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Review

Coatings in Photovoltaic Solar Energy Worldwide Research

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Abstract: This paper describes the characteristics of contributions that were made by researchers worldwide in the field of Solar Coating in the period 1957–2019. Scopus is used as a database and the results are processed while using bibliometric and analytical techniques. All of the documents registered in Scopus, a total of 6440 documents, have been analyzed and distributed according to thematic subcategories. Publications are analyzed from the type of publication, field of use, language, subcategory, type of newspaper, and the frequency of the keyword perspectives. English (96.8%) is the language that is most used for publications, followed by Chinese (2.6%), and the rest of the languages have a less than < 1% representation. Publications are studied by authors, affiliations, countries of origin of the authors, and H-index, which it stands out that the authors of China contribute with 3345 researchers, closely followed by the United States with 2634 and Germany with 1156. The Asian continent contributes the most, with 65% of the top 20 affiliations, and Taiwan having the most authors publishing in this subject, closely followed by Switzerland. It can be stated that research in this area is still evolving with a great international scientific contribution in improving the efficiency of solar cells.

Keywords: solar energy; coatings; scopus; material solar cell; thin film; polycrystalline; organic solar cell; thin film a-Si: H; optical design; light trapping

1. Introduction

Energy needs are a global growing problem in the era of technology. Citizens and governments are gradually becoming aware of the sustainable use of world resources [1]. Many are the developments in energy systems based on renewable energy, such as wind, photovoltaic, biomass, nuclear, etc., implemented on both a small and high scale. Renewable energy resources largely depend on the climate of the site; different renewable energies could be applied in different regions. Society demands clean and sustainable energy; this implies research in efficient clean energy. Among existing different renewable energies, solar energy is one of the most attractive for future energy sources [2–4] and photovoltaics is the most implemented one. Photovoltaic applications are very diverse, and they range from the incorporation into consumer products, such as watches, calculators, battery chargers, and a multitude of products from the leisure industry. They can also be applied in small-scale systems, like remote installations in structures, called solar gardens, or systems applied to the industrial and domestic facilities for small villages and water pumping stations. Not forgetting the large power production stations for supply of network connection. Energy policies play an important role in the development of renewable energy [5,6].

Currently, with the arrival of intelligent and sustainable buildings, solar modules that are installed in the building are installed in both roofs and part of the facade and windows, where, apart from energy efficiency, the aesthetics of the architecture are considered. Transparent and biphasic thin film solar modules contribute to their application in these structures [7].

These photovoltaic systems depend, to a large extent on the physical and chemical properties of their materials, the wavelength of the captured light, its intensity, and its angle of incidence, the characteristics of the surface or texture as well as the presence or absence of superficial coatings. In addition to these factors, temperature, pressure, ease of processing, durability, price, and costs throughout the life are important in material selection. Photovoltaic energy has been highly researched in the last 60 years, with the intention of reducing manufacturing costs and, at the same time, improving performance. The improvement of maintenance (protection against abrasion, corrosion, cleaning, etc.), increase in the life of the components, and incorporation of materials based on plastics and underlying substrates as coatings are among the cost reduction factors.

The starting silicon wafer is one of the main costs of silicon photovoltaic cells; the degree of purity largely defines the performance of the cell. This has led to the solar cells with nanostructure p-n radial junctions, where the quantity of Si and its quality is reduced. Improved light absorption in ultrafine solar silicon film is important in improving efficiency and reducing costs [8–10]. Thin-layer technologies also use less Si, reducing the production costs, although with limited efficiency, which increases the total system costs.

Research is being conducted for improving the capture of light in order to reduce the thickness of the layer, which entails reducing the material, and improving the efficiency, which has an impact on manufacturing costs. In this sense, solar cells have been improved by advances in diffractive optical elements (DOE) that are used in many areas of optics, such as spectroscopy and interferometry, among others. The shape of the grid slot can be used as an optimization parameter for specific tasks. In many cases, DOEs are manufactured on flat substrates for simplicity, but they offer many important additional advantages on curved surfaces [11]. With the development of computers and their application to different fields, such as homography, techniques such as interferometric recording have been developed. Digital homography (computer-generated holograms) has allowed for great flexibility in creating forms in substrates with high precision [12].

For this, nanostructures have been designed in different ways, depending on the type of solar cells. The compromise between optical and electrical performance currently limits solar cells. There are different proposals regarding whether nanostructures should be periodic or random. Non-fullerene acceptors (NFA) become an interesting family of organic photovoltaic materials and they have attracted considerable interest in their great potential in manufacturing large surface flexible solar panels through low-cost coating methods [13].

Research regarding the improvements in Solar Coating are in continuous evolution with the incorporation of new materials, structures, and the growing demand for energy; all these advances are mainly focused on improving the efficiency of photovoltaic panels. From this point of view, there are several scientific communities making continuous contributions from different fields. These contributions are doubled per decade, which entails a huge number of documents to deal with. The documents within the same field of research are distributed in scientific communities that are promoted through the interrelations between the authors and their publications. The collaboration of the authors in different communities makes the progress of science more productive, since there are not only research relationships between authors, but also between institutions that support the necessary tests with their laboratories and facilities. This exponentially increases the progress in science and technology. In this work, we study the different communities that have consolidated over time and the relationships between them.

2. Materials and Methods

This paper analyzes all of the scientific publications indexed on Scopus data base that deal with Solar Coating. There are search engines on the web based on Scientometric indicators, such as number and quality of contributions, according to the metric of the journal or the author. The results of these searches do not measure the relationships between the authors; this limits the establishment of collaborative communities. Technology, like science, advances through continuous collaborations between public or private research entities; therefore, it is important to develop metrics that incorporate the authors' relationships. There are different studies that carry out comparisons between Scopus and Web of Science, and they reach the conclusion that Scopus is the scientific database with the greatest contributions [14,15]. In addition, Scopus allows for the development of APIs (Application Programming Interface) that directly extract information from the database, allowing for an analysis of them [16]. Figure 1 shows the API developed, as it can be considered as the core of the methodology of this manuscript. Accordingly, a search for keywords related to Solar Coating has been carried out to find global relations between the generated communities, their authors, and research institutions. The search is performed for TITLE-ABS-KEY ("advanced glazing*" OR "Solar window*" OR "light trapping" OR "diffractive element*") obtaining many documents and their relationships. This requires a debugging process to avoid unnecessary information that prevents an overview, which reduces the number of documents and their relationships. Documents that have no relations within the generated communities are eliminated in the debugging process. The final data set was analyzed while using statistical tools that were based on diagrams and presentation of the data processed. The open source tool, like Gephi (https://gephi.org), was used, which incorporates statistical resources and data visualization, mainly the algorithm ForceAtlas2 [17]. In this way, the different clusters were automatically identified. After this, the information of each cluster was analyzed in Excel, while using the dynamic data tables and the word cloud has been realized with the software Word Art (https://wordart.com/create). Note that the size of the keyword must be proportional to its frequency and the number of times that keyword appears in the analyzed articles in a representation by cloud of words.

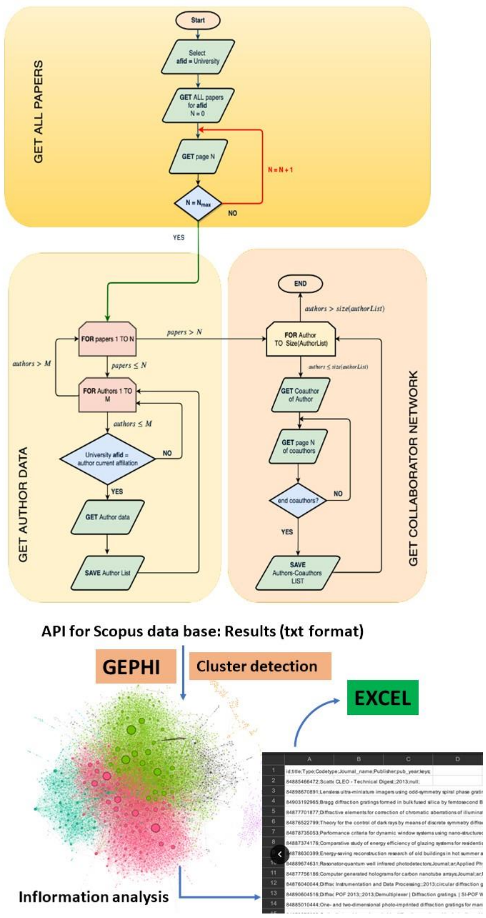


Figure 1. Flow diagram of the API that allowed for extracting the information of Scopus database.

3. Results

3.1. Communities Detection

A total of 6440 documents are obtained with a total of 21,301 relations between the authors after searching for the keywords. After the debugging process to avoid unnecessary information, documents are reduced by 39.1% and relations by 2.12%. Figure 2 shows the 3924 documents with 20,849 relationships that were obtained after the process of purification and statistical treatment. Figure 2 shows the distribution of the six detected communities that publish in Solar Coating topics with the Gephi program. As you can see, there is a main nucleus that is formed by five communities and another exterior formed by a single community. In Figure 2a, a node represents each publication and the size of the node is a function of their relationships, so that it shows the frequency with which the node appears in the shortest path between two randomly selected nodes in/between communities, showing the influence of the author within the community. In this way, not only the common metrics in search engines, such as Google Scholar, are considered, but also the collaborations between the authors. The size of a node varies according to its relationships to indicate the most influential nodes. The reason why an author who has a highly referenced and published document, but who works by himself, will only have a smaller node than a less referenced author with greater collaborations.

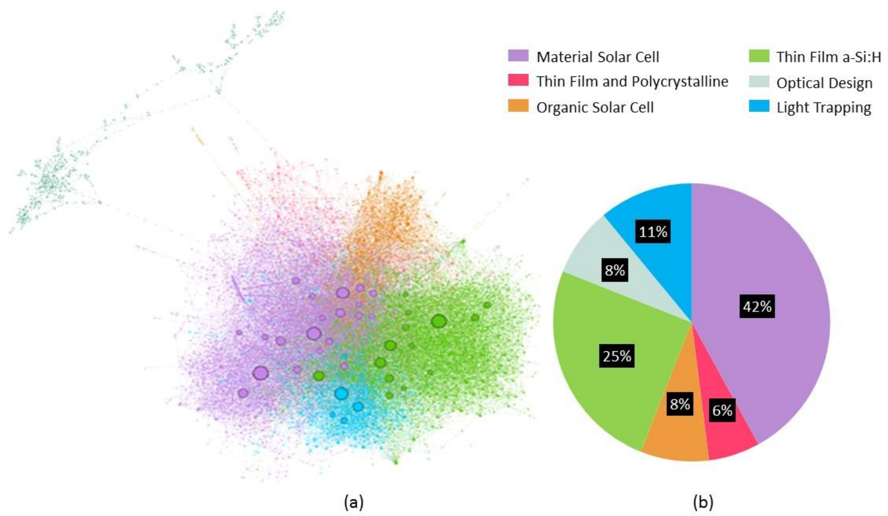


Figure 2. Representation of the communities investigating about "solar coating": (**a**) represent the interaction of the communities as a whole; and, (**b**) Representation for the distribution of the percentage of the communities.

Figure 2b presents the contribution in percentage of each community, since it is difficult to see the total size of each community due to the interrelation in Figure 2a. There are two communities that stand out for their size and they are the Material Solar Cell and Thin Fill Cells a-Si: H community. Community 0 (Material Solar Cell) is the largest with 42.2% of total publications. In this community, you can see the highest concentration of related nodes, where it publishes the advances on the materials used to improve the capture of light. The Thin Fill Cells a-Si: H community publishes 25.36% on the improvements in amorphous cells of hydrolyzed silicon. This community, besides being the second largest, is also the one that has a large concentration of authors that are related to other nodes, as it can be seen in Figure 2.

Figure 3 shows a cloud words of the global keywords obtained in the search. The most used keyword is "photovoltaic cells", with 147 times within the Material Solar Cell community, followed by "Thin film solar cells" with 96 times from the Thin film a-Si: H community. The third most used is "Silicon", also from the Solar Cell Material community with 85 times. The three words belong to the two communities with the largest number of publications, as shown in Figure 2b. Globally, the most repeated words are the most generic, such as “Film”, “Thin”, and “ZnO”, as shown in Figure 3.

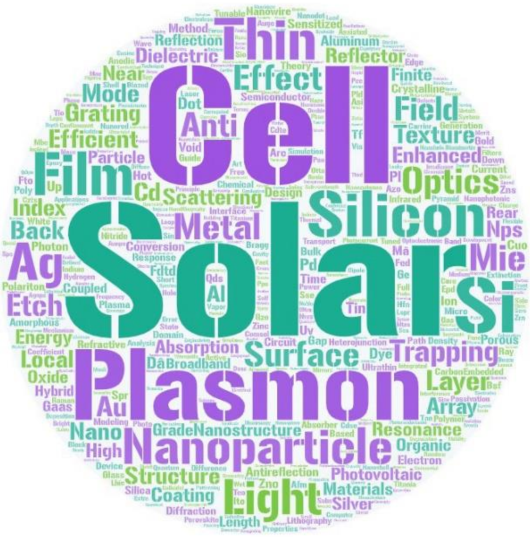


Figure 3. Cloud words of the keywords got in the global search.

3.2. Analysis of the Communities

Each community maintains a common theme, although being very interrelated with the rest of the communities. Next, the main nodes of each community and their most significant contributions are analyzed; this will allow for us to understand their research theme.

Community 0 (Material Solar Cell) investigates how to improve the capture of light by using different structures and materials used. Figure 4a shows the most representative keywords of the Solar Cell Material Community, which shows the number of times and their percentage of repetition within the community. The most representative word is “Photovoltaic cells”, followed by “Silicon”; these words are very generic in the subject of photovoltaic solar energy and hints that this community is the widest when publishing more generic developments from which other more specific communities are nurtured. Hence, it has three important nodes that are very referenced, as shown in Figure 4b, and a multitude of publications that are very referenced not only by this community, but by the remaining ones, as it can be seen in Figure 2. Publications of the most referenced nodes in Scopus in order of size are:

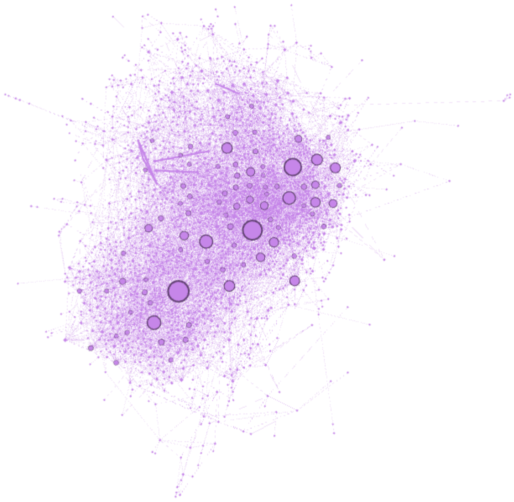
- “Light trapping in silicon nanowire solar cells” [18] with a total of 1572 cites.
- “Fundamental limit of nanophotonic light trapping in solar cells” [19] with 586 cites.
- “Improving thin-film crystalline silicon solar cell efficiencies with photonic crystals” [20] with 532 cites.

Si cable assemblies are studied in this community. These are an interesting architecture for solar energy collection applications, and they can offer a mechanically flexible alternative to Si wafers for photovoltaic energy. Cables must absorb sunlight in a wide range of wavelengths and angles of incidence to achieve competitive conversion efficiencies, despite only occupying a modest fraction of the array volume. These matrices show a better near-infrared absorption, which allows for its absorption of sunlight to exceed the ray optics that traps the light absorption limit for an equivalent volume of textured plane, over a wide range of angles of incidence. The geometry of the cable network, together with other nanostructured geometries, offers opportunities to manipulate the relationship between the lighting area and the volume of absorption being useful in improving the efficiency or reducing the consumption of materials of many photovoltaic technologies. Kelzenberg et al. [21] showed that arrays presenting less than 5% of the cable area fraction can reach up to 96% of maximum absorption, and that they can absorb up to 85% of the substances integrated in the day, above the direct sunlight band. Garnett et al. [18] developed a structure of nanowires with large radial surface photovoltaic splicing p-n with efficiencies between 5% and 6%.

Material Solar Cell

Keys	№	%
Photovoltaic cells	147	3.1
Silicon	85	1.8
Antireflection	29	0.6
Nanostructures	29	0.6
Photonic crystals	28	0.6
Silicon nanowires	26	0.6
Texturing	26	0.6
Photon management	25	0.5
Photonic cristal	23	0.5
Solar energy	23	0.5

(**a**)



(**b**)

Figure 4. Representation of the Material Solar Cell community: (**a**) keywords; and, (**b**) isolated distribution of the publications.

Brongersma el al. [22] review the theory of nanophotonic light capture in periodic structures. Light collection schemes can be used to improve absorption in photovoltaic (PV) cells. They help to increase cell efficiency and reduce the production costs. In a homogeneous bulk cell with reflection mirror backing, (in a homogeneous bull cell with a back reflection mirror) the maximum enhancement factor attainable by the light trapping schemes is $4n^2/\sin^2(\theta)$, where n is the index of refraction of the material and θ is half of the apex angle of the absorption cone. Ultrafine cells with efficiencies that can exceed the traditional 4n2 limit are investigated. It involves the development of new computational tools that are capable of operating in the domain of wave optics, dealing with non-periodic structures and performing a joint electrical and optical optimization [23]. Yu et al. [19] studied the case of the capture of light in grid structures with periodicity at the wavelength scale. Light capture can improve cell efficiency, because thinner cells provide a better collection of photogenerated cells and potentially higher open circuit voltage. Yu et al. [19,24] developed "a statistical coupled-mode theory for nanophotonic light trapping" theory. Yu et al. [24], this theory is applied to the one-dimensional (1D) and two-dimensional (2D) grids that have close or even smaller thicknesses than the wavelength of the light and conclude that the 2D grids have a greater improvement factor. Yang et al. [25] used the coupled wave analysis method for textured sub length wavelength (STDS), which are important in obtaining high efficiency, due to their almost perfect anti-reflective properties.

Another author's study method was based on geometric optics and wave optics applied to thin-film crystalline silicon solar cell [20]. They manage to increase efficiency with the use of photonic glass, increasing 24.0% in an optimized 1D to 31.3% by adding an optimized 2D grid.

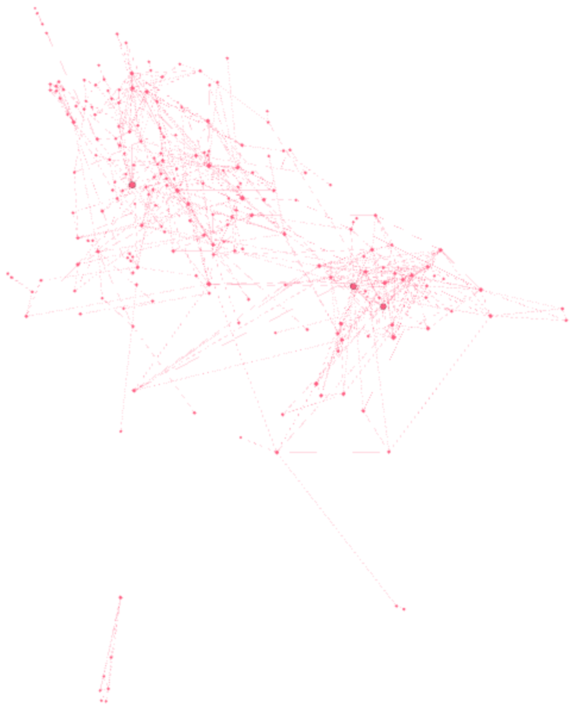
Wang et al. [26] present a double-sided grid design, in which the front and rear surfaces of the cell are separately optimized for antireflection and light capture, respectively. The authors propose a structure based on nano cones of different sizes for the upper layer (the period is 500 nm, the base radius is 250 nm, and the height is 710 nm) and lower layer (the period is 1000 nm, the base radius is

475 nm, and the height is 330 nm). Their experimental results approximate the limit of the theoretical absorption spectrum of Yablonovitch.

Community 1 (Thin Film and Polycrystalline) publishes the advances in the efficiency of thin cells and thin polycrystalline cells. Figure 5a shows the most representative keywords of the Thin Film and Polycrystalline community, which shows the number of times and their percentage of repetition within the community. The most representative word is "Silicon", followed by "Crystalline silicon" and "Epitaxy"; these words are generic of all communities. This community has a lot of keywords; it is the smallest and therefore its most repeated keywords are the most generic, the rest are more focused on the specific theme of the community. Figure 5b displays the distribution of published documents. Unlike the Material Solar Cell community, this is much more specific and, although it maintains connections with other communities, its articles do not have references from the Material Solar Cell and Thin film a-Si community: H.

Thin film & Polycrystalline

Keys	Nº	%
Silicon	11	2.5
Crystalline silicon	7	1.6
Epitaxy	7	1.6
Absorption enhancement	5	1.1
Impurity photovoltaic effect	5	1.1
Photovoltaic	5	1.1
Polycrystalline silicon	5	1.1
Thin-film solar cells	5	1.1
Nanoimprint lithography	4	0.9
Porous silicon	4	0.9



(**a**) (**b**)

Figure 5. Representation of Thin film and Polycrystalline community: (**a**) keywords; and, (**b**) isolated distribution of the publications.

In this community, a lot of research is being carried out to reduce the consumption of Si per watt peak. In addition to reducing the cost, a reduction in the thickness of the solar cell theoretically allows for an increase in the performance of the device. The long-term stability of thin film photovoltaic modules is increasing, while also reducing costs [27].

Thin film-based technologies show much lower surface production costs than bulk Si PV. Becker et al. [28] show the development of the i2 modules and the challenges that are faced by high-quality crystalline Si cells of thin film on glass, with the main ones being improvements in light trapping characteristics, low temperature junction processing, and cell metallization. Xue et al. [29] propose the Liquid Phase Crystallization Techniques (LPC) in the manufacture of high-quality crystalline silicon thin film solar cells in glass. Therefore, LPC is used for the development of double-sided silicon films, and different nanophotonic geometries of light capture are studied, concluding that this 10 mm thick double-sided silicon films can present maximum short-circuit current densities that are achievable in solar cells up to 38mA/cm^2 while assuming zero-parasite absorption.

Improvements in light entrapment in Si Polycristalline thin-layer solar cells (pc-Si) are based on the random scattering of light in the absorbent layer by glass substrate texture, or silicon film etching texture and plasmonic nanoparticles [29]. The thin-layer solar cells pc-Si on glass offer the possibility of achieving efficiencies of a single union of 15%. This is achieved by developing structures that improve light entrapment, being mainly based on silicon nanostructures, such as porous silicon, nanowires of silicon, and nano-silicon holes [29]. [30,31] proposes using a "seed layer" to obtain a high quality material, the use of ZnO and aluminum cladding as a method of improving light collection, and the use of high quality materials for the evaporation of the electron beam for the deposition of the absorbers, which offers a high potential for cost reduction, to obtain efficiency improvements and a reduction in costs. Another proposal is to use nanowire matrices to improve light entrapment and the design of the cell structure to minimize parasitic absorption, together with suppression of surface recombination, while using a multi-HIT configuration (hetero junction with intrinsic thin layer) core-based solar-based nanowire cells that were prepared in the thin film of low-cost pc-Si, developing an 8 μm pc-Si cell [32].

Another method that is based on surface plasmonic resonance (SPR) and a periodic hybrid matrix composed of a graphene ring at the top of the absorbent layer separated by an insulating layer to achieve an improvement of multiband absorption, increases the basis for simultaneous photodetection at multiple wavelengths with high efficiency and tunable spectral selectivity [33].

In [34], they propose a complete method for studying long-term light entrapment, the use of quantum efficiency data, and expressions of the calculation of Z0 and RBACK (reflectivity of the rear reflector defined in [10] for any solar cell), where Z0 is the optical path of short band length factor Z0 of Rand and Basore [35], and it is a multiple of the thickness of the cell necessary to generate equal to that found in the device. Although there are not very relevant nodes as compared to the others, it should be noted that the publications of the most cited nodes in Scopus for this scientific community in order of size are:

- "Polycrystalline silicon thin-film solar cells: Status and perspectives" [36] with a total of 117 cites.
- "Crystalline thin-foil silicon solar cells: Where crystalline quality meets thin-film processing" [37] with 64 cites.
- "Double-side textured liquid phase crystallized silicon thin-film solar cells on imprinted glasswith" [38] 37 times cited.

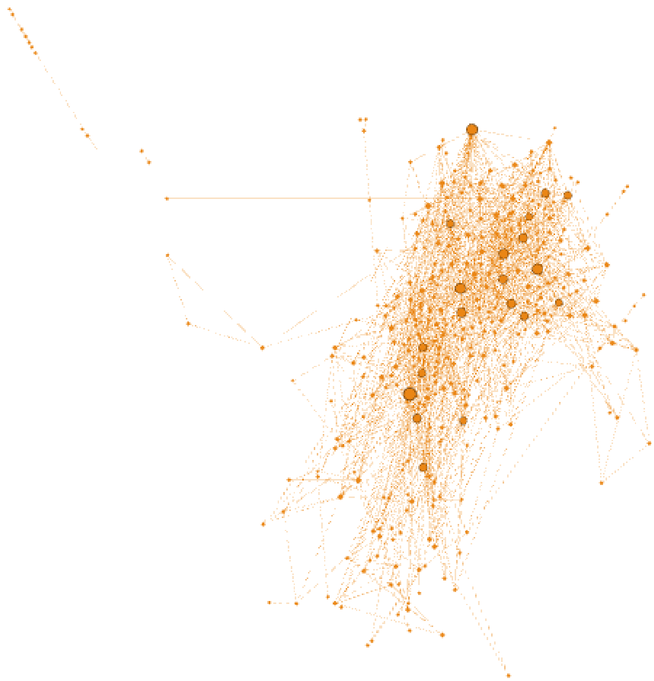
Community 2 (Organic solar cells) investigates an alternative to silicon-based photovoltaic cells, organic solar cells (OSC), or also called organic photovoltaic cells (OPV). Figure 6a shows the most representative keywords of the Organic solar cell's community, which shows the number of times and their percentage of repetition within the community. One of the most representative words is "Organic solar cells", after which the community is named. The following words are specific to the topic treated in this community, such as: "Organic photovoltaics", "Light harvesting", and "Polymer solar cell". Despite the small representativeness, 8.3% of the publications, (Figure 2), this community has a greater concentration of publications with references, as it can be seen in the size of the circles in Figure 6b, which is unlike the community Thin Film and Polycrystalline. This community has ties with the rest of the communities.

OSC cells have interesting advantages due to their characteristics, such as their lightweight, flexibility, and possibility of producing them profitably for large surfaces. These features have made of these cells very valid for applications in electronic textiles, synthetic leather, and robot, etc. The main disadvantage is their low energy conversion efficiency, which is mainly because the light absorption properties in an organic active layer have short optical absorption lengths (L_A ~ 100 nm) and exciton diffusion length (L_D ~ 10 nm). This implies that a reduction in the thickness of the active layer affects deterioration in performance, but an increase in thickness implies an increase in the series resistance and reduction in the collection of carriers. Therefore, a compromise between both of the situations is sought, efficient light collection and efficient load collection. The optical optimization that is used in other thin-layer technologies can be useful in achieving' maximum concentration in the absorbent layer, some of the proposals for improvement in light capture are based on modifying the structure, mainly plasmonic nanostructures, where photonic crystals are used, metal gratings, buried nanoelectrodes, etc.; however, in essence, they increase the organic surface layer [39,40]. Ko et al. [41] study the different nanostructure-based uptake systems for OSC cells while using both Plasmon surfaces and anti-reflective coatings, and photonic crystal (PC) nanostructure. Although theoretical calculations suggest that the efficiency increases the accumulation of absorption of light in nanostructured devices, the results show that they are still inferior to the highest reported conventional organic photovoltaic cells, which implies that further research in this field must be carried out to obtain thinner layers of photoactive material that improve the performance. The use of metallic nanomaterials can improve the capture of light in OSC and, although most nanoparticles (NPs) limit the improvement of the efficiency of power conversion to a narrow spectral range, broadband capture is desirable. The proposal of Li et al. [42] is the combination of Ag nanomaterials in different ways (Localized plasmonic resonances (LPRs), Ag nano prisms, and NPs mixed with Ag) for better broadband absorption and increased short-circuit photocurrent density. Out of the three experiments, the one with NPs mixed with Ag is the one with the highest efficiency with power conversion efficiency of 4.3%. They conclude that the cooperative plasmonic effects in metallic nanomaterials with different types of materials, shapes, size, and even the polarization incorporated in the active layers or between the layers or both should be further studied.

Organic solar cells

Keys	Nº	%
Light trapping	86	9.1
Organic solar cell	59	6.2
Solar cell	23	2.4
Organic photovoltaic	22	2.3
Polymer solar cell	20	2.1
Plasmonic	15	1.6
Metal nanoparticle	12	1.3
Light harvesting	11	1.2
Surface plasmon	11	1.2
Nanoparticle	10	1.1

(a)



(b)

Figure 6. Representation of Organic solar cells community: (**a**) keywords; and, (**b**) isolated distribution of the publications.

The review that was carried out by Gan et al. [43] proposes incorporating plasmonic nanostructures in the front and rear metal electrodes of an OSC, which is expected to reach broadband, polarization, and absorption independent of the angle, and this implies the possibility of exceeding 10% power conversion efficiency. Tvingstedt et al. [44] analyzes the use of micro lens to increase the capture of light and, thereby, improves the absorption rate of the solar cell. Xiao et al. [45] propose a hybrid system of micro lens for OSC (a matrix of hybrid micro lens, a mirror with a matrix of holes, and an OSC with a reflective cathode) to improve broadband absorption. Each isana chromatic hybrid refractive-diffractive singlet micro lens made of a single optical material, and these hybrids micro lens are separated from the cells to avoid direct contact with an organic layer that can cause electrical defects. Another proposal is the use of a V-shaped light capture configuration; the purpose is to increase the photocurrent for all angles of incidence. Rim et al. [46] tested in a 170 nm polymer thin film OSC, obtaining a 52% improvement in efficiency and conclude that this V structure in thin film OSC is effective for active layer thicknesses of the order of wavelength of light or less.

Müller-Meskamp et al. [47] study direct patterning interfering laser (DLIP) has been used to manufacture periodic surface patterns (substrates with a 4.7 µm and hexagonal line of 0.7 µm) large surface area on flexible polyethylene terephthalate (PET) substrates. The results are encouraging, achieving the best results for the hexagonal corrugated structures with greater short-circuit current (Jsc) and greater energy conversion efficiency (PCE). Other important studies should be cited for Perovskite Solar Cells related to High-Performance Solution-Processed Double-Walled Carbon Nanotube Transparent Electrode [48], and the Highly reproducible perovskite solar cells with an average efficiency of 18.3% and best efficiency of 19.7% being fabricated via Lewis base adduct of lead (II) iodide [49]. Publications of the most cited in Scopus in this cluster are:

- "Plasmonic-enhanced organic photovoltaics: Breaking the 10% efficiency barrier" [50]. Cited 391 times.
- "An effective light trapping configuration for thin-film solar cells" [46]. Cited 170 times.
- "Light manipulation in organic photovoltaics" [51]. Cited 23 times.

Community 3 (Thin film a-Si: H) presents advances on thin-layer solar cells of hydrogenated Amorphous (a-Si:H) or hydrogenated microcrystalline (µc-Si:H). Figure 7a shows the most representative keywords of the Thin film a-Si: H community, which shows the number of times and their percentage of repetition within the community. The most representative word is "Thin film solar cells", which makes part of the community name, the next word is "Silicon", which is generic, and the rest are already more specific to the topic treated in this community, such as " Amorphous silicon "and" Microcrystalline silicon ". This community, although its studies are focused on a-Si cells: H is the second community in relation to total publications (Figure 2). It has a central core with a large number of references and three somewhat lower, but considerable references (Figure 7b). In addition, it maintains a great interaction with the rest of the communities that supply it with references. The publications of the most referenced nodes in Scopus in the order of size are the following three:

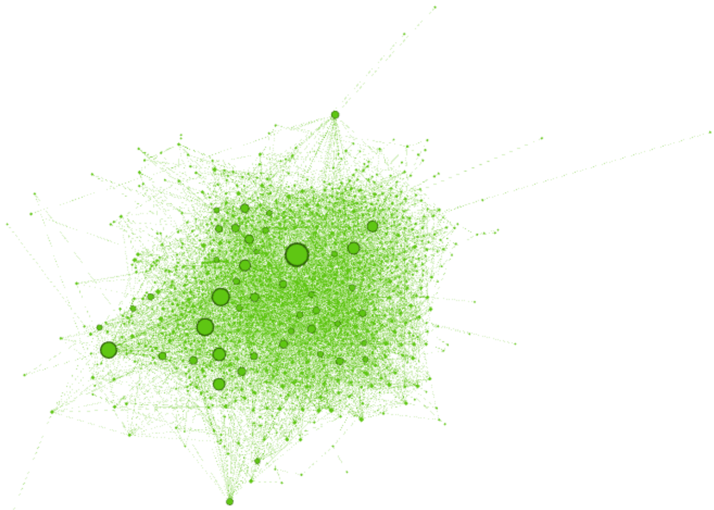
- "TCO and light trapping in silicon thin film solar cells" [52] with 869 cites.
- "Light trapping in solar cells: Can periodic beat random?" [53] was cited 369 but its node is large because it relates to major nodes.
- "Light trapping in ultrathin plasmonic solar cells" [54] had 512 cites, but with lower relations to major nodes.

The thin-layered Si (H-Si:H) or hydrogenated microcrystalline (µc-Si:H) thin-layer solar cells use an intrinsic layer (layer i) without doping between two highly doped layers (p and n). The optical and electrical properties of the i-layers are linked to the microstructure and, therefore, to the deposition rate of the layer i, which in turn affects the production yield [55]. The importance of contact and reflection in these solar cells require techniques to improve light uptake [52]. An integral part of these devices is the transparent conductor oxide (TCO) layers used as a front electrode and as a part of the rear side reflector [56]. When applied on the front side, the TCO must have high transparency in the spectral region, where the solar cell operates with high electrical conductivity. In p-i-n configuration, where the Si layers are deposited on a transparent substrate covered by TCO, with rough surfaces are applied in combination with the highly reflective rear contacts. TCO must have a strong dispersion of the incoming light in the silicon absorbent layer and favorable physicochemical properties for silicon growth. The application of zinc oxide films that were doped with aluminum (ZnO:Al) as a rear reflector result in a highly promising TCO material [57]. These films provide efficient coupling of the incident sunlight by refraction and light scattering at the interface TCO/Si to increase the length of the light path [52]. Another proposal for improving light entrapment is to use a return reflector; the use of Ag plasmonic nanoparticles can provide performance that is comparable to random textures in amorphous silicon solar cells n-i-p [58].

Thin film a-Si:H

Keys	№	%
Thin film solar cells	97	3.0
Silicon	40	1.2
Amorphous silicon	39	1.2
Microcrystalline silicon	32	1.0
Back reflector	31	1.0
ZnO	28	0.9
Light scattering	26	0.8
Photovoltaics	26	0.8
Zinc oxide	25	0.8
Plasmonics	20	0.6

(a)



(b)

Figure 7. Representation of Thin film Si:H community: (**a**) keywords; and, (**b**) isolated distribution of the publications.

Other researchers propose different nanostructures for improving light entrapment, which are very important in thin-film amorphous silicon solar cells. Battaglia et al. [53] compare a random pyramidal nanostructure of transparent zinc oxide electrodes and a periodic one of periodic glass nanocavity matrixes manufactured by nanosphere lithography. The results show that both options have approximately a short-circuit current density of 17.1 mA/cm^2 and a high initial efficiency of 10.9%. Waveguide Theory provides a mechanism to select the period and symmetry of the grid to obtain efficiency improvements. The relationship between the photocurrent and the spatial correlations of random surfaces have been proposed by [59], developing pseudo-random matrices of nanostructures that are based on their power spectral density, and their correlation between the frequencies and the photocurrent.

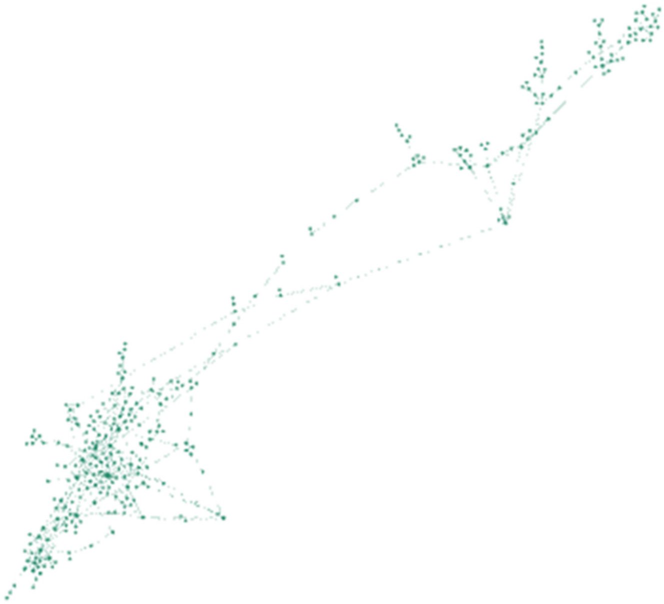
Another option is nanodome solar cells, which have periodic nanoscale modulation for all types of solar cells from the lower substrate, through the active absorber to the upper transparent contact. These devices combine many nanophotonic effects to efficiently reduce the reflection and improve absorption over a wide spectral range. Nanodome solar cells with only one layer of 280 nm thick hydrogenated amorphous silicon (a-Si: H) can absorb 94% of the light with wavelengths of 400–800 nm, which is significantly greater than 65% absorption of flat film devices. In [60], they propose a nanodome solar cell of union p-i-n a-Si: H. The cells are composed of 100 nm thick Ag as a rear reflector, 80 nm Thick transparent conduction oxide (TCO) as a bottom and upper electrode, and a thin active layer of a-Si: 280 nm H (top to bottom): pin, 10-250-20 nm). Ferry et al. [54] proposed a strategy that consists on the use of non-randomized nanostructured reflectors optimized for ultra-thin solar cells of hydrogenated amorphous Si (a-Si:H). This alternative increases the short-circuit current densities, which improves the results as compared to cells that have posterior contacts with a flat or random texture.

Community 4 (Optical design) works on improvements in the efficiency of solar cells from the point of view of optical design by creating nanostructures to improve the capture of direct and diffused light. Figure 8a shows the most representative keywords of the optical design community, which shows the number of times and their percentage of repetition within the community. All of the words are very representative of the community, such as “Diffractive Optics” or “Optical Design”, after which the community is named and it represents 11.5% each with respect to the community; the next words are "Diffractive Optics elements" and "Diffractive elements." This is the second smallest community, although it maintains links with the rest of the communities (Figure 2). This community incorporates publications from other disciplines, such as optics, which were not initially developed for solar energy, but whose impact on the optical behavior of a surface has been referenced by the other communities. In Figure 2, it appears as an emerging community. Unlike the other communities, it does not have a main nucleus, since this community does not have a great concentration of relationships in its articles (Figure 8b).

Optical design

Keys	Nº	%
Diffractive optics	22	6.9
Optical Design	22	4.6
Diffractive optical elements	18	4.0
Diffractive elements	14	4.0
Computer generated hologram	10	1.5
Diffraction	9	1.5
Diffraction efficiency	7	1.2
Polarization	7	1.0
Polarization gratings	6	1.0
Dual-band	5	0.8

(a)



(b)

Figure 8. Representation of Optical design community: (**a**) keywords; and, (**b**) isolated distribution of the publications.

The manufacture of solar cells requires a prior study of their optical behavior with the consideration of better light capture. Therefore, their behavior is studied as a diffractive element, and lithographic structures respond differently, depending on their structure, composition, and size. Herkommer et al. [61] show simulation techniques to evaluate the distraction efficiency prior to the manufacture of the solar cell. It is very important prior to manufacturing to simulate the behavior in real conditions, since different manufacturing systems can be used, depending on the wavelength range of the incident and its size characteristics. Depending on the wavelength, more than one material can be used to implement the grid structures. The dependence on the size of the diffraction efficiency characteristic can be considered as the manufacturing limitations. There is commercial software that calculates the diffraction efficiency for a given grid while considering the period, grid shape, wavelength, and angle of incidence.

The diffractive optical element (DOE) can be implemented on flat and curved surfaces [12]. Grilles can be designed and implemented more complexly according to the need for the range of light collection and its efficiency with the use of direct laser lithography or through computer-generated holograms. On curved surfaces, they can be manufactured while using single-point diamond turning [62] to reduce the material used.

Digital holography (computer-generated hologram) has improved its quality in recent years, leading to unthinkable implementations for its accuracy not many years ago. Patterns can be engraved on photosensitive materials at the appropriate scale, embossed on high precision materials in various directions with or without periodicity, with the arrival of the laser and its computer control. Some lithographic techniques combine the coating with a light sensitive film (photo-resistance). Digital holography and Computer-Generated Holograms reduce the choice of material and pattern generation scheme. The degree of freedom in the choice of parameters limits the choice of coding technique and its optimization. The coding allows for adapting the data to the existing hardware requirements [12].

Solar cells have benefited from the study of the behavior of diffractive elements applied to other fields of research. The most common diffractive elements are a diffractive lens, a matrix generator, and a correlation filter [63]. The design is based on the optimum performance of the optical system and its manufacturing restrictions. These diffractive elements have a disadvantage in that they produce chromatic aberrations. Some authors [64] propose the attachment to the lens of a corrective substrate of the diffraction for application in the headlights of a car and study these elements for the diffractive telescope system.

Hybrids are one of the most complex diffractive elements, where they are both reflective and dissipative throughout the visible band (400–700 nm). Designing achromatic refractive-diffraction hybrid lenses is complex and it requires prior study for its manufacture to optimize its efficiency in the capture range [65]. Publications regarding the most cited in Scopus in this cluster are:

- "Digital holography as part of diffractive optics" [66] cited 111 times.
- "Understanding diffractive optic design in the scalar domain" [67] cited 110 times.
- "I digital holography computer-generated holograms" [68] cited 23 times.

Community 5 (Light trapping) investigates the improvement of the capture of light in solar cells, while using nanoparticles for the purpose of improving efficiency. Although many authors investigate and test systems for improving the light entrapment by nanostructures, in their turn they produce an increase in surface area and, therefore, minority recombination that reduces the efficiency. Other researchers use the dispersion of metal nanoparticles by varying their shape, size, particle material, and ambient dielectric energy to determine the improvement of light capture with particle plasmons to avoid this adverse situation. Figure 9a shows the most representative keywords of the Light trapping community, which shows the number of times and their percentage of repetition within the community. All of the words are very representative of the community as "Plasmonic" or "Surface plasmons", and they represent 4% and 3.1%, each with respect to the community, other words, like "Nanoparticles", "Silver nanoparticles", and "Metal nanoparticles", are very specific to the community, although within the 10 most repeated words, there are other generics, such as "Photovoltaics" and "Silicon" with 2.5% and 1.6% each. This community is ranked third in size (Figure 2) and it has a main nucleus and a somewhat smaller one as seen in Figure 9b. It is a community that is closely related to the rest, since the main topic discussed affects the studies of other communities, such as the entrapment of light, which, regardless of the type of cell, is important to improve and increase the efficiency. The two publications of the most referenced nodes in Scopus in the order of size are the following:

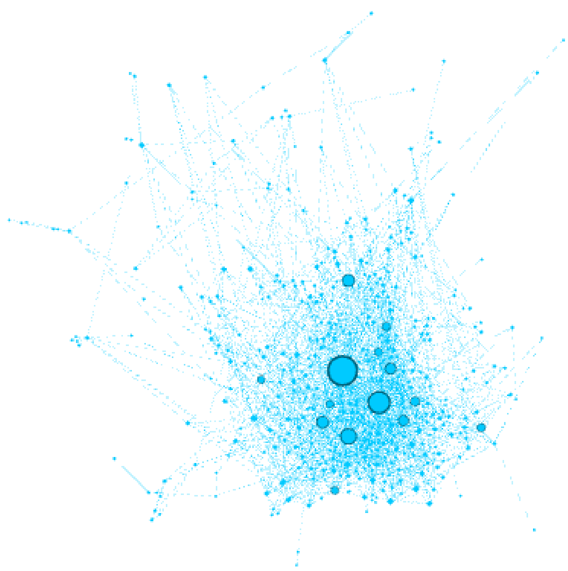
- "Surface plasmon enhanced silicon solar cells" with 1467 references and many relations with other communities [69].
- "Design principles for particle plasmon enhanced solar cells" [70] with 673 cites.
- "Tunable light trapping for solar cells using localized surface plasmons" [71] with 460 cites.

Catchpole et al. [70] show that the shape of the particles influences the path length, with the spherical shapes being worse than the cylindrical and hemispherical shapes. In addition, they conduct experiments with silver and gold particles, where the results show that those of silver provide a longer path length than those of gold. In Ouyang et al. [9], the effects of silver nanoparticles on polycrystalline silicon thin film solar cells on glass are studied, obtaining an improvement in the short-circuit current of a 1/3 increase when compared to conventional ones. The geometry of the matrix used also defines the entrapment of light (there are studies on random, quasi-periodic, and periodic matrices). Mokkapati et al. [72] study the behavior of silver nanoparticles in a periodic matrix and conclude that there is a very restrictive relationship between the optimal particle size and grid parameters of the periodic matrix; the case of silver particles of 200 nm, a 400 nm step is ideal for Si solar cells. Other authors analyzed the behavior of silver nanoparticles on the rear structure to reduce the entrapment losses that were produced with the long wavelength that escape (rear reflector dispersion), but with minimal electronic losses due to recombination effects. The photocurrent with the silver nanoparticles of a PERT (Passivated Emitter and Rear Totally Diffused) cell increases by 16% when compared to an aluminum rear structure [73].

Light trapping

Keys	Nº	%
Light trapping	104	7.9
Solar cells	65	5.0
Plasmonics	53	4.0
Surface plasmons	41	3.1
Photovoltaics	33	2.5
Nanoparticles	28	2.1
Silver nanoparticles	23	1.8
Silicon	21	1.6
Thin film solar cells	21	1.6
Metal nanoparticles	11	0.8

(a)



(b)

Figure 9. Representation of Light trapping community: (**a**) keywords, and (**b**) isolated distribution of the publications.

3.3. Analysis as Per Authors, Affiliations, and Countries of Investigation on Solar Coating

In total, there are 14,849 authors who research in 26 by subject area. The ten countries with the highest concentration of researchers contributing their scientific publications to the progress in Solar Coating have been analyzed. China makes the main contribution, with 3345 researchers (22.5%), being closely followed by the United States with 2634 (17.7%) and Germany with 1156 (7.8%). The rest is around 349 from Italy to 687 in South Korea, with percentages ranging from 2.4 to 4.6%, respectively. China and the United States are among the countries with the greatest contributions in scientific developments in all matters related to energy, and also in energy saving [16]. Figure 10 shows the distribution and percentages of participation of the authors according to the country of origin shown by colors. There are 28.8% of other countries of low percentage contribution, as can be seen in Figure 10, where Spain, Australia, and others appears.

The results show that China and the United States both actively collaborate in the progress by establishing collaborative ties with other countries in order to move forward and this can be seen from the intertwining of the communities in Figure 2. The main collaborations are established in Asia between Chinese, Koreans, Taiwanese, Japanese, and Indians, making a total of 38%. The European contributions between Germany, France, United Kingdom, and Italy make up for 16%. America is only represented by the United States.

Going deeper into the origin of the authors, the 20 most localized affiliations in the search have been analyzed, since it is important to know in which research and development centers the main contributions to Solar Coating are made. Table 1 shows the data; 12 of the 20 belong to the Asian continent with a contribution of 65% of the Top 20 publications. It is interesting how Switzerland, which was not among the 10 countries with the highest productivity in Solar Coating, is the second research institution in terms of the number of contributions with 6.6% of the top 20. In Europe, Germany stands out with the centers of the Fraunhofer Institute for Solar Energy Systems ISE and Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) with a total of 11.1%, which together with Switzerland contribute in 17.7%. America contributes in 12.6% with the USA and only three research institutions, being the one that Stanford University publishes the most.

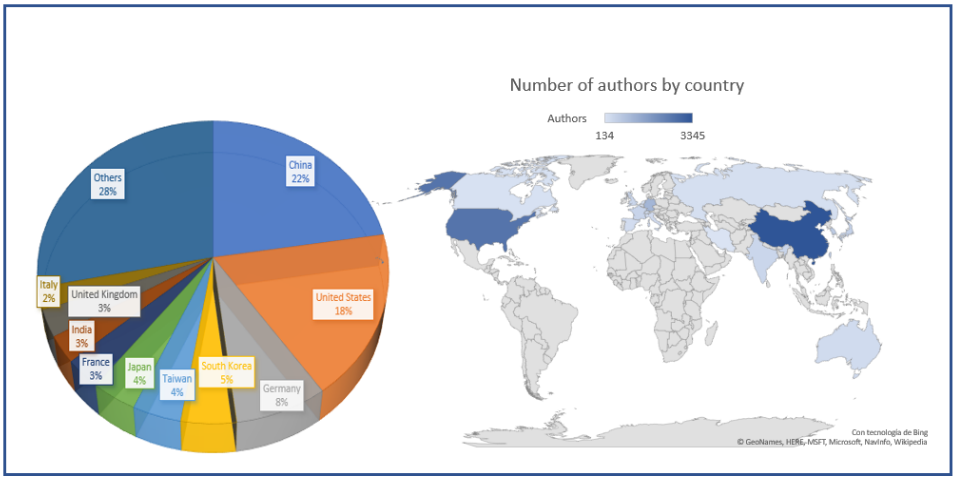


Figure 10. Author distribution per countries.

Table 1. Top 20 affiliations in Solar Coating.

Affiliation	Country	Publications
National Taiwan University	Taiwan	123
Swiss Federal Institute of Technology, Lausanne	Switzerland	115
Fraunhofer Institute for Solar Energy Systems ISE	Germany	108
Shanghai Jiao Tong University	China	105
Nankai University	China	103
Soochow University	China	103
Chinese Academy of Sciences	China	99
University of New South Wales (UNSW)	Australia	91
Forschungs zentrum jülich (FZJ)	Germany	84
Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)	Germany	83
Stanford University	USA	82
Nanjing University	China	79
National Chiao Tung University	China	77
Jilin University	China	76
Sungkyunkwan University	South Korea	74
Nanyang Technological University	Singapore	69
National Renewable Energy Laboratory	USA	69
Massachusetts Institute of Technology	USA	67
Australian National University	Australia	64
Sun Yat-Sen University	China	62

Table 2 shows a list of the 10 authors with the highest H-index in Scopus in relation to the search performed. The order of the authors does not correspond to the order by institution of Table 1. The author with the highest H-index of 230, 1471 published documents, and 258,107 citations belong to Switzerland and there is a second in position 9 both same affiliations appearing in Table 1 (Swiss Federal Institute of Technology, Lausanne). In the top 10 by H-index, there are mainly US authors from Harvard University, Georgia Institute of Technology, Stanford Linear Accelerator Center, and University of California (Berkeley); none correspond to the three affiliations in Table 1. There are two Chinese authors in positions 8 and 10, with H-indexes of 138 and 130, respectively, which have a number of significant citations of 77,076 and 72789, in both cases their center does not correspond to those of Table 1. There is a German author with H-index of 186 and 136,496 citations, but their affiliation does not correspond to the affiliations of Germany in Table 1. It is significant that only the affiliation of the authors of Switzerland corresponds within those seen in Table 1. This might be due to the fact that, although the group of contributions has great references, it does not establish collaborations between the communities, and that means that the software debugging process has been eliminated. Figure 11 shows the location of the author of the highest H-index in Table 2. As it can be seen in the figure, it corresponds to the border that has not been represented when analyzing the communities, since it remains as a node with no connection to the rest. This can be interpreted that the system correctly measures relationships and not just references, giving more value to relationships.

Table 2. Top 10 authors by H-index (Nco-author = Number of coauthors, Ncite = Number of cites, Ndoc = Number of documents).

Author Scopus ID	Name	H-Index	Nco-Author	Ncite	Ndoc	City	Country	Affiliation
35463345800	Gratzel M.	230	2222	258107	1471	Lausanne	Switzerland	Swiss Federal Institute of Technology, Lausanne
55711979600	Whitesides G.	187	1268	159450	1008	Cambridge	United States	Harvard University
7403027697	Xia Y.	186	952	136496	779	Atlanta	United States	Georgia Institute of Technology
7103185149	Antonietti M.	156	1047	84786	789	Golm	Germany	Max Planck Institut fur Kolloid Und Grenzflächenforschung Potsdam
35207974600	Cui Y.	155	994	99093	532	Menlo Park	United States	Stanford Linear Accelerator Center
7403931988	Yang P.	150	706	102859	408	Berkeley	United States	University of California, Berkeley
56605567400	Alivisatos A.	143	934	108954	445	Berkeley	United States	University of California, Berkeley
7403489871	Zhao D.	138	1189	77076	685	Shanghai	China	Fudan University
35463772200	Nazeeruddin M.	133	1090	82713	576	Lausanne	Switzerland	Swiss Federal Institute of Technology, Lausanne
56422845100	Jiang L.	130	2113	72789	1256	Beijing	China	Technical Institute of Physics and Chemistry Chinese Academy of Sciences

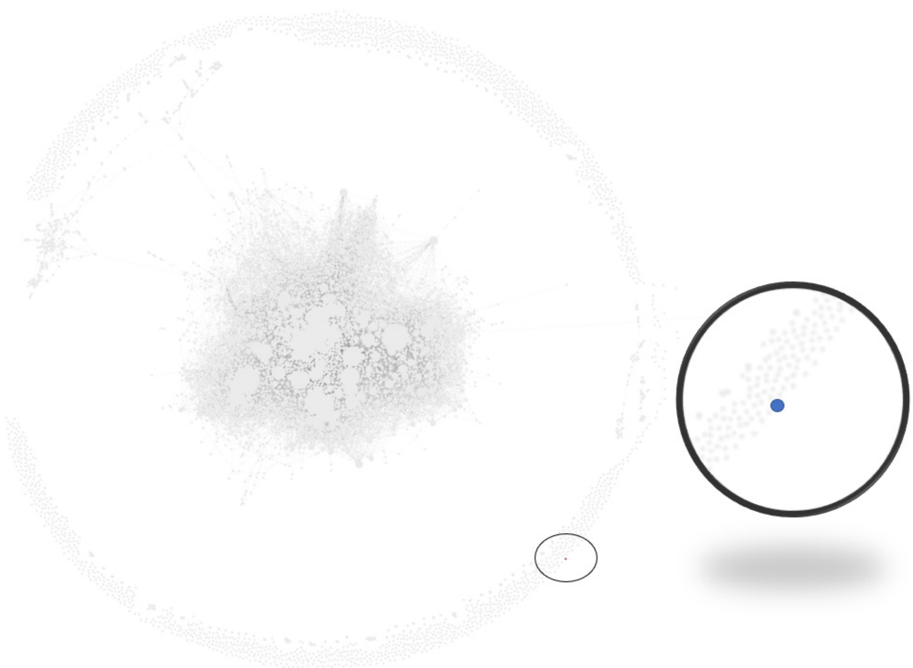


Figure 11. Location of the Author with the highest H-index with research in Solar Coating.

If we analyze the top 10 of the authors considered in the analyzed communities (Table 3), it is observed that they have lower H-index than those shown in Table 2 and, in this case, if they correspond to the affiliations in Table 1. An author from Belgium appears and another from France, which does not appear from its affiliations in Table 2, despite being in positions 5 and 8 of Table 3.

Table 3. Most important 10 for H-index analyzed in the communities (Nco-author = Number of coauthors, Ncite = Number of cites, Ndoc = Number of documents).

Author Scopus ID	Name	H-Index	Nco-Author	Ncite	Ndoc	City	Country	Affiliation
6701805412	Ballif C.	65	750	13344	461	Lausanne	Switzerland	Swiss Federal Institute of Technology, Lausanne
56216991600	Rech B.	48	514	10525	321	Berlin	Germany	Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)
6603242760	Blasi B.	21	201	1542	105	FreiburgimBreisgau	Germany	Fraunhofer Institute for Solar Energy Systems ISE
7004315658	Haug F.	37	282	5174	171	Lausanne	Switzerland	Swiss Federal Institute of Technology, Lausanne
56597035200	Poortmans J.	44	781	8334	523	Leuven	Belgium	Interuniversity Micro-Electronics Center at Leuven
55505896100	Zhao Y.	21	338	2607	462	Tianjin	China	Nankai University
55931076700	Zhang X.	17	420	2020	383	Tianjin	China	Nankai University
6602741595	Roca i Cabarrocas P.	43	683	7634	497	Palaiseau	France	Laboratoire de Physique des Interfaces et des Couches Minces
7402736621	Yi J.	33	617	4594	471	Jongno-gu	South Korea	Sungkyunkwan University
7006823424	Atwater H.	89	726	41733	654	Pasadena	United States	California Institute of Technology

4. Discussion

The scientific contributions that were published in the Solar Coating field from 1964 to June 2019 make a total of 6440 and 127 new ones published as of September. Until 1982, the publications were sporadic with a couple of publications per year, and then increased in 1990, but did not exceed 20 annual publications. From then on, the contributions are more numerous until 2004, being marked with 97 publications. From 2005 to 2019, this period is marked with a high concentration of publications (83%), due to the "renewable boom". The fact that the highest concentration has occurred, since 2005 might be due to global awareness of environmental concerns, such as global warming and the greenhouse effect, as shown by the agreement in Kyoto, Japan, on 11 December 1997 and entered into force on February 16, 2005. This has meant that the scientific community has turned to providing solutions; one of the clean energies that is most committed to the future is photovoltaic solar energy [73]. The main forms of publications are in original articles with 62.6% and in conferences with 32.6%, followed by far by review articles and book chapters with 1.9% and 1.1%, respectively. Book contributions are scarce, with only six published < 0.01% [74–80] and all with little impact on the number of references below 22. In [16], the authors analyze the bibliometric in energy saving and obtain a percentage of publication of articles of 50.7%, conferences 43.1%, and in books a percentage lower than 1%, which is very much in line with those that were obtained in this work.

English is the most used language for publications with 96.8% of the total publications, followed by Chinese, with a percentage of 2.6%, and the rest of the languages have a representation lower than < 1% (Russian, Japanese, Korean, German, Spanish, French, Lithuanian, Finnish, and Malay). It is usual for the English language to be the most widespread in scientific publications due to the edition standards of the journals to have maximum dissemination, regardless of the country of origin of the headquarters of the publisher. Only China produces a number of scientific publications in its own language, such as Taiyangneng Xuebao/Acta Energiae Solaris Sinica, Cailiao Gongcheng/Journal of Materials Engineering among others. The demand for energy increases with population growth and China is one of the largest consumers, due to its industrial expansion and population growth, which motivates China to investigate the production of clean energy, as seen in the results shown in Tables 1–3.

The thematic areas that are most used for scientific dissemination are mainly Physics and Astronomy (25.9%), Materials Science (23.6%), Engineering (21.6%), Energy 6.4%), Computer Science (5.6%), Chemistry, Mathematics (4.6%), Chemical Engineering (4.6%), and the rest with a contribution of less than 3%. The results show the great involvement of researchers from different disciplines, such as engineering, materials sciences, chemistry, and mathematics, among others, having all the purpose of contributing to improvements in solar energy collection. The contributions of the application of nanomaterials and nanostructures to the collection surfaces have allowed for improving efficiency by trapping light and generating new flexible, bifacial panels that have expanded the use of these panels as an architectural tool in industrial buildings and facilities, electric locomotion, and solar powered devices, thereby reducing the use of fossil fuels and CO_2 emissions.

5. Conclusions

This work has revealed data related to Solar Coating from 1957 to 2019. The total contributions found reached 6440 documents with a total of 21,301 relations between authors, where only 3924 with 20,849 relations after the use of bibliometric techniques. The study of efficiency improvements has driven a large number of contributions in different sub-themes, where each community develops its research on different perspectives, although they all have the improvement of light trapping as a system for improving efficiency in common. Publications have focused on six categories or communities Material Solar Cell, Thin Film and Polycrystalline, Organic solar cells Thin film a-Si: H, Optical design, and Light trapping. The communities with the highest representation are the most generic: The Material Solar Cell (42%), Thin film a-Si: H (25%), and Light trapping (11%). However, from a different perspective study aspect, they are provided with a main nucleus and multiple relations with the rest of the communities that nourish them of references. Organic solar cells (8.3%), Optical design (8%), and Thin Film and Polycrystalline (6%) are the other three communities. In addition to having less representativeness, these communities do not have a main nucleus, but small nuclei with a multitude of relationships in and between communities, with organic solar cells having 19 major nuclei, although much lower than all of the main ones of the more generic communities. The most repeated keywords correspond to the generic communities, which is consistent because they are the ones with the greatest ties and the most referenced publications. There are communities, like Optical design with keywords, which are very specific to their theme. This is because this community is tangential to Solar Coating incorporating research on the theme of Optics that are not specifically developed for solar cells, but their advances substantially influence the improvements of light capture, which is an essential theme for Solar Coating.

In total, there are 14,849 authors who research in 26 by subject area, China (3345 researchers) and the United States (2634 researchers) are from the countries with the greatest contributions in scientific developments in all matters related to energy, also in energy saving. The worldwide distribution is established between Asia (38%), Europe (16%), and America, with only the United States (17.7%), and there is no significant representation of the African continent. If we consider the authors' affiliation with a top 20, 12 of the 20 belong to the Asian continent (65%). It is interesting how Switzerland, which did not appear among the 10 countries with the highest productivity in Solar Coating, is the second research institution in terms of the number of contributions with 6.6% of the top 20. In Europe, Germany stands out with the Fraunhofer Institute for Solar Energy Systems centers ISE and Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) (11.1%). In the USA, which has 18% of the worldwide publications, with respect to the ranking of the top 20 affiliations only three research institutions are present, from them the best positioned is Stanford University.

The analysis of the 10 authors with the highest H-index in Scopus in relation to the search performed does not correspond to the order by institution, for example, the author with the highest H index of 230, 1471 published documents, and 258,107 citations belongs to the Swiss Federal affiliation Institute of Technology of Lausanne, (Switzerland). On the other hand, the first author in the Top 20 by affiliation is from National Taiwan University (Taiwan).

The main forms of publications are in original articles (62.6%), conferences (32.6%), followed by review articles (1.9%) and book chapters (1.1%), with scarce book contributions (<0.01%). As for the language, English (96.8%) is the most used for disseminating publications due to the standards of edition of the journals to have maximum dissemination, regardless of the country of origin of the headquarters of the publisher. The second language used is Chinese (2.6%), as it produces a significant number of scientific publications with international repercussions in their own language. All other languages have a representation of less than <1%.

The most used thematic areas are very diverse; this shows the great involvement of researchers from different disciplines, such as engineering, materials sciences, chemistry and mathematics, among others, all with the purpose of contributing to improvements in solar energy collection.

The final conclusion of the present work shows that the research on this subject is not completed and it requires even more research with different considerations that improve solar cell efficiencies. The joint collaboration of all researchers is required, with their valuable contributions opening new perspectives regarding the necessary improvement due to the growing need for global demand for energy consumption and the awareness of consumers and political entities of environmental care and implementation of renewable energy.

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