Hybrid Wind and Solar Photovoltaic Generation with Energy Storage Systems: A Systematic Literature Review and Contributions to Technical and Economic Regulations

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Abstract: The operation of electrical systems is becoming more difficult due to the intermittent and seasonal characteristics of wind and solar energy. Such operational challenges can be minimized by the incorporation of energy storage systems, which play an important role in improving the stability and reliability of the grid. The economic viability of hybrid power plants with energy storage systems can be improved if regulations enable the remuneration of the various ancillary services that they can provide. Thus, the aim of this study is to provide a literature review regarding the economic feasibility of hybrid wind and solar photovoltaic generation with energy storage systems and its legal and regulatory aspects. Observing the global tendency, new studies should address the technical and economic feasibility of hybrid wind and solar photovoltaic generation in conjunction with, at least, one kind of energy storage system. In addition, it is very important to take into account the regulatory barriers and propose solutions to remove them. It was observed that although regulatory aspects can influence the economic feasibility of hybrid projects, little is known about this relationship among regulatory frameworks. The findings presented in this article are important not only for Brazil, but also for other countries that do not have regulations in force to support the use of energy storage systems in hybrid systems.

Keywords: economic viability; legal aspects; intermittent energy; distributed generation; renewable energies

1. Introduction

Climate change is one of the biggest global challenges nowadays. The production of electricity from renewable energy sources (RESs) with low CO₂ emissions has become a crucial issue because the burning of fossil fuels is associated with greenhouse gas emissions [1]. Gallagher et al. [2] state that renewable energies represent one of the ways to reduce greenhouse gas emissions and make the necessary energy matrix changes. Thus, the use of renewable energies, such as wind and solar PV energy, has grown exponentially worldwide.
However, the operation of an electrical system is challenging due to the intermittent and seasonal characteristics of wind and solar energy [3–5]. These characteristics lead to the need for storage to regulate both the intermittency and seasonality of electricity generation [6].

Energy storage technologies can be applied to energy systems to perform such functions as providing operational support to the grid, load shifting, peak shaving, stabilizing the grid by frequency and voltage control, increasing reliability, and, in general, resolving issues related to power quality improvement [7,8]. In this way, energy storage systems (ESSs) can play an important role in the reliability and stability of the grid [7,9]. ESSs can generate revenue by providing ancillary services in addition to contributing to a greater insertion of RESs into the energy matrix. On a small scale, such as distributed generation (DG), ESSs can be used to add flexibility to operational strategies and achieve the objectives set by demand-side management. In both situations, one of the critical aspects is the cost of investment in ESSs [10]. Due to the complexity of these systems, technical and economic feasibility studies are essential.

Brazil has an extensive river network and adequate reliefs for the construction of hydroelectric power plants. This makes Brazil the largest hydroelectric reservoir in the world in proportion to demand [11]. However, socioenvironmental barriers have emerged in recent years that hinder the construction of new reservoirs. The trend is that the current reservoirs will soon be insufficient.

Brazil’s production of electricity from onshore wind farms grew from 27 MW in 2005 [12] to 18,150 MW in 2020 according to ANEEL [13]. In 2020, Brazil had 3200 MW of utility-scale solar photovoltaic energy, which began to be implemented in the country in 2017. The DG, most of which is made up of small-scale solar photovoltaic systems, started in 2012 and reached 5700 MW in 2020 [13]. As in the rest of the world, this insertion of intermittent RESs into the energy matrix requires a greater energy storage capacity. However, the lack of incentives and adequate regulations for inserting energy storage technologies into the energy matrix adds to the technical barriers and is considered to be an impediment to this market.

In some countries that have more advanced markets, discussions on the legal and regulatory framework have developed in order to increase the economic viability of energy storage technologies. In this sense, it is important for countries that do not currently have a proper regulatory framework, such as Brazil, to know the other countries’ legislation and what has been presented in the literature. Based on other experiences, these countries can develop their own legislation to facilitate the insertion of ESSs into hybrid systems.

The economic viability of hybrid plants with energy storage systems can be improved if technical regulations allow for the insertion of ESSs in order to increase the amount of assured energy that plants generate by reducing the natural intermittence and if economic regulation enables the remuneration of the various ancillary services that storage systems can provide.

Thus, the aim of this study is to provide a literature review regarding the economic feasibility of hybrid wind and solar PV generation with ESSs and its legal and regulatory aspects. It addresses the following research questions (RQs):

RQ1: What are the main characteristics of the literature regarding the economic analysis of wind and solar PV generation with ESSs?

RQ2: What are the studies’ remarks and the research frameworks used to explore regulatory and economic aspects?

RQ3: What are the main legal and regulatory aspects around the world of hybrid wind and solar PV energy generation systems with ESSs, and how they can contribute to the recent discussion on regulation in Brazil?

For that, a systematic literature review (SLR) was carried out. According to Kitchenham [14], the SLR is a tool that helps us identify, evaluate, and understand all available papers in a specific area of study or field of research. These studies are called primary studies, while the SLR is referred to as a secondary study. Morioka et al. [15] state that
the SLR allows us to focus on a global question or a collection of the empirical findings in a specific research field. Its result is the formulation of a general concept and not just a summary.

This article is structured into four sections. In Section 2, we present the used methodology along with the descriptors. Each step of the methodology and the descriptors are carefully explained. The results and a discussion are presented in Section 3, which is divided into two subsections. Section 3.1 is dedicated to presenting and discussing the results of the SLR, and we explain, step-by-step, how each result was obtained and the interactions among the results. In Section 3.2, we present the results of a review of the legislation and regulations of five countries and the European Union. Finally, conclusions and corresponding recommendations are provided in Section 4.

2. Methodology

A systematic literature review was the methodology chosen in this study, as it can be used to appraise, summarize, and communicate the results and implications of otherwise unmanageable quantities of research [10]. Unlike traditional systematic reviews, this type of review allows for transparency, replicability, and a reduction in authors’ bias [16]. To answer the research questions, this methodology was applied in three main stages: (i) definition of the sample; (ii) descriptive and network analysis; and (iii) content analysis.

(i) Definition of the sample The search for publications was performed in the ISI Web of Science (IWS) and Scopus (SC) databases, which are the most important bibliographic data sources for the physical sciences, as concluded by Visser et al. [17]. The research purpose was to study the technologies of wind, solar PV, and energy storage, together in hybrid systems, related to the knowledge fields of technical and economic viability and regulatory aspects. It was assumed that if a project is economically viable then it is also technically feasible. The bibliographic search in the databases was performed in June 2021. We used the following descriptors:

(i) (wind AND (solar OR photovoltaic) AND storage) AND (economic* OR financial*) AND (feasibility OR feasible OR viability OR viable); and
(ii) (wind AND (solar OR photovoltaic) AND storage) AND (law* OR legal OR legislation* OR rule* OR regulation*).

The descriptors were required to be present in the title, abstract, or keywords. Only publications with the following characteristics were included: (i) type of document: “article” or “review”; (ii) language: English; and (iii) publication year: no time frame restriction. We only considered publications whose full text in English was available. The studies were screened using elimination criteria by reading the title and the abstract of selected articles. Articles were excluded if the technology (wind, solar PV, or energy storage) was not a central subject of the study or if the economic or regulatory aspects were not addressed. A flowchart of the sample definition process is included in the results section.

(ii) Descriptive and network analysis The sample was initially analyzed descriptively using MS Excel. The global map of publication quartiles was constructed using the Geographic Information System QGIS 3.16.1 Hannover version software. The quartile distribution was calculated by Equation (1).

\[
Q_k \leq \frac{k \sum p}{4}
\]

where \(Q_k\) is the \(k\)th quartile; \(k\) is the quartile order from 1 to 4, and \(\sum p\) is the number of publications of the country with the greatest number of articles. The sample’s metadata were analyzed to identify the most frequent journals and the articles most cited in the sample. Then, the VOSviewer software [18] was used to provide the co-citation of the journal and the keyword network. Each type of information was analyzed in detail in order to provide an initial overview of the article’s sample. In
particular, the keyword network was relevant to identifying thematic groups, favoring the follow-up of the research phase related to the categorization, and qualitative analysis of the articles.

(iii) Content analysis The following types of information were used to compile the papers: authors; title; publication period; year of publication; country of main author; number of citations; and abstract. According to White and Marsh [19], content analysis is flexible and can be used as a systematic approach to assessing generated data on research in qualitative and quantitative ways.

This stage was dedicated to the interpretation of scientific findings. It is the study’s main step, as the results obtained during this stage are the core of the main study. Here, an overview of the articles was obtained, based on quantitative and qualitative analyses, by observing studies carried out focused on the three technologies together in hybrid systems as well the regulatory frameworks around the world.

To complete the legal and regulatory research, with the help of CEDOC/ANEEL (the center of documentation of the Brazilian electricity regulatory agency), we found all legislation on and regulation of renewable energies in five regions or countries for the purpose of a comparison with the Brazilian legal framework. The regions or countries considered were the United States, the United Kingdom, Spain as a representative of the European Union, India, and Australia. These regions or countries were chosen due to the geographic or/and electrical system similarity to Brazil. Russia and China are also very similar to Brazil; however, unfortunately, a full translation of the legislation was not found, which we consider to be a limitation of the research.

3. Results and Discussion

A systematic review of the literature was performed, based on the presented analyses, that integrates the economic and regulatory studies related to the three technologies (wind, solar photovoltaic, and energy storage technologies). In addition, a review of the legislation and regulation for renewable energies and energy storage systems was carried out.

3.1. Systematic Literature Review

Figure 1 shows the flowchart of the sample’s definition.
In the identification stage, publications were identified using the Web of Science (WoS) and Scopus (SC) databases for each descriptor. Duplicate articles were eliminated before the screening phase. According to the information in the methodology section, the articles were screened using some elimination criteria. At the end, the final sample for each descriptor was assembled. One article was deleted because it had been duplicated. The final sample was composed of 95 articles (for more information, see Supplementary Materials Annex S1) and, after reading these articles in full, we determined that 77 were connected to economic feasibility, 13 were connected to regulatory aspects, and 5 were connected to both aspects. The words ‘rule’ and ‘regulation’ have multiple meanings, such as technical rules and frequency or voltage regulation. This is the reason why few documents matched the regulatory aspects filters.

The data analysis began by responding to RQ1 (What are the main characteristics of the literature regarding the economic analysis of wind and solar PV generation with ESSs?) to provide an initial and general understanding of the literature. Thus, scientific studies on the economic and regulatory aspects related to the three technologies together in hybrid systems was found in 29 distinct countries, as presented in Figure 2.

China is the main country studied in this scientific field, followed by India, Iran, and Spain. A total of 42% of the studies are from these four countries. The next nine countries, with three or more publications, constitute 35% of the sample, and the other 16 countries with at least one publication in conjunction constitute less than 25% of the total sample. The three papers in our sample that were produced in Brazil addressed their research to other countries (Chile, Iran, and Nicaragua, respectively). So, a gap in the scientific literature is present with respect to Brazil.

Figure 3 shows the evolution of the number of annual publications related to wind, solar PV, and ESS technologies in the economic and regulatory studies present in the final sample. The oldest paper in the sample was published in 1994. The second oldest article was published 11 years later. After this publication, another decade passed during which few studies were published. An increase in the number of publications starts from 2016, indicating a growing interest in hybrid wind and solar PV generation with ESSs.
The main journals present in the final sample that have at least three articles are listed in Table 1.

Table 1. Main journals of the sample.

| Journals                                      | Number of Articles |
|-----------------------------------------------|--------------------|
| Renewable & Sustainable Energy Reviews        | 11                 |
| Renewable Energy                             | 7                  |
| Applied Energy                                | 5                  |
| Energy Conversion And Management              | 5                  |
| Energy                                        | 4                  |
| International Journal of Hydrogen Energy      | 4                  |
| International Journal of Energy Research      | 3                  |
| International Journal of Renewable Energy Research | 3              |
| Sustainable Energy Technologies and Assessments | 3              |

This analysis allows us to affirm the predominance of publications in journals focused directly on the energy area. The most significant journal in the sample was *Renewable & Sustainable Energy Reviews*, with 11 articles, followed by *Renewable Energy* with 7 publications and *Applied Energy* and *Energy Conversion and Management* with 5 articles each. The nine journals shown in Table 1 represent around 48% of the articles in the sample. The remaining 52% of the articles in the sample are divided among 40 journals. This subject is of widespread interest to many journals in the energy field but is also of interest in other related fields of knowledge.

Figure 4 shows a map of the co-occurrence of author keywords used by at least three documents in the sample. The keyword colors indicate the average year of publications that used a specific keyword. The keywords in dark blue are associated with the beginning of their use in older articles, and the keywords in yellow are associated with newer articles. The size of each node represents the number of times that each term was used as a keyword in the articles. This figure also reveals the importance of terms that were not used as search strings, such as “renewable energy”, “optimization”, “homer software”, and “cost of energy”, when compared with terms considered in the search, such as “wind” and “photovoltaic”. It is worth mentioning terms that have been used more recently, such as “optimal sizing” and “loss of power supply probability”. The recent use of the search string “energy storage system” stands out. Finally, considering that this article is dedicated to studies that deal with economic and financial aspects, there is a lower occurrence than expected of the term “techno-economic analysis” and terms such as “net present cost”.
To complement the information about the sample, Figure 5 shows the distribution of the most cited articles over time. For its elaboration, the 15 most-cited articles in the sample were selected (further details are presented in Table 2 below).

Table 2. The most-cited articles with more than 15 citations (SF, Search Field; R, Regulatory; E, Economic).

| Reference               | SF | Remarks                                                                 | Citations |
|-------------------------|----|-------------------------------------------------------------------------|-----------|
| Wolsink [20]            | R  | A review of the gap in social participation in RES implementation. A worldwide viewpoint study. | 277       |
| Ngan and Tan [21]       | E  | Feasibility of wind, PV, diesel, and storage using HOMER to calculate the NPC and LCOE in Malaysia. | 168       |
| Türkay and Telli [22]   | E  | A stand-alone pilot project for a hybrid wind, PV, and hydrogen ESS is analyzed using HOMER software in Istanbul, Turkey. | 128       |
| Shadmand and Balog [23] | E  | Feasibility of wind, PV, and batteries using MOGA to calculate the COE and availability in Texas, United States. | 127       |
| Ramli et al. [24]       | E  | Wind, PV, diesel, and batteries using MOSaDE to evaluate the LPSP, COE, and RF in Saudi Arabia. | 123       |
| Hosseinalizadeh et al. [25] | E  | Feasibility of wind, PV, and batteries or a fuel cell in Iran. Cost analyses. | 118       |
| Baneshi and Hadianfard [26] | R E | This study uses HOMER to analyze the feasibility of the three technologies together in Iran with government incentives. | 100       |
| Al-Sharafi et al. [27]  | E  | Hydrogen production in Saudi Arabia by a hybrid wind, PV, and storage system. COE analyses. | 98        |
| Mandal et al. [28]      | E  | This study uses HOMER to calculate the NPC and COE of the three technologies in Bangladesh. | 95        |
| Reference                  | SF  | Remarks                                                                 | Citations |
|----------------------------|-----|-------------------------------------------------------------------------|-----------|
| Liu et al. [29]            | E   | Power source sizing with integrated consideration of the characteristics of distributed generation, energy storage, and loads. | 88        |
| Maleki et al. [30]         | E   | Assessment of a hybrid PV, wind, and hydrogen storage system for the production of fresh water in Iran. | 81        |
| Sanajaoba and Fernandez [31] | E   | Explores the new software Cuckoo Search to optimize wind, PV, and storage in India. | 78        |
| Chang et al. [32]          | R   | Evaluates the policies and laws encouraging the use of renewable energy systems in China. | 76        |
| Shakya et al. [33]         | E   | An Australian study for the three technologies by LCOE and cashflow.    | 74        |
| Cabrera et al. [34]        | R   | A comparison among grid codes from Germany, the United States, Puerto Rico, Romania, China, and South Africa. | 68        |
| Fazelpour et al. [35]      | E   | HOMER is used to assesses a hybrid system in Iran.                      | 66        |
| Lian et al. [36]           | E   | A review study of optimization techniques for various hybrid energy systems worldwide. | 66        |
| Nadjemi et al. [37]        | E   | A literature review of optimization techniques for techno-economic analyses of hybrid wind, PV, and storage systems in Algeria. | 62        |
| Duman et al. [38]          | E   | The authors use HOMER to calculate the COE for a hybrid wind, PV, and battery or hydrogen storage system in Turkey. | 60        |
| Khan et al. [39]           | E   | A review on the feasibility of hybrid wind, PV, and storage systems.    | 59        |
| Khozravi et al. [40]       | E   | An energetic analysis was done on a hybrid wind, PV, and hydrogen storage system in Iran. | 54        |
| Zhou et al. [41]           | R   | The authors proposed a regulation system for typical energy communities with RES production in California, United States. | 50        |
| Elkadeem et al. [42]       | E   | Feasibility of a hybrid wind, PV, diesel, and storage system in isolated systems in Sudan. | 47        |
| Olatomiwa et al. [43]      | E   | The authors use HOMER for an economic assessment of a hybrid wind, PV, diesel, and storage system in Nigeria. | 44        |
| Maatallah et al. [44]      | E   | A Tunisian study using HOMER to calculate the NPV and LCOE of a hybrid wind, PV, diesel, and battery system. | 44        |
| Eypasch et al. [45]        | E   | Feasibility of a hybrid wind, PV, and hydrogen storage system in Germany. | 43        |
| Krishan and Suhag [46]     | E   | This study uses HOMER and MATLAB to calculate the NPC and COE for a hybrid wind, PV, and battery system in India. | 39        |
| Askari and Ameri [47]      | E   | Feasibility of a hybrid wind, PV, and battery system in Iran using HOMER to calculate the NPC. | 39        |
| Ali and Shahnia [48]       | E   | In Australia, feasibility was studied by HOMER to calculate the NPC and COE of a hybrid wind, PV, and battery system. | 33        |
| Kazem et al. [49]          | E   | The authors use HOMER to analyze a hybrid wind, PV, diesel, and battery system on Masirah Island, Oman. | 30        |
| Abdin and Merida [50]      | E   | Five locations in the United States, Canada, and Australia are studied using HOMER to calculate the COE for a hybrid wind, PV, and battery or hydrogen storage system. | 27        |
| Rad et al. [51]            | E   | A techno-economic feasibility study of a hybrid wind, PV, and ES system in a rural area of Iran. | 26        |
| Al Katsaparakakis [52]     | R   | A proposal for a better regulation of the licensing and dimensioning of and the land occupation by REIs on Greek islands. | 24        |
Table 2. Cont.

| Reference                          | SF | Remarks                                                                                           | Citations |
|------------------------------------|----|---------------------------------------------------------------------------------------------------|-----------|
| Telaretti and Dusonchet [53]       | R  | A review of States’ storage regulations in the United States.                                     | 23        |
| Al-Shetwi and Sujod [54]           | R  | A review of global grid codes focused on PV connections.                                          | 22        |
| Nyeche and Diemuodeke [55]         | E  | Feasibility of a hybrid wind, PV, and pumped storage system in Nigeria. HOMER, MATLAB, and Excel were used to calculate the LCOE. | 21        |
| Liu et al. [56]                    | R  | The LCOE was calculated for a typical case in Hong Kong in order to analyze the feasibility of the three technologies together, considering the cost and regulatory incentives. | 20        |
| Lacko et al. [57]                  | E  | The feasibility of a hybrid wind, PV, and hydrogen storage system was determined using the NPC in Slovenia. | 18        |
| Fathima and Palanisamy [58]        | E  | A study on the feasibility of a hybrid wind and PV system focused on battery storage investments in India. | 17        |
| Nguyen et al. [59]                 | E  | An optimization study for hybrid wind, PV, hydrogen, and battery systems for industrial purposes in Vietnam. | 16        |
| Combe et al. [60]                  | E  | An economic analysis for the replacement of diesel energy generation by RESs with ESSs in South Australia. | 16        |
| Al-Ghussain et al. [61]            | E  | A general study of the techno-economic feasibility of wind, PV, and storage systems.              | 15        |
| Al Katsaparakakis and Christakis [62]| R | Feasibility of hybrid wind, PV, and battery or hydrogen or pumped storage systems on Greek islands. | 15        |
| Kiwan and Al-Gharibeh [63]         | E  | A techno-economic study to supply all of Jordan’s energy load from hybrid wind, PV, and storage systems. | 15        |

Notes: UAE, The United Arab Emirates; wind, wind power electricity generation; PV, solar photovoltaic electricity generation; storage, any kind of energy storage.

Figure 5. Evolution of article citations over the years.

Despite the influence these 15 publications exerted on the literature, some trends should be highlighted. Shakya et al. [33] and Chang et al. [32] dominated the number of citations until 2011. However, the authors suffered a reduction in their influence on current
publications, considering the reduction in the percentage of citations received over time. Wolsink [20] is the author with the highest absolute number of citations, and since 2011 has had a great influence on recent publications, followed by Ngan and Tan [21] and Turkay and Telli [22]. Finally, the recent emergence of references that received a large number of citations in the years 2019 and 2020 should be noted, as these references stand out even among the others, as is the case for Ramli et al. [24] and Mandal et al. [28].

To answer RQ2 (What are the studies’ remarks and the research frameworks used to explore regulatory and economic aspects?), Table 2 lists the most-cited articles in the sample with at least 15 citations. This table was built from a reading of the articles that were reclassified in relation to the search field. It was noted that some articles, although they did not have terms related to both economic and regulatory aspects in their title, abstract, or keywords, may have discussed both aspects in the body of the text.

The most cited article (277 citations) is a Dutch review study published in 2012 that addresses a social and regulatory question faced by renewable energies, smart grids, and energy storage [20]. The most cited article in the economic feasibility field (168 citations) is a Malaysian paper that was also published in 2012 [21]. This paper analyzed the potential implementation of a hybrid system composed of photovoltaic panels, a wind turbine, and diesel machines. This list of the most-cited articles is composed of eight articles related to the regulatory or legal field, 34 articles related to economic feasibility, and two articles addressed to both aspects.

There are six reviews and 38 articles among the most-cited articles in the sample. Six of these articles are global studies. The others 38 articles are focused on a specific region or country. The most studied country is Iran, with seven papers, followed by the United States and Australia with four articles each. Three documents are addressed to India, Greece, Saudi Arabia, and Nigeria had two articles each, and more than 14 countries with one paper each are in the sample. The regulatory studies vary from global purposes to local regulatory assessments and reviews of regulatory frameworks.

The tool most used to perform techno-economic analyses in the sample was the Hybrid Optimization of Multiple Energy Resources (HOMER) software, which was produced by the U.S. National Renewable Energy Laboratory (NREL) to optimize hybrid energy systems. HOMER was used 12 times, while the Multiple-Objective Genetic Algorithm (MOGA), the Multiple-Objective Self-Adaptive Differential Evolution (MOSaDE) algorithm, and the Cuckoo Search algorithm were used only once each. The other articles did not identify the software used for economic analyses.

The preferred economic tools were Cost of Energy (COE) and Net Present Value (NPV), but authors also used Levelized Cost of Energy (LCOE), Net Present Cost (NPC), Loss of Power Supply Probability (LPSp), Life Cycle Cost Analysis (LCCA), and Renewable Factor (RF), among others that were not cited. It is worth mentioning that, in the research presented in Table 2, COE refers to the costs related to generation, investments, operation and maintenance (O&M), battery charging, and other cost variables, while the LCOE is a ratio between these costs and the energy generated. Finally, NPC and LCCA are seen as equivalent in the literature [10].

As articles published in 2019 and 2020 have not had enough time to become well cited but nevertheless may already be relevant in this field of study, Table 3 shows the most-cited articles in the sample published in 2019 or 2020 with 10 to 15 citations.

These papers show the tendency of the academic sector to study hybrid systems composed of wind power, solar PV, and energy storage systems, especially battery banks. This selection contains more worldwide studies conducted in recent years. The most used techno-economic tool remains the HOMER software, but some articles explored other economic tools.
Table 3. Most-cited articles in the sample published in 2019 or 2020 with 10 to 15 citations.

| Reference                  | SF | Remarks                                                                                                                                                                                                 | Citations |
|----------------------------|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Gonzalez-Garrido et al. [64] | R E | An economic study on an optimal strategy to face the market rules in the Iberian market (Portugal and Spain).                                                                                           | 14        |
| Ayodele et al. [65]        | E  | Feasibility of small, islanded hybrid wind, PV, and battery systems in Nigeria.                                                                                                                       | 13        |
| Meza et al. [66]           | E  | Techno-economic analyses of hybrid wind, PV, and ES systems on Ometep Island, Nicaragua.                                                                                                                 | 13        |
| Hemeida et al. [67]        | E  | An analysis of hybrid wind, PV, and battery storage systems in Egypt                                                                                                                                     | 13        |
| Kumar et al. [68]          | R E | Feasibility of a hybrid system in India in terms of the SDG7 issued by the United Nations.                                                                                                                | 11        |
| Mazzeo et al. [69]         | R E | A worldwide assessment of hybrid wind and PV systems considering techno-economic feasibility, feed-in tariffs, and subsidies.                                                                          | 11        |
| Al Katsaparakis et al. [70] | E  | Analyses of a hybrid wind, PV, and pumped hydro storage system on the Faroe Islands, Denmark.                                                                                                         | 10        |

Note: SDG7—The seventh United Nations Sustainable Development Goal.

The most recent studies (among them, those shown in Table 3) seem to be dedicated to the development of techno-economic analyses that support the sizing of hybrid power systems (optimal sizing), words that stand out in Figure 4 as being more recently used in the literature. At the same time, the frequent use of “Batteries Energy Storage Systems” stands out. In addition, some studies remain dedicated to issues such as power quality and reliability.

Table 3 also shows that the number of studies that consider economic and regulatory aspects together is increasing. This is one of the main findings of this literature review: only in the last few years have regulatory and economic aspects been discussed together. To analyze the connection between economic and regulatory aspects, Figures 6 and 7 were constructed. Using the VOSviewer software, a map was created that shows the citation connections between the documents in the final sample. Figure 6 presents all the articles in the sample. It is worth remembering that the letter that precedes the authors’ names refers to the search field (e, economic; r, regulatory; and er, both). In this map, 40 articles are connected to each other (at the bottom and in the central part of the figure) and 55 articles remain isolated from the others. Figure 7 shows only the 40 connected articles. In the first figure (Figure 6), articles related exclusively to regulatory aspects remain almost entirely among the non-connected articles. In Figure 7, the connected articles are all related to economic viability, with only two (Liu et al. [56] and Baneshi and Hadianfard [26]) that incorporate both aspects. This allows us to affirm that, although regulatory aspects can influence the—and may allow for a greater—economic viability of hybrid energy generation and storage projects, little is currently known about this relationship. Not having enough academic publications that can help to direct public policies to encourage the development of more sustainable energy generation and storage systems is problematic.

Among the authors who studied the economic and regulatory perspective, Baneshi and Hadianfard [26] evaluated the technical and economic feasibility of hybrid PV/wind/diesel systems with and without battery storage for commercial and industrial purposes. For this, using the HOMER software, the authors evaluated the impact of Iranian government regulations on the economic viability of energy generation systems. The impact of subsidized credit lines, a carbon tax, and the price of energy for grid-connected or isolated systems was evaluated. In the Iranian scenario, low interest rates on loans increase the viability of projects but do not guarantee their viability. Additionally, taxing carbon emissions can be a motivator for investments in renewable energy projects. Liu et al. [56] explored the feasibility of hybrid renewable energy systems for residential buildings in Hong Kong. Tests of energy generation systems with or without the use of battery storage were carried out through optimizations combined with TRNSYS and jEPlus + EA. A modified LCOE
was used in which the benefits generated by local energy policies (among them, feed-in tariffs) were discounted from the costs. The authors indicate that hybrid PV–wind systems that use batteries provide greater autonomy, while systems without batteries have a lower LCOE.

Figure 6. Citation map with all publications in the final sample.

Figure 7. Citation map with the connected publications in Figure 6.
Wolsink [20], Cabrera et al. [34], and Telaretti and Dusonchet [53] present literature reviews covering regulatory aspects and public policy formulation. Wolsink [20] conducts a literature review in an attempt to address the social construction mechanism of the smart grid. Cabrera et al. [34] propose a comparison of grid requirements from different countries in order to understand the technical need to integrate large-scale PV power plants into the grid, considering the existence of wind-based energy generation systems and the consequent need for ESSs. In addition, more generally, Telaretti and Dusonchet [53] deal with the trends in the development of the stationary battery sector within the North American territory.

Still, with regard to studies on regulatory aspects, other authors who have conducted research include Chang et al. [32] and Zhou et al. [41]. In 2009, Chang et al. [32] predicted that China would have strong growth in power generation from PV and wind sources, due to large government incentives, and that in the energy storage market lead–acid batteries could be leaders. To deal with uncertainties in energy prices, ancillary services, and wind and PV power generation, Zhou et al. [41] propose a robust optimization model for day-after programming in an integrated community energy system consisting of renewable and non-renewable energy generation units and electrical and thermal energy storage, among other things.

Finally, we observed that most of the studies in the sample aimed to carry out purely techno-economic or financial analyses. This finding indicates a gap in the literature on economic and financial feasibility studies that are dedicated to assessing the impacts of the regulatory framework.

3.2. Review of Legislation and Regulation

As can be seen in the literature, few articles are dedicated to feasibility studies involving regulatory aspects of electricity generation by hybrid wind and solar PV systems with ESSs. Thus, to answer RQ3 (What are the main legal and regulatory aspects around the world of hybrid wind and solar PV energy generation systems with ESSs and how can they contribute to the recent regulatory discussion in Brazil?), we decided to identify the main legal and regulatory instruments in force in six regions or countries and compare them to the Brazilian legal framework. The aim of this search was to provide an overview of how these foreign regulations can contribute to the discussion in Brazil or in other countries that do not yet have regulations for hybrid wind and solar PV systems with ESSs.

The results of the legislation search for six regions or countries show that there are many differences in the laws around the world, as shown in Table 4 (for more information, see Supplementary Materials Annex S2). In general, electricity sectors around the world are divided into four segments: generation, transmission, distribution, and electricity trading. Generation and trading are competitive markets and almost deregulated, while transmission and distribution are natural monopolies that are strongly regulated. These segments were defined by Decree nº 41019 [71] in the year 1957 in Brazil; however, the real separation occurred after the unbundling in the late 1990s. Brazil and the United States have more rules than the other countries, but this does not mean that these other countries are less regulated. In the European Union, for example, all regulation of renewable energies is codified in a single document.

As the United States is a federated nation, many of their regulations are State-issued. The federal regulation is addressed to interconnection policies [72], including all interstate and wholesale electricity trades. States have jurisdiction over intrastate interconnections, but they have no authority over facilities that provide services across state borders or participate in the interstate electricity markets. The transmission or distribution utilities, to which the generator proposes to connect, determine the final rules and technical specifications for the interconnection and use of the distribution or transmission grid. Generators under 20 MW of installed power are usually classified as DG and connected to the distribution grid.
Table 4. Legislation for renewable energies.

| Country                  | Low | Decree | Rule | Other | Total |
|--------------------------|-----|--------|------|-------|-------|
| United States            | 4   | 0      | 13   | 0     | 17    |
| United Kingdom           | 3   | 0      | 10   | 0     | 13    |
| Spain/European Union     | 1   | 5      | 5 (1)| 4     | 15 (11) |
| India                    | 2   | 0      | 3    | 0     | 5     |
| Australia                | 5   | 0      | 1    | 0     | 6     |
| Brazil                   | 3   | 5      | 7    | 2     | 18    |

Source: Research on government websites, 2021.

The Public Utility Regulatory Policy Act (PURPA) [73], enacted in 1978, is the foundational policy that paved the way for small non-utility generators to enter the market, including renewable energy generators such as wind and solar PV energy generators. In 1990, the U.S. Congress issued the Energy Policy Act of 20 Solar, Wind, Waste, and Geothermal Power Production Incentives [74], whose objective was to encourage the production of electricity from solar PV, wind, waste, and geothermal sources. There are two more U.S. Acts that make some changes to these two laws [75,76].

U.S. federal regulation regarding renewable energies is composed of 13 FERC orders. Among them, the FERC Order of 2006 [77] established a fast-track process and reduced the timeframe for and cost of interconnection for small renewable energy generators. Several states used the FERC Order of 2006 as a model for their own regulations for connecting small distributed generating plants, since the federal regulation does not affect small local connections. Some states, such as California, Hawaii, and New Jersey, have not imposed a size limit for DG [78]. Energy storage devices were included in the Small Generator Interconnection Procedure and Small Generator Interconnection Agreement by FERC Order 792 [79]. There are many regional, state, and municipal regulations for small producers connected to the distribution grid in the United States.

From the beginning of the 2010s, the European Union proposed the Energy Roadmap 2050 [80] with the objective of reducing greenhouse gas emissions and increasing energy efficiency, which later resulted in the Clean Energy for all Europeans Package (also referred to as the Clean Energy Package (CEP)) [81]. According to Nouicer et al. [82], the CEP is a compilation of eight legislative acts related to renewable energies. The European Commission published the final text in the Official Journal of the European Union in June 2019 after an agreement between the European Commission, Council, and Parliament. The CEP consists of four Directives and four Regulations. It is worth noting that the E.U. legislation and its guidelines are constantly being improved [80] as provided for in initiatives such as the European Green Deal [83].

The E.U. directives must be regulated by Member States, while the regulations are directly applicable in all of the European Union [84]. So, among the five Spanish regulations found in this study, four are designed to implement the E.U. directives. Thus, the legislation of Spain/the European Union for renewable energies consists of 11 documents. All Spanish legislation for electrical energy, including renewable energies, is codified in a unique document called the Código de la Energía Eléctrica [85].

The main U.K. electricity law is the Electricity Act, which was promulgated in 1989 [86] and contains general rules for the sector. The first law related to RESs is the Sustainable Energy Act 2003 [87], which contains provisions on the development and promotion of a sustainable energy policy. Sustainability and RESs are better regulated in the Energy Act 2004 Part 2 [88]. Microgeneration and DG are defined in this law.

There are also 10 national rules related to renewable energies and DG. The Office of Gas and Electricity Markets (Ofgem) is a non-ministerial government department and an independent National Regulatory Authority responsible for the regulation of gas and electricity markets in the United Kingdom.
In India, through the Electricity Act 2003 [89], the Indian Parliament has consolidated all previous legislation regarding the generation, transmission, distribution, trading, and use of electricity and constituted the regulatory authority named the Central Electricity Regulatory Commission (CERC). The main authority for renewable energies is the Ministry of New and Renewable Energy (MNRE).

In the Electricity Rules 2020 [90], which were published by the Central Indian Government in December of 2020, the notion of a ‘prosumer’ is defined and its rights and duties are regulated. Prosumers are allowed to install their own renewable energy plants by themselves or through a service provider. Each State’s regulatory body specifies limits on this kind of DG. The CERC has issued three acts for the technical, economic, and tariff regulation of renewable energy systems.

In Australia, the production of electricity from renewable sources has been regulated since 2000 by the Renewable Energy (Electricity) Act [91]. The law was well defined in Statutory Rule nº 2 of 2001 [92]. Still, in the year 2000, due to the intermittency and seasonality of renewable sources, a new Act was promulgated to regulate the large-scale generation shortfall charge [93]. Only in 2010 was the same regulation issued for small-scale energy generation from renewable sources [94].

Regulatory bodies were created in 2011. The Australian Renewable Energy Agency (ARENA), created by Act nº 151 [95], is a funding agency responsible for improving the competitiveness of renewable energy technologies and increasing the supply of renewable energy in Australia. Meanwhile, by Act nº 163 [96], the Clean Energy Regulator (CER) was established as a regulatory body for renewable energies.

Finally, in the Brazilian scenario, the first law related to renewable energy was Law nº 10,438 [97], promulgated in 2002, which created the Incentive Program for Alternative Sources of Electric Energy (PROINFA). This program aims to incentivize the installation of at least 3000 GW of capacity from wind and biomass sources. Currently, there are two bills pending in the Brazilian National Congress. The bill of Law (PL) 5829/2019 [98] creates a subsidy by reducing the tariffs on the use of transmission and distribution systems for DG. PL 616/2020 [99], on the other hand, deals with the prosumer regulatory framework, creates the the supplier of last resort and the retail trader, releases the sale of energy by prosumers, and revokes the electric energy compensation system (EECS).

Brazilian regulation of renewable energy addresses formal documentation, techno-economic aspects, and economic subsidies. Five decrees and seven norms regulate renewable energy in Brazil. They consider generation sources separately, and no regulations for energy storage systems were in force in 2021. The Normative Resolution (REN) 482/2012 [100], modified by REN 687/2015 [101], is the main norm regulating distributed energy generation systems of up to 5 MW of installed capacity. It lays down general conditions for accessing distribution systems and created the EECS. REN 538/2013 [102] establishes the procedures and conditions for obtaining and maintaining the operational situation and defining the installed and net power for all electricity generation enterprises, including installations of DG. REN 876/2020 [103] defines energy generation plants with a reduced installed capacity (up to 5 MW of installed power) and the bureaucratic procedures for ANEEL.

Conama Resolution 259/2001 [104] establishes procedures for simplified environmental licensing of electrical projects with a low potential environmental impact. With Resolution 462/2014 [105], Conama have dispensed with the requirement of an environmental licence for micro-centrals with up to 100 kW of installed power.

The electricity produced from new renewable sources is undergoing rapid growth in Brazil, despite the few economic incentives and the low level of investment in research and development compared with countries such as the United States and the European Union. Regulatory discussions are advancing slowly in Brazil; currently, there are no regulations in force for hybrid wind and solar PV energy generation systems or energy storage systems. In more developed countries, such as the United States and the European Union,
there is more mature and consolidated legislation that is subject to successive target updates, such as the directives that compose the CEP in the European Union.

Currently, in Brazil there are no direct financing mechanisms for the energy transition, such as the Just Transition Mechanism [106] present in the European Union, which aims to minimize the socioeconomic impacts in the most affected regions, with budgets of around €70 billion for the period 2021–2027. Despite the lack of resources in Brazil, some credit lines are subsidized through State banks.

Furthermore, the R&D budget for the entire Brazilian electricity sector is around 100 million dollars per year based on data from the last 10 years [107]. This is very different compared with other nations. At the end of the 2000s, the United States approved the Smart Grid Demonstration Program, which allowed for an investment of 1.5 billion dollars in research and development (R&D) for smart grid and energy storage projects [53].

The correct payment for ancillary services remains an important issue that is not well addressed in the Brazilian regulatory framework. FERC Orders 755 and 890 allow for installations such as energy storage systems to be paid for the ancillary services they provide [108,109]. Many U.S. States, such as California, Hawaii, New Jersey, New York, and Texas, have also offered economic incentives for energy storage systems as a form of financial support and as feed-in-tariffs [53]. Utilities and RES generators are obliged to install ESSs to provide stability, reliability, and frequency control, among other things.

In the European Union, as predicted in the CEP [81], the Member States have created mechanisms to incentivize the use of RESs and ESSs, such as subsidized financing, feed-in-tariffs, and tax exemptions. India and Australia consider clean energy production to be so important that they have created specific governmental bodies for this area: the Indian Ministry of New and Renewable Energy (MNRE) and the Australian regulatory agencies ARENA and CERC. Both countries have economic and financial incentives in place for RESs and ESSs [95,96,110].

Therefore, Brazilian legislators and regulators should follow the international example and create more kinds of incentives for the adoption of hybrid wind and PV energy generation systems and ESSs. Mixed auctions for wind and solar energy must be allowed and economic incentives offered for ESSs to be installed together with these installations. Resources for subsidies must come from the national treasury so that they do not affect the tariffs, as happened with the cross-subsidy.

4. Conclusions

This literature review allowed us to analyze the main elements of the research carried out on the economic feasibility and regulatory aspects of hybrid wind and solar PV energy generation with ESSs. Among the different results, this analysis identified the limitation in the connections of studies discussing the economic feasibility and regulatory aspects of these systems. In the context of Brazil, this is a major bottleneck: the lack of specific regulations for these hybrid systems creates uncertainties and little economic convenience for entrepreneurs. For this reason, we explored how the legislation in different countries around the world was organized in order to point out examples to be followed in the specific case of Brazil.

It was demonstrated that there are no studies that have carried out a literature review on the economic and financial viability of hybrid wind and solar PV systems using energy storage, highlighting the novelty of the proposed research. This research presented the state of the art of the literature through an SLR. Moreover, a review and a critical analysis of the regulations in force in different countries were presented. Our research results evidence not only the growing academic interest in these topics, but also the regulatory bodies’ interest in these topics. The study also sought to shed light on the existing regulatory frameworks with the aim of contributing to the recent regulatory discussions in developing countries such as Brazil.

Our research results indicate that, around the world, most scientific studies focus mainly on only one of the renewable energy technologies. Only a few studies focused
on wind, solar PV, and ESS technologies together, and even fewer studies also addressed regulatory or legal aspects. In fact, studies involving regulatory or legal aspects are rare, as these two themes are dynamic and have regional content. A few studies comparing regulatory frameworks, particularly grid codes, were found. We did not find any scientific studies addressed to the use of these three technologies together in Brazil. As the academic interest in these subjects is growing rapidly in other countries, there is an important gap to be filled here.

We also found that the recent themes of academic studies stand out, such as optimal sizing and loss of power supply probability. The problem of optimizing sizing was found to be more related to techno-economic and financial feasibility studies, while studies on the loss of power supply probability are related to issues involving grid quality and reliability and, therefore, are more related to energy storage systems.

Observing the worldwide tendency, new studies should address the techno-economic feasibility of hybrid wind and solar PV energy generation systems in conjunction with, at least, one kind of ESS. In addition, it is very important to take in account the regulatory barriers and propose solutions to remove them. It was observed that although regulatory aspects can influence the economic feasibility of hybrid energy generation projects, little is known about this relationship among the frameworks.

The Brazilian electricity matrix essentially uses a hydraulic source. However, the growth of renewable energy sources follows the same global pattern. The main difference is that, in Brazil, energy storage is carried out by storing water in hydropower reservoirs. The other kinds of energy storage are currently very incipient. Even the regulators of the electricity sector are not prepared to encourage the installation of devices for energy storage. It is important to emphasize that the findings presented in this article apply not only to Brazil but also to other countries that do not currently have regulations that support the use of ESSs in hybrid systems.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/en14206521/s1, Annex S1: Sample Articles found by SLR, Annex S2: Legal documentation found.

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Nomenclature

ANEEL National Electric Energy Agency, the Brazilian electricity regulatory body
ARENA Australian Renewable Energy Agency
BESS Battery Energy Storage Systems
CEP Clean Energy Package, the Clean Energy for all Europeans Package
CER Clean Energy Regulator, the Australian regulatory body for clean energies
CERC Central Electricity Regulatory Commission, the Indian electricity regulatory body
COE Cost of Energy
Conama Brazilian National Environment Council
DG Distributed Generation (it is used for installations of up to 5 MW of installed power connected to the distribution grid in Brazil)
EECS Electric Energy Compensation System
EES Energy Storage Systems
FERC Federal Energy Regulatory Commission, the U.S. electricity regulatory body
HOMER Hybrid Optimization of Multiple Energy Resources
IEA International Energy Agency
LCCA Life Cycle Cost Analysis
LCOE Levelized Cost of Energy
LPSP Loss of Power Supply Probability
MNRE Ministry of New and Renewable Energy of India
MOGA Multiple-Objective Genetic Algorithm
MOSaDE Multiple-Objective Self-Adaptive Differential Evolution
NPC Net Present Cost
NPV Net Present Value
NREL National Renewable Energy Laboratory
Ofgem Office of Gas and Electricity Markets, the U.K. gas and electricity regulatory body
PL Bill of Law
PROINFA Incentive Program for Alternative Sources of Electric Energy
PURPA Public Utility Regulatory Policy Act
PV Photovoltaic
REN Normative Resolution issued by ANEEL
RES Renewable Energy Sources
RF Renewable Factor
SDG7 The seventh United Nations Sustainable Development Goal
SLR Systematic Literature Review

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