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# Manufacturing processes, life cycle analysis, and future challenges for wind turbine blades

# Procesos de fabricación, análisis del ciclo de vida y retos futuros en los alabes de turbinas eólicas

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**Abstract**

Wind turbines obtain clean energy from the wind, however, there is a significant environmental impact due to the use of some of their materials. This article analyzes the manufacturing, life cycle, and dismantling of these machines, to under-stand new opportunities to improve these negative aspects, through the review of various articles. The search was focused on SCOPUS articles, using the word "wind turbine" in titles, abstracts, and keywords, obtaining 68,362 results. Subsequently, these results were filtered only articles, reviews, and research theses, reducing the search to 3,663 results, the search was limited to only 10 years, counting from 2020 to 2010, reaching 2,189 documents. The analysis of 2,189 documents obtained is carried out, reducing the literary base to 185 documents with information on manufacturing processes, life cycle analysis, and advances in some countries in the implementation of improvements in the manufacture of wind turbines, to reduce environmental impact. The use of thermosetting materials in wind turbine blades is a reality that must be modified by the environmental problems that these are causing, new materials for blades must be developed by the principles of the circular economy.

**Keywords:** Wind turbine blade; blade manufacturing processes; recycling; reuse and life cycle assessment analysis of blades turbine; renewable energy policies.

**Resumen**

Los aerogeneradores obtienen energía limpia del viento, sin embargo, existe una significativa afectación ambiental por el uso de algunos de sus materiales. Este articulo analiza la manufactura, el ciclo de vida y desmantelado de estas máquinas, para entender nuevas oportunidades para mejorar esos aspectos negativos, por medio de la revisión de diversos artículos. La búsqueda se centró en artículos SCOPUS, usando la palabra "aerogenerador" en títulos, resúmenes y palabras clave, obteniendo 68.362 resultados. Posteriormente, estos resultados fueron filtrados únicamente artículos, reseñas y tesis de investigación, redujendo la búsqueda a 3.663 resultados, la búsqueda se limitó a tan solo 10 años, contando de 2020 a 2010, alcanzando los 2.189 documentos. Se realiza el análisis de 2.189 documentos obtenidos, redujendo la base literaria a 185 documentos con información de procesos de fabricación, análisis de ciclo de vida y avances de algunos países en la implementación de mejoras en la fabricación de

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aerogeneradores, para reducir el impacto ambiental. El uso de materiales termoendurecibles en alabes de aerogeneradores es una realidad que debe ser modificada por los problemas ambientales que estos están provocando, los nuevos materiales para alabes deben desarrollarse de acuerdo con los principios de la economía circula.

**Palabras clave:** Alabes de aerogeneradores; procesos de fabricación de palas; reciclaje; reutilización y análisis de evaluación del ciclo de vida de alabes de turbinas; políticas de energías renovable.

## 1. Introduction

Renewable and clean energies, which include solar, wind, tidal, geothermal and biomass energy, among others, will be in the very near future those that support the need for electricity worldwide and will be the precursors of a sustainable and environmentally friendly energy [1]. This work presents a systematic review of research related to wind energy and the manufacturing processes and analysis of the life cycle of wind turbines. Likewise, an analysis of the challenges involved in the growth of the wind industry worldwide is presented [2].

Wind energy is one of the most used renewable energies after solar, on a global scale the installed capacity of wind energy has had a great growth in recent years, this is due to the low emission of CO2 that it emits into the environment. In addition, it has been shown that it is economically profitable energy [3]. As the use of wind turbines increases, their size also increases, these long blades are made of carbon or glass fiber, and the useful lifetime is around 25 years [4]. It is estimated that by 2050 some 500,000 tons of waste will be produced because of the dismantling of wind turbines at the end of their useful life; The continents with the highest concentration of waste would be Europe, Asia and finally the United States of North America [5], [6], [7], [8]. The recycling of glass or carbon fibers can be solved through mechanical, thermal or chemical processes. However, obtaining a fiber with the same properties as a virgin fiber costs a bit and is difficult, since due to the same recycling processes, these suffer damage to their compounds and therefore affect their final properties [9], [10], [11], [12], in this way it is possible to see the Inclusion in the circular economy, which generates great value and goes hand in hand with the sustainable development goals set forth by the United Nations [13],[14].

## 2. Methodology

The method used in this article consisted of searching for articles published in journals indexed in the SCOPUS database. The process used in the search for information was separated into two steps. First, the word "wind turbine" is searched in titles, abstracts, and keywords, as the central axis of the research search, obtaining 68,362 results. Later, these results were filtrated by the type of documents, only considering articles, reviews, and research theses, therefore reducing the search by almost half the documents, obtaining 3,663 results. Connectors such as OR or AND were used to limit or exclude the keywords, reducing the number just to 3,653 documents. Secondly, the search was limited to just 10 years, counting from 2020 to 2010, reaching 2,189 documents. Finally, an analysis of the abstracts was carried out to exclude some texts for better quality in the search process, thus obtaining 185 documents. Figure 1, shows the procedure used to choose the articles for analysis.

After reviewing the 185 texts, the results can be classified into four focus topics. The first is the design and manufacturing of turbines with innovation in their blades, corresponding to 50% of all the texts. In the majority of these documents, alternative materials were used.

The characterization of the geometric shape of the blades, manufacturing processes, and transformation of the raw material is also presented. The second subject of focus is the Evaluation of the components in operation, corresponding to 27% of all documents. These investigations carry out experimental tests on the wind turbines and their components, to monitor their capacity and performance, fatigue, non-destructive testing behavior, and blade failure analysis. The third topic of focus is Life Cycle Analysis, with 16% of all texts found. This focus area is one of the most special fields since the issues of reuse, reduction, and recycling of materials are today of great interest worldwide. The blade's materials and their corresponding residues are analyzed concerning possible reuse, recycling, or impact on the environment through the evaluation of their life cycle and energy generation. The last research topic is Energy Policies, with 7% relevance. This case study gives a more accurate vision of how some countries see the transition to renewable energy and establish criteria and steps to follow to comply with the sustainable development goals set by the UN. The aforementioned can be seen in Figure 2. In Figure 3, we can see how the 185 articles and the four research topics are distributed in the production of indexed content in scientific journals during the last 10 years.

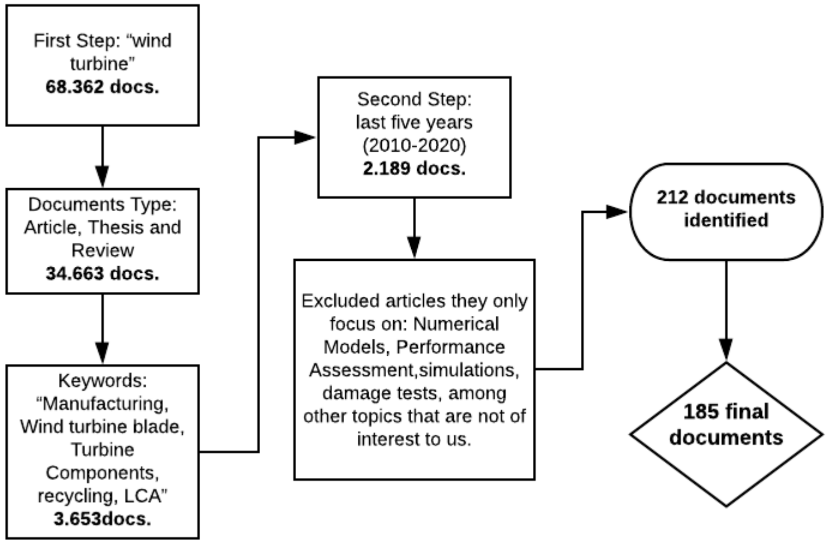



Figure 1. Steps in the search for information in the SCOPUS databases. Source: Author.

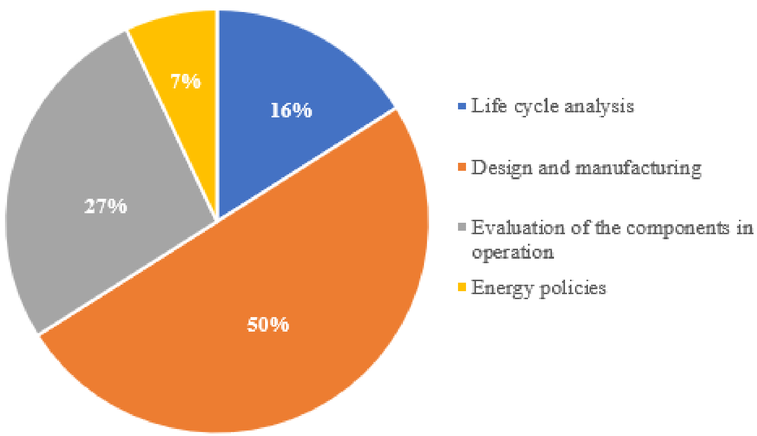
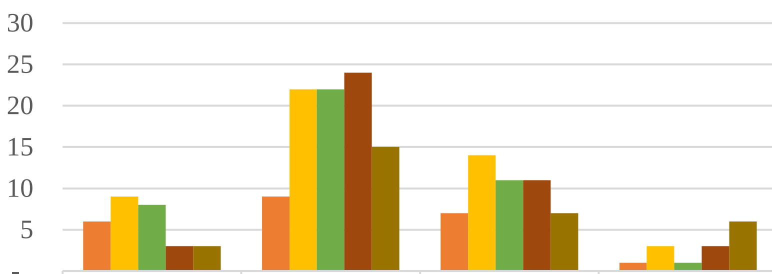



Figure 2. Research areas of investigation for the 185 documents analyzed. Source: Author.




| | Life cycle analysis | Design and manufacturing | Evaluation of the components in operation | Energy policies |
|---|---|---|---|---|
| Year 2020 | 6 | 9 | 7 | 1 |
| Year 2019 | 9 | 22 | 14 | 3 |
| Year 2018 | 8 | 22 | 11 | 1 |
| Year 2017 | 3 | 24 | 11 | 3 |
| Year 2016 | 3 | 15 | 7 | 6 |

Figure 3. Distribution in the 185 articles and the four groups, produced and indexed in scientific journals during the last 10 years. Source: Author.

## 3. Recent composition and development in the manufacture of blades in wind turbines

The conventional blades of wind turbines are mainly composed of glass, carbon, natural or synthetic fibers reinforcing matrices of mainly epoxy and polyester resins. Some thermoplastics, wood, and in some cases metals [15], [16] are used as well. See Figure 4. About the fibers, the literature review shows that carbon and glass fibers determine the stiffness of the composite, as the volume of fibers in the composites increases, stiffness, tensile, and compressive strength increase. However, more than 75% in the volume of fibers in the composite can cause a decrease in fatigue resistance, which is why in most cases the combination of 75% fiber and 25% epoxy resin is used [17].

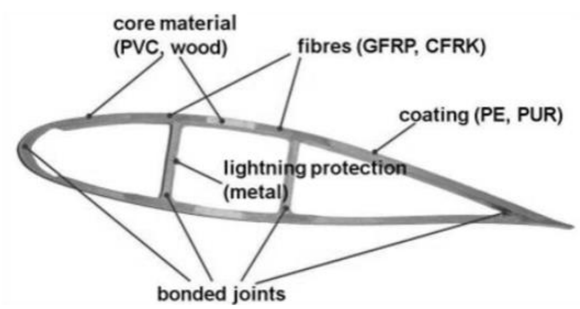



Figure 4. Typical materials for the manufacture of wind turbine blades. Source: [48].

Carbon fibers (C.F.) compete with glass fibers (GF) since they show greater rigidity and lower density, compared to GF, this has advantages in the design since more rigid blades can be obtained, at the same time. time light and with a smaller size. However, there is evidence of not very good resistance to compression and tension of glass fibers, in addition, carbon fiber is usually more expensive [18]. Aramid fibers (aromatic polyamide) show very low resistance to compression but very good mechanical resistance [19]. Basalt fibers show optimal mechanical conditions, they are 30% better, 15-20% more rigid, 8-10% lighter than glass fibers, and cheaper than carbon fibers [18]. Natural fibers are also studied in the literature and can offer particular benefits such as high resistance to stiffness, in addition to a cost much lower than the aforementioned fibers, they are naturally produced, and this research is growing for use in wind turbine blades [20], [21].

The literature shows that the most commonly used concurrent materials for the matrix are thermosetting materials (such as epoxies, polyesters, vinyl esters resins) and to a lesser extent of thermoplastics. Thermosetting compounds represent 80% of plastics on the market [22]. The advantages of thermosets are that they can be cured at room temperature; and have low viscosity, so their processing is easier. Polyester was used a lot in the past, but in recent years, manufacturers have moved to the use of epoxy due to the manufacturing size of the blades, since it is easier to work with this resin due to its rapid curing and better adhesion conditions with the fiber [23]. Thermoplastics are beginning to emerge for a simple reason: they are recyclable. On the other hand, their melting temperature is lower than their decomposition temperature, which allows the plastic to be remodeled [24]. The disadvantage concerning thermosets is that they require high temperatures, in addition, the fatigue behavior of thermoplastics is not as good as compared to thermosets. This does not mean that thermosets are a problem. However, before implementing these resins on a large scale careful analysis has to be made concerning the material processing [25], [26].

The wind turbine industry today conducts research to test new materials to improve the efficiency of their turbines. In this way, it seeks to innovate in the design, using components with lower density, longer useful life, higher performance, ease of processing, recycling capacity, and a lower cost, compared to the currently used thermostable parts [27]. The use of recyclable thermoplastics, combined with low-cost natural fibers and the incorporation of nanomaterials for obtaining lighter and stronger compounds, goes in the direction of the desired properties for the wind turbine blades [28]. Natural fibers are now an important focus of research not only due to the environmental problems caused by conventional materials, but also to their excellent mechanical properties, low cost, and biodegradability. Figure 5 are shown the different types of natural fibers classified according to their extraction source: plants, animals, or minerals.

It is noteworthy that thermoplastics have a great impact not only due to their ability to be recyclable but also because during the operation, these materials can be repairable because they can change their state without losing significantly their properties [26]. There are also alternative polymers such as polyetherimide (PEI), polyetheretherketone (PEEK), or polyphenylene sulfide (PPS), which exhibit better strength properties. Anionic polyamide-6 (APA-6) has better static and fatigue properties, which are important requirements to face wind conditions. The low cost of thermoplastics is an advantage hard to reach, which makes these materials economically viable for the application of wind turbine blades [29].

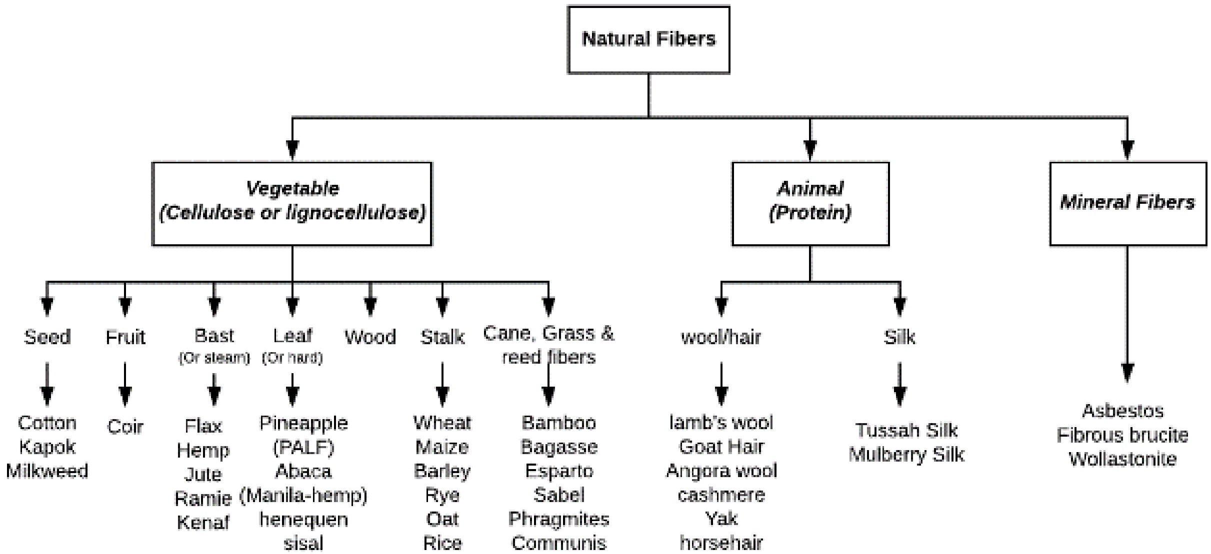



Figure 5. Classification of the types of natural fiber sources. Source: [26].

In the literature, there are investigations where they use nanocomposites. For example, carbon nanotubes offer advantages such as good toughness and high stiffness, Young's modulus of 1000 GPa, and tensile strength of 200 GPa, making the material stronger Loos et al., compared the properties mechanics of vinyl ester and dispersed epoxy resin with carbon nanocomposites, showing that these nanocomposites have better properties than the polymer and epoxy system [30]. Currently, hybrid composites are a growing trend due to their great success in performance tests. Pietro Bortolotti compared the properties of a typical fiberglass and epoxy composite with a composite made of natural fibers (hemp and jute with epoxy), concluding that the hybrid reinforcement not only has higher tensile, bending, and impact strength, but also was lighter. One of the disadvantages highlighted was that natural fibers were more complex to adhere to the polymer matrix [31].

## 4. Current manufacturing processes and future challenges

Wind turbines for electricity generation can be manufactured with electrical powers ranging between 1 and 15 megawatts, with blades that can measure between 30 and 170 meters in diameter [32].

The blades are manufactured from prefabricated molds, where two shells are generated using resins and fibers. These reinforcements are normally made with 75% E glass fiber and 25% cast with epoxy or polyester resins, which are arranged in layers, then a vacuum is made to the composite system to remove air bubbles, and once the two sections are obtained, they are assembled and joined using an adhesive epoxy joint. In the middle of these components, there must be a mast, whose function is to serve as a central column to withstand wind loads as evidenced in Figure 6. Finally, a few layers of protective paints are applied to the elements to avoid corrosion in the environment, which also serves as an electrical insulator to avoid the rays having adverse effects on the blade in case of being affected in such a situation [33].

Figure 7 shows the manufacturing process used by the company Gamesa in the construction of the blade, where the mold, resin, and fibers appeared. Figure 8 shows an automated design for the process of positioning and cutting the fibers for the mold.

One of the challenges is that once these large turbines have been manufactured, they are difficult to move to the installation site [34], which is in the research carried out by Juan Garate et al. A new manufacturing method is available, where smaller blades are obtained, to be able to be transported and later be assembled, see Figure 9.

The vacuum-assisted thermoforming process was carried out to manufacture the six blades of the turbine, using materials such as thermoplastics which are easy to recycle and reuse, the turbines are finally joined by fusion welding and adhesives. the turbine produced 20 W at low wind speeds, comparable to an existing commercial turbine [35].

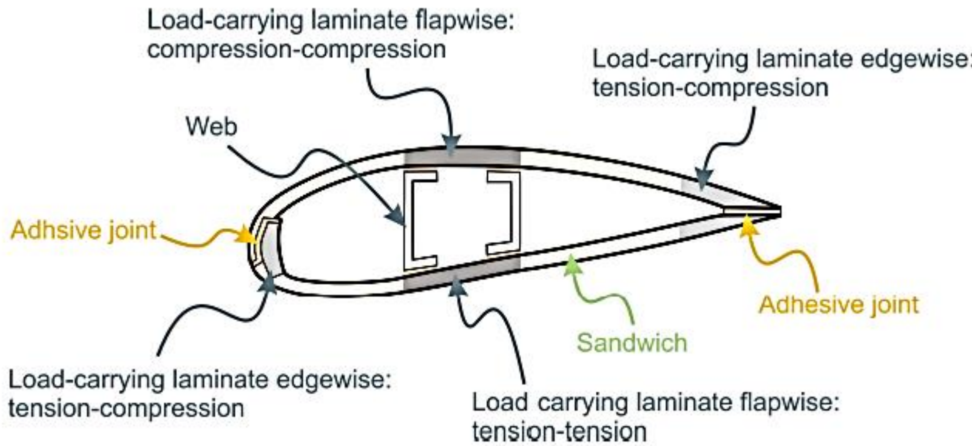



Figure 6. Typical conformation of a cross section of the blade. Source: [15].

Figure 7. At Gamesa's wind blade manufacturing plant in Navarra, Spain. Image from Gamesa. Source: [32].

Figure 8. MAG quick material placement system automatically sprays mold liners, cuts, and places fiberglass and carbon materials. Image from MAG IAS. Source [32].

Figure 9. Segmentation of turbine blades to be transported and then installed onsite. Source [35].

With the use of new technologies, which include computer-aided design (CAD, CAE, and CAM software), many optimal technological developments around wind turbines constantly appeared [36].

3D printing technologies are also revolutionizing small-scale wind turbines, such as the case study by Duan & Xinyan, which takes as its research object the simulation model of the wind turbine using solid works design software, and the construction of its different components using a 3D printer. The filament used to make the turbine was P430ABS. The disadvantages of building this wind turbine made all in 3D, are that the printing size is limited, and the precision of the printer is not very high, so several pieces had to be repeated to make it according to the design. In addition, the time of manufacturing is a factor that must be taken into account when deciding whether to produce the entire wind turbine in 3D or if it is only its blades [37], [38].

Another example of the blade's construction for small-scale turbines or laboratory prototypes was the research project led by Matthew J. et al. [39], who developed a prototype of an offshore wind turbine. Scale model tests provided important information on the response of the floating system with less risk, time, and fewer resources than a field scale test [40]. The design uses a scale of 1:50 and uses as a reference the type of blade LMH64-H utilized in NREL 5MW power generation turbines. The manufacturing material was PETG, see Figure 10. Finally, it is worth mentioning that the prototype design in the tests met the expected design power coefficient (PC) of 0.49 [41].

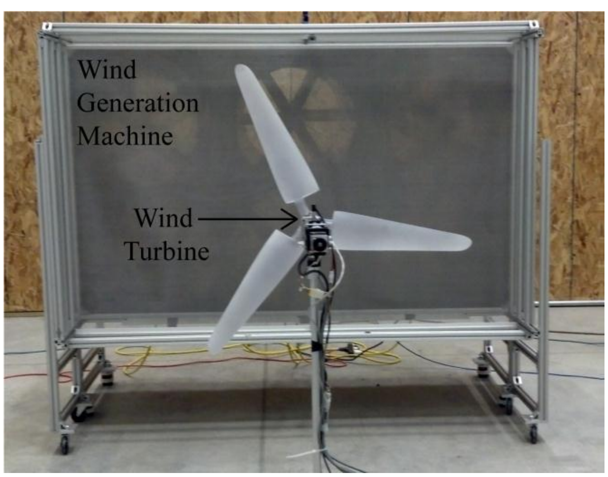



Figure 10. Floating turbine at 1:50 scale 50MW. Source: [41].

## 5. Life cycle assessments for wind turbines

Wind energy has a good environmental performance compared to other energies, its emissions are between (8-20 gCO2eq/kWh) and while nuclear energy (8-45 gCO2eq/kWh), hydroelectric energy (3-7 gCO2eq/kWh), and finally concentrated solar power (14-32 gCO2eq/kWh), reported the Intergovernmental Panel on Climate Change (IPCC) [42].

Wind turbines' traditional materials have been fabrics, metals, and wood, but as demand progressed, larger dimensions were required (today we see turbines with powers of up to 15 MW and rotors of up to 170 meters [43]) which led to the use of fiberglass with resins, which feasible more aerodynamic and thus efficient turbines [44]. The production of large wind turbines will generate a larger amount of waste in the upcoming years, for instance, turbines installed in 2010 have an average useful life of 20 to 30 years, a waste difficult to recycle due to the particular utilized composite materials [45].

According to Lefeuvre et al. [46], a future projection for 2050 in wind energy waste is estimated that there will be around 483,000 tons of carbon fiber reinforced polymer or CFRP in English, with Europe having 190,000 tons, Asia with 149,000 tons, and North America with 95,000 tons. Therefore, scientists, companies in the sector, and leading countries are very concerned about this situation, which has led to a search for different solutions to improve this potential large amount of waste via recycling techniques of both already installed turbines that will be dismantled soon, and those manufactured in future years.

Traditionally, the waste from the automotive and aeronautical sectors is disposed of in landfills or incinerated, causing significant environmental damage, which has led to other alternatives in many countries [47]. Figure 11 shows a diagram of the types of recycling that can be carried out today.

In mechanical recycling there are two methods, the first one is the grinding of the part components to produce fibrous materials and mix them with compounds or binders such as concrete, cement, or polymeric resins [49], [50]. The second one consists of powdering the parts typically to produce particle-reinforced composites. Yazdanbakhsh [51], took the recycled waste powder from the blade of a wind turbine and then mixed it with PLA, a biodegradable polymer. This was compared with pure PLA filament showing that the addition of 5wt% of recycled fibers led to a 16% and 10% increase in Young's modulus and tensile strength respectively.

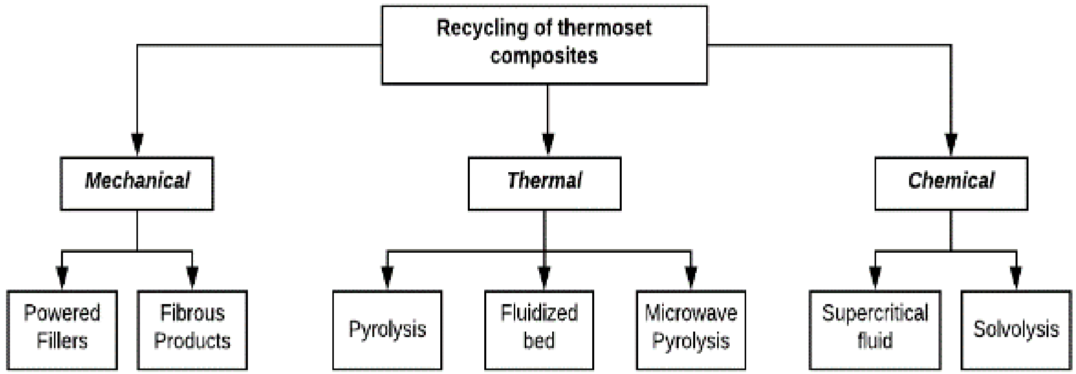



Figure 11. Previously investigated recycling methods for thermoset composites. Source: [48].

The mechanical recycling process is simple to operate, however, the recovered fiber is short because the fiber is significantly damaged during this process [48]. On the other hand, the thermal recycling technology is developed by a pyrolysis method, this method allows fibers to be recovered through the combustion of inert gas. These small fibers obtained can become competitive since their properties do not vary much concerning virgin fibers [52]. Lewandowski et al. obtained PVC compound with recycled glass fiber from the pyrolysis process [53], [54]. The increase in the fibers content used in PVC produced a clear increase in the modulus of elasticity of the compounds, while reducing both tensile strength and impact.

Finally, chemical recycling compared to mechanical recycling for thermosetting materials can be cumbersome and costly [55], [56].

Figure 12 represents the life cycle that the use of wind energy must have and its final provisions. It is clear that there are many ways to deal with the recycling and reuse of waste produced by the blades of wind turbines, and with collaborative work between countries, producers and consumers can manage to enhance the profit of the process. This could generate innovative solutions to the environmental problem, which include the use of recyclable and the prohibition of single-use materials, therefore constituting a green solution [57], [58].

## 6. Policies on Renewable Energy

To achieve the transformation of fossil energies to renewable energies, we must decarbonize our financial systems, this would be the basis for achieving this objective. This step will help mitigate climate change, which concerns much of the planet. Even though that there are climate change deniers there will always be a light of hope through science that shows that Climate change is mainly anthropic, given the need to reduce climate change, the recognition process for renewable energies should be speeded up [59], [60].

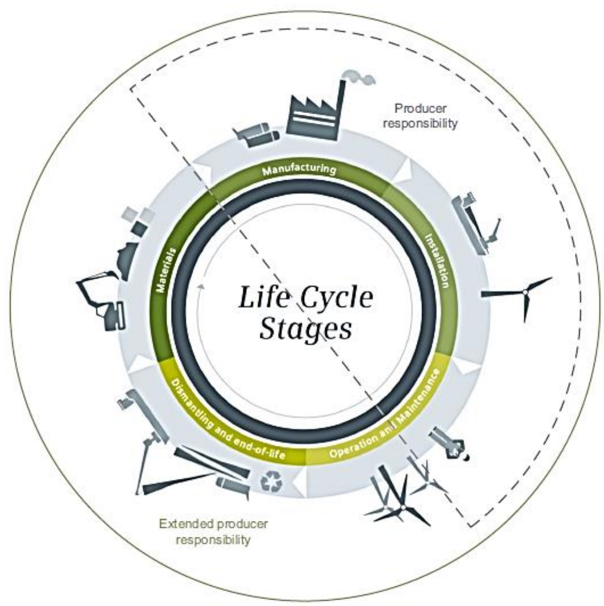



Figure 12. Expanded producer responsibility in the wind industry. Source [57].

At the 70th General Assembly of the United Nations held in September 2015, and after the signing of 193 heads of state and world governments, the document named the Sustainable Development Goals (SDG) by 2030 became a referent for sustainability worldwide (which is made up of 17 objectives, materialized in 169 goals, measured through 230 indicators) [61]. Countries should choose public-private cooperation (PPP) as the first option to obtain sufficient investments in order to guarantee energy production and availability [62]. According to the United

Nations in its 2020 report, they show that for the period between 2010-2018, an increase in access to the energy of 80% to 90% respectively was obtained for the world population. To meet the goal of access to energy for the entire world population, it must be increased by 0.82 percentage points and taken up to 0.87 for the period of time 2019-2030, however the UN states that if we continue at the current rate, 620 million people would continue without access to the energy grid by the year 2030 [63]. Figure 13 shows the proportion of the population with access to electricity in 2018.

The flow of money from governments with the greater financial capacity to developing countries in favor of the development of clean and renewable energies exceeded $21.4 billion in 2017, this is equivalent to an increase of 13% more compared to the year 2016 and double compared to 2010. Investments in hydroelectric projects represented 46% of flows in 2017, followed by investments in solar (19%), wind (7%), and geothermal (6%). However, only 12% of these financial flows reached the least developed countries, which are the furthest behind in achieving target 7 [63]. See Figure 14. Following the SDGs, for China the laws that affect renewable energy are the policies that advise on the development of renewable energy and the perspective of the Chinese government on the environmental situation worldwide, then there are the laws that specify what they are the approaches both at the rural level and the different technologies to be used [64].

Finally, the laws consist of incentives and management guidelines, providing important support to develop these projects in the initial stages. In the year 2020, more than 722 million pesos were invested in solar, wind, and biomass energy projects [65], [66], [67]. The Chinese government managed to reach the power output of 5 GW connected to the offshore wind grid by 2020. Currently, China has an installed capacity of offshore wind power of around 6.8 GW, positioning it as the third country with the most power generation. wind in the world. China has coastlines with an area of around 18,000 km and has a generation potential of more than 1,000 GW of offshore wind power at a height of 90 meters [68], [69], [70].

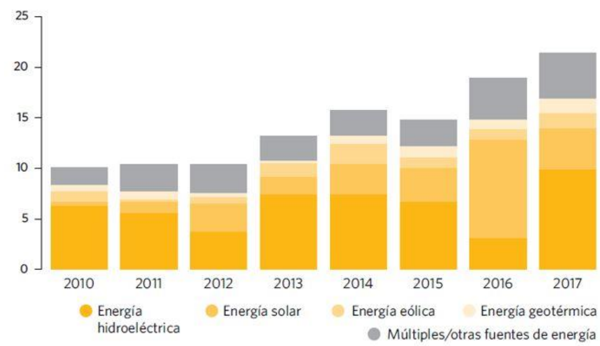



Figure 14. International financial flows to developing countries in support of renewable and clean energy, by type of technology (2010-2017) in billions of dollars at prices and exchange rates 2017 UN. Source [63].

The United States in compliance with the state program on climate and energy prepares the Action Guide on energy and the environment given by the Environmental Protection Agency (EPA) [71].

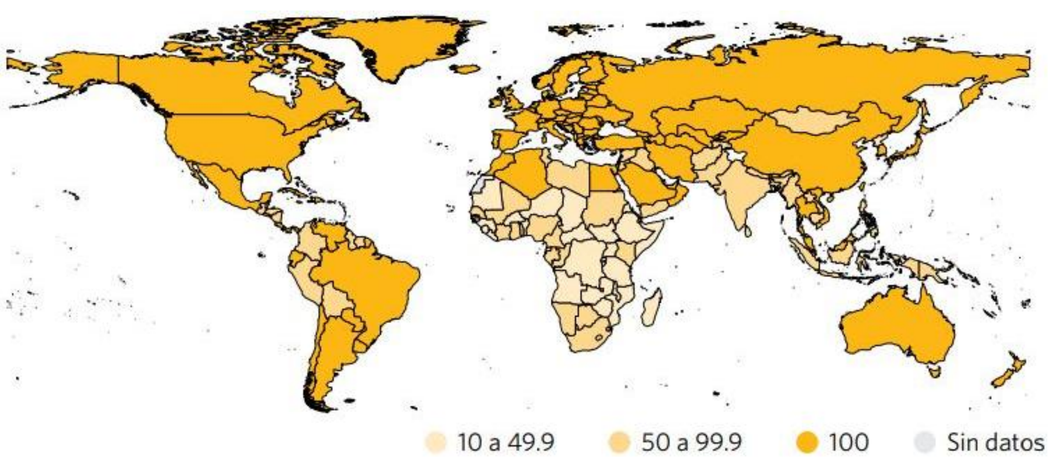



Figure 13. The proportion of the world population with access to electricity for the year 2018 (Percentage). Source: UN [63].

The best practices are documented to design, implement these policies, and demonstrate how policies have helped states save money, reduce air pollution, improve economic development, and maintain power reliability and resilience. Within the guide in chapter 3, the financing policies and tax incentives that the different states could apply are discussed. Financial incentive programs apply to direct cash, performance-based, tax incentives, loans, and financing programs such as revolving loans, clean energy financing with property appraisal (PACE), energy performance (EPC), energy efficiency mortgages, and credit enhancement (EEM), and green banks.

Individual states have defined programs, including tax incentives and research grants to attract investment. One study suggests that 600 to 1200 miles of the network should be built on projects in New England and York State. The United States Senate approved a tax extension agreement, which extended the Production Tax Credit (PTC) for one year [72]. The PTC of 1.5 cents / kWh (60% of the original PTC value) is available for electricity generation projects from renewable sources that will begin construction in 2020 and be put into operation by 2024.

The European Union has good resources to produce renewable energy, and a large part of the members of the union are currently world leaders in the development of renewable energy. For the year 2020, Europe established an energy consumption quota for 2020 corresponding to 20% in renewable energies and 32% for the year 2030 [73]. Greenhouse gas emissions for the European Union were 23% lower compared to those generated for the year 1990. Finally, cleaner electricity was the main driver of this reduction [74].

For the Swedes, their energy policies establish that 50% of the energy produced will be from renewable sources by 2030 and 100% production by 2040. They also have a goal of zero greenhouse gas emissions by 2045. Sweden currently has more than 3681 turbines, an installed capacity of more than 7506 MW, and an annual production of 19.8 TWh [75]. The Government of Denmark has a goal of installing 5,500 MW of wind power by 2030. Additionally, the government ordered the public services sector to buy wind power at a preferential price, guaranteeing a fixed price of 70 to 85% of the price. local electricity retailer, which was economically more viable compared to conventional power [76], [77]. For the Spanish, the government approved a bill that is interested in obtaining zero emissions by the year 2050, in addition the bill would prohibit all new coal, oil, and gas extraction projects, it would end fuel subsidies fossil fuels, and chart a path to generate 100% renewable energy. Greenhouse gas emissions are expected to decrease by 23% compared to 1990 levels by the end of this decade [78].

The climate and renewable energy policy in Germany proposes a goal of 80% electricity generation by 2050, this would come hand in hand with the reorganization of fossil fuel power plants allowing a faster expansion of renewable energies and their integration into the energy system [79]. Latin America and the Caribbean have one of the most variable renewable energy markets in the world, since a quarter of primary energy comes from renewable energies, some countries such as Brazil, Chile, and Mexico are implementing projects with solar, wind, and biomass while Costa Rica, Uruguay, and Paraguay generated practically all electricity through renewable energies [80].

Colombia, through Law 1715 of 2014, regulated the integration of non-conventional renewable energies into the National Energy System [81]. The main objective is to promote the development and use of non-conventional energy sources, this must be done through their integration into the electricity market, in addition to the integration to non-interconnected areas, the reduction of greenhouse gas emissions is also proposed. Renewable energy could generate security of energy supply. The droughts triggered by the El Niño phenomenon in 2015-2016 raised awareness that Colombia is highly vulnerable to the effects of climate change and therefore the Colombian electricity market auctioned 1,174 MW of wind power granted over 15 years according to the purchasing power of the agreements (PPAs) [82].

## 7. Conclusions

The use of thermosetting materials in wind turbine blades is a reality that must be changed due to the environmental problems these materials are causing and due to the uncertainty, they generate in society at the end of their useful life. Currently, there are three types of recycling for these materials: mechanical, thermal, and chemical processes. Each of these processes can give a longer life cycle to these materials, therefore, increasing their circularity, and thus contributing to a circular economy. However, the cost-benefit may not be so favorable concerning environmental and economic matters, a reason why new materials for blades should be developed according to circular economy principles. This will contribute to reducing worldwide pollution and avoid costly processes that make wind power look less viable for other energy sources. Some countries through their policies aligned with the sustainable development goals have promoted investments in the use of renewable energies, through public-private partnerships to guarantee the supply of electricity to all sectors of society.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reports in this manuscript.

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