Open Access.

Chapter II- de la Cruz-Lovera, C., Perea-Moreno, A. J., de la Cruz-Fernández, J. L., Alvarez-Bermejo, J., & Manzano-Agugliaro, F. (2017). Worldwide research on energy efficiency and sustainability in public buildings. *Sustainability*, *9*(8), 1294. **doi:** 10.3390/su9081294 **(O1)**

Chapter III.- de la Cruz-Lovera, C., Manzano-Agugliaro, F., Salmerón-Manzano, E., de la Cruz-Fernández, J. L., & Perea-Moreno, A. J. (2019). Date Seeds (Phoenix dactylifera L.) Valorization for Boilers in the Mediterranean Climate. *Sustainability*, *11*(3), 711.
doi: 10.3390/su11030711 **(O3)**

Chapter IV.- de la Cruz-Lovera, C., Perea-Moreno, A. J., de la Cruz-Fernández, J. L., G Montoya, F., Alcayde, A., & Manzano-Agugliaro, F. (2019). Analysis of Research Topics and Scientific Collaborations in Energy Saving Using Bibliometric Techniques and Community Detection. *Energies*, *12*(10), 2030. **doi:** 10.3390/en12102030 **(O1)**

Chapter V.- Analysis of energy consumption and proposal of energy efficiency measures in public buildings (Reina Sofía University Hospital, Córdoba) **(O2 and O4)**

I-3. Structure.

This thesis consists of six chapters, three of which are articles published in indexed journals: Chapter I *and* II, *Sustainability* - Chapter III, *Energies*, Chapters IV, V and VI.

The thesis is structured as follows:

- Chapter I: Introduction, hypothesis and objectives, and structure of the thesis.
- Chapter II: Worldwide research on energy efficiency and sustainability in public buildings.
- Chapter III: Date Seeds (Phoenix dactylifera L.) Valorization for Boilers in the Mediterranean Climate
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- Chapter V: Analysis of energy consumption and proposal of energy efficiency measures in public buildings (Reina Sofía University Hospital, Córdoba)
- Chapter VI: Summary and general conclusions.

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Chapter II. Worldwide research on energy efficiency and sustainability in public buildings.

Chapter II. Worldwide research on energy efficiency and sustainability in public buildings.

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II-I. Abstract.

The present study details the significant contribution that different international institutions have made to the field of sustainability and energy efficiency. This has been done making use of the database Scopus by applying bibliometric techniques and analysis of the contents of articles published from 1976 to 2016. All the materials included in the analysis have been reported from Scopus. Several key aspects of the publications have been considered such as document type, language, subject area, journals type and keywords. Sustainable Development, Sustainability, Energy Conservation, Energy Efficiency and Buildings have been verified as the most used keywords. The obtained contributions have been classified geographically and by institution, being United States, United Kingdom, China, Australia and Italy the leading research countries and Hong Kong Polytechnic University, Delft University of Technology and Tsinghua University the top contributing institutions. The most active categories in those fields are engineering, social sciences and environmental issues in that order. It can be assumed that the study of sustainability and energy efficiency across all its dimensions is of great interest for the scientific community. The global environmental issue leads many countries to incorporate a wide range of Energy Efficiency (EE) strategies in order to reduce energy consumption in public buildings, a highly valued aspect by European Union energy labelling.

Keywords: energy-saving; energy efficiency; sustainability, building.

II-2. Introduction.

During the last fifty years, world energy consumption has increased disproportionately in relation to population growth, mainly as a result of economic development and a lack of social awareness in more developed countries, where the energy consumed by each inhabitant is increasing [1]. For several years, the dependence on energy in developed countries has been increasingly alarming. From 1971 to 2014, worldwide energy consumption has grown 92%, according to the International Energy Agency [2].

Reducing energy consumption at a transnational and global level from a demand side point of view, is not only a challenge, but also a global duty, which requires immediate action and substantial improvement, being not only in the past but also nowadays a field with great potential for improvement in this regard [3,4].

The building industry with its high energy consumption requires more attention and effective actions than other sectors [5,6]. Despite the trend to focus on existing residential housing, due to the fact that they comprise over 60% of the total sector [7], the number of non-residential buildings continues to be too high to ignore. It is anticipated that energy efficiency measures could save over 28% energy costs of these buildings [8]. Energy efficiency is an issue that has acquired significant relevance in the first decade of the XXI century because of its considerable economic and environmental role [9]. There is a growing number of countries that have introduced energy-efficient strategies in their public-use buildings, due to the increase in energy needs, the obvious signs of climate change and limited resources, among other factors. All of this makes action plans for decreasing dependence on fossil fuels necessary, striving towards to an optimal, competitive and sustainable energy system [10].

The building and construction sector has undoubtedly contributed too much to this increase, due to energy consumption, which in this sector represents between 20% and 40% of the energy consumed in developed countries, and more than 30% of total greenhouse gas emissions [11]. This occurs not only in new buildings but also in historic buildings, taking into account that currently approximately 35% of buildings in Europe are more than 50 years old, so it is urgent to adapt the energy systems of these buildings, always preserving authenticity and integrity [12]. Semprini et al. [13] analysed a building with these characteristics, making some minor modifications to improve the energy efficiency and they obtained some very promising results. Moreover, on the urban scale, energy sustainability is also a point of reference for the rise of smart cities [14,15].

The energy consumption in buildings open to the public is 40% greater than that in residential buildings and 30% of the non-residential buildings in Europe are public buildings. For this reason, these buildings, as an entity at the service of the citizens, are responsible for taking all feasible steps towards securing long-term energy sustainability; first of all, because they consume energy and secondly because they play important roles, both in setting a positive example of the incorporation of energy efficiency measures and in encouraging energy saving and efficiency actions among the public. This approach not only will result in a gradual reduction of the public expenditure, but also minimizes the detrimental environmental impacts, contributing to the fight against climate change. It is therefore essential that further thought be given to this issue, and that great effort should be put into promoting more energy-efficient and environmental solutions that aim for the lowest possible costs and the highest possible profits with major advantages.

Improving energy efficiency is considered one of the basic keystones of the main national and international strategies to reduce greenhouse gas emissions with acceptable economic costs [16]. The need for simple and clear measures and for all citizens to contribute to energy savings have been addressed in many studies [17]. Changes and adaptations are required at the social, economic and technological level in order to preserve our wellbeing and the welfare of future generations, although they will result in a change in our way of living. To reduce the energy consumption of buildings, almost all governments have opted for the adoption of measures aimed at improving energy efficiency in buildings for public use. Governments and non-governmental organizations (NGOs) have focused on other issues in plans and programs to boost renewable energies, energy efficiency strategies and strategies to fight climate change [18]. In Europe, the legislation of the different countries in this area comes, on the one hand, from the creation of certificates of energy efficiency, developed in the early 1990s as a primary strategy to reduce energy use and carbon emissions. On the other hand, it comes from the energy policy adopted in 2007, called Horizon 20-20-20, in which the EU demands the fulfillment of certain objectives by the end of 2020: saving 20% of energy in its primary level in comparison with 2005; lowering greenhouse gas emissions by 20% compared to 1990; increasing renewable energy in the total energy mix to a minimum of 20% by 2020. It is popularly known as the "20-20-20 goal", which implies improvements in energy efficiency [19].

At the same time, the Directive on Energy Efficiency in Buildings [20] 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. This new concept refers to buildings with minimum levels of energy, whose origin is from renewable sources. Nevertheless, it is a very complex concept, especially because of the lack of a clear and standardized definition and a common energy calculation methodology for all countries to evaluate them with the same criteria [21].

The importance of showing the energy and environmental performances of public buildings is well known [22,23]. In fact, the European association of local authorities, launched its Display® Campaign in 2001 in order to encourage governments to share with citizens this information. Different assessment processes or evaluations were created over the last two decades, in order to combine and create a new way to audit the energy performance in buildings. The energy performance assessment for existing dwellings (EPA-ED) methodology is supported by software, and has been developed in the framework of a European project that focuses on energy related issues for existing residential buildings [24]. However, most of the time, the energy efficiency evaluations were not properly assessed or even not assessed at all [25]. The main reasons were to keep the audits simple and low cost. Part of the different evaluations were carried out by the users, in simple and not assessed DIY (Do-It-Yourself) evaluations.

Another idea that is receiving stronger support in recent years is the Inter-Building Effect [26], where the buildings are connected and share a spatial relationship which could vary the building's performance. This is also affected by the weather and climatology. All of this must be taken into account in order to predict the energy performance of buildings and their surroundings. These reasons have led to a growing tendency to search for new ways of enhancing public buildings' performance, especially in those opened with long-term projections and for many hours during the day, such as universities [27]. Many publications studied the new measures to incorporate them into university buildings and how these could affect in the energy costs of local authorities. Trying to achieve this goal of energy sustainability, governments have included new policies to improve both energy saving and renewable energy; for example, the inclusion of light-emitting diodes (LEDs) in indoor lighting instead of the old incandescent bulbs [28]. Not only lighting has been studied during the last 15 years; some studies focused their research on all kinds of energetic items and especially new renewable ways of energy, and their consumption was compared to the previously used items in the buildings [29].

The main goal of this study is to determine the status and development trends in the field of sustainability over the last 40 years to help the research community better understand the current and future situation as well as to predict dynamic changes that may take place in lines of research. This kind of research has been successfully employed in other research projects [30–32].

II-3. Materials and Methods.

Bibliometric is one of the main research approaches that is extended to almost all scientific fields, being increasingly used to assess peer reviewed research outputs. Scopus is accepted by the international scientific community as the largest database of citations and abstracts of refereed literature for the analysis of scientific publications [33]. It was selected as the database used in this study because it has a complete catalogue of 20,500 publications from more than 5000 international publishers.

A full search was carried out with this database using the subfields' title, abs, and authkey to find publications dealing with the topics of Sustainability and Energy Efficiency. The search scope was from 1976 to 2016. Other analyses show the success of this methodology [34,35].

Avoiding risks of distorting the results, the best option to search for the exact content was to use the following search string:

TITLE ({sustainability}) OR ABS ({sustainability}) OR AUTHKEY ({sustainability}) OR TITLE ({energy saving}) OR ABS ({energy saving}) OR AUTHKEY ({energy saving}) AND TITLE ({building}) OR ABS ({building}) OR AUTHKEY ({building}) OR TITLE ({buildings}) OR ABS ({buildings}) OR AUTHKEY ({buildings}) OR TITLE ({school}) OR ABS ({school}) OR AUTHKEY ({school}) OR TITLE ({schools}) OR ABS ({schools}) OR AUTHKEY ({schools}) OR TITLE ({office}) OR ABS ({office}) OR AUTHKEY ({office}) OR TITLE ({offices}) OR ABS ({offices}) OR AUTHKEY ({offices}) OR TITLE ({university}) OR ABS ({university}) OR AUTHKEY ({university}) OR TITLE ({universities}) OR ABS ({universities}) OR AUTHKEY ({universities}) OR TITLE ({public buildings}) OR ABS ({public buildings}) OR AUTHKEY ({public buildings}) OR TITLE ({public building}) OR ABS ({public building}) OR AUTHKEY ({public building}).

By combining the information gathered with the results of the field work, different indices and statistics of many fields of interest may be elaborated. The obtained publications referring to sustainability and energy efficiency during the period from 1976 to 2016 were analyzed through different aspects such as publication type, language, characteristics of scientific output, publication distribution by country and institution, distribution subject categories, citation analysis as well as the keyword occurrence frequency. The citation analysis includes a study on the influence of the h-index. This index was proposed in 2005 by Jorge E. Hirsch for the qualitative evaluation of researchers in the field of physics [36]. Researchers consider it not only the safest way of measuring the scientific quality of the work, but also quite a useful tool to evaluate the regularity of production and to predict future scientific output, as it takes into account both productivity and impact [37,38].

II-4. Results and discussion.

II-4.1. Type of publications and languages of publications.

The search has considered 26653 documents in various fields or type of documents. After analyse the different types of publications (see Table 1), mostly of the work in the searching were articles (14768; 57%) and conference papers (7291; 28%). With a significant smaller quantity are Book Chapters (1364; 5%), Reviews (1323; 5%) and with a less significant number other type of publications as Books, Article in Press or Conference

Review. The Figure 1 shows a chart representation of document type distribution during period 1976–2016.

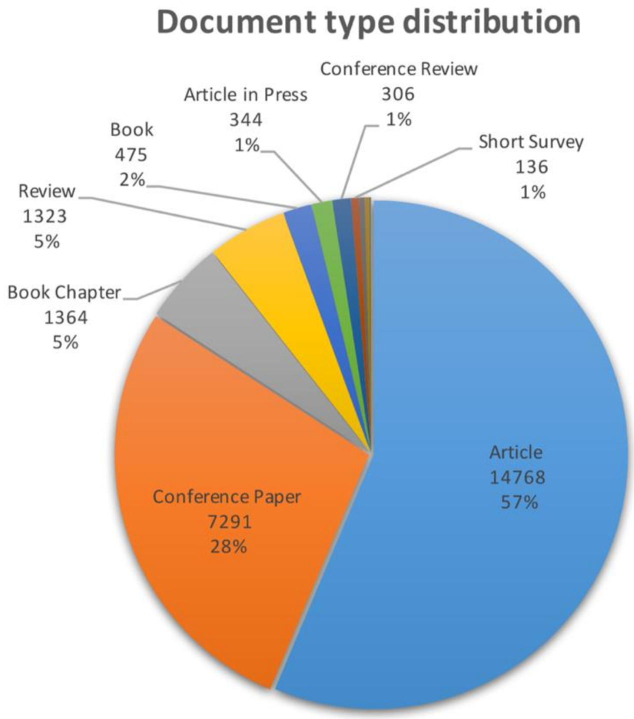


Figure II-1. Chart representation of document type distribution during period 1976–2016.

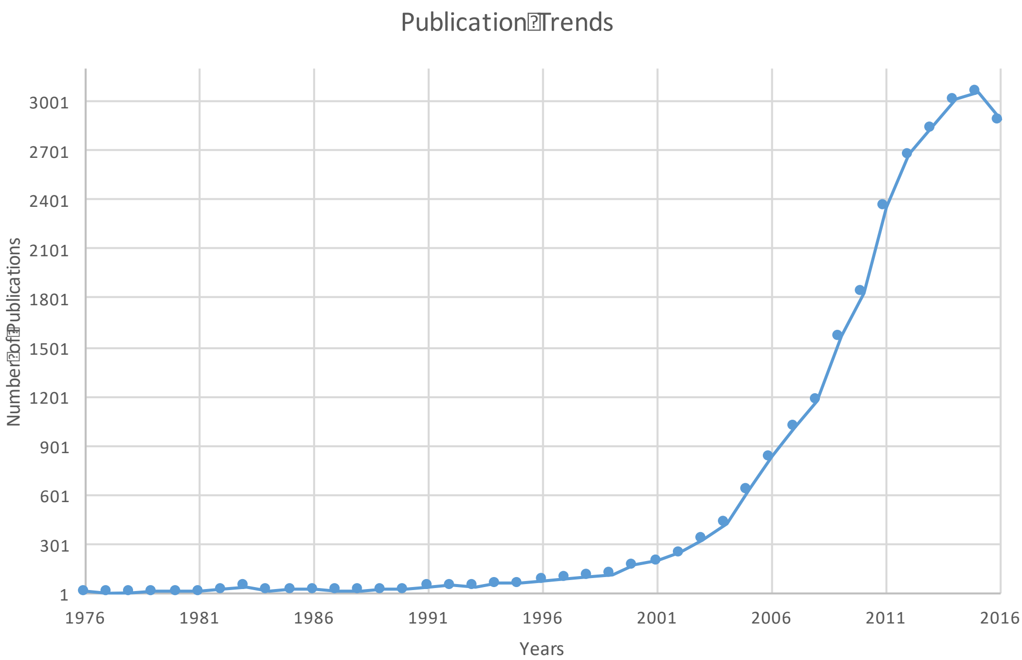
Table II-1. Number of publications based on the language used.

Language	Number of Publications
English	25320
Chinese	477
German	337
Spanish	213
Portuguese	122
Japanese	118

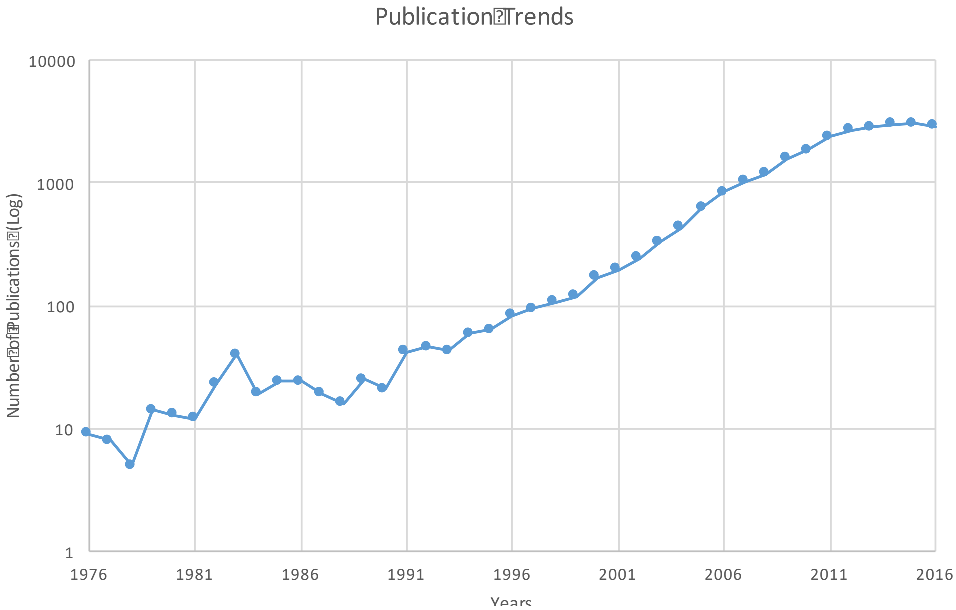
French	74
Italian	54
Russian	31

II-4.2. Characteristics of scientific output.

Figure 2a shows the output of the search in relation to the number of publications during the last 40 years. As we can see, the number of articles in this area was not very high until the early 2000s, when it started to grow from less than 300 publications per year to more than 3000 in 2015. This significant growth stems from the awareness of the ecological problem in the first decade of the century. Many policies were established around the different governments and institutions in order to reduce pollution and encourage efficiency and sustainability in public buildings. Figure 2b presents the same data but this time on a logarithmic scale, which provides some insight into the growth rate.



(a)



(b)

Figure II-2. (a) Trend in sustainability and energy efficiency publications during the period of 1976–2016. (b) Trend in sustainability and energy efficiency publications showing the data with a logarithmic scale along the y-axis.

II-4.3. Publication distribution by regions and institutions.

Figure 3 shows the distribution of publications according to country. Turquoise colour indicates the largest number of publications, whereas the grey colour indicates no publications at all. We can see how United States is the country with more publications, followed by China, England and Ireland. Other countries with a large number of publications are Australia, Germany or Italy. This information leads us to the idea of how important has become the energy efficiency and sustainability in the developed countries, where governments are submitted to stricter policies and this subject has become part of the goals of the richest countries. Table 2 shows the top 50 contributing countries and its total number of publications.

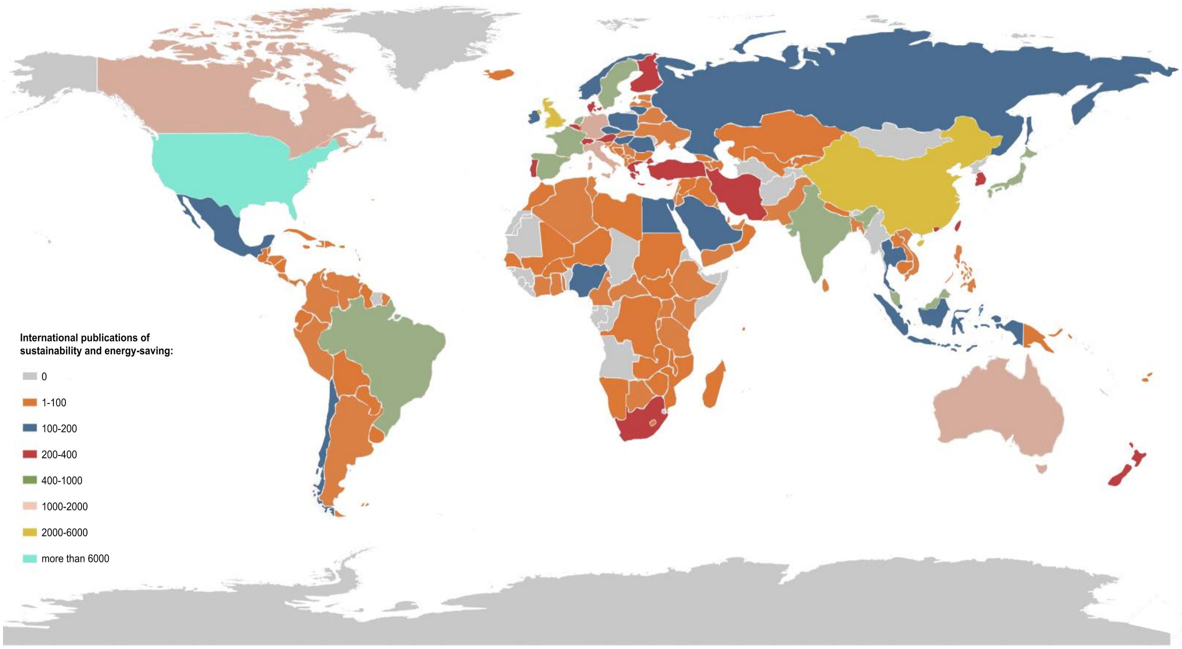


Figure II-3. Distribution of publications according to country. A big number of publications is represented by turquoise colour, whereas the orange colour indicates a small number of publications.

Table II-2. Number of publications according to country.

Country	Number of Publications	Publications/100,000 Inhabitants
United States	6175	1.92
United Kingdom	2825	4.34
China	2352	0.17
Australia	1676	7.05
Italy	1341	2.21
Canada	1164	3.25
Germany	1094	1.34
Spain	742	1.59
The Netherlands	734	11.35
Japan	626	0.49
India	544	0.04
Malaysia	505	1.67
Sweden	486	4.96
Brazil	466	0.22
France	435	0.65
South Africa	372	0.68
Hong Kong	363	4.97

Switzerland	359	4.33
Turkey	345	0.44
Portugal	342	3.30
South Korea	336	0.66
New Zealand	272	5.92
Taiwan	261	1.11
Austria	235	2.73
Greece	230	2.13
Belgium	227	2.01
Denmark	219	3.86
Iran	208	0.26
Norway	190	3.66
Singapore	183	3.18
Czech Republic	156	1.48
Romania	151	0.77
Mexico	147	0.12
Ireland	145	3.12
Russian Federation	138	0.10
Thailand	138	0.20
Egypt	135	0.15
Nigeria	132	0.07
Poland	119	0.31
Lithuania	117	4.02
Indonesia	110	0.04
Saudi Arabia	110	0.35
Hungary	103	1.05
Chile	100	0.56
Slovakia	97	1.79
United Arab Emirates	95	1.04
Colombia	81	0.17
Pakistan	81	0.04
Kenya	80	0.17
Serbia	80	1.13

Figure 4 shows the number of publications per year in relation with the country. As we can see, the United States is the most active country in this subject with more than 600 publications from 2012. The United States is followed by the United Kingdom and China with around 300 publications each year from 2012. All the countries show exponential growth in the number of publications during the years 2001 and 2003 as we have mentioned before. In Figure 5, the top 8 contributing countries during the last 16 years are presented.

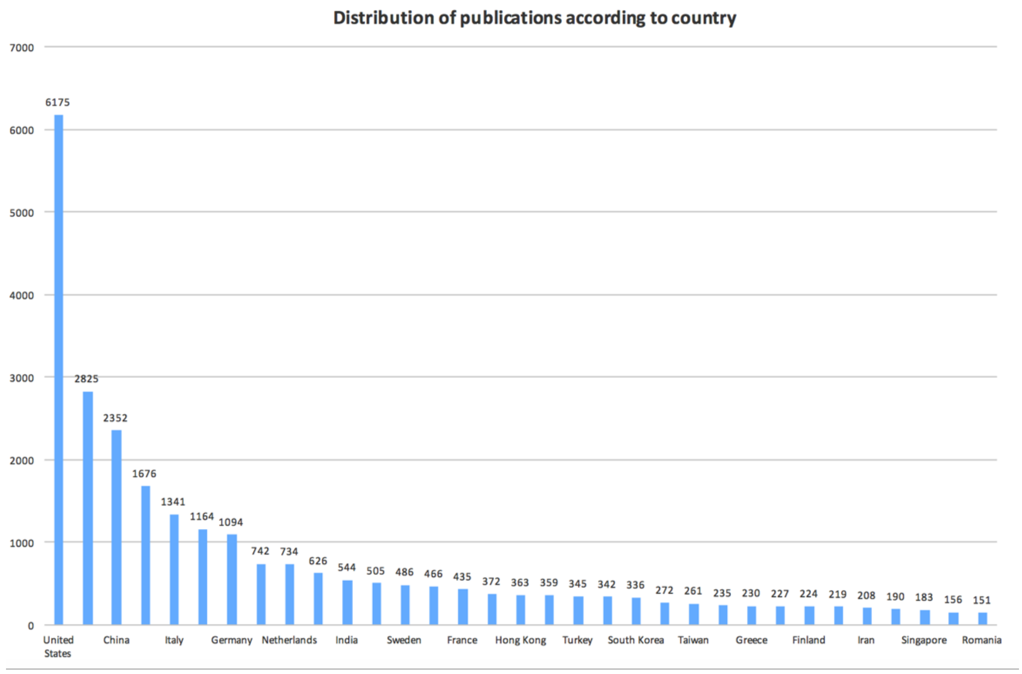


Figure II-4. Number of publications per year in relation with the country.

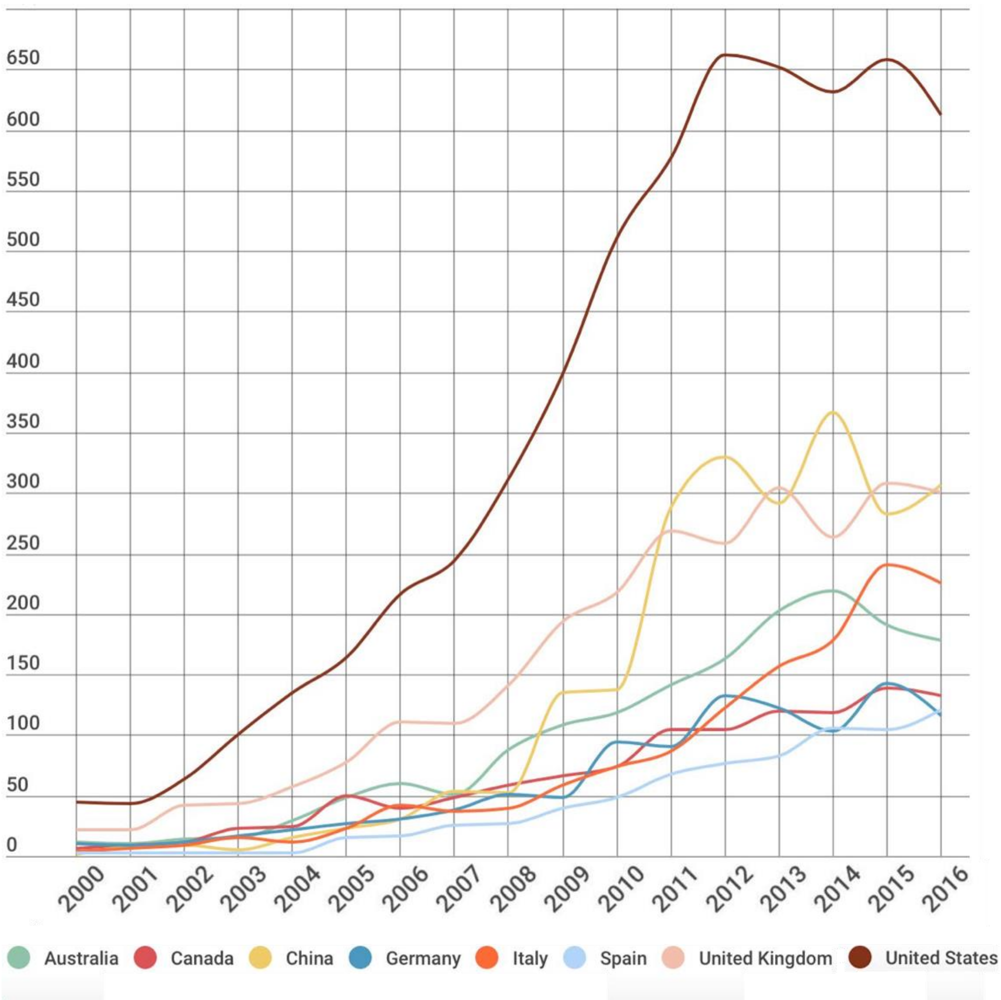


Figure II-5. Top 8 contributing countries during the last 16 years.

Figure 6 shows the ranking of the top 15 most productive international institutions around the world in the last 10 years. The three institutions with the highest numbers of published works on the subject are Hong Kong Polytechnic University, Delft University of Technology and Tsinghua University. In Figure 7, we can see the activity of the top 10 institutions during the last 10 years as well as the percentage of the total publications in the subject. Table 3 shows the exact number of publications of each institution per year, during the period 2006–2016.

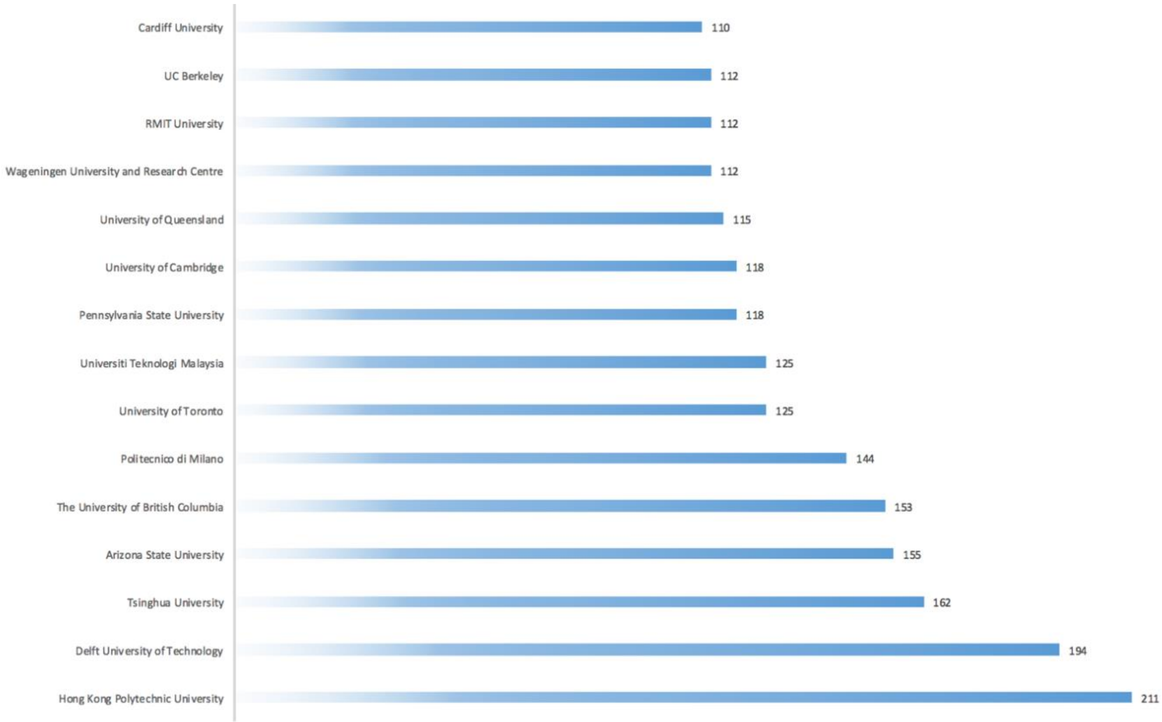


Figure II-6. Ranking of the top 15 most productive international institutions.

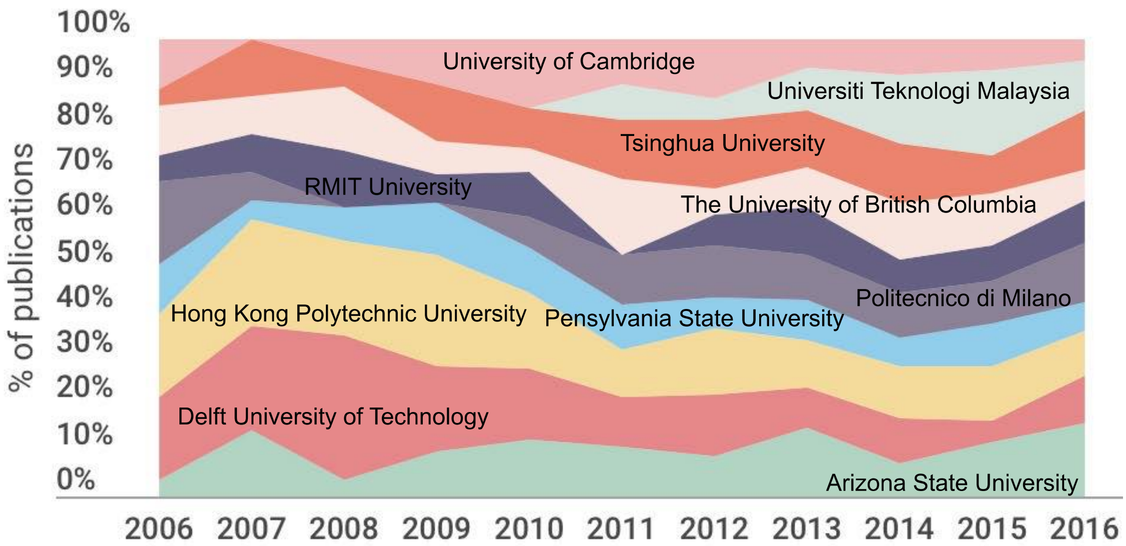


Figure II-7. Time evolution of the 10 most productive institutions during the period 2006–2016.

Table II-3. Publications from the 10 most productive institutions during the period 2006–2016.

Institution	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
Hong Kong Polytechnic University	10	11	12	20	12	11	20	18	20	24	18	176
Delft University of Technology	10	11	18	15	11	11	19	15	18	10	19	157
Tsinghua University	2	6	3	10	6	13	21	21	23	17	23	145
Arizona State University	2	7	2	8	9	11	12	26	13	24	30	144
Politecnico di Milano	10	3	0	0	5	11	16	17	18	19	24	128
The University of British Columbia	6	4	8	6	4	17	8	15	22	23	13	126
Universiti Teknologi Malaysia	0	0	0	0	0	8	6	16	27	37	20	118
University of Cambridge	6	0	3	8	11	10	18	11	14	14	9	106
Pennsylvania State University	6	2	4	9	7	10	9	15	11	18	11	102
RMIT University	3	4	7	5	7	0	9	18	13	16	17	102

Figure 8 is a map in which the relation between different countries that share a co-author in different publications is analyzed. The map was obtained with the software VOSviewer v.1.6.5 (CWTS Leiden of Leiden University, Leiden, The Netherland) including a CSV file obtained in Scopus with the most significant terms of our search. We can see a strong relationship between the USA and Canada; also between the UK and the USA, and the UK and Italy. The exchange of information and works between developed countries and also countries that share the same language is normal, although it is obvious that English is the international language and that is no longer a barrier. We can also see some countries that have no relationship with any country in this field.

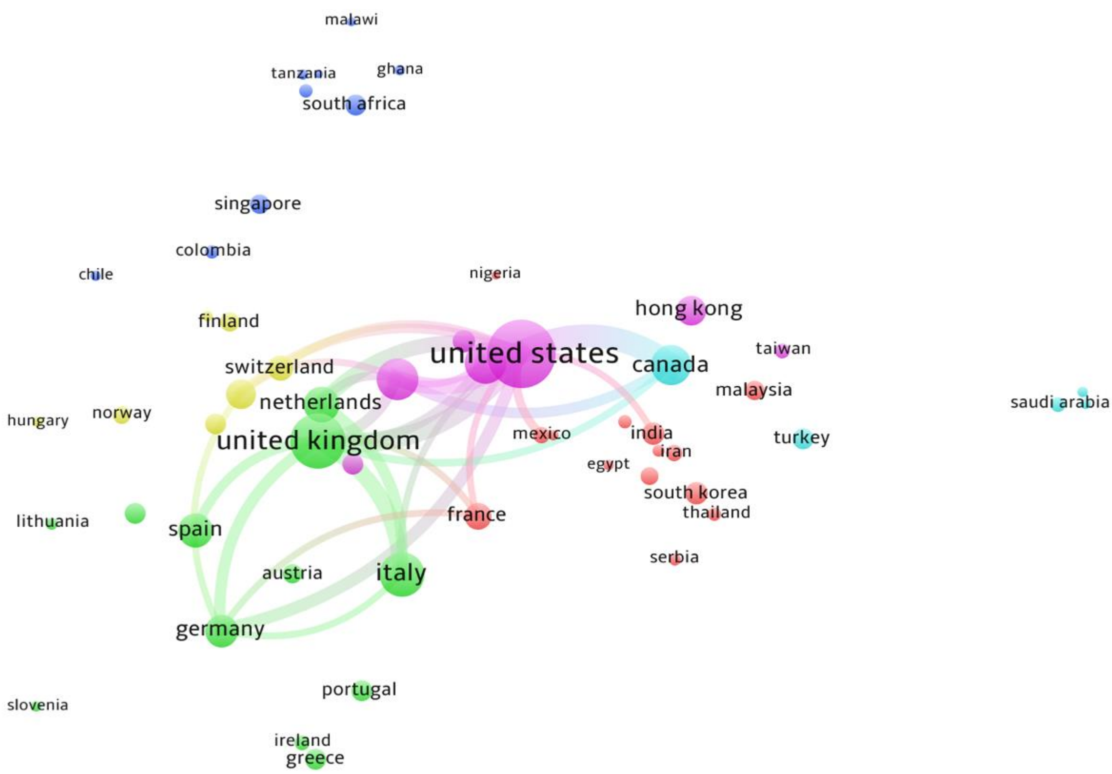


Figure II-8. Network collaboration between countries.

II-4.4. Distribution of output in subject categories and journals.

Figure 9 presents a graphic with the search results classified by subject. Engineering is the one with the highest rate (36.8%), followed by Social Sciences (27.4%) and Environmental Sciences (19.5%). We can observe an area called "Other" which includes the undefined subjects or areas. Table 4 gives us information about the number of publications according to the subject.

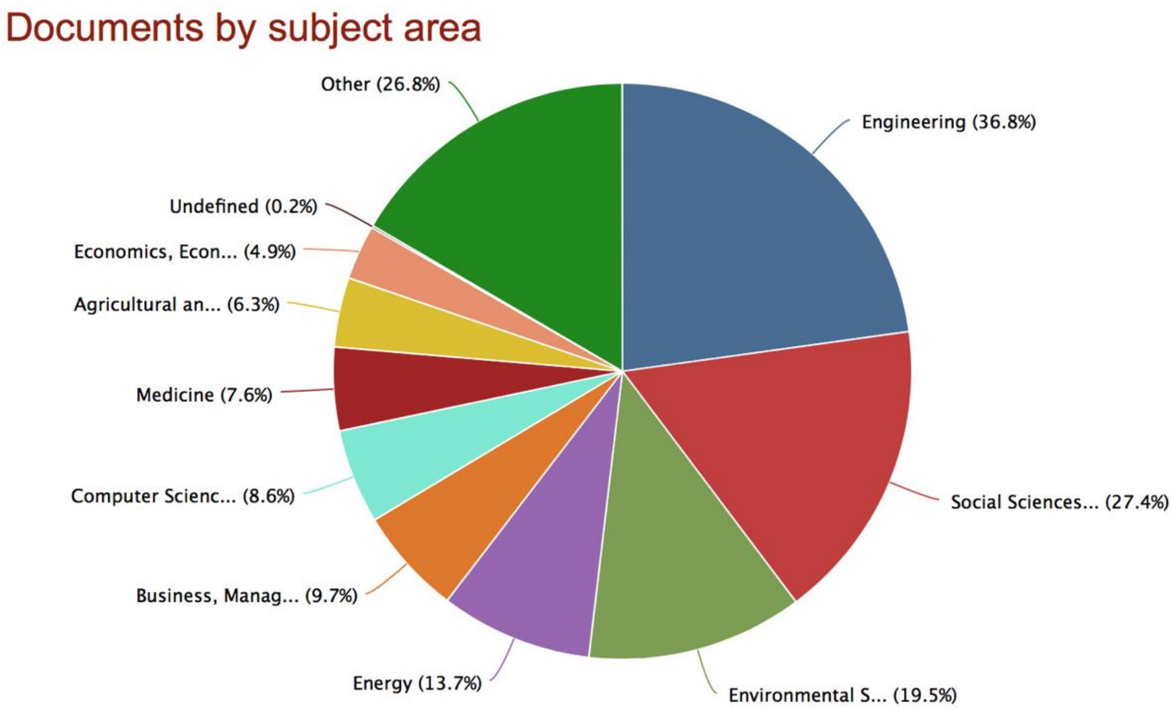


Figure II-9. Distribution of publications according to subject, as classified by Scopus. Note: A document can be assigned to more than one single subject.

Table II-4. Number of publications according to subject.

Subject Area	Number of Publications
Engineering	9761
Social Sciences	7260
Environmental Science	5178
Energy	3637
Business, Management and Accounting	2578
Computer Science	2267
Medicine	2005

Agricultural and Biological Sciences	1671
Economics, Econometrics and Finance	1302
Materials Science	1008
Earth and Planetary Sciences	963
Arts and Humanities	882
Chemical Engineering	693
Mathematics	594
Physics and Astronomy	473
Decision Sciences	465
Psychology	375
Nursing	344
Chemistry	343
Biochemistry, Genetics and Molecular Biology	331
Multidisciplinary	200
Health Professions	146
Immunology and Microbiology	103
Pharmacology, Toxicology and Pharmaceutics	86
Veterinary	42
Neuroscience	24
Dentistry	17
Undefined	56

Figure 10 and Table 5 show the top five journals in which most of the work has been published. We have presented this data through the h-index, which is the most commonly used to analyze the publication level of a journal. In first place, we have the journal Energy and Buildings with a 103 h-index, followed by Journal of Cleaner Production with a 96 h-index and in third place is the International Journal of Sustainability in Higher Education with a 29 h-index. In the graph, we can see a relation between the SJR (Scientific Journal Ranking) index and the JCR (Journal Citation Report) index; we tried to obtain the most accurate data.

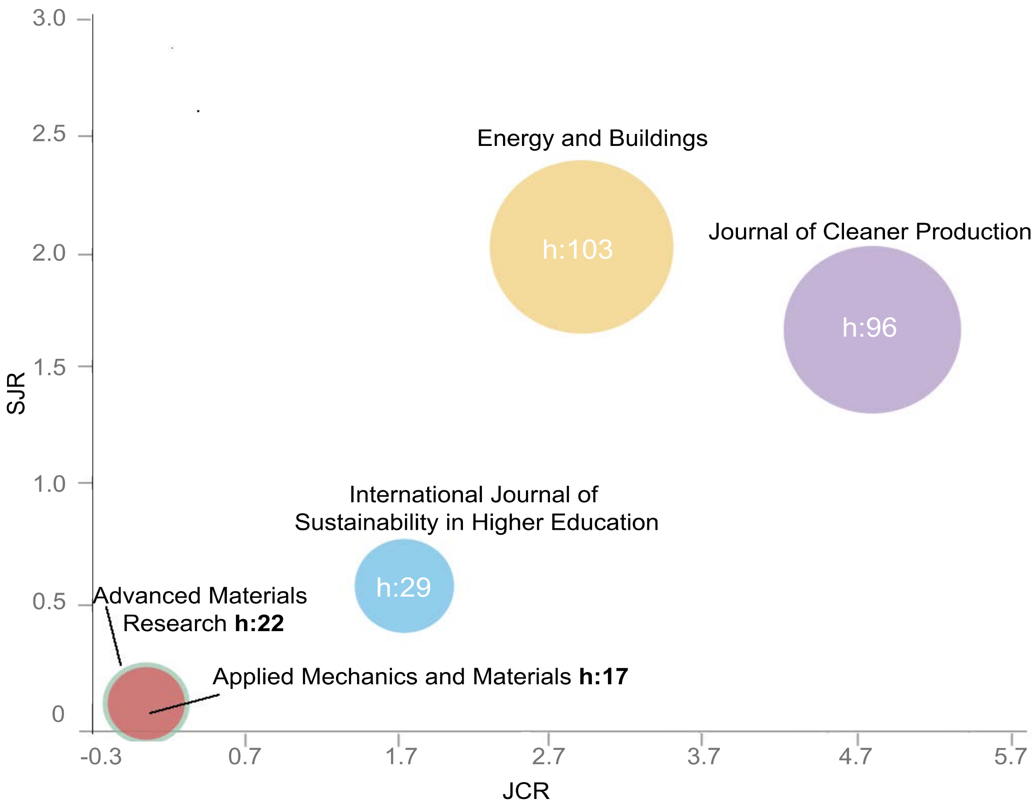


Figure II-10. Ranking of the top five journals. JCR is the ranking in the Journal Citation Report by Thomson–Reuters, New York (USA), and SJR is the Scimago Journal Rank by Elsevier, Amsterdam (The Netherland). H-index is represented by the size of each circle.

Table II-5. International journals with the most impact factor of scientific publications.

Journals	Q	SJR	h-index	JCR	Total Docs (2015)	Total Docs (3 Years)	Total Refs.	Total Cites (3 Years)	Cites/Doc (2 Years)	Country
Advanced Materials Research	Q4	0.115	22	#N/A	94,801	256,334	5553	18,689	0.077	Switzerland
Applied Mechanics and Materials	Q4	0.113	17	#N/A	82,984	168,077	4079	9926	0.064	Switzerland
Energy and Buildings	Q1	2.073	103	2.973	775	2207	17,211	39,819	3.392	The Netherlands
International Journal of Sustainability in Higher Education	Q2	0.616	29	1.763	42	101	1741	2043	2.328	United Kingdom
Journal of Cleaner Production	Q1	1.721	96	4959	1167	2582	19,373	40,166	5.283	United Kingdom

Today, it is necessary to combine different techniques and, above all, to look for applications of generated representations that allow us to go beyond the obvious from the analytical point of view. Figure 11 shows the overlay of the top journals in Environmental Science, Engineering and Energy areas at an international level, with 1597 journals being found. This graphic is a useful tool to analyze the presence of Scopus publications in the scientific domain that concerns us, as well as the global distribution of the editorial capacity of the different countries or regions.

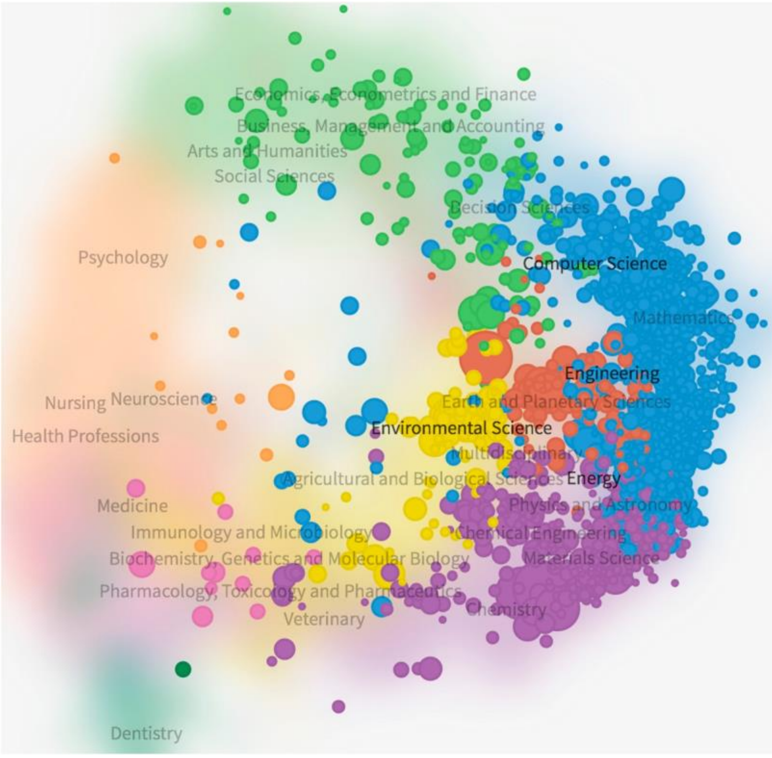


Figure II-11. Overlay in the subject areas Environmental Science, Engineering, Computer Science and Energy with the SJR-2015 representing the size of the node.

The map is generated from the relational matrix based on citation, co-citation and bibliographic coupling that form the almost 20,000 publications (magazines and congress proceedings) registered in Scopus. The interface allows the visualization of the bibliometric indicators of the publications and the structure of clusters that they form based on their use by the authors of the works. The interface can use the overlay mapping methodology to place the subsets of selected publications in the context of the overall structure of publications. The nodes' colors correspond to the different clusters that the algorithm detects. There is a green cluster at the top devoted primarily to the social sciences and humanities. On the left side, there is an orange cluster corresponding to Psychology, Neuroscience, Nursing and Health Professions. Below is a pinkish cluster dedicated to Medicine. At the bottom, this cluster is merged with a blue–green dedicated to Ophthalmology and Optometry, and another green of Dentistry. Then, on the right side, two clusters are observed, one yellow dedicated to the sciences of the life (Agricultural and Biological Sciences, Environmental Science...) and another purple one dedicated to Chemistry, Materials Science and Chemical Engineering. These two clusters are merged with two others, one reddish brown from Earth and Planetary Sciences and another light blue, rather elongated beginning with Physics and Astronomy, Mathematics, Computer Science and ending with Decision Sciences when it merges with

Economics, Econometrics and Finance. It is observed that the main group of magazines is in the right part of the thread, which matches with the areas of Environmental Science, Engineering, Computer Science and Energy.

II-4.5. Analysis of authors and keywords.

Figure 12 and Table 6 show the five most relevant authors in the field of sustainability in the last 10 years. It can be clearly observed that Cotana, F. is at the top of the ranking with 113 publications since 2006. This author has an h-index 18 and most of his works have been published by the Universita degli Studi di Perugia. Following him is Orosa, J.A. with 105 works. This author of the University of Coruña has an h-index of 13, while Jia, Q.S., Pisello, A.L. and Bragança, L. have published a total of 97, 73 and 51 articles respectively in the period 2006–2016. It is also observed how in recent years there has been a significant increase in the number of publications on the issue at hand. A relevant fact that supports this assertion is that the sum of publications over the last three years accounted for more than 50% of all publications in the last decade. In 2014, a total of 84 publications were obtained among the works of the five most relevant authors.

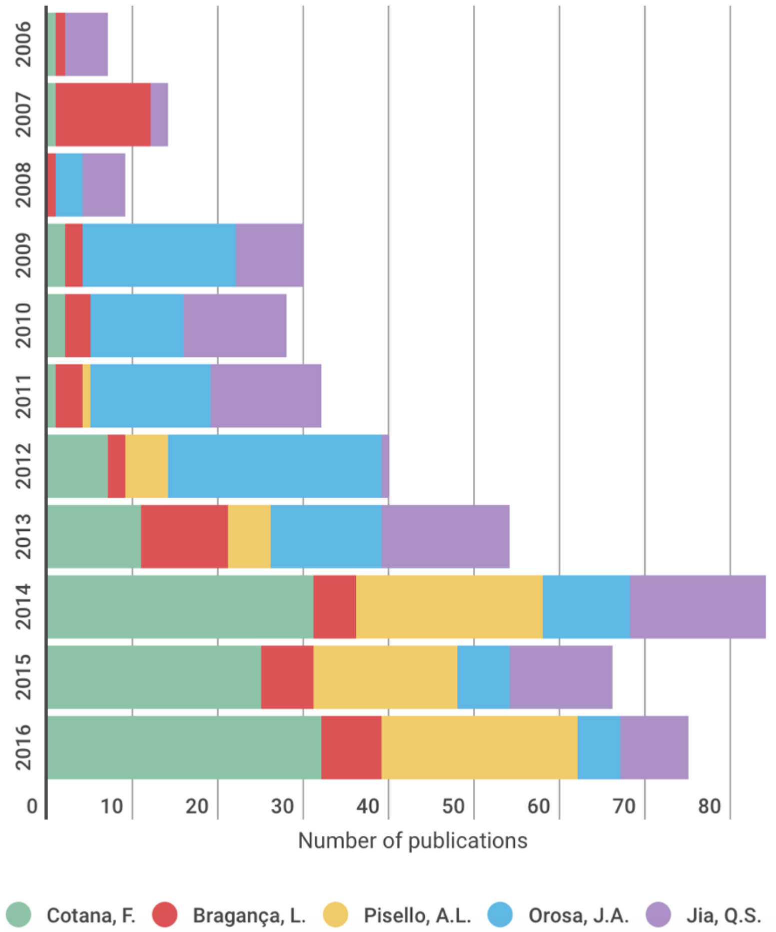


Figure II-12. Distribution of authors according to the number of publications during the period 2006–2016.

Table II-6. Number of publications of the most relevant authors between 2006 and 2016.

	Cotana, F.	Orosa, J.A.	Jia, Q.S.	Pisello, A.L.	Bragança, L.	Total
2006	1	0	5	0	1	7
2007	1	0	2	0	11	14
2008	0	3	5	0	1	9
2009	2	18	8	0	2	30
2010	2	11	12	0	3	28
2011	1	14	13	1	3	32
2012	7	25	1	5	2	40
2013	11	13	15	5	10	54
2014	31	10	16	22	5	84
2015	25	6	12	17	6	66
2016	32	5	8	23	7	75
Total	113	105	97	73	51	439

In Figure 13, the relation between co-authors who collaborated with the most important authors of Table 6 are shown. We can see a more frequent relationship between Asian authors, probably because of the language and the close distance of their institutions.

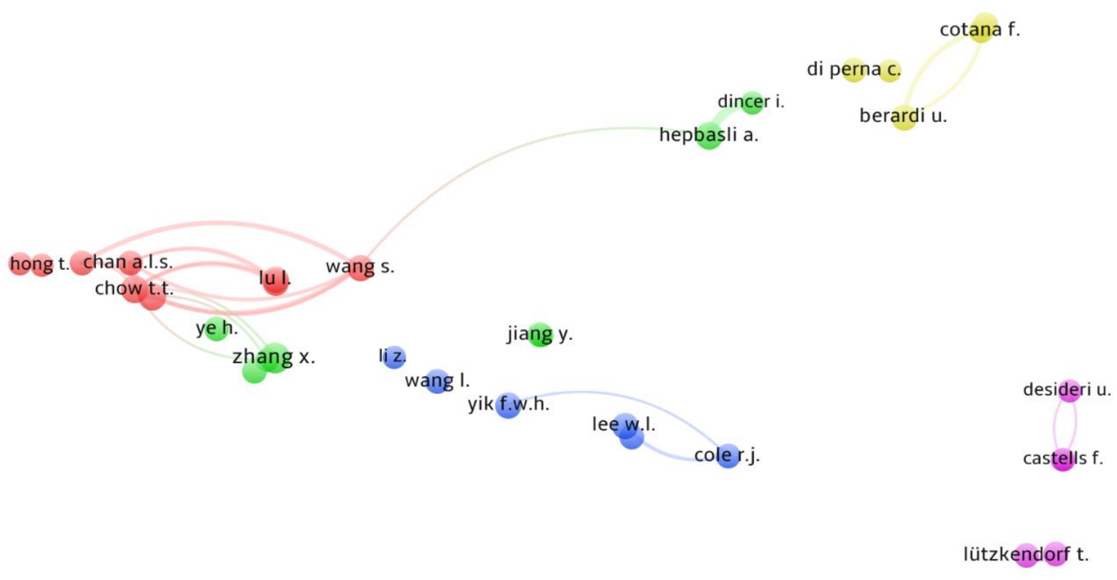


Figure II-13. Co-authorship network (related to Table 6).

It is important to analyze the keywords used in the search, in order to specify which branches and areas have been taken into account in the work. In total, our search resulted in 26,644 items in the last 40 years. The keyword "Sustainable Development" was present in 6679 items (25.1%). This was followed by "Sustainability" with 5864 (22%) and "Energy Conservation" with 3512 (13.2%). Table 7 shows the 40 most relevant keywords during the analyzed period.

The analysis of keywords in scientific articles is of great interest for the follow-up and search of tendencies in the branches of science and engineering. In order to obtain the before mentioned data, it was necessary to carry out a process of filtering in the data provided by Scopus. It should be remarked that numerous variants, depending on how each author writes the keyword, were detected. For example, "ENERGY" can be written as "Energy", "energy", "Energies" or "energies", giving rise to different versions of the same concept. For example, in our table, the first position was the concept "Sustainable Development" and the second one "Sustainability"; both concepts would have aspects in common, although they do not have the same meaning at all.

A string with a combination of different keywords was used to determine the number of scientific publications in this field. The first term to include in the search was "sustainability", then other concepts such as "energy saving", "building" and many more; it was necessary to evaluate the possibility of including quite similar terms such as "school" and "university" in order to encompass the term "public use building". The string of terms tried to be specific to each concept, as follows: TITLE ({sustainability}) OR ABS ({sustainability}) OR AUTHKEY ({sustainability}) OR TITLE ({energy saving}) OR ABS ({energy saving}) OR AUTHKEY ({energy saving}) AND TITLE ({building}) OR ABS ({building}) OR AUTHKEY ({building}) OR TITLE ({buildings}) OR ABS ({buildings}) OR AUTHKEY ({buildings}) OR TITLE ({school}) OR ABS ({school}) OR AUTHKEY ({school}) OR TITLE ({schools}) OR ABS ({schools}) OR AUTHKEY ({schools}) OR TITLE ({office}) OR ABS ({office}) OR AUTHKEY ({office}) OR TITLE ({offices}) OR ABS ({offices}) OR AUTHKEY ({offices}) OR TITLE ({university}) OR ABS ({university}) OR AUTHKEY ({university}) OR TITLE ({universities}) OR ABS ({universities}) OR AUTHKEY ({universities}) OR TITLE ({public buildings}) OR ABS ({public buildings}) OR AUTHKEY ({public buildings}) OR TITLE ({public building}) OR ABS ({public building}) OR AUTHKEY ({public building}).

Table II-7 List of the 40 most used keywords.

	TERM	ITEMS	%
1	Sustainable Development	6679	25.1
2	Sustainability	5864	22.0
3	Energy Conservation	3512	13.2
4	Energy Efficiency	2585	9.7
5	Buildings	2273	8.5
6	Energy Utilization	2263	8.5
7	Human	1525	5.7
8	Energy Saving	1521	5.7
9	Article	1454	5.5
10	Humans	1330	5.0
11	Education	1083	4.1
12	Environmental Impact	1077	4.0
13	Intelligent Buildings	1009	3.8
14	Design	978	3.7
15	Office Buildings	948	3.6
16	Architectural Design	910	3.4
17	Construction Industry	873	3.3
18	Air Conditioning	869	3.3
19	Life Cycle	823	3,1
20	United States	737	2.8
21	Students	727	2.7
22	Decision Making	718	2.7
23	Climate Change	717	2.7
24	Research	675	2.5
25	Housing	655	2.5
26	Building	652	2.4
27	Economics	649	2.4
28	Teaching	649	2.4

29	Building Materials	637	2.4
30	Carbon Dioxide	630	2.4
31	Environmental Sustainability	601	2.3
32	Heating	596	2.2
33	Curricula	586	2.2
34	Planning	572	2.1
35	Environmental Protection	522	2.0
36	Investments	522	2.0
37	Environmental Management	513	1.9
38	Urban Planning	512	1.9
39	Organization and Management	511	1.9
40	Ventilation	509	1.9

Figure 14 shows a map of the most common keywords that our search revealed. They are divided by their field, indicated by colours. We can see that the biggest circles represent the more frequent terms such as "sustainable development", "sustainability", "energy conservation", "energy efficiency" and "buildings". Also, the lines that link the circles represent the connection between keywords through different articles or publications.

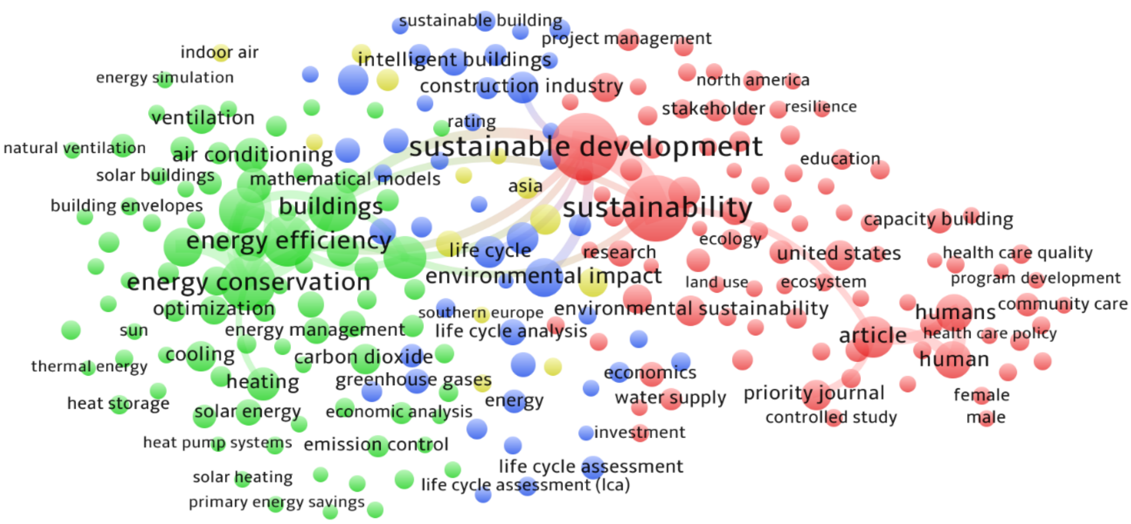


Figure II-14. Co-occurrence-keywords.

Figure 15 shows a trend graph of these five terms throughout the analyzed period. There is an evident inclination in the use of the first two terms, where the term sustainability appears. Sustainability is a narrow area of equilibrium in the complex relationship between the environment, the economy and society [39].

These two keywords are followed by "energy conservation" and "energy efficiency", which are also related to sustainability. Although these terms are commonly joined together, they have very different meanings. While energy conservation involves sacrificing the quality of energy services and well-being to reduce energy consumption, energy efficiency is related to saving, producing more with less energy, without affecting the comfort factor [40]. The clear upward trend is observed at the beginning of 2004 and this evolution continues until 2015, when the growth tends to stagnate or fall. This shows that the terms used are replaced by others in the most recent year, although the topics treated continue to be of great interest to the scientific community.

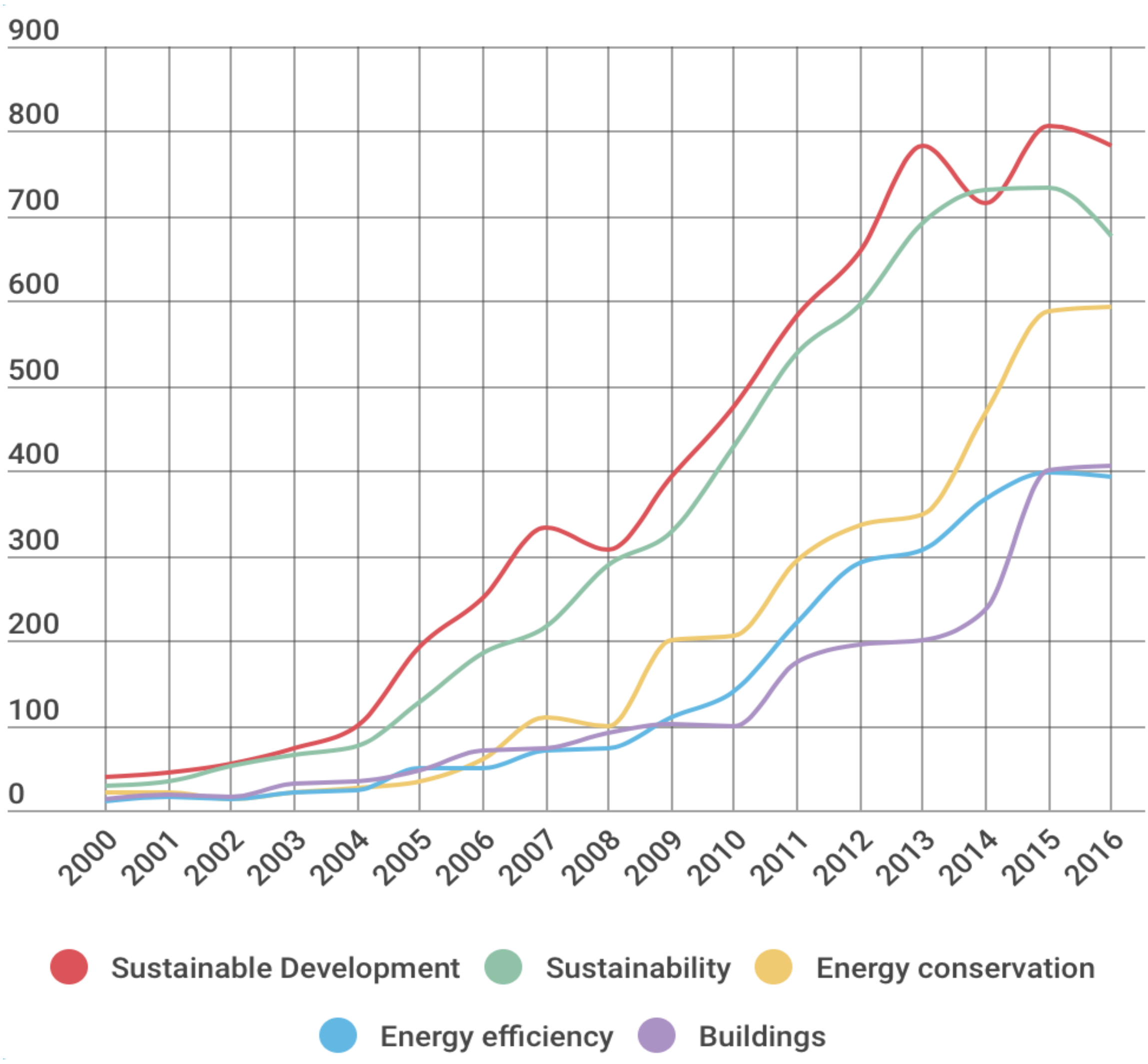


Figure II-15. Evolution of the 5 words most used within the keywords of authors in the period 1976-2016.

II-5. Discussion and conclusions.

A search was made for energy saving and transport, to compare it later with the search of energy saving and buildings. The transportation sector is characterized by a high consumption of fossil fuels and a strong environmental impact [41]. Some countries have policies to promote electric vehicles as an alternative to reduce and limit fossil fuel consumption and move towards the sustainability of the transport sector [41].

For this comparison, the methodology described above was used, but instead using the terms "transport" and "Energy saving". The results are shown in Figure 16. It is observed that, in general, there are less published items in the transport sector (17,304) than in the buildings sector. However, on the other hand, it is observed that the countries deeply involved in sustainability through energy efficiency are equally active in the building sector as in the transport sector.

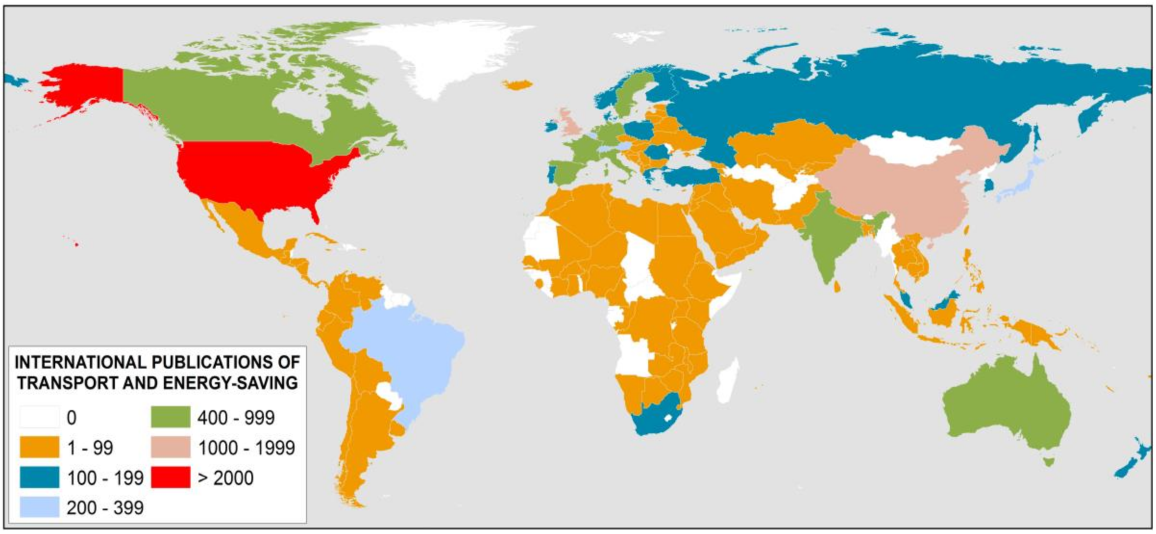


Figure II-16. Distribution of Transport and Energy Saving publications according to country.

Returning to the central research topic, a wide range of data on the international contribution to the scientific knowledge in the field of sustainability and energy-efficiency during the period 1976–2016 has been highlighted. In total, 26,585 publications have been found in more than 27 different categories. In this period, there has been an exponential increase in the number of publications, highlighting the categories of Engineering, Social Science and Environmental Science.

It is identified that the year of greatest productivity was last year with a total of 3207 publications, with Energy and Buildings being the journal that published most on this subject; several authors have been responsible for producing most of the work.

The works have mostly been published in international journals (57%) and congresses (28%), with English being the most common language in which the papers were written (more than 95%).

The institutions that publish the most are Hong Kong Polytechnic University, Delft University of Technology and Tsinghua University. They are located in Hong Kong, The Netherlands and northwest Beijing, China, respectively, representing more than 30% of the total publications during the last 10 years among the three of them. Something not to be ignored is that these three are public universities.

In Europe, the United Kingdom, Italy, Germany, Spain, The Netherlands, Sweden, and France are the countries with the highest number of international publications, with the United Kingdom accounting for almost 60 per cent of the total European publications in this field.

The analysis of the keywords for the studied publications reveals a great dispersion in the use of the set of keywords selected. Many compound terms are used which give rise to a larger number of unique terms. In addition, very similar concepts are written in different ways, giving rise to a greater variety which is clearly artificial as it does not mean any real complexity in the terms.

The most commonly used terms are "Sustainable Development", "Sustainability", "Energy Conservation", "Energy Efficiency" and "Buildings". In addition to these terms, others such as "Energy conservation" or "Energy efficiency" allude to the general environmental concern about energy prices and their environmental impact in the international community, especially in the last years.

As a final remark, this work shows that the international contribution to sustainability research is well preserved, generating a large number of publications in relevant journals and conferences. The strong development in energy efficiency in Europe has also stimulated research in this field, as seen from the data analyzed.

Author Contributions: Carmen de la Cruz-Lovera dealt with literature review and article writing. José-Luis de la Cruz-Fernández and José Antonio Alvarez-Bermejo analyzed the data. Francisco Manzano-Agugliaro and Alberto-Jesús Perea-Moreno: Research idea, article writing and formatting. They share the structure and aims of the manuscript, paper drafting, editing and review. All authors have read and approved the final manuscript.

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest."

Abbreviations

The following abbreviations are used in this manuscript:

DIY: Do-It-Yourself

EE: Energy Efficiency

EPA-ED: Energy Performance assessment for existing dwellings

JCR: Journal Citation Report LEDs: Light-Emitting Diodes

NGOs: Non-Governmental organizations

SJR: Scientific Journal Ranking

ZEB: Zero-Energy Buildings

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Chapter III. Date Seeds (*Phoenix dactylifera L.*) Valorization for Boilers in the Mediterranean Climate.

Chapter III. Date Seeds (*Phoenix dactylifera L.*) Valorization for Boilers in the Mediterranean Climate

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III-I. Abstract.

Energy saving is a global priority, as it is helping both energy and environmental sustainability by reducing CO_2 emissions. The search for new energy solutions is therefore necessary. In the Mediterranean climate, resources are generally scarce, and all energy sources need to be explored, including biomass from agricultural or industrial waste. There is a clear upward trend in date worldwide production, having doubled its world production in the last 10 years, and this trend is particularly relevant for Mediterranean climate countries, especially in North Africa and nearby countries. This study analyzes the properties associated with the date seed (*Phoenix dactylifera* L.) to evaluate its suitability and viability as a new biofuel. Specifically, the viability of replacing the existing gas boiler in a university building in the south of Spain with a system of biomass boilers using this biomass was analyzed as a case study. The results reveal that this biomass has HHV values very similar to those of other biomass sources, 19.121 MJ/kg. With the replacement of the gas boiler by a biomass that uses the date seed, a reduction of 95 tons of CO_2 per year is obtained and an economic saving of more than 66% is achieved. In short, this work opens new perspectives for the use of this biomass of date seed in boilers and it is an efficient solution for large public buildings such as the buildings of Mediterranean climate universities.

Keywords: **date seed; sustainability; biomass boiler; renewable energy; CO_2 reduction; energy efficiency**

III-2. Introduction.

Sustainable development promotion should prioritize sustainable technologies [1] such as clean and sustainable energies, providing importance to energy efficiency [2] and to the reduction of environmental pollution [3]. In this way, sustainable development promotion also creates solutions that encourage the reduction of emissions [4]. However, it should not be forgotten that policy is particularly important, such as for limiting the use of non-renewable fuels or plans to stop global warming. More and more policies are seeking energy efficiency and the rational use of energy, which reduce costs for companies and individuals [5]. The clearest example is the Paris agreement of 2015, which promotes a global action plan to limit global warming to below 2ºC [6].

The building industry has a greater impact on sustainable development than others due to its high energy consumption [7], and is therefore one of these sectors that requires more attention [8]. Measures are framed within all the steps in which this industry is involved in order to reduce energy consumption by incorporating energy efficiency strategies in the design [9], construction and management of buildings [10,11], as well as in the application of technology to improve the efficiency of existing buildings [12], including the retrofit strategies [13].

An efficient building will be one that consumes little energy and that a large part of that energy would be of renewable origin [14]. This energy efficiency is measured by CO_2 emissions or by the consumption of non-renewable primary energy derived from final energy consumption (electricity or fuels). At the end of 2018, the policy became more and more strict, and near zero energy consumption became part of a compulsory legal specification for constructors of buildings. The standard EN15251 specifies indoor environmental criteria that have an impact on energy efficiency. Air quality, lighting and acoustics are some of the environmental parameters it regulates [15]. This framework presents us with the study of energy efficiency in public buildings as not only a subject with an increasing interest, but also makes it mandatory to study new measures and seek solutions to promote greater energy efficiency in local institutions [16].

There has been a growing interest in recent times towards energy efficiency and sustainability in universities, acquiring this important knowledge in creating an increasingly cleaner and more sustainable future. The energy consumption of buildings is largely dependent on the criteria used for the design and operation of the interior space. Aspects such as lighting, noise, ventilation or temperature are of vital importance. Because of this, they can even have an impact on a state of health of a person or their work efficiency [16]. Today, in industrialized countries, city dwellers spend 60%–80% of their time in enclosed spaces, so poor quality living conditions can seriously affect people. If these enclosed spaces are educational buildings, the quality of the indoor environment has direct repercussions on the performance and concentration of students and other staff working in them. In order to improve the living conditions of users inside buildings, it is necessary to implement self-monitoring plans for indoor environmental quality [17].

Once a conceptual framework has been established, there is a need to establish what real changes can be made in universities in order to improve their energy efficiency and consequently their environmental impacts. Biomass is becoming more popular as a high sustainable energy source. Its carbon neutral condition and high availability worldwide are making it an appealing choice for new ways of energy in the field. It can be obtained from agricultural and industrial waste and has grown from 9% to 14% of total primary energy consumption in the agro-industrial sector. However, it can be discarded by the industry without even being used as an energy source [18]. The most common and widely accepted fuels derived from biomass are pellets, wood chips, firewood or olive seeds [19,20]. In recent years, however, more and more waste fruits have been emerging in the marketplace that may be extremely appropriate as biomass sources. Recent studies show the high suitability of other fruit stones such as avocado or mango as biofuel in both domestic or industrial heating facilities [21–23]. This work focuses its attention on the use of biomass as a renewable energy fuel and studies the suitability of date seeds as a solid biofuel to produce heating energy. To achieve this objective, their energetic qualities are described and parameters such as higher heating value, lower heating value, moisture, elemental composition or ash content are evaluated [24].

The date is the fruit obtained from the species *Phoenix dactylifera* L., popularly called the finger palm, see Figure 1. The production of dates is one of the most important agricultural activities in the arid regions of East Asia and North Asia [25]. They can also be found in southern Europe, the African continent, Asia, Australia, South America and the USA, especially in southern California, Arizona, and Texas [26]. Much agricultural waste is generated from date palms in the most desert-filled areas of the earth and in Mediterranean climates [27]. It is not only produced in the food sector, for humans and animals, but also in the construction sector, including textiles, among others. The tree begins to bear fruit between 3 and 5 years and ripens definitively at the age of 12. In general, there is a clear upward trend in the production of dates. A clear example of this is the increase over time of the metric tons of dates produced. From 4,569,532 metric tons in 1994 has almost doubled production in 2016, reaching 8,460,443 metric tons produced in 1,353,159 hectares [28].

Until the 1990s, Iran and Iraq were the world's largest producers, but currently, the country at the top of the ranking is Egypt with an approximate annual production of 1,470,000 metric tons of dates, assuming 17% of global date production. Egypt has increased its production more than 100% since 1993 and currently has a figure of 15,582,000 date palms. Iran and Saudi Arabia follow in this order with more than 1,000,000 metric tons of dates being produced annually in some countries, such as Oman, Egypt, Pakistan and the United Arab Emirates, where there has been a significant increase in the production of dates. In contrast, due to the trade embargo, production decreased in Iraq and in Morocco, due to phytosanitary problems.

For this reason, this article seeks to study new possibilities of date seeds as biofuel for boilers in the Mediterranean climate, using a University in the south of Spain as a case study, in which the calculated carbon footprint has halved from 2012 to 2017, which should improve energy saving in the buildings of the university.

Figure III-1. *Phoenix dactylifera*, popularly called finger palm.

III-3. Materials and Methods.

III-3.1. Materials.

In order to test the energy efficiency in the Mediterranean climate and economic viability of the date bone as a solid fuel, a building has been chosen located on a university in the south of Spain (37° 54′ 55.4′′N, 4° 43′′ 09.06′′ O).

The university population has a total of 19,435 people (end 2017), of which 16,610 are students (14,321 Grade, 1636 Masters and 653 Exchange Programs), 2825 staff (1452 teachers, 770 members of administration and services staff and 603 contracted from projects). In this university there is already an indicator of the environmental impact produced by the institution, since environmental awareness is the order of the day. This indicator can help us to know the current situation as far as energy consumption is concerned. This energy indicator is known as the "Carbon Footprint Calculation". The quantification of emissions allows us to be aware of the impact generated by the activity of the university on global warming, thus turning the carbon footprint into a valuable awareness tool. Measuring the carbon footprint is a way of evaluating the institution's contribution to climate change. In addition, understanding the emissions generated by its activity, quantifying them and knowing their sources, is necessary as a first step to propose reduction strategies.

The building under study has a cruciform floor, with 5 levels distributed in a semi-basement, ground floor, first floor, second floor and third floor. It has a total living area of 4752 square meters and was built between 1953–1956. Its use is mostly for teaching classes, with departmental spaces and several classrooms.

It is proposed to replace the existing natural gas boiler in the building with the introduction of a biomass boiler system. This use of biomass as an alternative for fossil fuels would provide cost savings and reduction in greenhouse gaseous emissions [29]. The biomass boiler would be used to generate heating in that building, using radiators as terminal elements to thermally acclimatize the spaces. The operation of a biomass boiler is similar to a conventional boiler. First the natural fuel is burned, recovering the heat generated during the combustion of the biomass to heat the water of the circuit of the boiler exchanger, taking the hot water to the heating circuit.

The heating system (hot water heating) uses water as a carrier heat between the boiler and the terminal elements located in the buildings. The boiler (natural gas), located in the semi-basement of the building, heats the cold water, which by means of a transport system and groups of electric pumps that drive the hot water through a network of pipes, reaches the radiators located on each floor of the building, acting as heat exchangers with the environment, heating the temperature of the environment through the temperature of the water that runs through the tubes of these terminal elements. The radiators are monotube, that is to say, they are characterized by having the hot water inlet and the cold water outlet in the same faucet. The hot water runs through the rings of the radiators until the reverse circuit is made, returning the cold water, through the same faucet, to the boiler, where the heating cycle is repeated. The circuits are separated by means of devices called collectors, one for the hot water circuit and the other for the cold water circuit. The number of cast iron radiators distributed throughout all its plants is 346 radiators. It also has gas heaters as domestic hot water devices, with 4 heaters of 100 litters each for use as fountains or sinks. Figure 2 shows the operating diagram of the gas natural boiler.

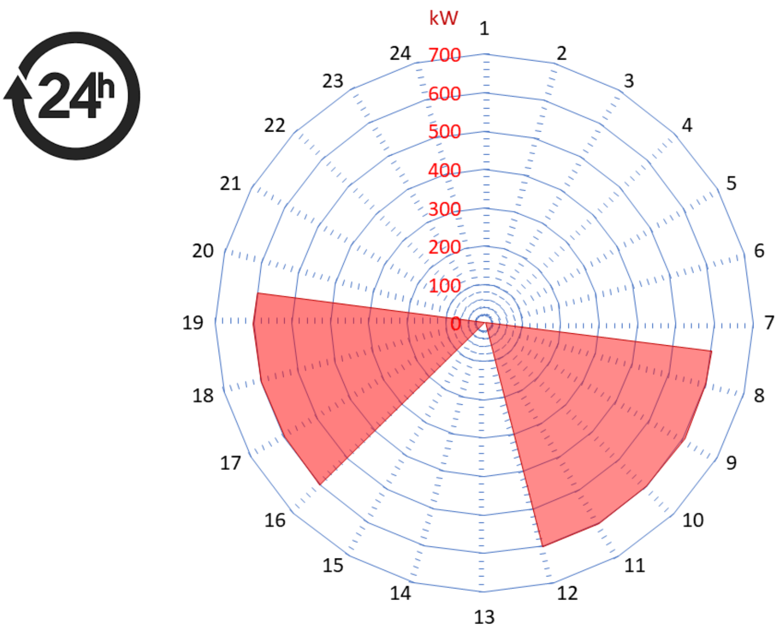

Figure III-2. Operating diagram of the natural gas boiler.

III-3.2. Performance Values.

The performance values are specified in Part 1 of standard EN 14961. This is a very generic norm that describes how to classify biomass to be used for energy purposes and details the main commercialized forms of solid biofuels [30]. The indication of the most significant characteristics of biofuels is obligatory and must be quoted in the fuel specification. The characteristics are very varied, depending on different factors. However, the most important parameters are the following where the determination standards (EN) used are referred to: Moisture (EN 14774-1), Ash (EN 14775), Higher heating value (EN 14918), Lower heating value (EN 14918), Total carbon (EN 15104), Total hydrogen (EN 15104), Total nitrogen (EN 15104), Total Sulfur (EN 15289), and Total chlorine (EN 15289).

These characteristics could depend to a large extent on climatic and soil conditions. Water consumption is an important limitation in arid regions where there is an abundance of date palms and makes the crop's drought resistance an important factor.

III-3.2.1. Physical Values: Humidity.

One of the most important parameters is the moisture content of the sample. This parameter decisively affects the energy we can obtain from biomass. It is essential that all the water contained in the product is completely removed before the heat is released. There are two data related to moisture content: intrinsic moisture, where meteorological conditions do not influence and the extrinsic moisture, which takes into account several factors such as the climate present during the ripening of the fruit, which will affect the moisture of the biomass. The main determinant feature examined is how much extrinsic humidity it presents, because the amount of intrinsic humidity can be obtained in a laboratory. In this study extrinsic moisture has been chosen. The lower the moisture content of the material, the more that tar emissions, which tend to retain traffic exhaust and cause corrosion and clogging problems in chimneys, will be reduced [31].

III-3.2.2. Physical Values: Element composition.

The UNE-EN 15104 standard has been applied to calculate the total carbon, hydrogen and nitrogen content of the sample. The elemental biomass structure is obtained burning the sample in contact with the air, in such a way that the combustion gases and ashes are acquired. Carbon contents, hydrogen, and nitrogen are expressed as mass fractions of the dry simple and are quantitatively specified using instrumental methods. A precise analysis is very relevant to precisely define the suitability of biofuel, its calorific value (CV) and to evaluate the possible environmental impact. CO_2 emissions are evaluated considering the carbon content as well as the Nitrogen content to facilitate estimation of the NOx emissions.

III-3.2.3. Chemical Values: Ashes.

Another important factor in biofuel energy is ash content. The method for detecting it is based on the UNE EN 14775 standard. It is always measured with reference to the dry product and refers to the solid residue that persists after total combustion, where weight, time and temperature conditions are strictly measured. The lower the percentage of ash in the product, the greater its available energy will be. The accumulation of ash implies a greater maintenance of the boiler, due to the problems of accumulation in the deposits and corrosion in the equipment.

III-3.2.4. Chemical Values: Oxygen.

The standard UNE-EN 15296 has been used to calculate the oxygen level as the remaining percentage after subtracting the percentage of the other elements (nitrogen, carbon, hydrogen sulfide and chlorine) plus the ashes.

III-3.2.5. Chemical Values: Content of Chlorine and Sulfur.

To obtain the chlorine and sulfur content, the standard UNE EN 15289 was followed, which specifies the methods for the determination of these minerals in solid biofuels. For the calculation of sulfur, the method of high temperature combustion in a tube furnace was used, together with the quantification of the gaseous products formed during combustion, a process that resembles accounting for the total content of carbon, nitrogen and hydrogen, as explained above. Chlorine, on the other hand, was obtained using digestion in a calorimetric technique. This was collected in the wash water produced by combustion and quantified by expending silver nitrate through potentiometric methods.

III-3.2.6. Energy Values: Gross Heating Value and Lower Heating Value.

We can say that a biofuel is any biological material that can be burned or is not used as a source of thermal energy. This energy can be measured through a parameter known as calorific value. The total calories produced by combustion are called gross heating value (GHV) or higher heating value (HHV).

The lower heating value (LHV) which is the total amount of heat released in the complete combustion of fuel without counting the part corresponding to the latent heat of the water vapor of the combustion, since there is no phase change, but the LHV is expelled in the form of steam. The moisture content in the fuel is a determining factor, because the higher it is, the greater the contrast between HHV and LHV and the lower the total energy available.

These parameters were calculated according to UNE-EN 14918. In this study, the following equation was used to calculate the LHV without moisture from the elemental chemical composition and the constant volume of HHV [32–34].

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

where:

$H\%$: Hydrogen content of biofuel given in %.

$O\%$: Oxygen content of biofuel given in %.

$N\%$: Nitrogen content of biofuel in %.

III-3.3. Boiler.

In the market there is a wide range of boilers which vary based on the type of biomass and the power required. In our case we used the date bone as fuel and the power requirements were 600 kW, which that can be supplied by a single boiler or several boilers, installed in cascade, whose sum of powers guarantees the required value. The option of several boilers has the advantage that the eventual failure of one of them would not leave us totally without heating, which could happen with the failure of the single boiler.

With this train of thought, we could have opted for five biomass boilers of 128 kW nominal power, maximum marketed by the company Ökofen. Another manufacturer specializing in biomass boilers such as Hargassner offered us more possibilities to combine powers, such as five boilers of the type ECO 70–120 kW, three boilers of the type ECO 150–200 kW or two boilers of the type ECO 250–330 kW.

To ensure the proper functioning of the installation, in addition to maintenance tasks, a check of some parameters must be carried out such as:

- Water temperature and pressure at the boiler inlet and outlet.
- Boiler room temperature.
- Boiler Smoke Outlet Pressure.
- Flue gas temperature.
- Percentage of CO, CO_2, nitrate, sulfate in the gases.

III-4. Results and Discussion.

In order to analyze and study the energy properties of date seeds, it is very useful to compare them with other biomass residues. In this way, the assessment from the energetic point of view of the biomass heating installation is estimated.

III-4.1. Date Seed Values.

With the goal of measuring and evaluating the performance values, 2000 g of date seeds were analyzed. Data as the mean value or the limit values are reflected in Table 1. All standards, except moisture which is referenced as wet basis, are referenced as dry basis.

Table III-1. Main quality parameters for date seed derived from the test of 2000 g samples.

Magnitude	Unit	Mean Value	Standard Deviation (SD)	Maximum Value	Minimum Value
Moisture	%	6.5	---	6.5	6.5
Ash content	%	1.4	0.08	1.48	1.32
HHV	MJ/kg	19.121	0.024	19.145	19.120
LHV	MJ/kg	17.568	0.017	17.585	17.551
Total carbon	%	51.61	0.007	51.617	51.603
Total hydrogen	%	6.74	0.013	6.753	6.727
Total nitrogen	%	0.52	0.041	0.561	0.479
Total sulfur	%	0.16	0.003	0.163	0.157
Total oxygen	%	40.89	2.427	43.317	38.463
Total chlorine	%	0.08	0.003	0.083	0.077

The low percentage of moisture contained in the bone of the date compared to other sources is striking: this data, 6.5%, greatly facilitates the drying phase and does not lengthen the whole process. This is not durable and implies that the energy efficiency in the combustion is the maximum level and there are no losses.

With regard to calorific value, only the pine pellet has a higher index than the date bone. Both the calorific value of the almond shell and that of the olive stone are lower than that of the date seed, so it would be necessary to burn more solid matter to generate the same amount of heat.

The ash content must be checked during direct combustion, as this is an unfavorable factor. The ash content in the range 1.32–1.48% may appear to be high compared to the other fossil fuels. However, in comparison with other biofuels used in biomass boilers, for example peanut shell, whose average ash content is 4.26% [23], it can be seen that the latter significantly exceeds the product under study in ashes.

Table 2 shows the quality of date seed in comparison with other common solid combustibles such as wood pellets, almond shell and olive stone. Energy parameters related to calorific value, the physical parameter moisture that influences calorific value, chemical parameters that affect the corrosion of boilers, and the ashes that are expelled during combustion, among others, have been analyzed. In view of the results it could be concluded that "date seeds" work as an optimum energy source in the form of a biomass.

Table III-2. Date seed compared with other solid combustibles.

Variable	**Unit**	**Date Seed**	**Almond Shell [35]**	**Olive Stone [36,37]**	**Wood Pellet [38]**
Moisture	%	6.50	8.70	4.53	7.70
HHV	MJ/kg	18.275	19.490	21.100	20.300
Ash content	%	1.40	2.20	0.6	0.51
Total carbon	%	46.40	49.30	49.50	50.3
Hydrogen	%	6.74	5.70	6.40	5.70
Nitrogen	%	0.52	0.30	0.20	0.22
Oxygen	%	40.89	47.50	40.70	43.57
$\frac{\text{HHV}_{biomass}}{\text{HHV}_{date\ seed}}$	%	100.00	106.64	115.45	106.17

III-4.2. Energy Analysis.

The analysis has been achieved, relying on the historic need for hot water used for heating in recent years. The power required by the building is obtained from its surface area (4752 m^2) and the average thermal load per unit area (126.1 W/m^2). With this data, a useful power of 599.23 kW is obtained.

Useful power = 4752 m^2 x 0.1261 kW/m^2 = 599.23 kW

Taking into account the operating time of heating, established in 8 hour days (in the morning from 7:30 h to 12:00 h and in the afternoon from 16:00 h to 19:30 h) from Monday to Friday during the winter months, spanning approximately 16 weeks, the energy needs of the building are around 380,000 kWh annually.

III-4.3. Environment Analysis of the Biomass.

III-4.3.1. CO_2 Analysis

The exploitation of biomass as a primary energy resource is carried out through a combustion process, since, if it cannot be used directly as fuel, its transformation into substances that are suitable for use in this type of process is sought [39]. It should be kept in mind that in the different processes of transformation of biomass into other combustible substances, also produce pollutants that are discharged into the environment. These include particles, carbon dioxide and monoxide, sulfur compounds, nitrogen oxides and solid and liquid waste [40]. However, unlike fossil fuels, carbon dioxide originating in the combustion process of biomass is returned to the atmosphere, from where it was taken during its generation. According to this, the use of biomass as a fuel does not increase the carbon dioxide content of the atmosphere and therefore does not contribute to the greenhouse effect. The CO_2 it emits is the same as the CO_2 the plant assimilated during its developing process, so this CO_2 is deemed nil [41].

We can assume that plants retain more CO_2 when they grow than when they release when it burns. When taking this into account, this gas has near-zero emissions. Table 3 shows how a biomass heating installation in this case could mean a total reduction of 95,760 kg of CO_2.

Table III-3. Total CO_2 emission reduced.

Boiler	**CO_2 (kg/kWh)**
Gas natural boiler	0.252
Biomass boiler	0
Total emission reduced annually (kg)	95,760

The emission of natural gas would be:

$$CO_{2\ natural\ gas} = C_{natural\ gas} \times E_{natural\ gas}$$

Where:

$CO_{2\ natural\ gas}$: is the mass of carbon dioxide emitted (kg/year).

$C_{natural\ gas}$: is the consumption of natural gas in annual heating (kWh/year).

$E_{natural\ gas}$: the carbon dioxide emission factor of natural gas (kg/kWh).

The annual consumption is 380,000 kWh and the factor is 0.252 kg/kWh.

$$CO_{2\ natural\ gas} = 380{,}000 \times 0.252 = 95{,}760\ kg/year$$

Since natural gas is a source of fossil energy and knowing that the largest generation of electricity comes from a non-renewable source, it has a much higher emission factor than date bone, whereby a year's use of biomass heating would mean kgs of reduced CO_2.

In the first 12 months, carbon dioxide emissions would be reduced by 95.76 tons. It would be highly recommended to complete a study on the energy capability of date seeds as biofuel and determine how this would impact on reducing CO_2 emissions around the world. To start the study, after figuring out the calorific value of the dates seeds and after being aware of the production of the different countries per year, the power generation is calculated by applying the following formula:

$$E_c = P_c \times f_s \times LHV \times U_c$$

where P_c refers to the total production, measured in kg, of date fruits; f_s is the seed factor in a whole date fruit (30%); LHV is the Lower Heat Value previously determined (17.568 MJ/kg); and U_c is the factor to convert J to Wh (0.000277778) and E_c (MWh) is the power that would be obtained with all the date fruits generated.

If we choose Spain as an example, date fruits production was 2996 t in 2016. With this amount of production, we could generate a total of 4386.15 MWh. So, considering that the total production around the world of date fruits seed was 8460.443 tons, the energy generated that would be obtained with this date seeds is appraised at 12,386.25 GWh.

Therefore, we could say that the total energy generation potential of the countries is reached using this equation. Figure 3 shows the energy generation through the different countries producing date fruits. We can see that countries such as Egypt, Iran and Algeria have a greater energy potential in comparison with other countries around Europe. As we can see, the zone between Africa and Asia has several countries with great potential. In Asia, Pakistan is the country with the largest energy production capacity, while in the Americas just Mexico, Peru and Colombia have some potential in this area.

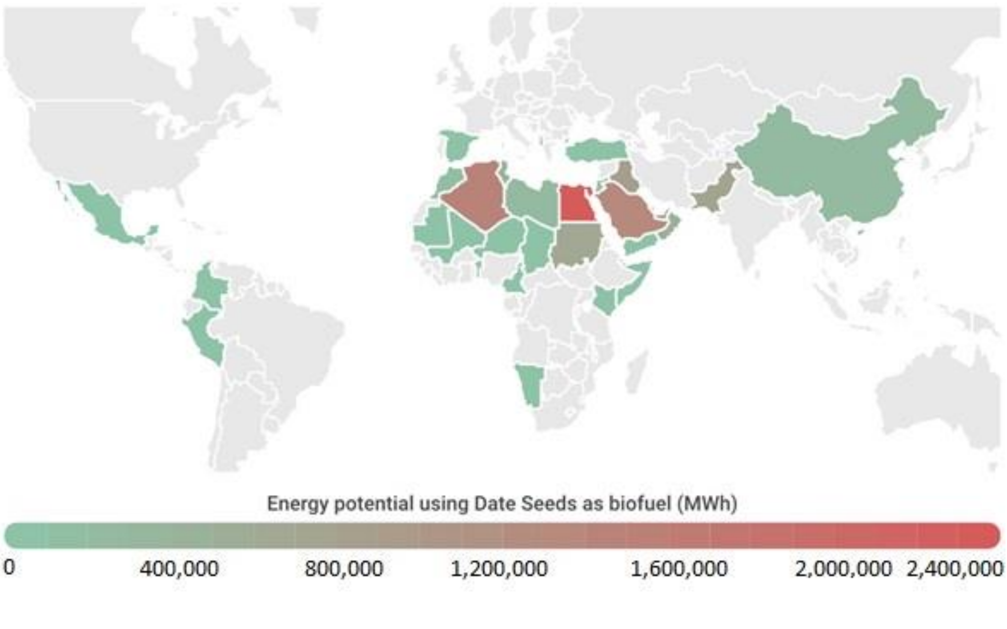

Figure III-3. Energy produced using date seeds as biofuel (MWh).

In order to analyze the potential of date seeds to reduce CO_2 emissions, emissions data from fossil fuels must be considered. These data are obtained in the World Data Bank, and with this information we can affirm that for each MWh generated, 357 kg of CO_2 are expelled into the atmosphere.

Not surprisingly, countries with higher date production have a higher energy production potential. This also means greater potential for reducing CO_2 emissions. The countries with a greater production in dates are: Egypt with almost 1.7 million tons, followed by Iran (1.1 million tons), Algeria (1 million tons), Saudi Arabia (0.9 million tons), the United Arab Emirates (0.7 million tons), Iraq (0.6 million tons) and Pakistan (0.5 million tons) [42].

On the other hand, when comparing the total CO_2 emissions of each country according to the world data bank with the total CO_2 emissions reduction associated with the use of date seeds, we see that the data vary. The countries with the highest percentage are in the north of Africa. These countries are Sudan, with almost 15% of the total, Chad (14.3%), Somalia (11.5%), Niger (4.6%), Egypt (4.4%) or Mauritania (4.3%).

III-4.3.2. Particle size emissions..

Until recently combustion plants such as thermal power plants had a control of total particulate emissions, i.e. PM_{10} [43]. However, it has been demonstrated that for human health the emissions of particles of a smaller size are even more harmful. $PM_{2.5}$ and PM_5 [44], already present a greater health risk due to their high penetration capacity in the respiratory tract, particularly in the case of the former [45]. The latter have an anthropogenic origin in a high proportion since they come largely from emissions from diesel vehicles in cities [46].

Regarding the levels of air quality in the study area, i.e. compliance with European regulations and their transposition into Spanish legislation, compliance with the annual limit value of PM_{10}, there should be no more than 35 days per year exceeding the limit value of 50 μg/m^3 in 24 h, established on the compliance date in January 2005 [47].

There is a European directive, Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 [48], concerning the limitation of emissions of specific pollutants into the air from medium-sized combustion plants. This regulation can be applied to facilities with a nominal thermal input equal to or greater than 1 MW and less than or equal to 5 MW, i.e. those considered as average combustion plants. It states that until 1 January 2030, Member States may exempt medium-sized combustion plants that are using solid biomass as their main fuel, the idea of the legal regulation being to increase the use of biomass as a fuel. For plants burning exclusively solid woody biomass, the limits for various gases such as SO_2 are not applicable. There are studies showing that certain reprocessing methods such as torrefaction can significantly improve the HHV and reduce emissions. As an example, HHV increased for pine shells by 25% and for olive pits by 18% [49]. This is because when there are higher temperatures there are higher emissions and above all $PM_{2.5}$, therefore the boiler operating temperature has a great influence on the total particles (PM_{10}).

III-4.4. Economical Balance.

In order to compare from an economical perspective, the old natural gas installation and the new one, a comparative analysis has been carried out that analyzes the cost per year required to cover the total energy demanded by the university building with each of the combustibles: natural gas or biomass. Table 4 shows both the total liters of the gas that is consumed in the previous installation per year and the annual expense.

Knowing the value of the annual heating demand, the consumption of biomass is calculated with the following formula:

$B_{year} = C_{year}/\text{LHV}$

Where:

B_{year}: Biomass consumed in one year (kg/year).
C_{year}: Annual heating consumption (kWh/year).
LHV: Lower heating value of biomass (kWh/kg).
The annual heating consumption is 380,000 kWh and the LHV is 4.88 kWh/kg.

Thus, 93,442.62 kg of solid biomass are consumed per year, considering the efficiency of the boiler.

Table III-4. Cost of thermal energy demand with each of the fuels, natural gas and biomass.

Magnitude	**Natural gas**	**Date seeds**
LHV	13.1 kWh/kg	4.88 kWh/kg
Combustible price	$5.85 \cdot 10^{-4}$ €/L	0.09 €/kg
Efficiency of the boiler	90%	80%
Useful power	600 kW	600 kW
Running hours	634 h	634 h
Heating demand	380,000 kWh/year	380,000 kWh/year
Consumption	42,945,350.43 L	93,442.62 kg
Cost per year	25,123.03 €	8409.84 €

While it is true that the gas is clean fuel in daily operation and does not require much maintenance, two decisive factors such as automation and technological advances, on the one hand, and the competitive price, on the other, make it profitable and beneficial to switch from gas to biomass boilers currently. The price of gas is raising, particularly in some countries with an increased level of taxes and this is levied on fossil combustibles. This causes solid biofuels to be considered as a useful alternative not only for the economy, but also for ecology, safety and comfort reasons. Bearing in mind that the cost of biomass is 0.09 €/kg, the analysis reveals an annual cost of 8409.84 € with the use of date seed as biofuel versus 25,123.03 € as the cost of maintaining the facility with natural gas. Therefore, using date seed as a biofuel entails an annual saving of 16,713.19 €, representing a savings percentage of 66.53%.

III-5. Conclusions.

The study concludes that the viability of date seed as an alternative source of energy is feasible. The study asses the physical aspects of date seeds and highlights the high level of volatile matter if it is used as fuel. Numerous combustion experiments have been carried out, in which the high rate of gasification has been verified, and in the case of occurring in high combustion air conditions, combustion rates and heat transfer are multiplied. In this study the characteristics of date seeds have been compared with other fuels such as coal, obtaining a higher combustion rate per unit of mass for date seeds. The same applies to heat transfer. This is due to the high levels of volatile matter in date bone. In addition to this, date seeds have a low ash content, allowing more direct combustion in the furnaces.

It is a global goal for all countries to reduce of energy consumption. This is a challenge to be achieved in the coming years and therefore measures must be taken to improve this problem immediately. With this research a waste product such as date bone has been evaluated and in doing so adds a new clean energy form that can be used as fuel. The study shows that replacing a natural gas boiler with a biomass one and using the date bone as biofuel, we would obtain an annual saving of 95,760 kg of CO_2. In addition, the calorific power of the date bone gives it optimal properties as a source of thermal energy comparable to other biofuels currently being marketed.

It is a reality that most buildings have small independent boilers to cover the heating needs of each building and for that reason the total installed power is much higher than what is needed. A good way to save energy is to centralize the heating system of the entire campus. This would increase the coefficient of simultaneity to reduce the installed power and at the same time reduce the loss in combustion of the raw material. This study could contemplate a next phase in a future focused on analyzing the centralization of the system in the campus. Other additional phases could be the study of other waste products as biofuel in biomass boilers and expand the production of this type of renewable energy to other types of buildings.

Author Contributions: Carmen de la Cruz-Lovera dealt with the literature review and article writing. José-Luis de la Cruz-Fernández and Esther Salmerón-Manzano analyzed the data. Francisco Manzano-Agugliaro and Alberto-Jesús Perea-Moreno: Research idea, article writing and formatting. They share the structure and aims of the manuscript, paper drafting, editing and review. All authors have read and approved the final manuscript.

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Chapter IV. Analysis of Research Topics and Scientific Collaborations in Energy Saving Using Bibliometric Techniques and Community Detection.

Chapter IV. Analysis of Research Topics and Scientific Collaborations in Energy Saving Using Bibliometric Techniques and Community Detection.

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IV-1. Abstract.

Concern about everything related to energy is increasingly latent in the world and therefore the use of energy saving concepts has been increasing over the past several years. The interest in the subject has allowed a conceptual evolution in the scientific community regarding the understanding of the adequate use of energy. The objective of this work is to determine the contribution made by international institutions to the specialized publications in the area of energy-saving from 1939 to 2018, using Scopus Database API Interface. The methodology followed in this research was to perform a bibliometric analysis of the whole scientific production indexed in Scopus. The world's scientific production has been analysed in the following domains: First the trend over time, types of publications and countries, second, the main subjects and keywords, third, main institutions and their main topics, and fourth, the main journals and proceedings that publish on this topic. Then, these data are presented using community detection algorithms and graph visualization software. With these techniques, it is possible to determine the main areas of research activity as well as to identify the structures of the collaboration network in the field of renewable energy. The results of the work show that the literature in this field have substantially increased during the last 10 years.

Keywords: energy-saving; energy conservation; energy utilization; energy efficiency; scientific collaboration

IV-2. Introduction.

The energy problem has become a global issue in a world where science and technology are undergoing a great evolution in a short period of time [1]. Consequently, the development of renewable energy and the use of energy saving concept has been increasing in last years, becoming a research focus around the world [2]. The growing interest in the subject has allowed a conceptual evolution in the scientific community regarding the understanding of the adequate use of energy.

While there is a close relation between the terms "energy saving" and "energy efficiency", there are certain distinctions that need to be clarified. The energetic saving entails a change in the habits of consumption. Sometimes it is enough to eliminate habits that waste energy. On the other hand, energy efficiency is the fact of minimizing the amount of energy needed to satisfy the demand without affecting its quality [3]; it supposes the substitution one machine to another that, with the same benefits, consumes less electricity. Therefore, this does not mean changes in consumption habits. The behaviour of the user remains the same, but less energy is consumed due to the consumption of energy to carry out the same service, which is lower. In Alcott, an extensive review of the literature on the subject of "sufficiency" can be found [4]. To achieve greater energy sustainability as much as possible, renewable energy and energy saving have been combined [5]. In this way, we will achieve a twofold purpose thanks to a combined strategy of energy saving and energy efficiency, without reducing the quality of life. In fact, it will be maintained, and even increased. These concepts are also making significant advances in the residential construction sectors [6]. Energy saving is not only linked to monetary savings [7], it also contributes to reducing greenhouse gas emissions [8], sustainable development and achieving a sustainable energy supply. However, the reduction of energy demand is not as easy to carry out as is thought and the actions that are imposed are in many cases insufficient to achieve real transformation [9].

Thus, it is necessary to emphasize that, sometimes, many improvements of the energetic efficiency do not reduce the consumption of energy in the amount predicted by the simple engineering models [10]. This is called a rebound effect, since the fact that energy services improve means that they are cheaper and, in turn, that the consumption of these services increases [11]. The Paris Agreement on climate change is an agreement within the framework of the United Nations Framework Convention [12] and energy consumption was the main point to deal with and the creation of an agreement worldwide. To achieve the objectives of this agreement, an outstanding change in the energy sector is necessary, the origin of at least two thirds of greenhouse gas emissions.

The transformation of the electricity sector, with renewable energy, has focused attention on a new debate on the design of the electricity market and electrical safety [13]. However traditional concerns about energy security have not disappeared. In addition, there are also pending issues related to energy access and affordability, global warming and CO_2 emissions. Therefore, the massive social concerns can be understood and lead to an increasing demand for ways to improve social and individual energy efficiency.

There remains an urgent demand for ways to improve the energy efficiency of society and people and a need to move increasingly to alternative, low-carbon or non-carbon energy systems. [14]. If we want to achieve sustainable development, energy efficiency becomes a key factor. It is a reality that only a few countries are engaged in research into renewable energy, representing between 70% and 80% of scientific production [15]. In general, countries are in the process of achieving, and in some cases exceeding, many of the objectives set in their commitments under the Paris Agreement. This is enough to reduce the expected increase in global CO_2 emissions related to energy, but it is not enough to limit the global warming to less than 2 °C. The increase in energy consumption, especially in HVAC systems (heating, ventilation and air conditioning), and CO_2 emissions have contributed to more energy policies focusing on the development of energy saving and efficiency strategies as an absolute priority [16]. An example of this is the European Energy Performance of Buildings Directive.

The major advanced economies: USA, the European Union, and Japan appear to be clearly on track to achieve their climate commitments, although it will be vital that these countries introduce other additional improvements in energy efficiency. A clear example of it would be the cement production industry, one of the most polluting. However, several mitigation measures are gaining importance in the recent years, and this industry is increasingly turning towards cleaner production. This is because new alternatives are used as raw materials and fuels. In existing industries, mathematical statistical models, simulation processes, optimization of procedures are everyday methods [17]. Natural gas and oil are going to continue to be the essence of the global energy system for years to come, as governments have indicated in terms of climate. Faced with this situation, the fossil fuel industry should consider the risks of a more direct transition. The interdependence between energy and water will become more pronounced in the upcoming years. In this sense, the management of the relationship between energy and water is crucial for the successful fulfilment of a series of development and climate objectives. It is evident that, to promote energy saving, it should be tried to create efficient energy systems and banish old ones. In fact, there is great potential for energy savings in the renovation of the housing stock in many cities, as is the case in Denmark, where 75% of the buildings were built before the eighties, when the first important demands were introduced for the energy performance of the building [18].

In this way, without altering the development of the technique, significant energy savings will be achieved. Nor should we ignore the human factor; the education and global awareness of citizens is important to achieve energy savings.

Recent studies show how construction technologies have been developed to improve comfort and energy savings in both conventional buildings using concrete or heavy structures, and also in timber buildings. An example of these technologies is the thermal insulation added to the facades and the improvement of the performance of the glazing or a district heating designed in a residential area. Nevertheless, although these technological advances can be implemented in concrete and wood buildings, the studies carried out highlight how timber construction is associated with thermal comfort and is perceived as innovative [19].

This is paradoxical because, after having expanded the use of gravel and concrete, the wood construction was increasingly neglected for a period of time. However, in recent years the Kyoto Protocol has pushed to limit CO_2 emissions in all productions. The use of sustainable materials is definitely being stimulated worldwide, as they can store carbon dioxide. The advantages of using sustainable materials have been confirmed by various scientific studies [20].

Buildings using sustainable materials are called green buildings. They reduce and optimize their energy and water consumption as much as possible and integrate into their environment, whether natural or urban, causing the least possible environmental impact. Smaller buildings tend to achieve these objectives satisfactorily. However, in larger green buildings it is much more difficult to meet the requirements of comfort, lighting, noise, use of space, or more hours of operation. It is feared that these innovative buildings will run the risk of repeating past mistakes, especially if they are too difficult to manage [21].

In this process of constructing eco-friendly buildings, it is fundamentally important to know the user's perception of indoor environmental quality and satisfaction in green buildings. Numerous studies show that employees perceive green spaces better than conventional buildings, but those surveyed are not able to differentiate between both types of buildings. However, there is an unequivocal correlation between ecological attitudes among employees of green buildings, showing them to be more satisfied and more prone to sustainable attitudes [22].

In order to achieve appropriate low-carbon rehabilitation interventions, users play a very important role. A sound learning process must be ensured for occupants, designers and building managers. The behavioural habits of citizens are themselves an essential component in reducing consumption patterns [23].

IV-3. Materials and Methods.

The aim of this work is to analyse all the world scientific publications of renewable energy indexed in the Scopus database in order to study the most important areas of investigation in energy saving, as well as to highlight the existing worldwide relationships between researchers and institutions. It is decided to select Elsevier's Scopus for this study as it is the largest database in the world. Thanks to the API interface, it is very easy to automate the search for literature related to the topic by selecting it by authors or by institutions. The two main scientific databases, Scopus and Web of Science pose the question of the comparability and consistency of the results of the different data sets [24]. With respect to journals reported in the two main scientific databases Scopus and Web of Science, a comparative study reveals that the volume of journals on the Web of Science is inferior to the number of journals in Scopus [25], and the relationships obtained in the results with both databanks for the items and the citation numbers by country, and for their rankings, are very robust (R2 ≈ 0.99) [26]. This methodology was successfully used in several scientific fields, so only Scopus data has been used in this research [27].

IV-3.1. Automated Data Collection Applying Scripts.

The flowchart shown in Figure 1 explains how automatic data extraction would be carried out from Scopus. The process that is carried out by Research Network Bot (ResNetBot) [28] could be separated into the following stages: (1) Obtaining information on documents containing 'energy savings' as keywords or included in the title. We must notice that analyse the keywords in scientific articles is one of the most common research topic in different fields of engineering science. This information is represented graphically, where the size of the nodes is proportional to the h index and the lines between two nodes indicate that they are cited. (2) Obtaining information from authors of the works mentioned in step (1), which includes for each author the Scopus author identification number, affiliations, publications and dates, number of citations and h-index. (3) Processed to obtain the collaborative network of authors who have published articles that contain 'energy savings' as keywords or are included in the title. The information stored refers to the number of collaborations between co-authors and their affiliations, country and city. With all this information a graph will be created where the size of the nodes will indicate the scientific production according to the country and will be proportional to the H index and the distance between them will represent the collaboration with one another.

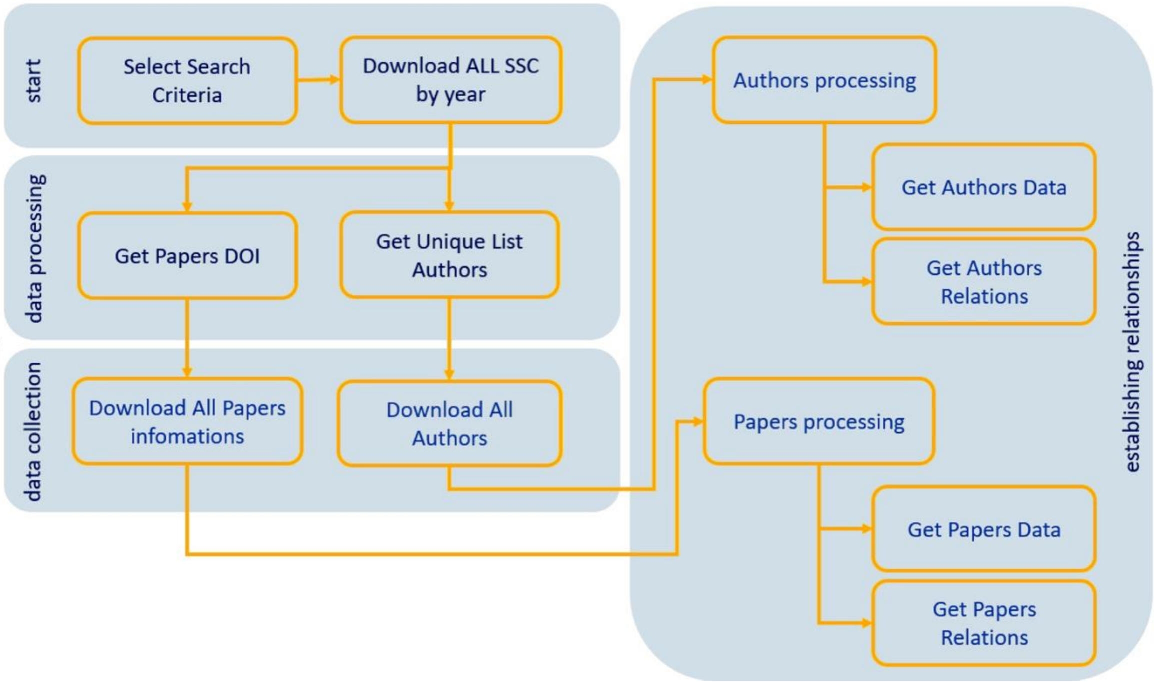

Figure IV-1. Flow diagram showing how the software obtains information from the Scopus database (ResNetBot).

IV-3.2. Data Evaluation and Polishing of Texts.

ResNetBot obtained data that was classified by domains and stored as a compendium of text files in JSON format., http://www.json.org. The Scopus API gives the option of requesting information through all type of details, so we programmed the bot to request all the information available in the files and choose the most convenient data for our work. As a result of the vast volume of data, some irregularities were observed during the work of checking the information. This, however, is a frequent and common problem in these large databases [29]. Phrases with a very similar meaning may sometimes appear written with slight changes. For this reason, it is very important to carry out a debugging process that allows us to obtain the appropriate information. The same expression may not be exactly the same written depending on whether we use capital letters in the first word, the second word, or both. We see an example of this, "Energy saving", "energy Saving", and "Energy Saving".

Therefore, some of the improvement criteria are applied from OpenRefine (http://openrefine.org), which contains some formulae such as clash of keys and neighbourhood algorithms to combine all expressions that correspond to the same idea but are not written in the same way. In order to classify data information and identify singular values, data sheets are finally used; this program has already been successfully carried out in former studies [30] and could be performed on key-words and author names.

Diagnostics and Data Viewing.

The data collected by ResNetBot and further processed with OpenRefine was archived in a separate databank. Once this process has been completed, the latter information will be analysed using visualisation tools and statistics based on diagrams.

A graph is a set of vertices(elements) joined by edges. Graphically, the vertices are points and the edges are lines that join them, representing a relationship between two vertices. The visualization of graphs is a great help to determine the interrelation between the different parts. On the other hand, this representation makes it possible to incorporate specific values of the elements and their links. Over the last few years, powerful graphic representation programs have been created that enable the exhaustive analysis of the particularities of the graphics through the use of various functions, such as the reorganization of the vertices and the design of the vertices represented with different colours and sizes depending on their properties. One of the best known when using open source instruments is Gephi [31], which encompasses several statistical tools.

IV-4. Results.

IV-4.1. Energy Saving Publication Relationship.

In Figure 2, the documents obtained in the search described above have been represented all together. The graph represents the relationship between the documents, with each node representing a file. Of the total of 20,095 papers, in the outer halo formed by 12,402 individual papers are represented those that do not cite any other Energy Saving paper, this is 61.7%. Then there is another intermediate halo of 1,919 papers that are linked to at least one other paper, but do not connect with the central core, which represent 9.6%. Finally, there is the central nucleus formed by 5,774 nodes that are linked together, and that account for 28.7% of the total, is what could be defined as works that scientifically deepen in that field, because they are based on the previous ones to make some type of contribution.

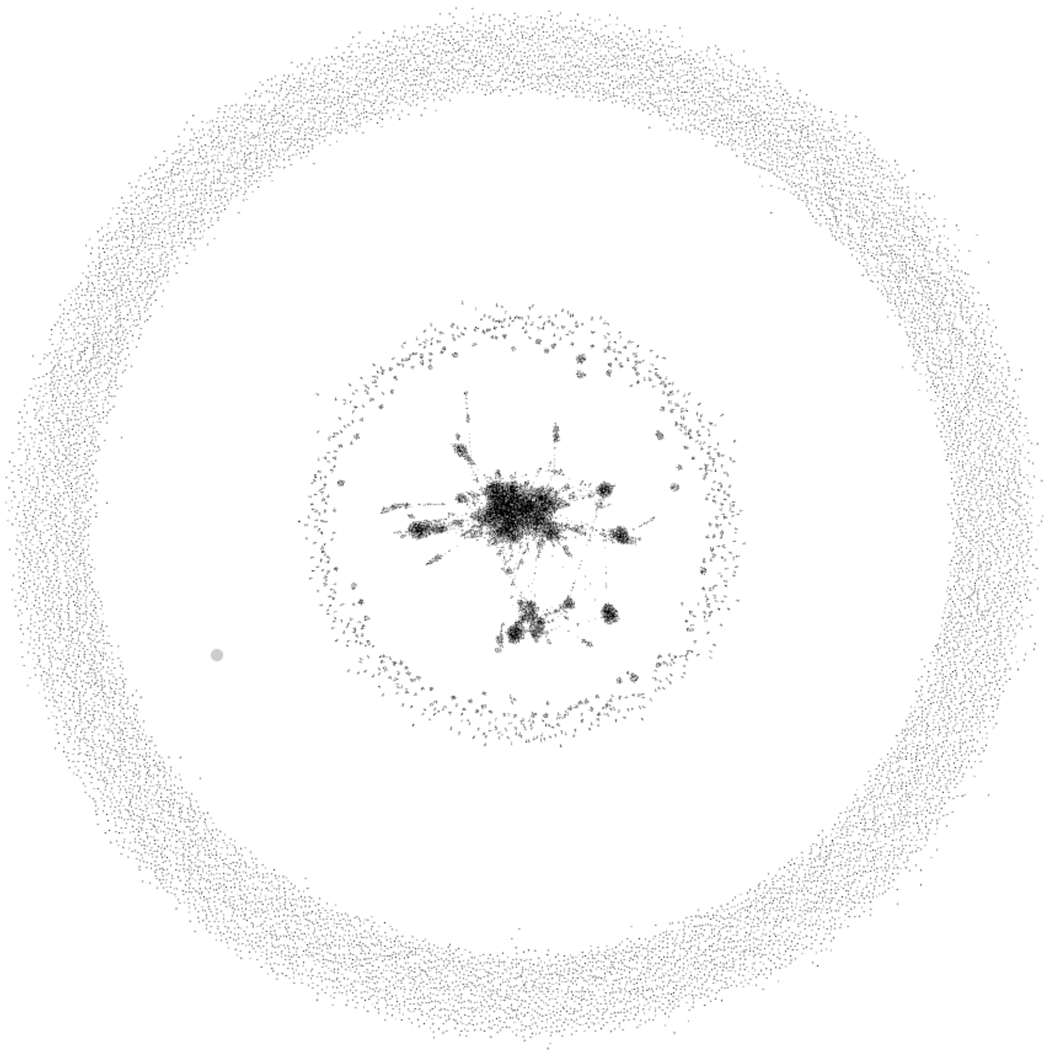

Figure IV-2. Display of the whole energy saving publication relationship indexed by Scopus.

In our research, there are a total of 70,951 keywords. As there is a large number of papers that are not part of the central core, we proceed to a refining of the 5774 core papers. 23,083 unique keywords were obtained, which after the refining process, 10,119 different keywords remain. After this process, the analysis of the documents that are related to each other is done, and they are represented according to the communities detected with the modularity algorithm of Gephi. Once this process is finished, Figure 3 is obtained. Of the 29 communities detected, the 15 main ones, with a percentage higher than 2%, have been represented in colour to distinguish them.

This process has been necessary to reduce the excess of information that would impede the global vision we pursue.

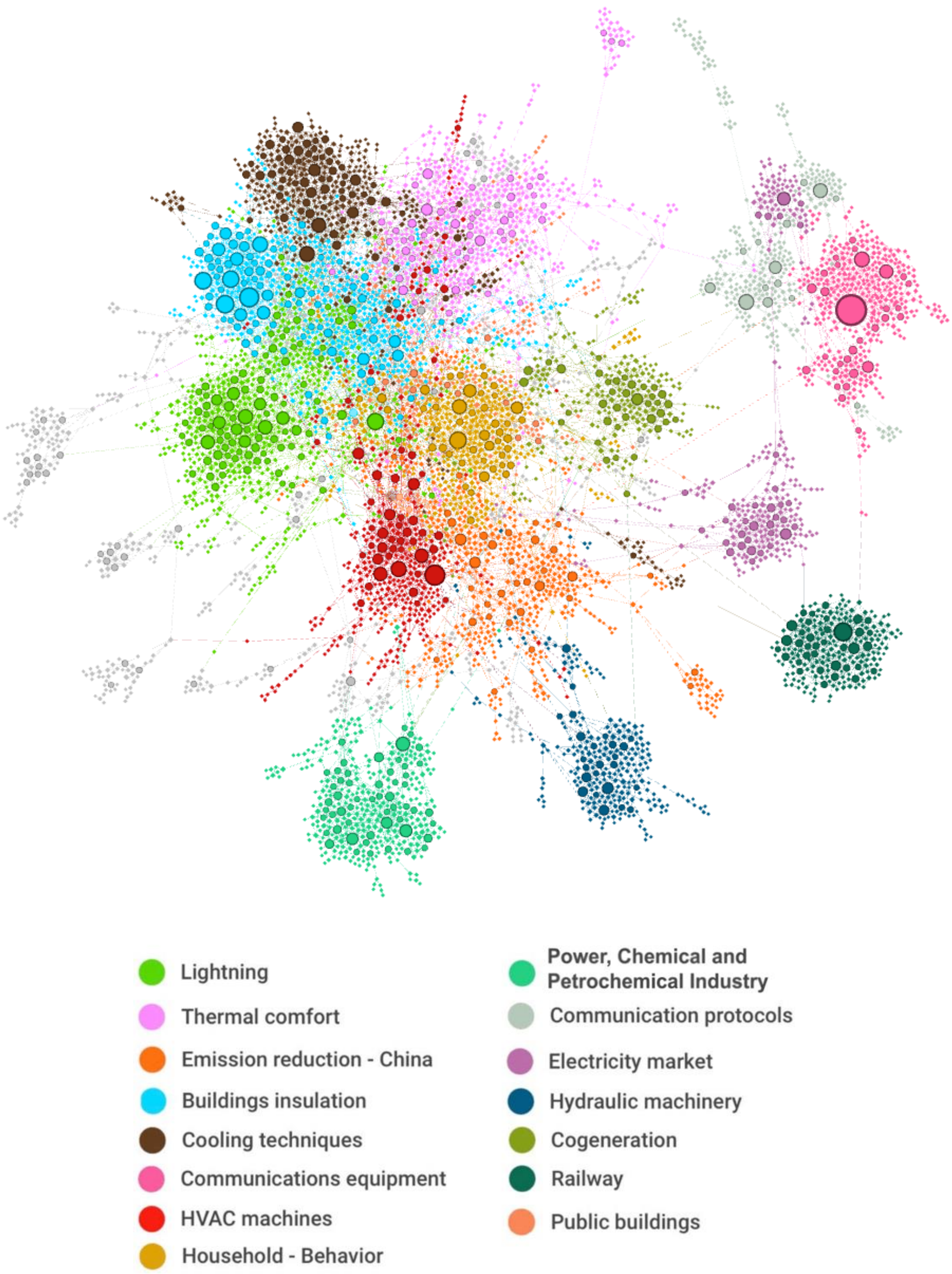

Figure IV-3. Display of the whole energy saving publication relationship indexed by Scopus.

Figure 4 shows the main 15 communities which have been named to facilitate the analysis. This table shows the main keywords of each community detected.

Lightning	Thermal comfort	Emission reduction	Buildings insulation	Cooling techniques
(9.44 %)	(9.18 %)	(8.76%)	(8.61%)	(6.94 %)
Daylighting	Thermal comfort	China	Optimum insulation thickness	Phase change material
Energy efficiency	Energy efficiency	Energy saving potential	Buildings	Cool roof
Lighting control	Air conditioning	Energy intensity	Energy consumption	Energy efficiency
Daylight	HVAC	Energy saving and emission reduction	Residential buildings	Thermal comfort
Lighting	Indoor air quality	Emission reduction	Building envelope	Green roof
Lighting systems	Evaporative cooling	Energy consumption	Thermal comfort	Buildings
Energy consumption	Building energy saving	Energy saving device	Insulation	Building energy saving
Energy conservation	Natural ventilation	Data envelopment analysis	Thermal insulation	Passive cooling
Lighting system	Data center	Economic growth	Energy	Thermal energy storage
Thermal comfort	Liquid desiccant	CFD	Life cycle cost	Building envelope
Energy saving potential	Ventilation	Waste heat recovery	District heating	Urban heat island
Energy audit	Optimization	Energy-saving technology	Payback period	Solar reflectance
Building automation	Fuzzy logic	Sustainable development	Retrofit	PCM
LED	Office buildings	Iron and steel industry	Energy saving measures	Non-linear complex heat transfer
Optimization	Free cooling	Energy conservation	Insulation thickness	Finite element modelling
Energy saving system	Air conditioner			Sustainability

Communications equipment	HVAC machines	Household - Behavior	Power, Chemical and Petrochemical Industry	Communication protocols
(6.29%)	(6.25%)	(6.01%)	(5.95%)	(5.02)
Heterogeneous networks	Emission reduction	Energy consumption	Distillation	IEEE 802.16e
LTE	Variable speed drive	Energy saving behaviour	Heat integration	Cloud computing
Cellular networks	Energy consumption	Behavior	Dividing wall column	Energy efficiency
Green communications	Thermal comfort	Household	Reactive distillation	Sleep mode
Sleep mode	Energy management	Residential buildings	Heat pump	Smartphone
Green networks	Efficiency	Residential sector	Process simulation	Energy consumption
Green networking	Air conditioning	Climate change	HIDiC	WiFi
Small cell	Energy	White certificates	Self-heat recuperation	WiMAX
Energy consumption	Optimization	Energy conservation	Extractive distillation	Cellular networks
Base station	HVAC system	Energy saving potential	Economics	Power control
Optimization	Compressed air systems	Energy audit	Process design	LTE
Green Internet	Energy conservation	Willingness to pay	Heat exchanger network	Mobile TV
Traffic Engineering	Energy audit	Occupant behavior	Simulation	offloading
Energy-saving management	Induction motors	Energy	Optimization	Mobile cloud computing
LTE-Advanced	Machine tool	Persuasive technology	Exergy analysis	Virtualization

Electricity market	Hydraulic machinery	Cogeneration	Railway	Public buildings
(4.75%)	(4.47%)	(4%)	(3.46 %)	(2.63%)
Energy saving and emission reduction	Hydraulic excavator	Cogeneration	Optimization	Energy consumption
Electricity market	Excavator	Primary energy saving	Regenerative braking	Energy efficiency
Energy-saving generation dispatching	Accumulator	Trigeneration	Genetic algorithm	Activity recognition
Energy-saving and emission-reducing	Energy efficiency	Energy efficiency	Supercapacitor	School buildings
Energy-saving dispatch	Hybrid system	Optimization	Energy storage	HVAC
Smart grid	Energy recovery	Economic analysis	Energy-saving operation	Occupancy
Sleep mode	Hydraulic system	Operational planning	Electric railway	Energy management
Distribution network	Hybrid power	Emission reduction	Regenerative brake	Ventilation
Passive optical networks	Hydraulic transformer	Combined heat and power	Energy storage system	Energy audit
QoS	Load sensing	CHP	Speed profile	Wireless sensor networks
Energy efficiency	Control strategy	Energy saving rate	Simulation	Office buildings
EPON	Power matching	Solar energy	Efficiency	Thermostat
Unit commitment	Hydraulic accumulator	Supermarket	metro	Smart Home
Genetic algorithm	Construction machinery	Carbon dioxide emissions	Dynamic programming	Ambient intelligence
Power system	Mechanical engineering	Fuel cells	Traction power supply	IoT
				Context-awareness
				Schools

Figure IV-4. Communities detected for Energy Saving.

Fifteen communities are detected within the large network of publications related to the term energy saving. In Figure 5, it can be seen that the area with the highest number of publications is lightning and thermal comfort, followed by emission reduction and building insulation. The high energy consumption that occurs in homes and businesses, together with the growing concern about the impact that energy consumption has on the environment, could show how important the search for facilities and systems that enable energy savings in these field is becoming. On the contrary, the railway and public buildings communities are in the last place of the ranking, with a percentage lower than 4%.

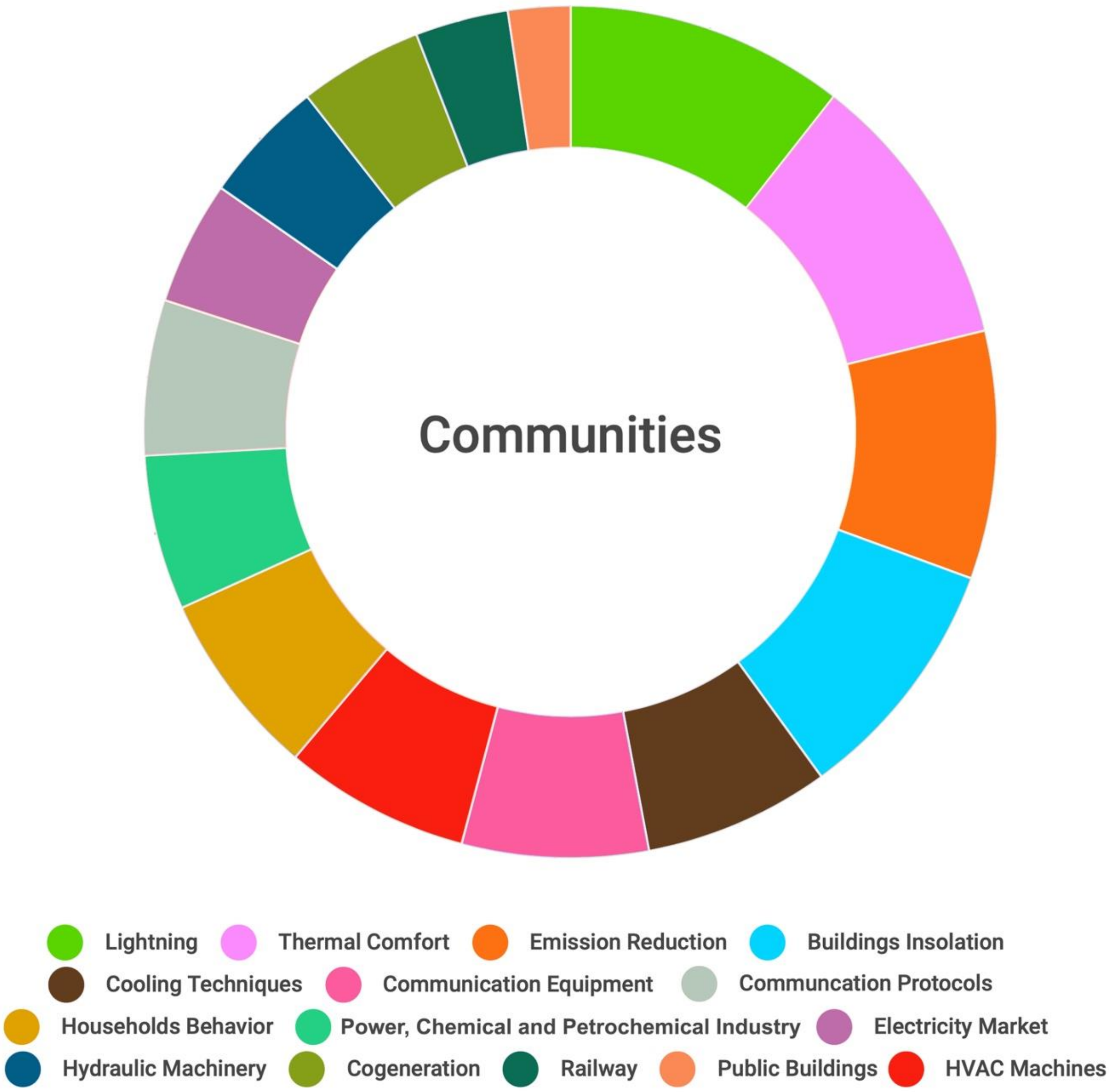

Figure IV-5. Communities are detected within the large network of publications related to the term energy saving.

IV-4.2. Authors, Affiliations and Countries in Energy Saving.

Regarding the authors and their relationship among them, it has been seen that in total there are 43,860 researchers. In Figure 6, the authors have been represented by colours according to the country of origin. This figure shows that the researchers that contribute most to the development of scientific production, come from academic and scientific institutions from China, which has the highest number of authors with more than half of the total number, followed by Italy (9.5%), the USA (8.9%), and Japan with 6.8%. Afterwards, with less percentage are Malaysia (4.77%) and Spain (2.2%), and finally a block of countries with a percentage below 2%. Null means that the Scopus register does not contain information on the country of the author.

From Figure 6 it can be drawn as conclusions that among Chinese researchers there is a tendency to collaborate among themselves, but also at the international level with American authors, Malaysians, and to a lesser extent, Japanese authors.

Whereas at European level, the relationship between its authors is with those authors belonging mainly to the European environment. These appear isolated, as can be observed in the lower left part of the graph, where it is extracted that the Italian researchers, the most productive, are mainly connected with the Spanish or with Greek authors among others, but also Japanese and Canadian.

Several layers are observed, being the most external (as explained above) that of the authors who have written about energy saving, but who do not collaborate with anyone in energy saving. Here are 2763 authors, which means a large minority. Then there are intermediate layers, where groups of collaborations are going from less to greater intensity. In this intermediate layer there are 41,097 authors, and it is observed that it is the most numerous. As a result of this international collaboration, many papers have been published.

The method is focused not only on the analysis of the scientific collaborations between institutions of each country, but also to determine which of these institutions are more involved in energy saving.

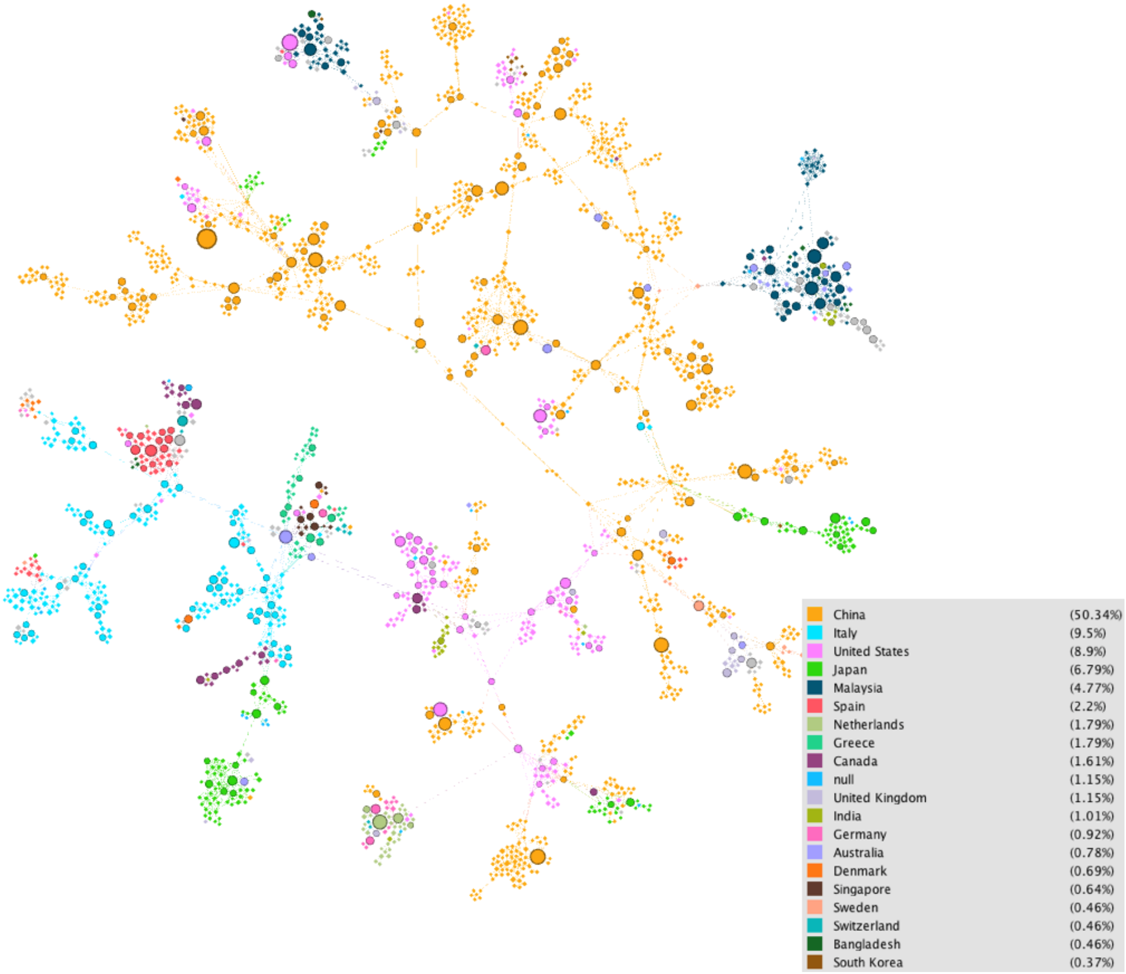

Figure IV-6. Collaborations between scholars from various countries. The size of the nodes is proportional to the H index.

Researchers associated with Chinese institutions is shown in Figure 7, highlighting the number of people involved in energy savings in the following order: Tsinghua University (2.27%), North China Electric Power University (1.98%), and Tianjin University (1.91%).

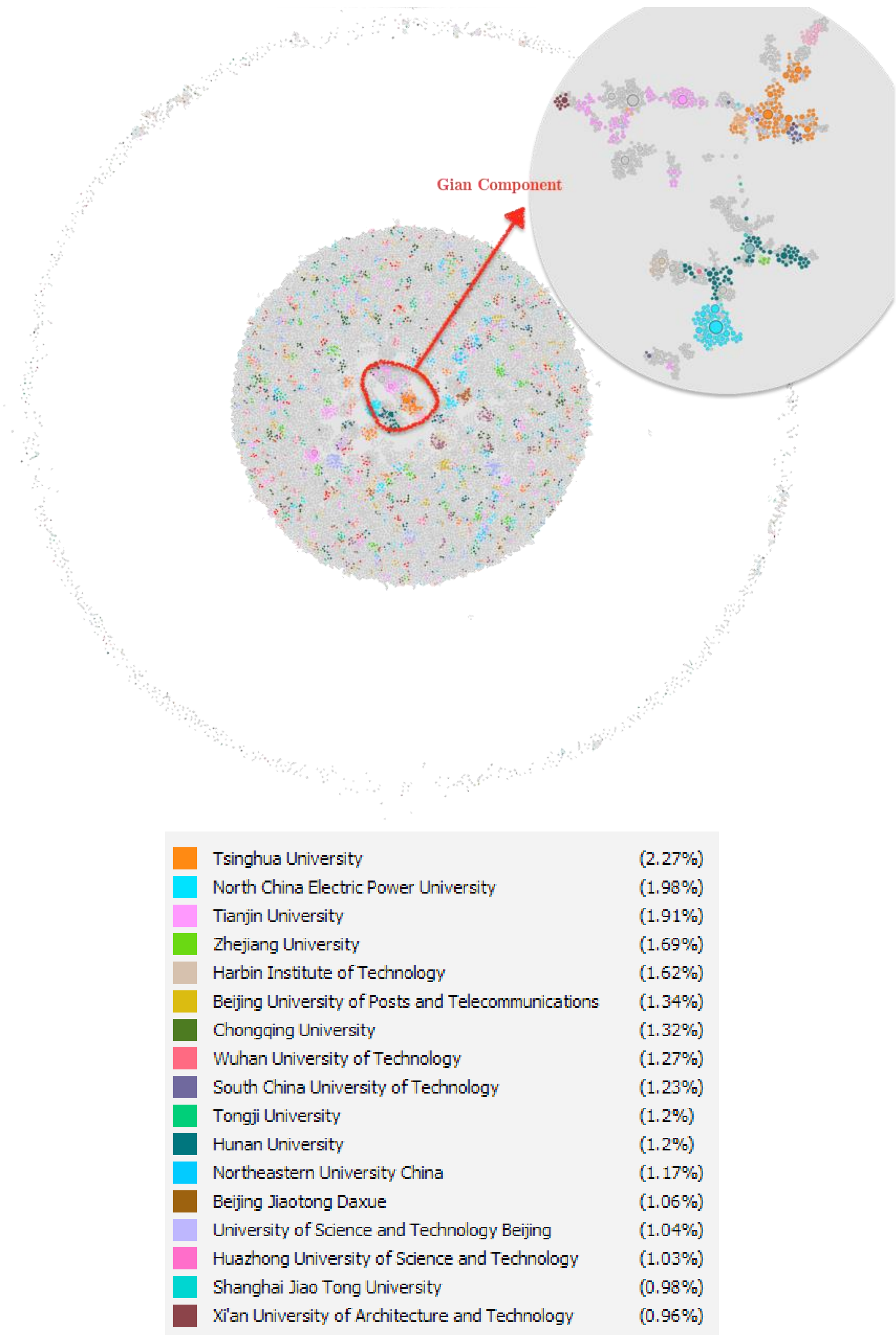

Figure IV-7. Connection of authors belonging to Chinese institutions.

In Figure 8 and Table 1 we can see the evolution of the publications developed by the most productive institutions worldwide in the last 10 years (2009–2018). On the bottom of the figure, the production of Ministry of Education of China can be seen, which is the most important institution registered. It does not surprise that, as a fact, it would englobe a lot of researching in the most populated country in the world. This institution represents the 1.64% of the total research (718 publications). Above it, the Tsinghua University represents the 1.59% (699 publications). This institution is one of the biggest universities in Asia with more than 40,000 students, 32,000 of which belong to masters or doctorate degree. After them, we have more institutions and as we can guess, all of them belong to China. It was a highlight surprise to notice all the research developed in this country and the high difference between China and other countries, at least in this search.

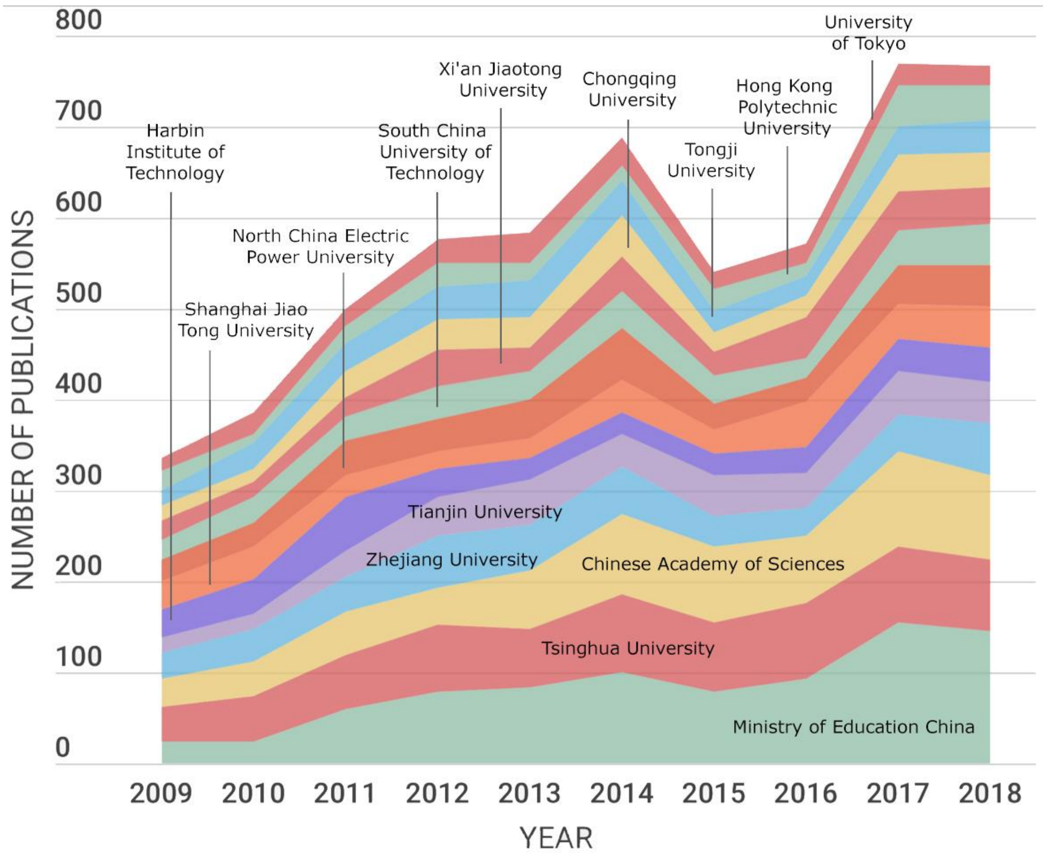

Figure IV-8. Ten most productive institutions during the period 2009–2018.

Table IV-1. Number of publications of the ten most productive institutions and universities between 2009–2018.

Institution	Total	%	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ministry of Education China	847	1.93	24	25	60	78	83	101	78	93	154	146
Tsinghua University	703	1.60	38	48	60	74	64	85	77	83	85	78
Chinese Academy of Sciences	685	1.56	30	40	46	41	64	88	82	73	103	92
Zhejiang University	443	1.01	29	35	38	56	50	53	34	31	42	59
Tianjin University	383	0.87	18	17	30	43	52	34	45	39	48	45
Harbin Institute of Technology	352	0.80	29	38	59	32	23	25	25	28	34	36
Shanghai Jiao Tong University	344	0.78	33	34	23	18	22	36	26	50	38	46
North China Electric Power University	376	0.86	22	28	38	36	41	57	29	26	44	45
South China University of Technology	337	0.77	22	27	26	36	32	40	31	23	38	45
Xi'an Jiaotong University	331	0.75	21	17	22	41	25	39	26	44	43	42
Chongqing University	303	0.69	18	16	28	33	34	45	22	25	39	37
Tongji University	308	0.70	16	27	32	35	40	37	23	21	32	36
Hong Kong Polytechnic University	260	0.59	21	11	20	27	20	17	23	14	46	39
University of Tokyo	235	0.54	14	22	18	27	33	30	20	22	23	20

IV-4.3. Typology of Literature, Languages of Publications and Distribution of output in subject categories.

Table 2 shows the different types of publications during period 2009–2018. We can see how more than half of the total of publications of the search are articles (50.7%). Following them, the conference papers, with 43.1% of the total. After that, the quantity decreases to different types of documents as Reviews (2.3%), Book Chapter (1.6%), or Conference Revision (1.05%).

Table IV-2. Distribution of the searching documents according to the type of publications between 2009–2018.

Type	**Publications**	**%**
Article	18,510	50.67
Conference Paper	15,792	43.13
Reviews	848	2.32
Book Chapters	582	1,59
Conference Reviews	384	1.05
Article in Press	188	0.52
Short Survey	75	0.21
Note	70	0.19
Book	49	0.13
Editorial	32	0.09
Other	21	0.1

The vast majority of articles are published in international journals. Because of that reason, more than 87% of the work have been published in English (31,992), approximately 10% have been published in Chinese (3642) and only 3% includes other languages as Japanese, German, Russian, Polish, or Korean. In Table 3, shows the publications organized by language. Figure 9 shows the classification of publication results by subject, according Scopus.

Table IV-3. Most used languages in documents.

Language	**Publications**	**Percentage (%)**
English	31,992	87.31
Chinese	3642	9.94
Japanese	395	1.08
German	203	0.55
Russian	150	0.41
Polish	71	0.19
Korean	56	0.15
Spanish	54	0.15
French	48	0.13
Ukranian	29	0.08

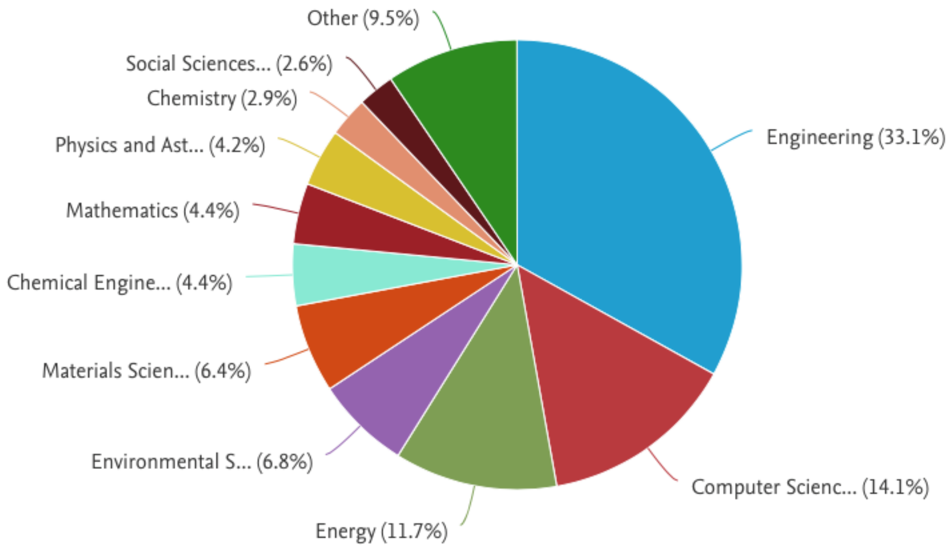

Figure IV-9. Classification of publication results by subject, according Scopus.

IV-4.4. Literature Distribution by Area and Entity.

Figure 10 shows the distribution of publications by country. On the map, red is associated with a high number of publications. Green indicates that there are less publications or grey means that there are no publications or a very limited number of them. It is easily observed how China is the country with more publications (18,309), followed by United States (3716), Japan, and Italy. Also highlight Germany, United Kingdom or Taiwan. This information leads us to the idea of how important the energy saving in the industrialised countries has become, as the richer states have also become involved in this issue by using harsh policies to achieve the proposed objectives. Figure 11 shows the 15 countries that have contributed the most in the last decade.

It should be taken into account the number of inhabitants of each country in order to properly analyse the results. It is not a big surprise to find out that China is the country with more publications as the population in China is the highest in the world (1,386,000,000 in 2017). This is followed by United States, also with a high population: 327,200,000 at 2018 and Japan with 126,800,000 in 2017. However, it is interesting to find countries such as Italy (60,590,000 in 2017) or Germany (82,790,000) with a lower population but still with a significant number of publications.

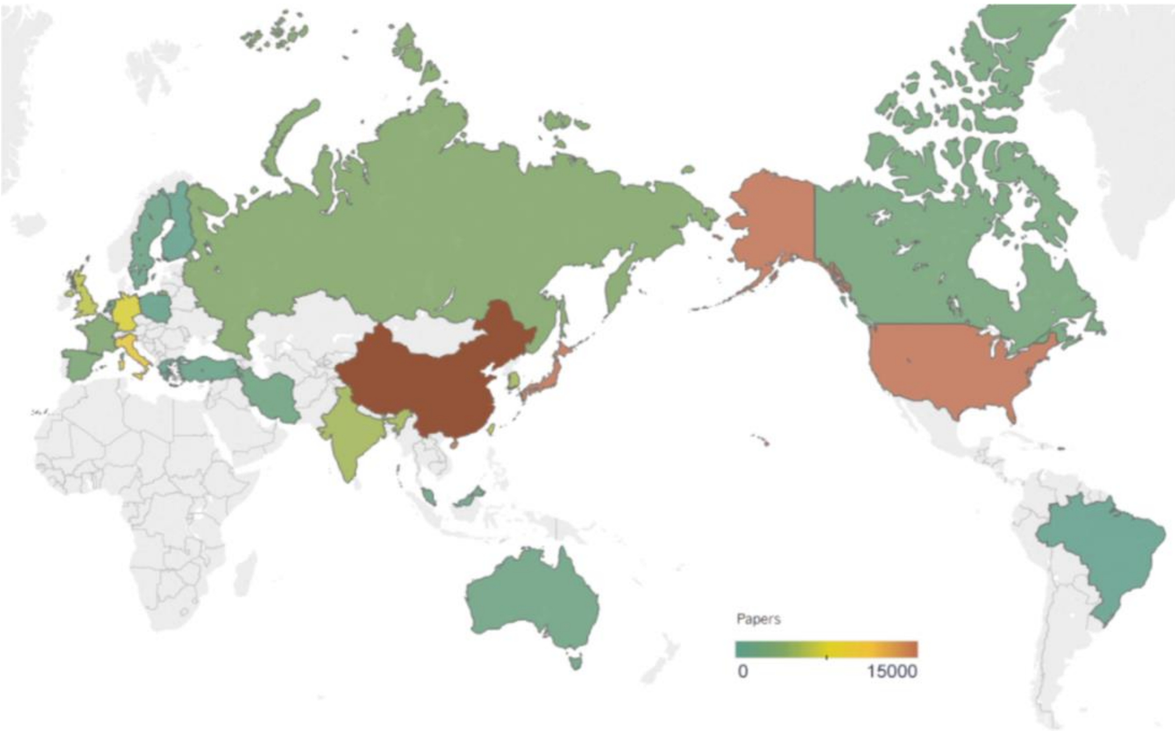

Figure IV-10. World Map with the 25 countries with a higher number of publications.

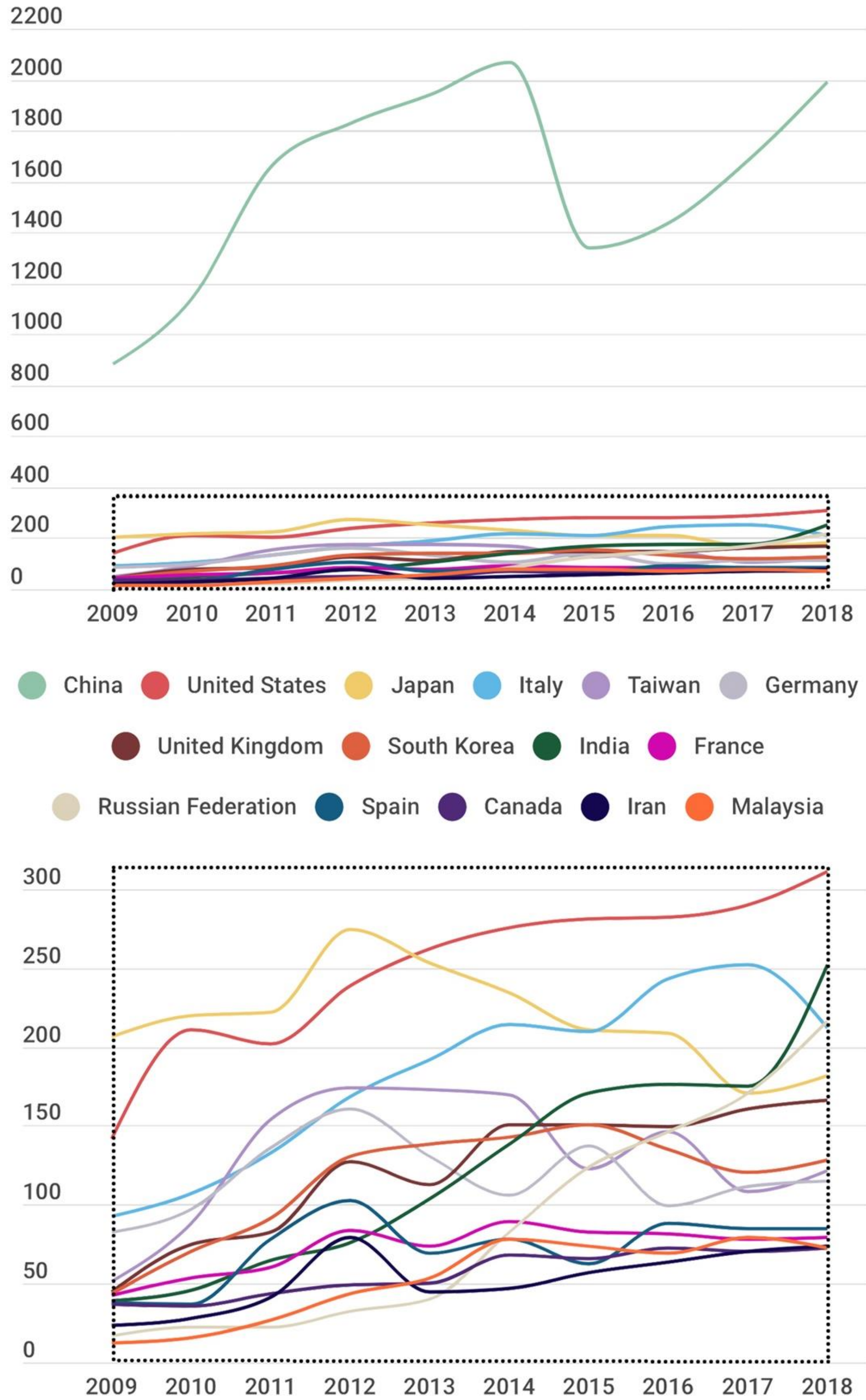

Figure IV-11. 15 countries that have contributed the most in the last decade.

In Figure 12, the five keywords that appeared the most in our search are shown. 4/5 of these are related to energy, being the usual investigation and research of this field to create and find new ways of energy optimization and its use in new technologies. We can see how the term "Energy Conservation" started to be used in the beginning of the century and it has increased remarkably from 2013. In the second place, there is the term "Energy utilization" followed by "Energy Efficiency". After them "Energy saving" was very often used from 2008–2010, but it decreased as the researchers tend to focus their work in the conservation of the energy more than the saving of it.

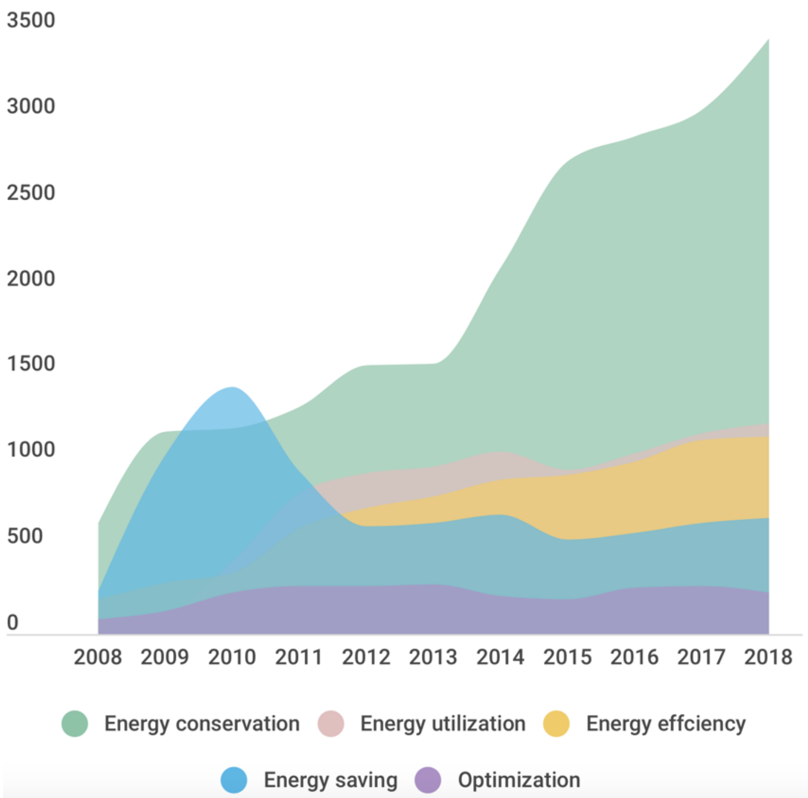

Figure IV-12. 5 most important Keywords and how often they were used during the last decade.

In Figure 13 and Table 4, the ranking of the six most important journals are shown. We have analysed not only the Scimago Journal Rank by Elsevier, but also the CiteScore. The metric of the latter calculates the citations of all papers submitted in the past few years preceding a title. It also includes Source Normalized Impact per Paper, SCImago Journal Rank, quotation and documents counting, and quotation rates. In the figure we have included also the H-Index as it has become very popular in the last decade and the reader can figure it out by the size of the circle according to each of the journals. We can see how

“Renew. Sust. Energ. Rev.” is the journal with higher not only SJR (3.04), but also CiteScore (10.54).

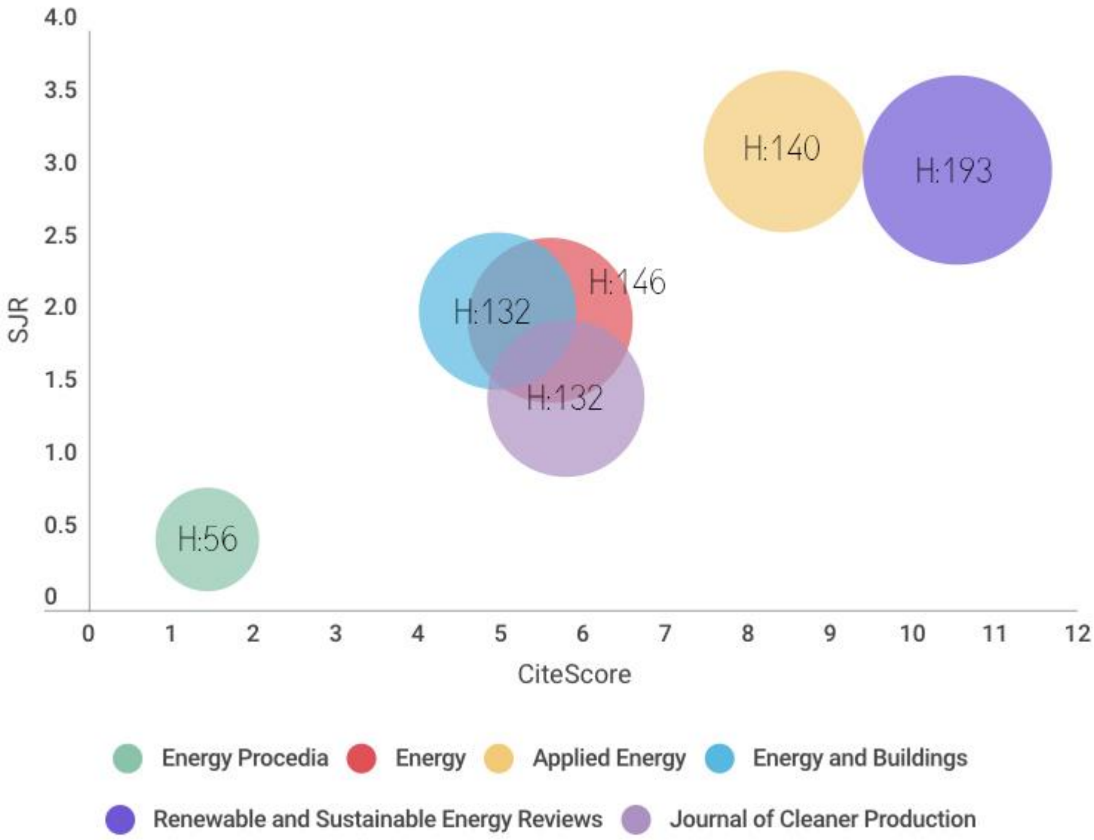

Figure IV-13. Classification of the first 6 journals. CiteScore is the Scopus ranking and SJR (Scimago Journal Rank) by Elsevier. The size of the circles indicates the H-index.

The 21st century is the century of sustainability. This is why the building sector is investing a lot of resources in increasing energy efficiency, concerning both the materials and technologies used to make buildings and building techniques more energy efficient. In other words, it is not only a question of constructing more energy-efficient buildings, such as passivehause buildings and internship rehabilitation, but also of how to construct them, applying more efficient construction techniques, energy savings that must also be extended to the manufacture of construction materials and their transport to the construction site.

Table IV-4. Most important journals through the research.

Journals	Country	Quartile	JCR	H index	Cite Score	SJR	SNIP
Energy Procedia	U. Kingdom	Q2	#N/A	56	1.44	0.49	0.799
Energy	U. Kingdom	Q1	4.968	146	5.6	1.999	1.923
Appl. Energy	U. Kingdom	Q1	7.900	140	8.44	3.162	2.765

Energ. Buildings	Netherlands	Q1	4.457	132	4.96	2.06	2.120
Renew. Sust. Energ. Rev.	United States	Q1	9.184	193	10.54	3.04	3.594
Journal of Cleaner Production	United States	Q1	5.651	132	5.79	1.467	2.194

In Figure 14 we can see the most important authors related with the search through 2009 to 2018. The most important author is Kansha, who against all odds, is not from China, he is from Japan and has published a total of 57 papers related to the search, representing the 0.16% of the total of publications. He has a total of 1103 citations through all his work and a h-Index of 21. After him, Yang has a total of 47 works (0.13%) related to energy saving. All his work has a total of 8829 citations, getting a 45 H-Index. Other authors such as Li go after with 45 works (0.12%) and the Japanese Tsutsumi with 44 (0.12%).

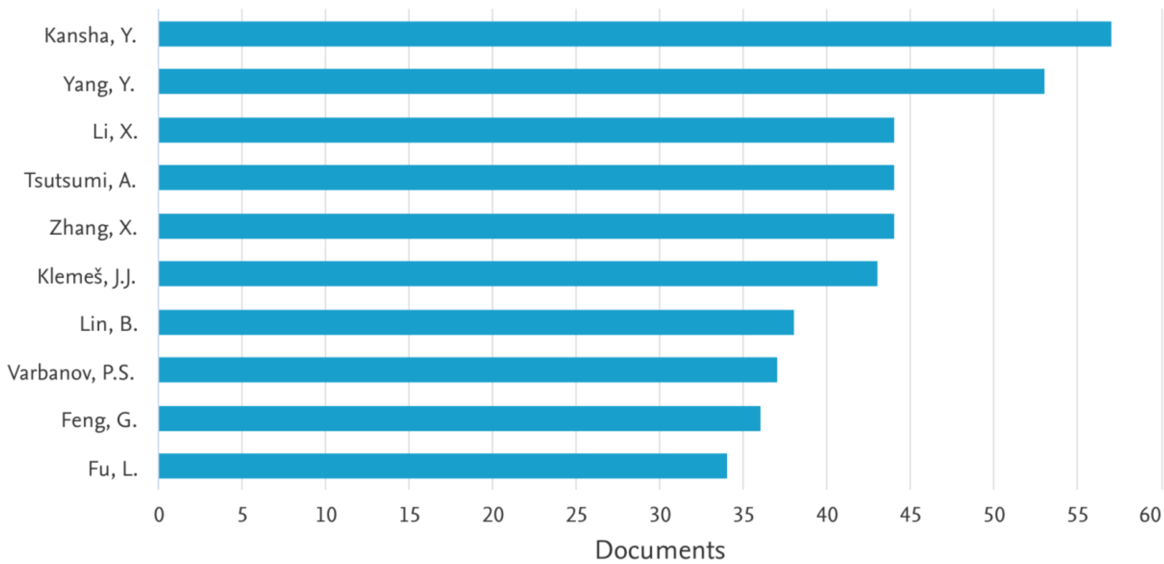

Figure IV-14. Authors who have published related with the search through the last 10 years.

IV-5. Discussion.

The scientific publications in relation to energy saving have had an exponential growth since the year 2000, from that date until now more than 90% of scientific production is condensed. This indicates that the last 20 years are those that have generated the interest of the States through their researchers and programs to support this research. For example, the research related to energy saving in communication and computation [32]. The works published in the topic of energy saving, are mainly in the form of scientific articles (50.7%), but there is an important number in the form of conference papers

(43.1%), which indicates that today it is a novel field of research, in which this topic is addressed in many scientific meetings. It is observed that the books are a percentage below 1%, which means that it is not yet a very well established issue.

Regarding the language of publication, as expected, is dominated by English in more than 87.1%. However, when compared to other scientific fields, it is usual to be above 90%, which suggests that journals in particular countries address this issue in a significant way. As example the Dianli Xitong Zidonghua/Automation of Electric Power Systems, or Zhongguo Dianji Gongcheng Xuebao/Proceedings of the Chinese Society of Electrical Engineering. Such is the case of China, which contributes almost 10% of all publications in its own language. To a lower extent, German (e.g. the journal eb—Elektrische Bahnen) and Japanese (e.g. the journal IEEJ Transactions on Power and Energy from The Institute of Electrical Engineers of Japan), both around 2%, stand out. In any case, it is clear that China, as one of the world largest consumers of energy, has a great concern for energy saving [33], as was to be expected. This is also evident if it is observed that the main institutions that publish on this subject are also from China, Table 2. If the analysis focuses on the scientific fields where these works are assigned, Figure 9, it is remarkable that the first is not energy, but that the first place is occupied by engineering with 33.1%, showing that developments in this field are the largest part of the contributions, especially those related to energy conservation [34]. On the other hand, it is surprising that Computer Science plays such an important role in this field; this is justified by optimisation-related works [35]. Finally, it should be noted that one of the largest group is "others" with 9.2%. This should indicate the great diversity of scientific fields from which this subject is approached, being important the contribution to the energy saving that is studied from the greater number of points of view [36], which is what will allow to contribute to the global energy saving including geographical areas with serious energy shortages [37].

From the point of view of the networking of the works among themselves, this work shows a vast number of works published on the subject of energy saving, but the most important fact is that about 62% do not cite other work related to this subject. This implies great individualism, and scarce scientific connection in this field, which should make researchers reconsider, because it is important that research is based on previous studies to progress. However, it may also imply that they are researchers from other fields of knowledge who are becoming aware of or are including these items in their work, which is very encouraging. Within the works that are related to each other and are the core of scientific research in energy saving through the identification of communities have been detected the top 15. In the central positions, we find the scientific fields that might be said are most popular, see Figure 4: Lighting, thermal comfort, building insulation, cooling techniques, HVAC techniques, household-behaviour, or public buildings. Lighting has undergone a revolution since the emergence of solid-state light sources. The efficiency of solid-state technology provides, in a multitude of applications, energy savings, and environmental benefits [38]. Above all energy saving based on lighting has been studied for residential issues [39], public buildings, schools [40], or shopping malls [41]. Another one of the great challenges of energy saving is thermal comfort. Thermal comfort implies a good indoor climate that is important for the success of a building [42], not only by making its occupants feel comfortable, but also by deciding their energy consumption and thus influencing its sustainability [43]. On the other hand, persons have a natural trend to adapting to the conditions changing in their surroundings. This is especially the case with the scientific communities found around the central core of energy saving: building insulation, cooling techniques or HVAC techniques. Therefore, saving energy from households is one of the priorities of most countries, such us China, Italy, USA, or Japan. Those that occupy external positions are considered less integrated with the others, still have great possibilities of integration with the core and are generally the smallest. This is the way to find it: Distillation, communication protocols, electricity market, communication equipment, or railway. Related to these scientific communities it should be mentioned that distillation is still the most popular separation technology of chemical plants, and it uses around half of the operational costs, which shows the major concern of the researchers in applying here the energy saving. The energy savings in the communication protocols has been developed mainly using mobile telephony, where the terminals have a limited battery capacity. The third scientific community found is that related to the electricity market, being this one of variable tariffs, makes energy savings in certain time slots is of special interest. Regarding communication equipment, given the rising digital level of the developed countries, there is a growing concern about the data centres, especially in two respects, cooling and IT load. The amount of world energy consumption has gone from 0.5% in 2000 to 1% in 2005. With respect to the railway, the electric railway system is considered the most environmentally friendly means of locomotion. This is due to two important points: Firstly, the low resistance to running and secondly, the regeneration of energy during braking.

IV-6. Conclusions.

This study presents a wide range of data on the international contribution to scientific knowledge in the field of energy savings during the period from 1939 to 2018. The newness of this work is the application of community detection algorithms which identify scientific communities in the world that develop their work in fields related to energy saving. They also detect the collaboration preferences of their authors at an international level or even at an institutional level as in the case of China. It should be noted that many of the published papers have been the result of this international collaboration.

This methodology makes it possible to understand two complex systems: the network of publications based on quotations and the network of scientific collaborations based on the nationality of the co-authors.

Research Network Bot was used to search for publications indexed by Scopus containing 'energy savings', in the title or keywords. The information obtained was used for the analysis and graphical representation of these networks of scientific collaboration of researchers working in this field.

49,539 documents have been found, from which 55.5% are articles and 38.5% are conference papers. In this period there has been an exponential increase in publications, highlighting the categories of Engineering, Energy, and Computer science.

In light of the data obtained, Chinese institutions have provided an important contribution to the field. It is noted that, logically, the compound terms related with energy are the most used keywords, being energy conservation, energy utilization, energy efficiency, energy saving, and fifthly, optimization, proved as the most popular terms. Different aspects of the publications are analysed, such as language, type of publication, scope, top contributors' countries, institutions, journals, authors, as well as the frequency of appearance of keywords. Geographically, the giants China and United States, followed by Japan and Italy are highlighted as the top contributors' countries. The most active categories within the field of Energy are Lighting with 9.44%, Thermal Comfort (9.18%), Emission reduction and Buildings Insulation, both of then representing more than 8,5%. These 4 fields represent areas where energy saving plays a very important role as buildings, responsible for more than 40% of the energy consumption. In order to reduce this, there should be a release of a kind of regulation or policy to control systems for the installation of lighting.

Therefore, the communities that are in the lead, refer to the state of comfort, but also to the latent concern for the waste emitted into the atmosphere and how these can directly affect our planet in the future. Policies actually adopted in developed countries are insufficient to ensure a significant reduction of the energy consumption. It forecasts that the current global demand for energy in buildings will double by 2050. Thus, it is necessary to implement, at the global level, effective saving policies [44]. The challenge is always to reduce the energy consumption without forgetting the comfort of the user and the requirements of the building. The results of the work show that during the last 10 years have substantially increased the number of publications in this field, which indicates that research in terms of energy saving is assumed as an important and relevant issue in the international scientific scene.

During the last decade China, the most productive country in "energy saving" has become the main leader in the growth of energy efficiency. Its GDP grew a total of 7.8%

per year and the energy intensity fell a total of 18.2%. This outstanding result is related with how energy efficiency policies have become the center of the political landscape through these year [45]. Energy efficiency was first included in the five-year plans, in the mid-2000s. It was a first sign of China's acceleration towards greener policies. In addition, energy efficiency has played a role in number of key Chinese economic policies: The market liberalisation and privatisations of the 1990s, the quest for energy security, economic development, or the fight against climate change.

This shows that there is a correlation between the number of publications in this country and the application of energy policies, but we do not have data to extend this assertion to the rest of the countries of the world. The study of the implementation of energy policies in each country, the energy savings achieved and the relationship with its scientific production on the subject, both quantitatively and qualitatively, would be the subject of future work.

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Chapter V. Analysis of energy consumption and proposal of energy efficiency measures in public buildings. (“Reina Sofía” University Hospital)

Chapter V. Analysis of energy consumption and proposal of energy efficiency measures in public buildings. ("Reina Sofía" University Hospital).

V-1. Objective.

The object of the chapter is an energy review of the Reina Sofia University Hospital in Cordoba, belonging to the andalusian health service. This chapter identifies current energy sources and analyses current and past energy use and consumption, analysing data from the last 3 years. The areas of significant energy use and the equipment or installations with the highest energy consumption, susceptible to energy improvements, will be identified, and the first lines of improvement will be proposed, which will materialise over time, and a first energy baseline will be established for this period. This may be taken as a reference for calculating energy savings, before and after implementing actions to improve energy performance.

Figure V-1: View of Reina Sofía Hospital [1].

After compiling the basic information on energy management, a diagnosis is made of all the variables that may have a direct impact on the rational use of energy and the main areas to be investigated in order to detect possible energy improvements are:

- Energy sources and general uses.
- Characteristics of consumption elements.
- Operating conditions.
- Conditions of use.
- Degree of efficiency of the equipment.
- Maintenance.
- Control and regulation.

V-2. General Data.

V-2.1. General Characteristics.

The following is a summary of the main characteristics of the centre, such as the number of beds or workers, timetables, management units present in the installation and surfaces.

Table V-1: General information.

BUILDING	REINA SOFÍA HOSPITAL	
ADDRESS	Menéndez Pidal s/n	
BEDS	715	
WORKERS		
SCHEDULE	Outpatient Consultations	8:00 a 22:00
	Emergency Room	24 h
	Hospitalization	24 h
FLOORS	8	

CLINICAL MANAGEMENT UNITS (*)	Palliative Care Thoracic Surgery Ophthalmology Gynecology and Obstetrics Emergency General Surgery Radiodiagnosis Digestive system Pediatric Surgery Rheumatology Pathological Anatomy Locomotive Apparatus Immunology, Allergology Neurosurgery and Neurophysics Orthopedic Surgery and Traumatology Pneumology Medical Oncology Cardiovascular Surgery Rehabilitation Dermatology Nephrology Neurology Radiation Oncology Maxillofacial Surgery Microbiology Urology Pharmacy Nuclear Medicine Clinical Analyses	
OTHER UNITS (*)	Maintenance Electromedicine Staff Economic address Formation Prevention of occupational risks	
SURFACE (m2)	Main Hospital	101,798.07
	Maternal and Infant Hospital	19,861.97
	Outpatient consultations Building	13,888.22

	Pathological Anatomy	4,356.43
	Warehouse Platform	3,471.19
	Maintenance Workshops	1,733.76
	Laundry	1,637.89
	Government Building	2,895.08
	Sterilization Warehouse	3,471.19
	TOTAL SURFACE	150,696.45 m^2

V-3. Energy sources and general uses.

First, the energy sources used in the centre and the general uses for each of the sources are identified.

Table V-2: Energy sources and general uses.

ENERGY SOURCES AND GENERAL USES		
Energy source	Principal use	Specific Use
Electricity	Air Conditioning	Chillers Air conditioning distribution pumps Air handling units (engines) Ventilation (extractors) Fancoils (engines) Cold rooms CPD (air conditioning) Cafeteria
	Lighting	Industrial lighting Street lighting Interior
	Power	Elevators Domestic hot water pumps Sterilization Kitchen Cafeteria Outdoor lighting, industrial lighting Compressors Pneumatic conveying Laboratories CPD (SAIS and servers)

Thermal energy	Natural Gas	Heating Domestic hot water Laboratories Kitchens Cafeteria
	Gasoil	Generating sets Boilers in emergency
	Solar Energy	Sanitary Hot Water

V-4. Specific uses and equipment.

Once the general uses have been identified, the equipment and specific uses of the Centre are detailed below.

Source	Centre	Principal Use	Equipment	Electrical Power (kW)	Hours	Variator Frequency?
Electricity	Reina Sofia	Air Conditioning	6 chillers	2500		YES
Electricity	Reina Sofia	Air Conditioning	337 machines	664		YES
Electricity	Reina Sofia	Air Conditioning	90 air handling units	430		YES
Electricity	Reina Sofia	Air Conditioning	117 pumps	993		YES
Natural Gas	Reina Sofia	Air Conditioning	2 boilers	8362		NO
Natural Gas	Reina Sofia	Steam Production	2 boilers	14500		NO
Natural Gas	Reina Sofia	Kitchen / Cafeteria	Stoves	592	8	NO
Electricity	Reina Sofia	Radiology Equipment	47 machines	1565	16	NO
Electricity	Reina Sofia	Clinical Equipment	3000 machines	450	8	NO
Electricity	Reina Sofia	Interior Lighting	15000 items	300	12	NO
Electricity	Reina Sofia	Elevators / Forklifts	41 machines	700	24	YES
Electricity	Reina Sofia	Computer Equipment	2400 computers	240	8	NO
Electricity	Reina Sofia	Televisions	450 Televisions	45	5	NO
Electricity	Reina Sofia	Outdoor Lighting	170 items	51	12	NO
Natural Gas	Reina Sofia	Laundry Room	13 heaters	2480	10	

Table V-3: Specific uses and equipment.

Table V-4: Electricity and natural gas use and installed power (kW).

Electricity		Natural Gas	
Use	Installed power (kW)	Use	Installed power (kW)
Air Conditioning	4587	Steam Production	14500
Radiology	1565	Air Conditioning	8362
Elevators	700	Laundry	2480
Electromedicine	450	Kitchen / Cafeteria	592
Lighting	351		
Computers/TV	285		

On the basis of the data obtained, a first estimate was made of the electrical power and natural gas installed by main use, with the result that the main electricity consumers are air conditioning (including pumping), radiology equipment and lifts and that the main gas consumers are steam production, air conditioning and laundry, as can be seen in the following graphs:

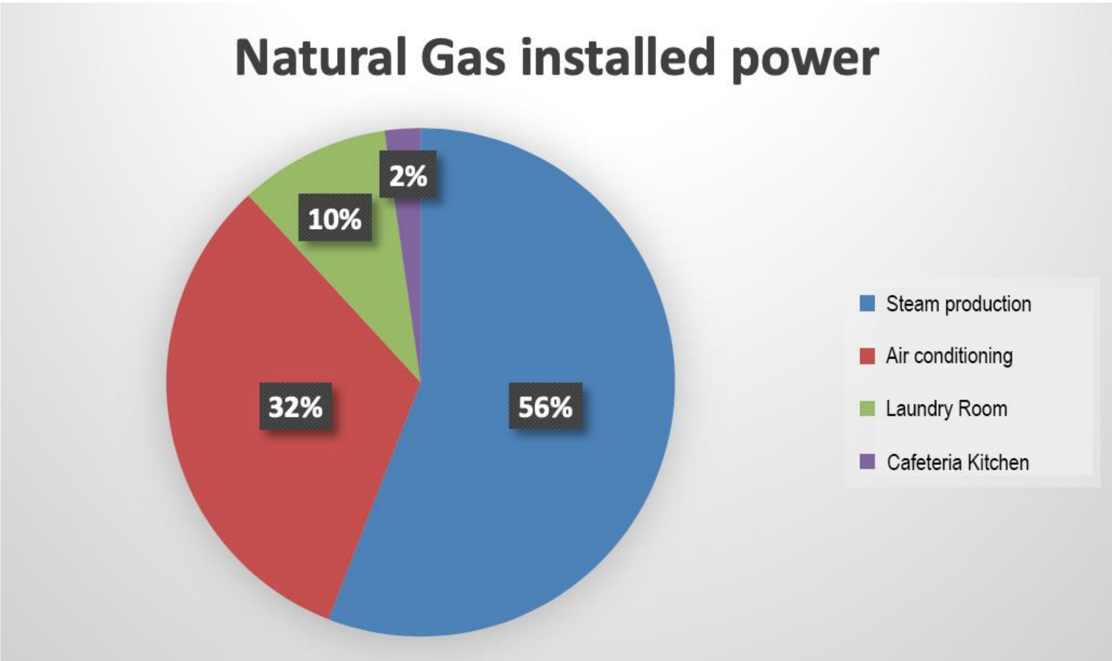

Figure V-2: Natural gas installed power.

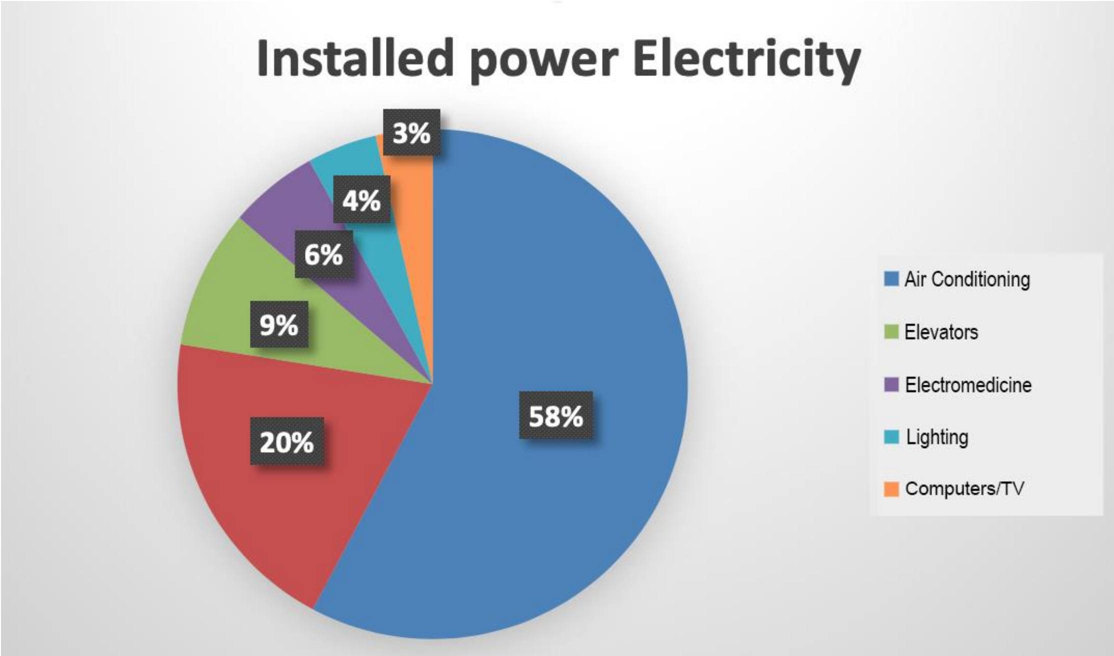

Figure V-3: Installed power electricity.

V-5. Significant energy uses.

Significant energy uses are defined as those that result in substantial energy consumption and/or offer considerable potential for improving energy performance. Thus, the general criteria established to establish significant use are as follows:

- Consumption: The value of the energy consumption of the use in relation to the total is more than 10%.
- Increase: The value of the indicator with which use is measured has varied with respect to the previous year by more than 15%.
- Power: The value of the installed power for use in relation to the total installed power is greater than 15%.
- Improvement: A potential energy improvement has been detected that can reduce the consumption of the use in a relevant way.

Therefore, according to the information analyzed, the degree of detail of the existing data, and the criteria established in Procedure PGE-01 Energy Review [3], the significant energy uses determined for the Reina Sofia Hospital are summarized below:

Table V-5: Significant uses.

SIGNIFICANT USES				
Energy Source	Use	Independent control	Estimation	Criteria
Electricity	Global Electricity Consumption	Bills	-	Consumption
Electricity	Air conditioning	Yes	Measurement Campaign	Improvement
Electricity	Lighting	No	No	Improvement
Natural Gas	Global Natural Gas Consumption	Bills	-	Consumption
Natural Gas	Heating	No	No	Improvement
Natural Gas	Sanitary hot wáter	Yes	.	Improvement

V-6. Basic data.

This section includes the basic data necessary for the calculation of the Energy Performance Indicators (IDEn) and the Energy Baseline (LBEn).

V-6.1. Existing Consumption Controls.

The following table summarizes the existing control methods for each of the energy sources considered.

Table V-6: Control of energy consumption.

CONTROL OF ENERGY CONSUMPTION		
Source	Control	Controlled Uses
Electricity	Counter for main switchgear	Consumption per building
Natural Gas	Telematic counter	Central thermal gas
Natural Gas	Bill and meter	Laundry room Kitchen / Cafeteria Main Hospital Kitchen / Cafeteria outpatient consultations building

The Reina Sofía Hospital has the following energy control equipment installed:

Table V-7: Energy consumption control equipment.

ENERGY CONSUMPTION CONTROL EQUIPMENT			
Unit	Brand	Quantity	Specialty / Location
Network Analyzer	Schneider	21	Transformation centre 1
Network Analyzer	Schneider	6	Light overview Main Hospital
Network Analyzer	Schneider	10	Light overview Outpatients consultations building
Network Analyzer	Schneider	1	Logistics warehouse
Contador de gas natural telemandado		1	Thermal power plant
Enthalpic counters		20	Boilers 4, Chillers 4, Hot Water, Cold Water, cold and hot water circuits of 5 subcentrals.
Network analyzers		3	Heat pumps for DHW
Flowmeters Steam		2	Laundry, sterilization

V-6.2. Energy Consumption Data.

The following table presents the different controlled uses in the Centre, as well as the type of control and the energy source of origin, defined in Procedure PGE-01 Energy Review.

Table V-8: Energy consumption.

ENERGY CONSUMPTION		
Source	Type of Control	Controlled Uses
Electricity	Bill	Global consumption
	Partial counters	Meter for transformer station and high power circuit breakers
Natural Gas	Bill	Cafeterias, Laundry, Thermal Power Plant
Gasoil	Bill	
Solar	Partial counters	Meter by installation

The following tables show the monthly consumption data in MWh by energy source for 2015, 2016 and 2017.

Table V-9.1: Consumption data year 2015.

BASIC DATA YEAR: 2015				
	CONSUMPTION DATA (MWh)			
MONTH	Electricity	Natural Gas	Gasoil	Solar
January	1,526	2,587		42.40
February	1,437	2,676		31.70
March	1,596	2,594		53.60
April	1,595	1,870		46.40
May	1,831	1,606		62.40
June	2,117	920		57.30
July	2,559	778		51.91
August	2,244	607		50.39
September	1,773	656		38.80
October	1,654	1,166		33.80
November	1,549	1,978		34.40
December	1,590	3,112		26.40
TOTAL 2015	21,471	20,551	0	529

Table V-9.2: Consumption data year 2016.

BASIC DATA YEAR: 2016				
	CONSUMPTION DATA (MWh)			
MONTH	Electricity	Gas Natural	Gasoil	Solar
January	1,629	2,673		15.90
February	1,543	2,706		20.40
March	1,601	2,285		34.50
April	1,569	1,752		37.10
May	1,687	1,129		43.60
June	2,038	767		46.70
July	2,351	684		63.70
August	2,343	637		57.10
September	1,995	551		59.10
October	1,767	1,040		48.80
November	1,576	1,996		39.47
December	1,629	2,737		31.91
TOTAL 2016	21,727	18,958	0	498

Table V-9.3: Consumption data year 2017.

BASIC DATA YEAR: 2017				
MONTH	CONSUMPTION DATA (MWh)			
	Electricity	Gas Natural	Gasoil	Electricity
January	1,606	2,610		44.63
February	1,474	2,312		33.70
March	1,625	2,191	12	57.40
April	1,462	1,022		54.10
May	1,711	928		51.00
June	2,157	446		61.70
July	2,224	415		52.00
August	2,239	391		47.80
September	1,904	420		53.00
October	1,727	457		46.50
November	1,383	1,452		38.60
December	1,394	2,042		30.00
TOTAL 2017	20.906	14.687	12	570

A small table is included with three data to consider, which are the total area of the Centre, and the conversion factors of natural gas and diesel for transforming the units of some energy consumptions.

Table V-10: Other data.

OTHER DATA	
Total area (m^2)	150,696.45
NG conversion factor (kWh/m^3)	11.7
Diesel conversion factor (kWh/l)	9.98

The following is a summary of annual consumption by source of supply:

Table V-11: Summary of annual consumption by source of supply.

YEAR	CONSUMPTION DATA					
	Electricity (MWh)	Natural gas (MWh)	Gasoil (MWh)	Solar (MWh)	TOTAL	% SOLAR/TOTAL
2015	21,471	20,551	0	529	42,551	1.24%
2016	21,727	18,958	0	498	41,184	1.21%
2017	20,906	14,687	12	570	36,175	1.58%

As you can see the consumption of solar energy is maximum in the months of higher insolation and represents a small percentage compared to total consumption. The annual differences are due to variations in the solar radiation received since no investments have been made to justify the increase observed in 2017. It would be advisable to increase the percentage of renewable energies, increasing solar energy installations and installing biomass boilers. These require important investments at the beginning, but they are profitable in the medium term and, in addition, the pollution of the natural environment is reduced.

Given that diesel consumption is insignificant in relation to the consumption of other fuels, since it is only used in the replacement of fuel for emergency generators (March 2017), we will focus on electricity and gas.

The electricity and natural gas consumption of the Reina Sofía Hospital, corresponding to the last 3 years, are summarised in the following tables.

Table V-12: Hospital electricity consumption (MWh).

REINA SOFÍA HOSPITAL			
MONTH	Electricity consumption (MWh)		
	2015	2016	2017
JANUARY	1,526	1,629	1,606
FEBRUARY	1,437	1,543	1,474
MARCH	1,596	1,601	1,625
APRIL	1,595	1,569	1,462
MAY	1,831	1,687	1,711
JUNE	2,117	2,038	2,157
JULY	2,559	2,351	2,224
AUGUST	2,244	2,343	2,239
SEPTEMBER	1,773	1,995	1,904
OCTOBER	1,654	1,767	1,727
NOVEMBER	1,549	1,576	1,383
DECEMBER	1,590	1,629	1,394
TOTAL	21,471	21,727	20,906

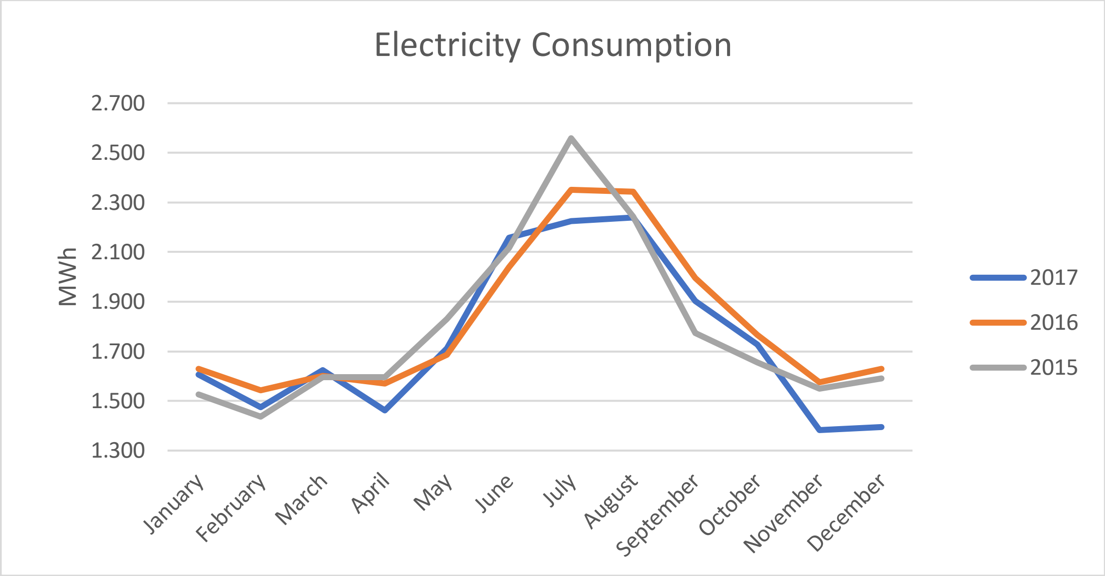

Figure V-4: Electricity consumption.

Table V-13: Hospital gas natural consumption (MWh).

REINA SOFÍA HOSPITAL			
MONTH	Natural Gas consumption MWh		
	2015	2016	2017
JANUARY	2,587	2,673	2,610
FEBRUARY	2,676	2,706	2,312
MARCH	2,594	2,285	2,191
APRIL	1,870	1,752	1,022
MAY	1,606	1,129	928
JUNE	920	767	446
JULY	778	684	415
AUGUST	607	637	391
SEPTEMBER	656	551	420
OCTOBER	1,166	1,040	457
NOVEMBER	1,978	1,996	1,452
DECEMBER	3,112	2,737	2,042
TOTAL	20,551	18,958	14,687

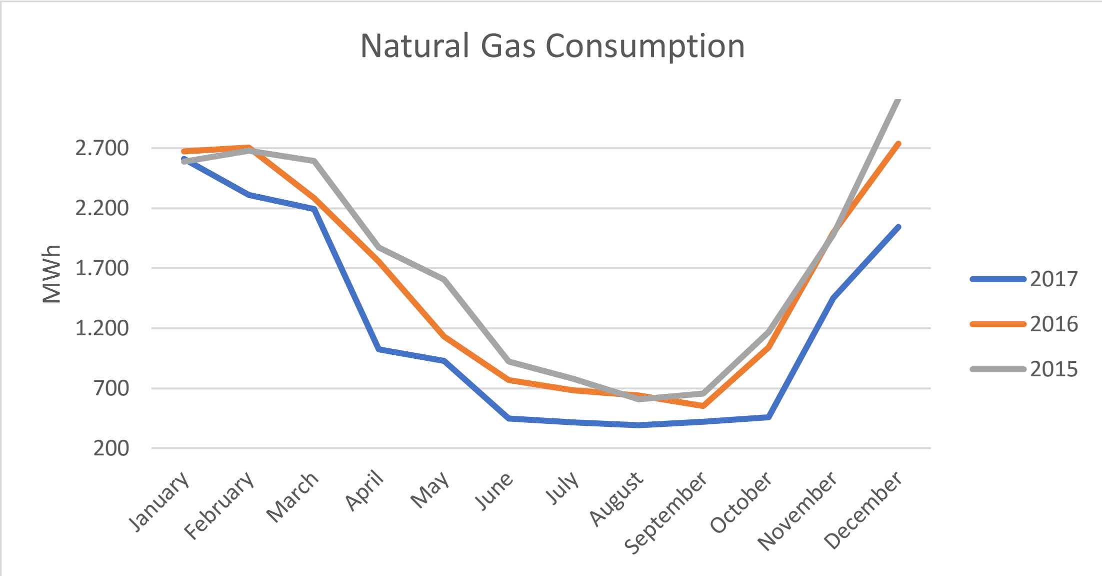

Figure V-5: Natural gas consumption.

In a first estimate, based on the power of electricity and natural gas installed by main uses, it was found that one of the main applicants for power of electricity and natural gas is air conditioning, with 58% and 32% respectively of the installed power.

The consumption graphs represent that air conditioning is also one of the main consumers of energy, both electricity and natural gas, as can be deduced from the fact that most of the electricity consumption is due to air conditioning, which increases very significantly in the summer season; and that most of the consumption of natural gas is due to the demand for heating, as it increases very significantly in the winter season. Hence the importance, for buildings in general and for public use in particular, of good thermal insulation and a temperature control system.

There is also a significant reduction in consumption in 2017 and yet there is no reduction in activity in the hospital that justifies it or a noteworthy climatic variation. The reason for this reduction is the entry into operation of the energy services contract in April 2017, which has meant greater control of timetables, the adjustment of air conditioning to the real situation of the hospital, and the application of measures to improve the regulation of the hospital's energy circuits.

V-6.3. Other variables to consider.

In order to define indicators and establish the energy baseline, other secondary variables must be considered with which to weight the data relating to energy consumption. The following is a list of the data to be considered, the frequency and their sources of information.

Table V-14: Other variables.

OTHER VARIABLES (MINIMUM)		
Data	Frequency	Source
Number of beds	Monthly	Welfare Indicators
Number of stays (in the hospital)	Monthly	Welfare Indicators
Number of users (Primary Care)	Monthly	Welfare Indicators
Surface	Significant changes	Diagnosis / Initial Energy Review
Average Daily Temperature	Monthly	State Meteorological Agency
Hours of operation	Monthly	Occupation Profiles
OTHER VARIABLES (ADITIONAL)		
Thermal Power Production (kWh)	Monthly	Natural Gas Boiler Meters
PCI fuels	Significant changes	Bills / Supplier Information
Hours of Operation Generating Groups	Monthly	Monthly Review
Solar Energy Production (kWh)	Monthly	Meters

In the case of the Reina Sofia Hospital, I have taken into consideration the calculation variables established as necessary (minimum) in the energy review for the calculation of the basic Energy Performance Indicators and the Energy Baseline, recording the data in the following tables corresponding to the years 2015, 2016 and 2017.

Table V-15.1: Basic data - Calculation variables – Year 2015.

	BASIC DATA YEAR: 2015				
	CALCULATION VARIABLES				
MONTH	Number of beds	Number of stays	Operating Hours (h)	Average Daily Temperature (ºC)	Degrees month (22ºC)
JANUARY	699	15,459	24	7.10	14.90
FEBRUARY	720	15,443	24	9.50	12.50
MARCH	723	16,204	24	13.30	8.70
APRIL	722	14,862	24	17.40	4.60
MAY	721	15,158	24	23.20	1.20
JUNE	723	15,211	24	26.40	4.40
JULY	694	14,098	24	31.10	9.10
AUGUST	677	12,577	24	28.40	6.40
SEPTEMBER	703	12,869	24	23.40	1.40
OCTOBER	718	14,742	24	19.20	2.80
NOVEMBER	719	15,175	24	13.40	8.60
DECEMBER	726	14,721	24	10.70	11.30
TOTAL 2015	8,545	176,519	288		

Table V-15.2: Basic data - Calculation variables – Year 2016.

	BASIC DATA YEAR: 2016				
	CALCULATION VARIABLES				
MONTH	Number of beds	Number of stays	Operating Hours (h)	Average Daily Temperature (ºC)	Degrees month (22ºC)
JANUARY	695	15,239	24	11	11
FEBRUARY	704	14,877	24	11.10	10.90
MARCH	706	15,356	24	11.50	10.50
APRIL	700	14,539	24	15.80	6.20
MAY	699	15,265	24	19	3
JUNE	702	14,524	24	25.80	3.80
JULY	697	13,182	24	29.40	7.40
AUGUST	684	11,994	24	29	7
SEPTEMBER	692	12,635	24	25.30	3.30
OCTOBER	703	14,222	24	19.80	2.20
NOVEMBER	704	14,254	24	12.50	9.50
DECEMBER	704	13,813	24	10.20	11.80
TOTAL 2016	8,390	169,900	288		

Table V-15.3: Basic data - Calculation variables – Year 2017.

	BASIC DATA YEAR: 2017				
	CALCULATION VARIABLES				
MONTH	Number of beds	Number of stays	Operating Hours (h per day)	Average Daily Temperature (ºC)	Degrees month (22ºC)
JANUARY	705	15,020	24	7.48	14.52
FEBRUARY	706	14,297	24	11.80	10.20
MARCH	706	15,521	24	13.71	8.29
APRIL	704	14,324	24	16.72	5.28
MAY	705	14,094	24	21.41	0.59
JUNE	702	13,818	24	28.58	6.58
JULY	690	13,514	24	29.17	7.17
AUGUST	679	12,764	24	29.45	7.45
SEPTEMBER	690	12,560	24	25.18	3.18
OCTOBER	701	13,515	24	21.77	0.23
NOVEMBER	709	13,844	24	12.50	9.50
DECEMBER	715	14,637	24	8.44	13.56
TOTAL 2017	8,412	167,908	8,760		

The basic consumption data and other (minimum) variables taken into account for the years 2015, 2016 and 2017 are detailed together in the following tables:

Table V-16: Consumption data and calculation variables.

MONTH	CONSUMPTION DATA				CALCULATION VARIABLES				
	Electricity (MWh)	Natural gas (MWh)	Gasoil (MWh)	Solar (MWh)	Number of beds	Number of stays	Operating Hours (h per day)	Average Daily Temperature (ºC)	Degrees month (22ºC)
January_15	1,526	2,587		42.40	699	15,459	24	7.10	14.90
February_15	1,437	2,676		31.70	720	15,443	24	9.50	12.50
March_15	1,596	2,594		53.60	723	16,204	24	13.30	8.70
April_15	1,595	1,870		46.40	722	14,862	24	17.40	4.60
May_15	1,831	1,606		62.40	721	15,158	24	23.20	1.20
June_15	2,117	920		57.30	723	15,211	24	26.40	4.40
July_15	2,559	778		51.91	694	14,098	24	31.10	9.10
August_15	2,244	607		50.39	677	12,577	24	28.40	6.40
September_15	1,773	656		38.80	703	12,869	24	23.40	1.40
October_15	1,654	1,166		33.80	718	14,742	24	19.20	2.80
November_15	1,549	1,978		34.40	719	15,175	24	13.40	8.60
December_15	1,590	3,112		26.40	726	14,721	24	10.70	11.30
TOTAL 2015	21,471	20,551	0	529	8,545	176,519	8760		
January_16	1,629	2,673		15.90	695	15,239	24	11.00	11
February_16	1,543	2,706		20.40	704	14,877	24	11.10	10.90
March_16	1,601	2,285		34.50	706	15,356	24	11.50	10.50
April_16	1,569	1,752		37.10	700	14,539	24	15.80	6.20
May_16	1,687	1,129		43.60	699	15,265	24	19.00	3

June_16	2,038	767		46.70	702	14,524	24	25.80	3.80
July_16	2,351	684		63.70	697	13,182	24	29.40	7.40
August_16	2,343	637		57.10	684	11,994	24	29	7
September_16	1,995	551		59.10	692	12,635	24	25.30	3.30
October_16	1,767	1,040		48.80	703	14,222	24	19.80	2.20
November_16	1,576	1,996		39.47	704	14,254	24	12.50	9.50
December_16	1,629	2,737		31.91	704	13,813	24	10.20	11.80
TOTAL 2016	21,727	18,958	0	498	8,390	169.900	8760		
January_17	1,606	2,610		44.63	705	15,020	24	7.48	14.52
February_17	1,474	2,312		33.70	706	14,297	24	11.80	10.20
March_17	1,625	2,191	12	57.40	706	15,521	24	13.71	8.29
April_17	1,462	1,022		54.10	704	14,324	24	16.72	5.28
May_17	1,711	928		51	705	14,094	24	21.41	0.59
June_17	2,157	446		61.70	702	13,818	24	28.58	6.58
July_17	2,224	415		52	690	13,514	24	29.17	7.17
August_17	2,239	391		47.80	679	12,764	24	29.45	7.45
September_17	1,904	420		53.00	690	12,560	24	25.18	3.18
October_17	1,727	457		46.50	701	13,515	24	21.77	0.23
November_17	1,383	1,452		38.60	709	13,844	24	12.50	9.50
December_17	1,394	2,042		30.00	715	14,637	24	8.44	13.56
TOTAL 2017	20,906	14,687	12	570	8,412	167,908	8760		

Indicate that the temperature is presented as degrees month considering a reference temperature of 22ºC, which means that in the column of degrees month, the value that appears corresponds to the deviation with respect to the reference value, calculated as the difference in absolute value between the monthly average of the average daily temperatures and a reference temperature of 22ºC. This is so because the growth in consumption occurs both at temperatures above the reference temperature for the consumption of refrigeration, and at temperatures below the reference temperature for consumption in heating. The choice of 22ºC as reference temperature is due to the result of the study in the pilot centres of the Andalusian Health Service, as it is the one that has provided the best result in the calculation of the baselines.

V-7. Energy performance indicators.

Energy performance consists of measurable results specifically related to energy efficiency, energy use and energy consumption [5].

The IDEn (Energy Performance Indicator or quantitative value or measure of energy performance) will be those that allow quantifying the energy performance of the organization and, generally, will be parameters measured or calculated from the basic data of the previous section.

Thus, according to the characteristics and information available, their IDEn will be determined, considering as a minimum the Indicators defined as basic in Procedure PGE-01 Energy Review, although it could be complemented with other Indicators that can be calculated and for which information is available.

V-7.1. Basic Indicators to be considered by all Centres.

Table V-17: Basic indicators.

BASIC INDICATORS		
INDICATORS	UNIT	DATA
Total Energy Consumption	MWh	Electrical Consumption Fuel Consumption
Total energy consumption per area	MWh/m^2	Total Energy Consumption by SurfaceElectrical Consumption Fuel Consumption Surface
Total energy consumption per area and hour of operation	kWh/m^2·h	Electrical Consumption Fuel Consumption Surface Hours of operation

Total energy consumption per temperature	MWh/ºC month	Electrical Consumption Fuel Consumption Average Monthly Temperature
Total Energy Consumption by number of stays (Hospitals)	kWh/stay	Electrical Consumption Fuel Consumption No. of rooms
Total Energy Consumption by Number of Users (Primary Care)	kWh/user	Electrical Consumption Fuel Consumption Number of users
Total Energy Consumption per No. of Beds (Hospitals)	kWh/bed	Electrical Consumption Fuel Consumption Number of beds

Table V-18: Total energy consumption.

MONTH	Total energy consumption (MWh)	Consumption Total energy / surface	Total energy consumption / surface area	Total energy consumption / temperature	Total energy consumption / stays	Total energy consumption / beds
YEAR:	2015					
January	4,155.75	0.02758	0.00115	278.91	0.27	5.95
February	4,144.56	0.02750	0.00115	331.56	0.27	5.76
March	4,243.68	0.02816	0.00117	487.78	0.26	5.87
April	3,511.53	0.02330	0.00097	763.38	0.24	4.86
May	3,499.90	0.02322	0.00097	2.916.58	0.23	4.85
June	3,094.62	0.02054	0.00086	703.32	0.20	4.28
July	3,388.73	0.02249	0.00094	372.39	0.24	4.88
August	2,900.76	0.01925	0.00080	453.24	0.23	4.28
September	2,468.27	0.01638	0.00068	1.763.05	0.19	3.51
October	2,854.65	0.01894	0.00079	1.019.52	0.19	3.98
November	3,561.03	0.02363	0.00098	414.07	0.23	4.95
December	4,727.74	0.03137	0.00131	418.38	0.32	6.51
AVERAGE VALUE	3,545.93	0.02353	0.00098	826.85	0.24	4.97
YEAR:	2016					
January	4,318.09	0.02865	0.00	392.55	0.28	6.21
February	4,269.76	0.02833	0.00	391.72	0.29	6.06
March	3,920.92	0.02602	0.00	373.42	0.26	5.55

April	3,358.72	0.02229	0.00	541.73	0.23	4.80
May	2,858.94	0.01897	0.00	952.98	0.19	4.09
June	2,851.82	0.01892	0.00	750.48	0.20	4.06
July	3,098.64	0.02056	0.00	418.73	0.24	4.45
August	3,037.11	0.02015	0.00	433.87	0.25	4.44
September	2,605.28	0.01729	0.00	789.48	0.21	3.76
October	2,854.96	0.01895	0.00	1,297.71	0.20	4.06
November	3,611.67	0.02397	0.00	380.18	0.25	5.13
December	4,398.06	0.02918	0.00	372.72	0.32	6.25
AVERAGE VALUE	3,432.00	0.02277	0.00	591.30	0.24	4.91
YEAR:	2017		0.00			
January	4,272.19	0.02835	0.00	294,23	0.28	6.06
February	3,819.81	0.02535	0.00	374,49	0.27	5.41
March	3,885.82	0.02579	0.00	468,74	0.25	5.50
April	2,538.51	0.01685	0.00	480,78	0.18	3.61
May	2,690.22	0.01785	0.00	4.559,70	0.19	3.82
June	2,664.45	0.01768	0.00	404,93	0.19	3.80
July	2,691.23	0.01786	0.00	375,35	0.20	3.90
August	2,677.99	0.01777	0.00	359,46	0.21	3.94
September	2,376.62	0.01577	0.00	747,36	0.19	3.44
October	2,230.70	0.01480	0.00	9.698,71	0.17	3.18
November	2,873.05	0.01907	0.00	302,43	0.21	4.05
December	3,466.52	0.02300	0.00	255,64	0.24	4.85
AVERAGE VALUE	3,015.59	0.02001	0.00	1,526.82	0.21	4.30

In order to facilitate the analysis of the Centre's Energy Performance, graphical representations have been made of total energy consumption and total energy consumption/temperature (MWh/ degrees month).

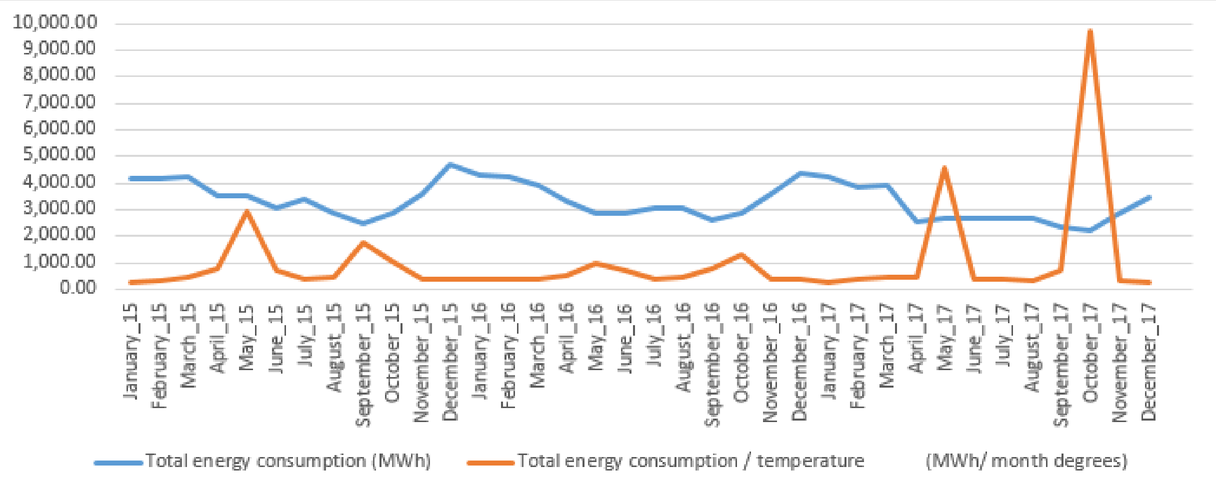

Figure V-6: Total energy consumption and total energy consumption/temperature.

The total energy consumption / temperature indicator (MWh/ degrees month) is obtained by making the quotient between total energy consumption and the indicator degrees month (22ºC).

It can be seen that the total energy consumption/temperature indicator (MWh/gr/month) has several peaks, the most significant in October 2017 with a value of 9,698.71 MWh/gr/month, but this does not mean higher energy consumption during that month, which is the lowest annual consumption with 2,230.70 MWh. However, this month's average monthly temperature was 21.77ºC, so its deviation from the 22º reference temperature was 0.23.

V-7.2. Other Possible Indicators.

Table V-19: Other indicators.

OTHER INDICATORS		
INDICATOR	UNIT	DATA
Electricity Consumption by Area / Unit / Use: Air Conditioning Lighting Strength Hot water Hospitalization Nuclear Medicine / Radiodiagnosis / Radiotherapy Operating theatres Other	kWh/Surface	Data Specific Consumption Area / Unit /Use

% Electricity Consumption by Area, Unit, Use versus Total Electricity Consumption	%	Data Specific Consumption Area / Unit /Use Total Consumption
Thermal Power Plant Performance	%	Energy Losses PCI Fuel Fuel Consumption Thermal Energy Produced
Solar energy production by surface plates	kWh/m²	kWh produced surface plates installed
Solar Energy Production (kWh) / Hot water Consumption (kWh)	%	Solar Energy Production (kWh) Hot water Energy Consumption (kWh)
Lighting with LED	%	Total Luminaires LED Luminaires
Motors and Pumps with Frequency Variators	%	Total Motors and Pumps Total Frequency Variators
Electricity Consumption per ºC	kWh/ºC	Electrical Consumption Average Monthly Temperature
Electricity Consumption per m²	kWh/m²	Electrical Consumption Surface
Thermal Energy Consumption per m²	kWht/ m²	Thermal Power Plant Production Surface
Thermal Energy Consumption per ºC	kWht/ºC	Thermal Power Plant Production Average Monthly Temperature
Natural Gas Consumption in Boilers per m²	m³/ m²	Natural Gas Consumption in Boilers Surface

V-8. Energy baseline.

The energy baseline is defined as the quantitative reference that provides the basis for comparison of energy performance, so it must take into account the quantities, values and data available for the period of study and represent them graphically relating them to each other.

A baseline reflects a specified period of time. A baseline can be normalized using variables that affect energy use and/or consumption, e.g. at production level, day degrees (outside temperature), etc. The energy baseline is also used to calculate energy savings, as a reference before and after implementing energy performance improvement actions.

In this way, the represented line will be set as a reference to evaluate if the evolution of the energy performance improves, maintains or worsens with respect to the calculated Baseline.

The energy baseline for the HURS has been determined using the analysed data, its level of detail and the identified significant uses, in accordance with procedure PGE-02 Energy Planning [4]. The variables used were those that, as a result of the study in the Pilot Centres of the Andalusian Health Service, were the ones that best fit for the determination of a theoretical equation that provides the basis for the comparison of energy performance.

In this sense, relating global energy consumption with the temperature in degrees month (with respect to 22ºC) and stays (in the case of hospitals) or users (in the case of primary care centers or schools), through linear regressions, results have been obtained with values for the regression coefficient R2 higher in all cases than 80%, and in many of them, 90%.

Therefore, in accordance with the above, the way to proceed for the calculation of the Energy Baseline in the HURS will be to calculate the linear regression by selecting the data corresponding to the dependent variable (Y, which will be the energy consumption) and the independent variables (X1 and X2, which will be the degrees month and the stays/users).

Table V-20: Energy baseline for year 2017.

YEAR:	2017			
MONTH	Total energy consumption (MWh)	Grades (22ºC)	Month	Stays (Hospitals) or Users (Primary Care)
January	4,272.19	14.52		15.020,00
February	3,819.81	10.20		14.297,00
March	3,885.82	8.29		15.521,00
April	2,538.51	5.28		14.324,00
May	2,690.22	0.59		14.094,00
June	2,664.45	6.58		13,818.00
July	2,691.23	7.17		13,514.00
August	2,677.99	7.45		12,764.00
September	2,376.62	3.18		12,560.00
October	2,230.70	0.23		13,515.00
November	2,873.05	9.50		13,844.00
December	3,466.52	13.56		14,637.00

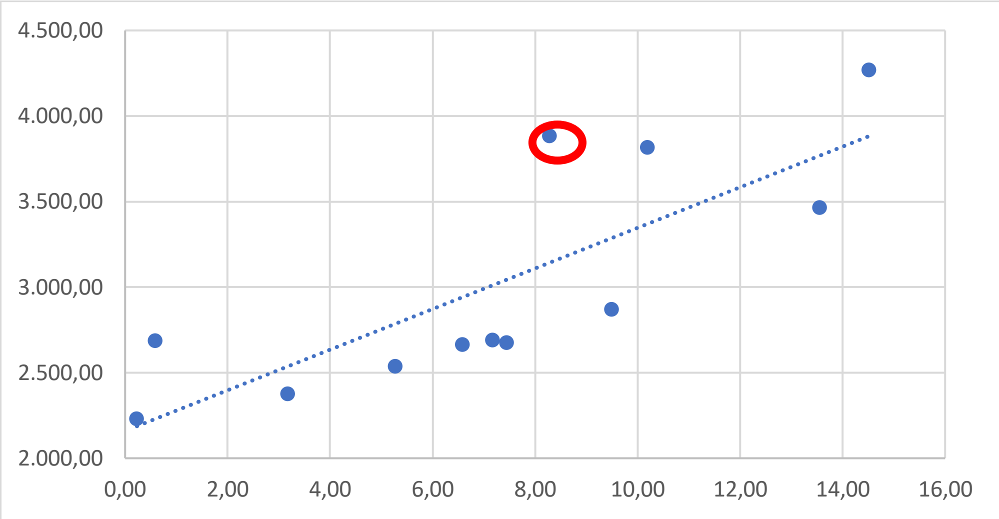

Figure V-7: First lineal regression.

It is decided to omit the March data because it has too significant a deviation and to calculate a second linear regression.

Table V-21: Results 1st multiple regression.

Regression statistics	
Multiple correlation coefficient	0.80223374
Determination coefficient R^2	0.643578974
Adjusted R^2	0.564374301
Typical error	566.0623362
Observations	12

Table V-22: Analysis of variance.

	Degrees of freedom	Sum of squares	Average of squares	F	Critical value of F
Regression	2	5207263.55	2603631.775	8.125517766	0.009634627
Waste	9	2883839.117	320426.5685		
Total	11	8091102.667			

	Coefficients	Typical error	Statistical t	Probability	Inferior 95%	Superior 95%	Inferior 95%	Superior 95%
Interception	10429.98224	970.11324	10.75130388	1.95182E-06	8235.433623	12624.53085	8235.433623	12624.53085
Variable X 1	1.326758377	0.4241798	3.127820742	0.012164337	0.367197004	2.286319749	0.367197004	2.286319749
Variable X 2	-60.81245462	63.05340541	-0.96445948	0.360013295	-203.4491673	81.82425806	-203.4491673	81.82425806

Table V-23: Results 2nd multiple regression.

Regression statistics	
Multiple correlation coefficient	0.897337918
Determination coefficient R^2	0.805215339
R^2 adjusted	0.756519173
Typical error	315.2172258
Observations	11

Table V-24: Analysis of variance.

	Degrees of freedom	Sum of squares	Average of squares	F	Critical value of F
Regression	2	3285996.957	1642998.478	16.53549789	0.001439524
Waste	8	794895.1956	99361.89946		
Total	10	4080892.152			

	Coefficients	Typical error	Statistical t	Probability	Inferior 95%	Superior 95%	Inferior 95,0%	Superior 95,0%
Interception	-2071.469445	2147.379306	-0.964649999	0.362970475	-7023.335004	2880.396114	-7023.335004	2880.396114
Variable X1	86.46748054	25.64434446	3.371795316	0.009759577	27.33151616	145.6034449	27.33151616	145.6034449
Variable X2	0.317090686	0.161872534	1.958891226	0.085805001	-0.056188046	0.690369418	-0.056188046	0.690369418

In the second correlation, a multiple correlation coefficient close to 0.9 is obtained.

The calculation of the Base Line is made by adding the products of variables X1 and X2 by their respective coefficients, 86.46748054 for variable X1 and 0.317090686 for variable X2 with the Interception coefficient.

Table V-25: Calculation of the base line.

Month	X1: Month Degrees	X2: Stays	Real Consumption (MWh)	Base line consumption
January	14.52	15,020.00	4,272.19	3946.740474
February	10.20	14,297.00	3,819.81	3343.944392
March	8.29	15,521.00	3,885.82	3566.910504
April	5.28	14,324.00	2,538.51	2927.085836
May	0.59	14,094.00	2,690.22	2448.622495
June	6.58	13,818.00	2,664.45	2879.045674
July	7.17	13,514.00	2,691.23	2833.665919
August	7.45	12,764.00	2,677.99	2620.058799
September	3.18	12,560.00	2,376.62	2186.156157
October	0.23	13,515.00	2,230.70	2233.898695
November	9.50	13,844.00	2,873.05	3139.775075
December	13.56	14,637.00	3,466.52	3742.28596

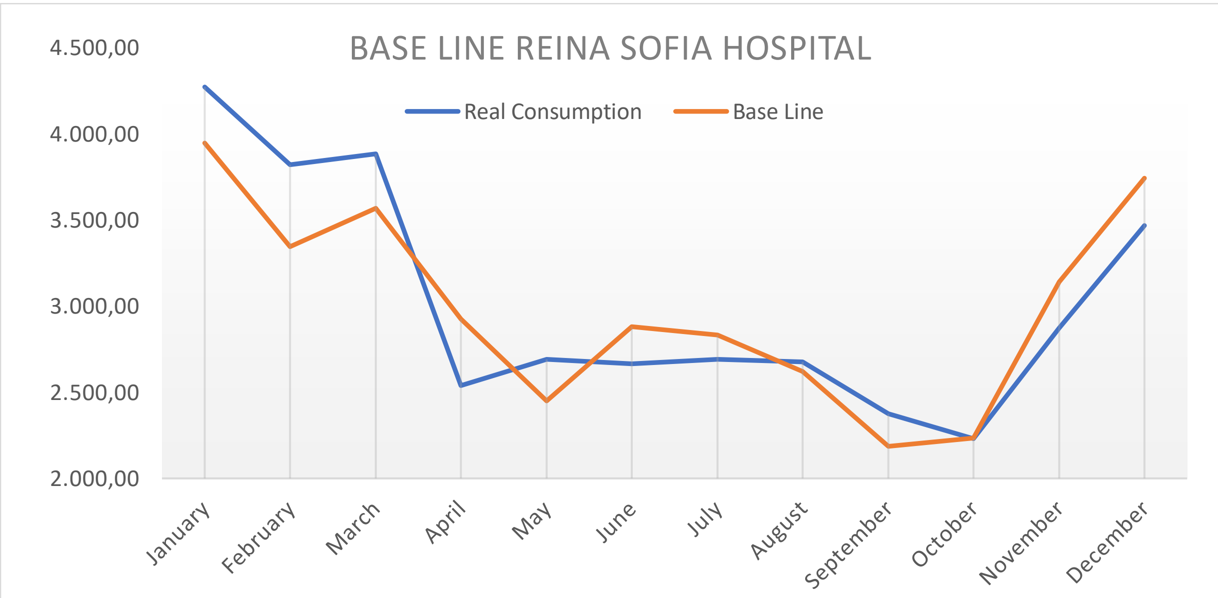

Figure V-8: Base line Reina Sofia Hospital.

V-9. Improvement actions.

Finally, as a conclusion to the initial energy review, the identified improvement actions are proposed and may be taken into consideration for the improvement of the energy performance of the Reina Sofía University Hospital.

Each of the improvement measures is detailed below. It is necessary to point out that, in order to improve the rating, combinations of these are recommended.

<u>Window Replacement.</u>

With the aim of making the Hospital more energy efficient, it is proposed:

- The incorporation of low emissivity glasses

- The substitution of carpentry

Given that air conditioning, as we have seen, is the main consumer of both electricity and natural gas, it is proposed to renovate the openings of the Center, with the replacement of carpentry and existing glass.

Poorly insulated openings mean large thermal bridges, or, in other words, large heat losses, with the result that interior comfort conditions are not adequate. This has the consequence of increasing the demand for air conditioning, both refrigeration and heating to maintain an adequate temperature.

Low emissivity glasses minimise heat loss as they reflect part of the energy generated by the air conditioning units and return it to the indoor environment.

Carpentry accounts for 20% of the total surface area of the window, so, after glass, is where more heat energy is dissipated to the outside. Aluminium is a conductive material that does not break the thermal bridge and completely allows the transfer of heat or cold. A good measure would be to replace this material with a more efficient one, such as PVC, due to its low conductivity.

<u>Biomass boiler installations.</u>

It is proposed that existing natural gas boilers be replaced by the introduction of a biomass boiler system, as biofuel is more environmentally friendly. This change would be made due to the high energy efficiency involved in the change of boilers and the use of fuels based on natural waste or organic waste, such as wood pellets, olive pits, firewood, forest residues, date pits, etc.

The main savings in biomass boilers and stoves are achieved in the raw material, i.e. fuel. While natural gas has a higher price and has risen in recent years, pellets and other biomass waste are much cheaper and its price remains stable.

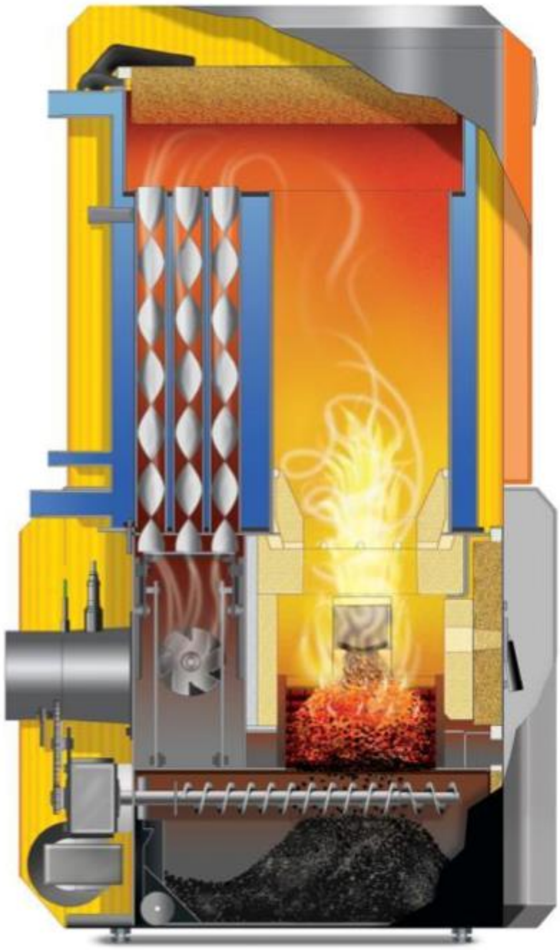

Figure V-9: Biomass boiler [2].

Taking into account these data, it is estimated that the profitability of a biomass boiler can be reached in the medium term, when the initial investment has been amortized and the low price of biomass begins to be the only expense to be faced.

Biomass boilers would be used to generate steam, heating and DHW. The operation of a biomass boiler is similar to that of a conventional boiler. First the natural fuel is burned, recovering the heat generated during the combustion of the biomass to heat the water in the boiler exchanger circuit, taking the hot water to the heating circuit.

<u>Green roofs.</u>

An extensive green roof is proposed for the new mother-child outpatient clinic building (as it is free of solar panels).

The installation of a green roof generates numerous environmental benefits, contributing to improving the microclimate of the environment, reducing its temperature, or capturing greenhouse gases, among others.

But it also generates benefits for the Hospital building itself, since:

- The amount of noise that reaches the interior is reduced as the green roof creates a natural protection barrier against noise.
- As the roof is covered, the surface area of the roof exposed to deterioration is limited. This allows the roof to last much longer than if it were not protected.
- A green roof reduces the amount of energy needed to heat the building, saving money.
- The green roof increases the fire resistance of the Hospital.
- A green roof can be used as a public space, such as a garden or recreation area to be enjoyed by patients.
- Incorporating a green roof into a building increases its value, as it improves its energy performance, and improves its aesthetics.

In short, the implementation of green roofs generate multiple economic benefits, since they reduce the energy consumption of the building, improving its air conditioning and insulating it thermally and acoustically, which means both energy and economic savings.

Other measures that may be taken into consideration in order to optimize energy use and achieve a reduction in cost in the electricity bill could be:

a) Increase the percentage of renewable energies.
b) Increase control over air conditioning installations, such as, for example, the installation of presence detectors.
c) Increasing the measurement of energy parameters in installations, as the recording of data is of enormous importance for transforming them into information and identifying points for improvement.
d) Development of awareness-raising campaigns for professionals.

<u>Thermal insulation of the facade placed by the interior.</u>

With interior insulation, by definition, thermal performance can be improved without altering the external appearance of the façade. It is therefore a perfectly valid solution for achieving energy savings.

The interior insulation systems are always carried out with the so-called insulating board panelling, i.e. a new interior partition superimposed on the existing one. Conceptually, there are two possibilities for carrying out this insulation from the inside:

- Direct sheathing: interior insulation is carried out with laminated plaster plates placed on an insulating board, which is in direct contact with the wall to be insulated.
- Self-supporting sheathing: interior insulation is carried out with the insulating board separated from the wall to be insulated.

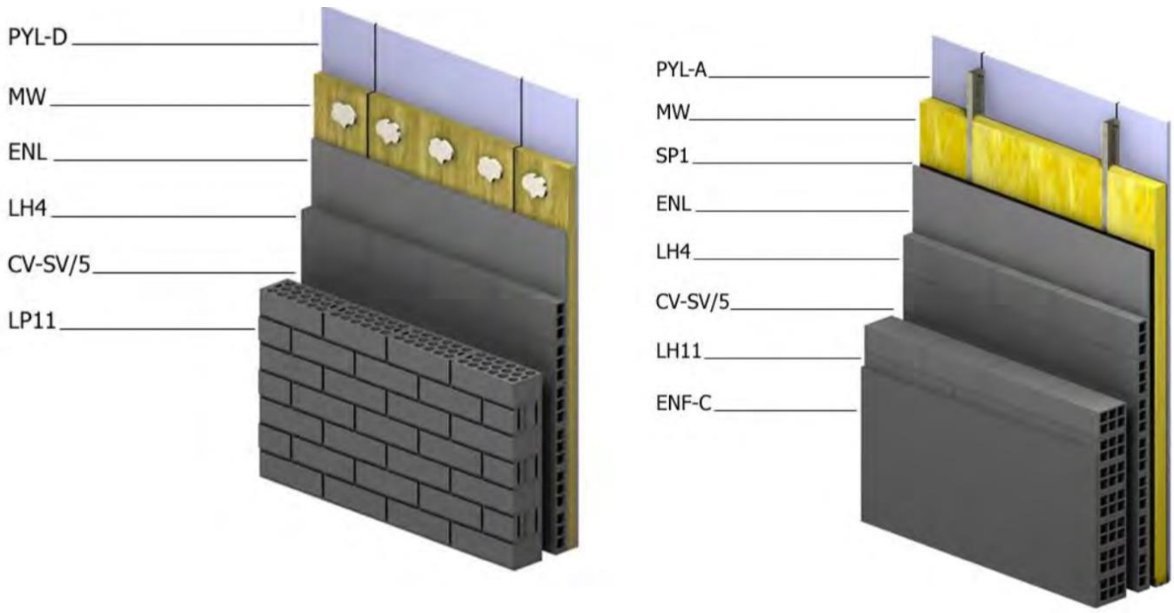

Figure V-10: Direct and self-supporting sheathing [6].

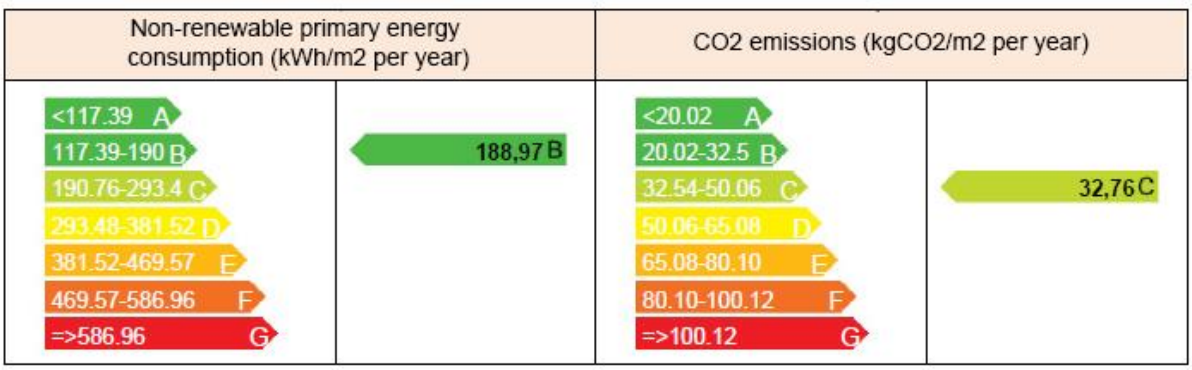

Figure V-11: Energy qualification [7].

This result, given the age of the Hospital (inaugurated in 1976), and taking into account the reforms that have taken place, is classified as medium-high energy qualification.

Considerable annual heating and cooling emissions are observed, since the buildings have construction elements that are not efficient enough, such as frames and hollow glasses, thermal bridges, old installations, which give these results on the energy label. On the other hand, it can be seen that lighting consumption is practically negligible, and we should therefore focus on improving cooling, heating and water vapour emissions.

Implementing the aforementioned measures would undoubtedly lead to better energy efficiency in the Hospital, saving on bills and reducing greenhouse gas emissions.

V-10. References.

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Chapter VI. Summary and conclusions.

Chapter VI. Summary and conclusions.

VI-1. Summary.

The world population has doubled in the last 60 years and is expected to grow to 9700 million people in 2050 and to 11,200 million by the end of the 21st century, which will have a strong impact on population structure, size, and distribution that will have profound consequences for environmental sustainability.

This significant increase in population has resulted in global energy consumption increasing by more than 90% in the last decade and, consequently, CO_2 emissions. These emissions contribute to the increase in the greenhouse effect caused by global warming. The alarming thing is that this has been caused by human activities and it is predicted that, if the current emissions trajectory continues, the Earth could exceed the limit of 2 °C of global warming, the limit established by the Paris Agreement to avoid dangerous warming that generates irreversible damage.

The last five years have been the hottest since registration, with 2016 being the warmest, and successively 2015, 2017, 2018 and 2014. But global warming not only results in higher temperatures or adverse weather conditions, but the effects go even further, causing an increase in sea level, a change in ecosystems with the consequent disappearance of some species, the spread of diseases or an increase in the price of some foodstuffs, among others.

These devastating effects that we are currently suffering and that are a consequence of the current development model, based on a continuous growth in energy consumption, should activate us to seek energy efficient solutions from an environmental point of view, as this model cannot be maintained indefinitely.

It is indisputable that social, economic and technological changes and adaptations are required to preserve our well-being and the well-being of future generations. To this end, international agreements and policies have been implemented, such as the Paris Agreement on Climate Change in 2015, in which all the signatory countries committed themselves to participating in global reductions in greenhouse gases, Directive 2009/28/EC on the promotion of the use of energy from renewable sources or Directive 2012/27/EU on energy efficiency within the European Union, with the main objective of increasing energy efficiency.

As the building sector is Europe's largest consumer of energy, almost all governments have opted for measures to promote renewable energy, energy efficiency strategies and climate change strategies.

In this area, the European Union takes into account energy efficiency certificates, to classify the building according to its carbon emissions and energy consumption; and the 2020 objective, which requires by the end of next year a 20% saving in primary energy compared to 2005; a 20% reduction in greenhouse gas emissions compared to 1990 and an increase in renewable energies of at least a 20% by 2020.

At the same time, Directive 2010/31/EU on the energy performance of buildings stipulates that all new buildings should be categorised as nZEB by the end of 2020 and, in the case of public buildings, this deadline is shortened to the end of 2018.

Given the social concern to improve energy efficiency in buildings, considered as one of the basic pillars of the main national and international strategies to reduce greenhouse gas emissions, the scientific community has delved into this area by contributing an extensive production.

Chapter II provides a bibliographical review of research on energy efficiency and sustainability during the period 1976-2016, in which some of the key aspects of publications are studied, such as the type of document that predominates, the language used, the area of knowledge in which it has been most published, the main journals, key words or authors.

After having carried out in-depth research on sustainability and energy efficiency, Chapter III analyses the viability of replacing the existing gas boiler in a university building in the south of Spain with the introduction of a biomass boiler system. In environmental terms, biomass has a clear advantage over fossil fuels, since, although it produces atmospheric emissions when burned like any other fuel, these emissions are considered carbon neutral. This is due to the fact that the carbon dioxide emitted during combustion is compensated with that absorbed by the plant during its growth, thus not altering the balance of the concentration of carbon in the atmosphere. On the other hand, the properties associated with the date bone are analysed to evaluate its suitability as a new biofuel, obtaining that this waste product has a high calorific value that gives it optimum properties as a source of thermal energy comparable to other biofuels currently marketed. In addition, it would reduce about 95 tons of CO_2 that are emitted by the natural gas boiler and would obtain an economic savings of more than 66%.

Chapter IV studies the important contribution made by different international institutions in the field of energy saving. Energy saving and energy efficiency are terms related to a reduction in consumption, but there is nevertheless an important difference. While energy saving leads to a change in consumption habits, such as turning off lights when leaving a room, energy efficiency is the fact of minimising the amount of energy needed to satisfy demand without affecting its quality, for example, replacing existing light bulbs with others that consume less energy. It does not imply, therefore, changes in consumption habits, the behavior of the user, in this case, remains the same, but consumes less energy because the energy consumption to carry out the same service is lower. Obviously, in order to reduce energy consumption as much as possible, it would be necessary to combine energy saving and efficiency measures.

In this chapter a bibliometric analysis of all the scientific production indexed in Scopus is carried out. World scientific production is analysed in the following areas: Firstly, the trend in time, types of publications and countries, secondly, the main themes and keywords, thirdly, the main institutions and their main themes, and fourthly, the main journals and proceedings they publish on this subject. These data are then presented using community detection algorithms and graphics visualization software. With these techniques it is possible to determine the main areas of research activity, as well as to identify the structures of the collaborative network in the field of renewable energies. The results of the work show that the literature in this field has increased substantially over the last 10 years.

Finally, Chapter V carries out an energy review of the Reina Sofia University Hospital in Cordoba, analyzing data from the last 3 years. On the basis of these data, the current energy sources and areas of significant use of energy and equipment with the highest consumption, susceptible to energy improvements, are identified, and the first lines of improvement are proposed, which will materialise over time. A first energy baseline is also established for this period, which may be taken as a reference for calculating energy savings before and after implementing actions to improve energy performance.

In conclusion, this Thesis proposes a reflection on energy efficiency and energy saving in public buildings, as well as the sustainability of the measures from an environmental and economic point of view, deepening the scientific production referred to these lines of research. At the same time, it tries to provide useful information on energy consumption in public buildings and propose possible energy-efficient actions in order to evolve towards a new more sustainable energy model, without diminishing the quality of life.

Resumen

La población mundial se ha duplicado en los últimos 60 años y se prevee que crezca hasta alcanzar los 9700 millones de personas en 2050 y hasta los 11.200 para el final del siglo XXI, lo que causará un fuerte impacto en la estructura, el tamaño, y la distribución poblacionales que tendrá profundas consecuencias para la sostenibilidad medioambiental.

Este significativo aumento de la población ha tenido como consecuencia que el consumo global de la energía se haya incrementado más de un 90% en el último decalustro, y, consiguientemente, el aumento de las emisiones de CO_2. Estas emisiones contribuyen al aumento del efecto invernadero que provoca el calentamiento global del planeta. Lo alarmante es que este ha sido causado por actividades humanas y se prevee que, de seguir con la actual trayectoria de emisiones, la Tierra podría superar el límite de 2 °C de calentamiento global, límite establecido por el Acuerdo de Paris para evitar un calentamiento peligroso que genere daños y perjuicios irreversibles.

Los últimos cinco años han sido los más calientes desde que se tiene registro, siendo el 2016 el más cálido, y sucesivamente los años 2015, 2017, 2018 y 2014. Pero el calentamiento global no sólo tiene como consecuencia el aumento de las temperaturas o unas condiciones meteorológicas adversas, sino que los efectos van más allá provocando el aumento del nivel de mar, el cambio en los ecosistemas con la consiguiente desaparición de algunas especies, la propagación de enfermedades o el incremento en el precio de algunos alimentos entre otros.

Estos efectos tan devastadores que actualmente estamos sufriendo y que son consecuencia del modelo de desarrollo actual, basado en un crecimiento continuo del consumo de energía, deberían activarnos a buscar soluciones eficientes energéticamente eficientes desde un punto de vista medioambiental, pues este modelo no se puede mantener indefinidamente.

Es indiscutible que se requieren cambios y adaptaciones a nivel social, económico y tecnológico para preservar nuestro bienestar y el bienestar de las generaciones futuras. Para este fin se han implementado acuerdos y políticas internacionales como han sido el Acuerdo de Paris sobre el cambio climático en 2015, donde todos los países firmantes se comprometían a participar en las reducciones globales de gases de efecto invernadero, la Directiva 2009/28/CE relativa al fomento del uso de energía procedente de fuentes renovables o la Directiva 2012/27/UE relativa a la eficiencia energética dentro de la Unión Europea con el objetivo principal de aumentar la eficiencia energética.

Por ser el sector de la edificación el mayor consumidor de energía en Europa, casi todos los gobiernos han optado por la adopción de medidas destinadas a impulsar las energías renovables, las estrategias de eficiencia energética y las estrategias de lucha contra el cambio climático.

La legislación en Europa en esta materia contempla, por un lado, la creación de certificados de eficiencia energética, desarrollados a principios de los años noventa como estrategia primaria para reducir el consumo de energía y las emisiones de carbono. Por otro lado, de la política energética adoptada en 2007, denominada Horizonte 20-20-20, en la que la UE exige el cumplimiento de ciertos objetivos para finales de 2020: ahorrar un

20% de energía en su nivel primario con respecto a 2005; reducir las emisiones de gases de efecto invernadero en un 20% con respecto a 1990; aumentar la energía renovable en el total de la combinación energética a un mínimo del 20% hasta 2020.

Al mismo tiempo, la Directiva 2010/31/UE sobre la eficiencia energética de los edificios establece que todos los edificios de nueva construcción deben ser clasificados como "edificios de energía cero" (nZEB) a finales de 2020 y, en el caso de los edificios públicos, a finales de 2018.

Dada la preocupación social por mejorar la eficiencia energética en los edificios, considerado como uno de los pilares básicos de las principales estrategias nacionales e internacionales para reducir las emisiones de gases de efecto invernadero, la comunidad científica ha ahondado en esta área contribuyendo con una extensa producción.

En el Capítulo II se hace una revisión bibliográfica de la investigación sobre eficiencia energética y sostenibilidad durante el periodo 1976–2016, en el que se estudian algunos de los aspectos claves de las publicaciones como el tipo de documento que predomina, el idioma utilizado, el área de conocimiento en el que más se ha publicado, las principales revistas, palabras clave o autores.

Después de haber llevado a cabo una profunda investigación sobre sostenibilidad y eficiencia energética, el Capítulo III analiza la viabilidad de la sustitución de la caldera de gas existente en un edificio universitario del sur de España por la introducción de un sistema de calderas de biomasa. En términos ambientales, la biomasa tiene una clara ventaja sobre los combustibles fósiles, ya que, aunque produce emisiones atmosféricas al quemarse como cualquier otro combustible, estas emisiones se consideran neutras en carbono. Esto se debe a que el dióxido de carbono que emite durante la combustión se compensa con el que absorbe la planta durante su crecimiento, no alterando de esta forma el equilibrio de la concentración de carbono en la atmósfera.

Por otra parte, se analizan las propiedades asociadas al hueso de dátil para evaluar su idoneidad como nuevo biocarburante, obteniéndose que este producto de deshecho posee un alto poder calorífico que le confiere unas propiedades óptimas como fuente de energía térmica comparable a otros biocarburantes que se comercializan actualmente.

Además, se reduciría unas 95 toneladas de CO_2 que son las que emitiría la caldera de gas natural y se obtendría un ahorro económico de más del 66%.

En el Capítulo IV se estudia la importante contribución que han realizado diferentes instituciones internacionales en el campo del ahorro energético. Ahorro energético y eficiencia energética son términos relacionados con una reducción del consumo, pero sin embargo existe una importante diferencia. Pues, mientras el ahorro energético conlleva un cambio en los hábitos de consumo, como por ejemplo, apagar las luces al salir de una habitación, la eficiencia energética es el hecho de minimizar la cantidad de energía necesaria para satisfacer la demanda sin afectar a su calidad, sería por ejemplo, sustituir las bombillas existentes por otras que consuman menos energía. No supone, por tanto, cambios en los hábitos de consumo, el comportamiento del usuario, en este caso, sigue siendo el mismo, pero se consume menos energía ya que el consumo energético para llevar a cabo el mismo servicio es menor. Evidentemente, para reducir al máximo el consumo energético habría que aunar medidas de ahorro y eficiencia energética.

En este capítulo se realiza un análisis bibliométrico de toda la producción científica indexada en Scopus. La producción científica mundial se analiza en los siguientes ámbitos: En primer lugar, la tendencia en el tiempo, los tipos de publicaciones y países, en segundo lugar, los principales temas y palabras clave, en tercer lugar, las principales instituciones y sus principales temas, y en cuarto lugar, las principales revistas y actas que publican sobre este tema. Luego, estos datos se presentan utilizando algoritmos de detección de comunidades y software de visualización de gráficos. Con estas técnicas es posible determinar las principales áreas de actividad investigadora, así como identificar las estructuras de la red de colaboración en el campo de las energías renovables. Los resultados del trabajo muestran que la literatura en este campo ha aumentado sustancialmente durante los últimos 10 años.

Por último, en el Capítulo V se lleva a cabo una revisión energética del Hospital Universitario Reina Sofía de Córdoba, analizando datos de los últimos 3 años. A partir de estos datos se identifican las fuentes de energía actuales y las áreas de uso significativo de la energía y de los equipos con mayores consumos, susceptibles de mejoras energéticas, proponiéndose unas primeras líneas de mejora que irán concretándose con el tiempo. Igualmente se establece una primera línea base energética para este periodo, que podrá tomarse como referencia para el cálculo de ahorro energético, antes y después de implementar las acciones de mejora del desempeño energético.

En conclusión, esta Tesis propone la reflexión de la eficiencia energética y el ahorro energético en edificios de uso público, así como de la sostenibilidad de las medidas desde el punto de visto ambiental y económico, profundizando en la producción científica referida a estas líneas de investigación. Al mismo tiempo trata de proporcionar información útil sobre el consumo energético en edificios de uso público y plantear posibles acciones energéticamente eficientes con objeto de evolucionar hacia un nuevo modelo energético más sostenible, sin disminuir la calidad de vida.

VI-2. Conclusions.

1. Reducing global energy consumption from the point of view of demand is not only a challenge, but also a global duty, requiring immediate action and substantial improvement. The sharp increase in population will have an impact on population size, structure and distribution that will have profound implications for environmental sustainability. This is why more and more countries are incorporating energy efficiency strategies in their public buildings, due, among many other factors, to the existing increase in energy needs, evident climate change or the scarcity of current resources. The challenge is always to reduce energy consumption without forgetting the comfort of the user and the needs of the building. (Chapter I, II, III, IV and V).

2. Public buildings take on a dual responsibility. On the one hand, they must contribute to energy saving and, on the other, they must assume an exemplary role for society, serving as a model of energy performance for sustainability. (Chapter I, II, III, IV and V).

3. The international contribution to research on sustainability and energy efficiency, led by China, generates a large number of publications worldwide, which is of great interest to the scientific community. The strong development of energy efficiency in Europe has also stimulated research in this field, with Italy being the country with the most scientific contributions. (Chapter II).

4. In the study on the replacement of a natural gas boiler in a University building in southern Spain, it was found that date seeds are a viable alternative as biofuel, given that its high calorific value gives it optimum properties as a source of thermal energy comparable to those of other biofuels currently marketed. In addition, they have a high volatile matter content and are characterized by relatively high rates of combustion, gasification, heat transfer and a very low ash content, properties that facilitate their combustion, as analyzed in that chapter. This study highlights a waste product such as dates and proposes a new clean energy to the biofuels catalogue. (Chapter III).

5. The study on the exchange of a natural gas boiler in a University building in the south of Spain shows that replacing a natural gas boiler with a biomass one and using the date as biofuel would result in an annual reduction of 95 tons of CO_2 per year and an economic saving of more than 66%. (Chapter III).

6. A good way to save energy in the buildings of a university in the south of Spain is to centralize the heating system. This would increase the coefficient of simultaneity to reduce the installed power and at the same time reduce the loss of combustion of the raw

material, which would be much more efficient than the current system of distributed boilers. (Chapter III).

7. The application of community detection algorithms has made it possible to identify, on a worldwide level, the scientific communities that develop their work in fields related to energy saving and the collaboration preferences of their authors at an institutional and international level. It should be noted that many of the articles published have been the result of this international collaboration. This methodology allows us to understand two complex systems: the network of publications based on citations and the network of scientific collaborations based on the nationality of the co-authors. (Chapter IV).

8. Chinese institutions have made an important contribution in this area. Over the last decade China has become the main leader in energy efficiency growth, establishing energy efficiency policies that have resulted in an 18.2% reduction in energy intensity despite GDP growth of 7.8% per annum. This leads us to suspect that there is a correlation between the number of publications in this country and the application of energy policies. (Chapter IV).

9. The categories of greatest interest in terms of scientific contributions to energy savings are Lighting (9.44%), Thermal Comfort (9.18%), and Building Insulation (8.61%). These 3 categories are related to energy saving in buildings, this sector being responsible for more than 40% of global energy consumption. In order to reduce it is necessary to implement, at a global level, effective saving policies such as the European Directive on the Energy Efficiency of Buildings (2010/31/F) on so-called buildings with almost no energy consumption (Chapter IV).

10. The researchers, aware that the current global demand for energy in buildings will double by 2050, also show a latent concern about the emission of waste into the atmosphere and how these may directly affect our planet in the future by compromising sustainability. (Chapter IV).

11. During the last 10 years the number of publications in the field of energy saving has increased substantially, indicating that research in this field is assumed to be an important and relevant topic on the international scientific scene. (Chapter IV).

12. Procedures PGE-01 Energy Review and PGE-02 Energy Planning implemented on 15 October 2018 to improve the energy performance of public hospitals, in accordance with the Energy Policy adopted by the Andalusian Health Service, aimed at reducing greenhouse gas emissions, as well as the costs of energy through its systematized management, arrive late and are insufficient for compliance with the European Directive on the Energy Efficiency of Buildings (2010/31/F) which states that buildings by 2020, and

in the case of public buildings, from last December 31, 2018, would become almost zero-energy buildings. (Chapter V).

13. Based on the power of electricity and natural gas installed by main uses in the "Reina Sofía" hospital, it turned out that one of the main applicants for power of electricity and natural gas is air conditioning, with 58% and 32% respectively. (Chapter V).

14. The main energy sources of the "Reina Sofía" hospital are electricity and natural gas, assuming solar energy only 1.58 % of total energy consumed, although the trend over the last 3 years is to increase this percentage. However, this is not due to a significant increase in solar energy, but to a reduction in total consumption. (Chapter V).

15. The "Reina Sofía" hospital consumption graphs represent that air conditioning is one of the main consumers of energy, both electricity and natural gas. It can be deduced that most of the electricity consumption is due to air conditioning, which increases very significantly in the summer season; and that most of the consumption of natural gas is due to the demand for heating, as it increases very significantly in the winter season. Hence the importance, for buildings in general and for public use in particular, of good thermal insulation and a temperature control system. (Chapter V).

16. The Energy Performance Indicators selected for the calculation of the Energy Baseline, relating the Global Energy Consumption with the Temperature in degrees month (with respect to 22ºC) and the Hospital Stays, through linear regressions with the multiple regression coefficient R2, have turned out to be the best fit for the determination of a theoretical equation that provides the basis for comparison of energy performance. (Chapter V).

17. The "Reina Sofía" hospital has a medium-high energy rating, considering the reforms that have taken place. However, considerable annual heating and cooling emissions are observed, as buildings have construction elements that are not efficient enough, such as hollow frames and glazing, thermal bridges, old installations, which give these results on the energy label. Applying energy rehabilitation measures in the "Reina Sofía" hospital, such as the improvement of voids, the replacement of natural gas boilers for others of biomass, the placement of green roofs or the insulation of the façade placed by the interior, would achieve better energy efficiency of the hospital, saving on the bill and reducing emissions of greenhouse gases. (Chapter V).