

Review

Econometric Studies on the Development of Renewable Energy Sources to Support the European Union 2020–2030 Climate and Energy Framework: A Critical Appraisal

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Abstract: One of the key objectives of the European Union is the transition to a total decarbonization of the economy by 2050. Within this strategic framework, the renewable energy development target plays a key role. This renewable energy deployment must be translated into national and European Union realities through specific political decisions. The econometric analysis techniques have the capacity to represent, in a mathematical and objective way, the system of relations comprising the economic, technical, and political factors that contribute to the deployment of renewable energy, and the impact that such an investment in renewable energy has at an economic, environmental, and social level. Therefore, econometric studies have a high potential to support policymakers who have to translate the guidelines of the strategic plan for renewable energy deployment into concrete policies. This article analyzed the capacity of the econometric literature on renewable energy development to provide this support, by means of a bibliometric study carried out on a sample of 153 documents related to 1329 keywords. The results show that, in general, there is a large literature based on econometric methodology to support the different renewable energy guidelines provided by the European Union 2020–2030 climate and energy strategic framework.

Keywords: renewable energy sources; decision-making; econometric analysis; European Union

1. Introduction

One of the key objectives of the European Union (EU) is the transition to a total decarbonization of the economy by 2050 [1]. Various programs are promoted from different EU bodies, such as the Horizon 2020 [2] or the Program for the Environment and Climate Action (LIFE) [3] programs, to achieve this challenge. Within these programs, the transition to clean energy plays an important role, including aspects such as innovation [4,5], improvement of energy efficiency, global leadership in renewable energies through a reduction in costs, the improvement of its performance, and ease of the adoption of the renewable solutions in the market, as well as the integration of renewables and a more active role by consumers, so that the impact of fossil waste is reduced, while also taking into account a global perspective—that is, a technological but also a social and economic dimension. In this sense, the European Council agreed on a 2030 framework for climate and energy, concentered in four fundamental targets: a 40% cut in greenhouse gas emissions (GHG) compared to 1990 levels, at least a 32% share of renewable energy (RES) consumption, an improvement in energy efficiency at the EU level of at least 32.5%, and an electricity interconnection target of 15% [6].

Within this strategic framework, the RES development target plays a key role. This commitment to RES implies, at the level of policymakers, three questions.

Firstly, what should be the investment in the different RES technologies and what policies and instruments should be applied? This question encompasses questions around the degree of maturity of these technologies, their growth potential, which factors and barriers determine their growth, and which policy tools are most effective in promoting their deployment.

Secondly, why is it necessary to commit to RES? This question determines aspects such as the reasons for supporting their development through public policy instruments, to the detriment of other alternatives, such as fossil fuel-based technologies. In short, it is a question of determining the beneficial effects that justify public support for RES.

Lastly, another underlying question relates to the conditions under which the deployment of renewable energies must be developed in order to meet the targets set in 2030, first, and in 2050 thereafter. These conditions refer to aspects that act as restrictions to such development: market conditions, level of energy prices, or effects on the competitiveness of national economies.

The above three questions are raised throughout the EU 2020–2030 climate and energy strategic framework [6]. Table 1 summarizes the main references to each of the above issues in such a strategy.

Table 1. Key elements of the EU 2020–2030 climate and energy strategic framework related to the development of renewable energy (RES).

WHICH TECHNOLOGIES AND HOW?	
Question	Main References in the Framework
Which technologies?	RES target: increase 32% by 2030.
Which technologies?	The electricity system needs to adapt to increasingly decentralized and variable production (solar and wind).
Which technologies?	
	An improved biomass policy will be necessary to maximize the resource efficient use of biomass.
How?	Subsidies for mature energy technologies (including RES) should be phased out entirely in the 2020–2030 timeframe. Subsidies for new and immature technologies with significant potential to contribute cost-effectively to RES volumes would still be allowed.
How?	Being cost-effective.
How?	Providing regulatory certainty and transparency for investors in low-carbon technologies.
How?	Enhancing policy coherence and coordination across the EU.
How?	Deployment of smart grids and interconnections between member states to ensure a level of electricity interconnections equivalent to or beyond 10% of their installed production capacity.
WHY?	
Question	References in the EC Report
Environmental issues	RES contribute to achieve GHG emissions target.
Environmental issues	RES reduce air pollution.
Security	RES promote security of energy supply
Security	RES reduce the exposure to volatile prices of fossil fuels.
Security	Member states must act collectively to diversify their supply countries and routes for imported fossil fuels.
Security	Diversification of energy imports and the share of local energy sources used in energy consumption over the period up to 2030.
Economic growth	RES drive growth in innovative technologies.
Economic growth	RES create jobs in emerging sectors.
Economic growth	RES drive technological innovation (R&D expenditure, EU patents, competitive situation on technologies compared to third countries).
UNDER WHAT CONDITIONS?	
Question	References in the EC Report

Competition in energy markets	Ensuring competition in integrated markets.
Competition in energy markets	Exploitation of local sustainable energy sources (RES, domestic reserves of conventional and unconventional fossil fuels (natural gas) and nuclear) according to preferences over their energy mix and within the framework of an integrated market with undistorted competition.
Competitiveness and affordability	Competitive and affordable energy for all consumers.
Competitiveness and affordability	Energy price differentials between the EU and major trading partners.

Source: own elaboration based on European Commission [6].

Hence, the study of the development of renewable energies is considered to be a crucial aspect in achieving the energy transition objective so that tools can be provided to better assess the environmental, social, and economic impact of renewable energy solutions. As part of this future area of study, it is also necessary to analyze the relevant drivers that impact on the transition to RES and the barriers to overcome. The aim of which is to provide a clear and detailed diagnosis of its operation and provide public authorities with support to improve the decision-making process through measures including the development of scenarios with greater coherence and consistency based on scientific evidence. Consequently, a review of the existing literature in the field of renewable energy study is necessary.

In this paper, a systematic review of empirical studies related to the development of RES is presented in order to map the research landscape through which future inquiry will be developed. Specifically, we have focused on econometric analysis. Econometric techniques have the benefit of being able to represent, in an objective and reproducible way, the system of relations that characterizes the development of RES. Such techniques identify the main variables that influence this development and allow an analysis on this system of the repercussions of various technical, economic, political, and social scenarios [7]. Obviously, there is a wide range of mathematical and statistical techniques that can contribute to the analysis of the development of RES. The application of econometric or other alternative techniques, or even the complementary use of several types of techniques in the same research (e.g., [8]), will depend on the nature of the research itself. However, there is a trend in the use of econometric tools in nearly all sciences. In the case of energy economics, “developments in applied econometric estimation methods have been the catalyst for a rich body of applied energy economics research” [9]. As it states in [10], “empirical papers in energy economics closely follow and draw on developments in the econometric theory. [...] Thus, it is not surprising that energy and environment economists have shown so much interest in econometric methodology”. In turn, there is an interest in funding projects related to econometric analysis. The Community Research and Development Information Service (CORDIS), as the European Commission’s primary source of results from projects funded by the EU’s framework programs for research and innovation, has reported 610 funded projects that applied econometric techniques. In the field of climate change and environment and energy, CORDIS has reported 33 funded projects by the EU framework programs [11].

Therefore, the aim of this critical appraisal was more complex than providing a list of bibliographic citations classified by topics. An analysis of quantitative research was carried out in order to know what has been investigated in the field of RES deployment and related topics according to the EU energy strategy framework. In this way, it will be possible to determine the intensity with which research on these topics has been taken to the scientific literature using econometric methodology, in what context, with what objectives, and by means of which techniques. In turn, all of this will help to identify what needs to be done by developing new lines of research, discovering relevant variables for the subject, and establishing a context of it, identifying in turn the main research methodologies and techniques that have been used, as well as framing research in a historical context showing the evolution that has been carried out in the state of the art [12–14]. In short, we proposed an exhaustive review of the state of the art in the development of RES that would allow us to know

which topics considered by the strategic framework of energy in the EU have been analyzed by means of econometric methodology, so that a map of the experiences that can be useful for the effective application of this strategy is established.

The article is structured as follows. Section 2 provides the methodology used in the review, the search strategy of literature in the field of renewable energy development through an econometric analysis, and the data evaluation. Section 3 provides the main results, which are discussed in Section 4.

2. Materials and Methods

2.1. Search Strategy and Data Collection

Figure 1 shows the methodology followed in the current research. The right-hand side summarizes the part of the methodology referred to the literature review. The left-hand side shows the analysis of the EU 2020–2030 climate and energy strategic framework and the identification of the key elements related to the development of renewable energies, which have been classified into the three major issues raised in the Introduction. As can be seen in the lower part of the figure, by comparing these elements with the results of the bibliometric analysis, the key elements with econometric analysis support have been identified and those are the key elements that have to be supported.

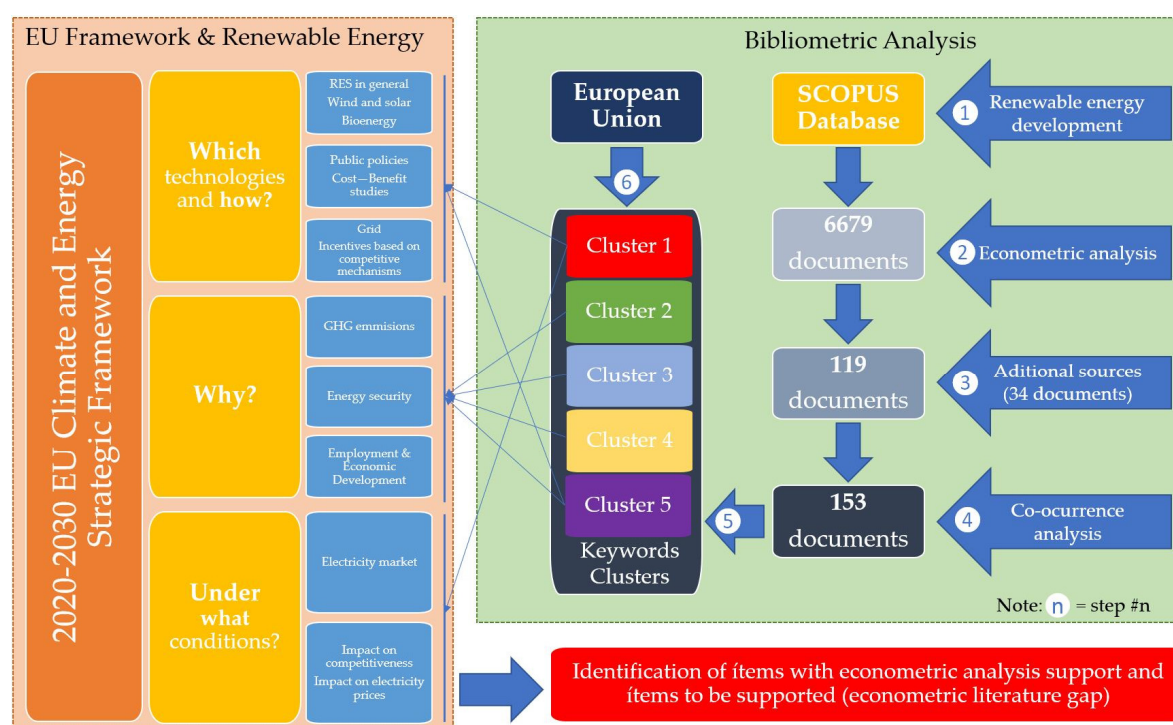


Figure 1. Methodology for identification of econometric contributions supporting EU 2020–2030 climate and energy strategic framework.

Focusing on the bibliometric analysis, on the right side of the Figure 1, different steps followed in its development have been numbered. They are detailed in Sections 2 and 3. Firstly, the initial collection of data on empirical studies of RES has been carried out through the Scopus database (as it is considered the largest database of reviewed literature) in the field of study of the development of renewable energies. For this purpose, the search term was “renewable energy development” (Figure 1, step #1), reporting a result of 6679 documents from 1978 to 2019. The areas of knowledge in the study of the development of the RES were very diverse (Figure 2), showing the area of energy in the first position, encompassing about 30% of the publications related to the development of the RES, followed by the environmental sciences (with 20% of total publications), and thirdly, there is the

area of engineering knowledge (with a total of 14% of publications). The area of economics, econometrics, and finance, was in 7th place, with a total of 387 publications, being 3% of the total documents that make up the global studies on renewable energy development. However, this area of knowledge is considered as a key tool in decision-making, taking into account the three dimensions—technological, economic, and social, which the European Union considers essential for the fulfillment of European objectives.

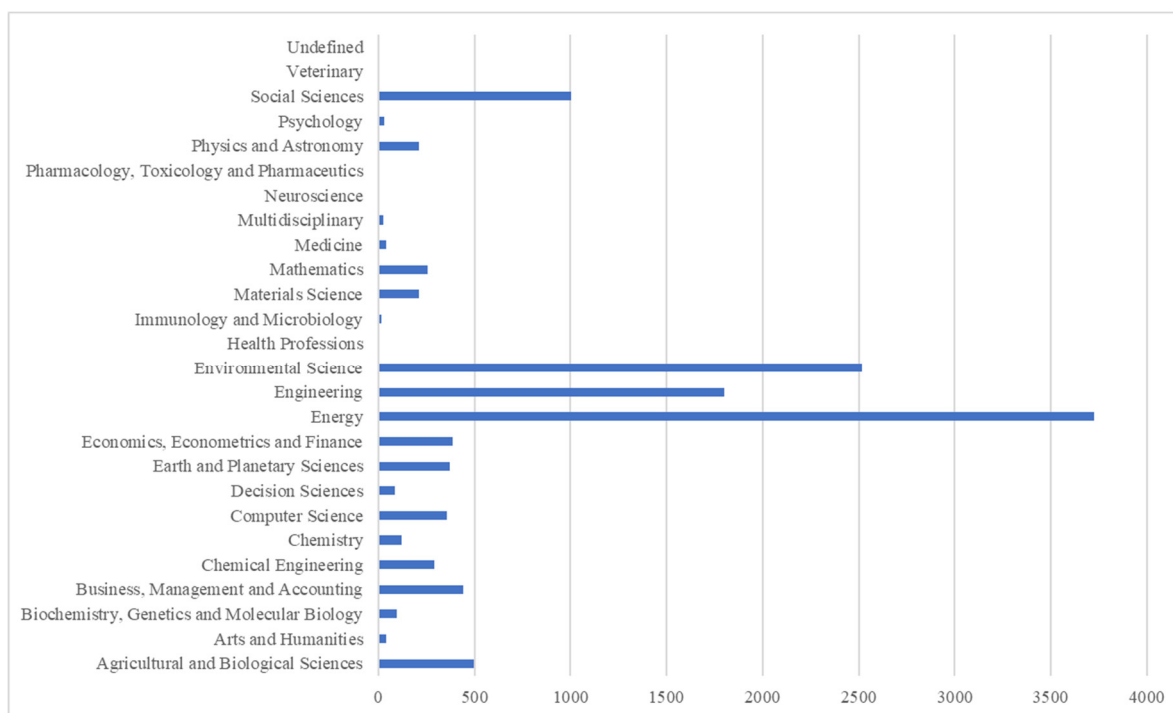


Figure 2. Publications in the field of RES development by area of knowledge.

As argued in the introduction, this state-of-the-art review will focus on the study of the development of renewable energies, through an econometric analysis, using the Scopus database as the largest database of peer-reviewed literature, to later be completed by other databases such as Google Scholar for article suggestions and Mendeley and the ResearchGate network for the application of bibliographic references. On the other hand, the relevant references of the previous documents, as well as the references made to those documents, have also been investigated.

With the previous search strategy, initially a total of 119 documents were obtained from the Scopus database using the combination “renewable energy development” and “econometric analysis” (Figure 1, step #2). Subsequently, this initial review was completed with 34 additional documents (Figure 1, step #3). Hence, there are a total of 153 documents that make up the empirical studies using econometric analysis that were examined in this literature review.

2.2. Data

The so-called concept matrix presented by Webster and Watson [15] has been used to organize the framework of this review (see the complete list of the documents of the literary review in Appendix A). The documents finally selected for study have been classified according to the following categories:

1. *Type of document availability*: classified as “Open Access”, those journals in which all its peer-reviewed academic articles were available online without registration, subscription, and/or payment requirements. Overall, 18 of the total 153 documents were open access. The rest of the documents, 135, were those that required a prior registration, subscription, or payment in order to have them for analysis.

2. *Year of publication:* the literature review includes studies from 2002 to 2019. The largest number of econometric studies that analyze the development of renewable energies were published in years 2017 and 2018. Figure 3 shows the year-wise frequency of publication from 2002 to 2017 in this field.

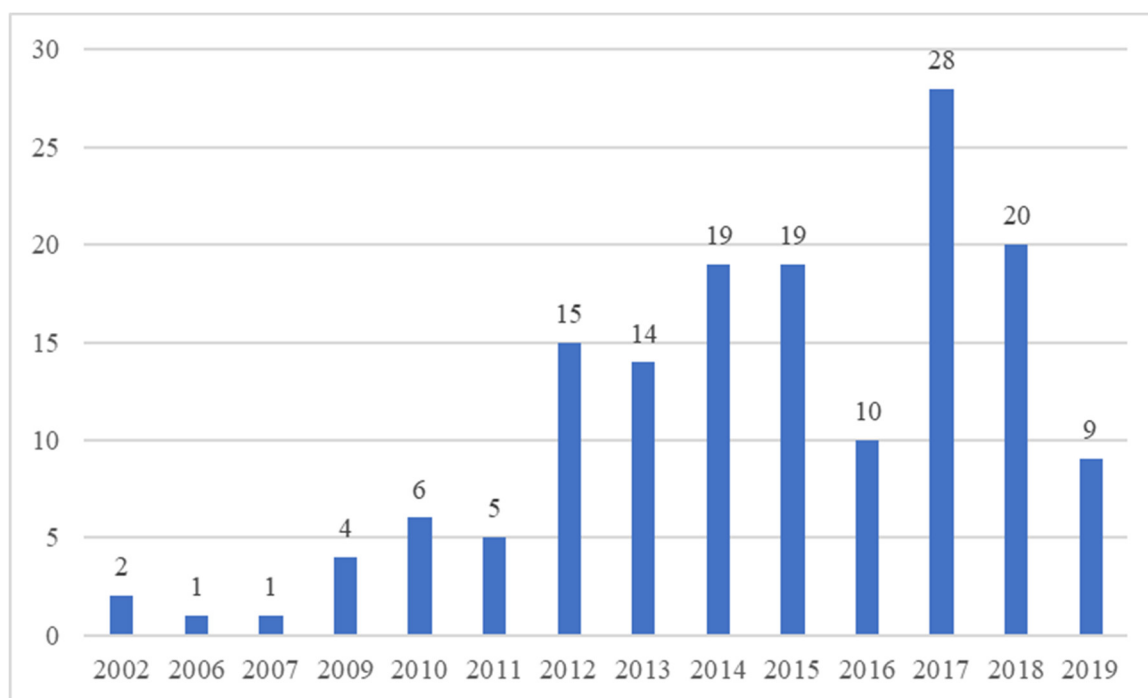


Figure 3. Year-wise frequency of publication in the field of RES development—econometric analysis. 2002–2019.

3. *Knowledge area:* the results offered by the Scopus database were classified into four broad thematic groups (life sciences, physical sciences, health sciences, and social sciences and humanities), which, in turn, were divided into 27 main thematic areas and more than 300 minor themes. Table 2 has been elaborated where the number of documents of the literary review are shown according to the thematic area provided by Scopus. In total, 92% of the publications of the review were included in the thematic areas of energy (with 35% of the total documents); environmental sciences (25%); economics, econometrics, and finance (11%); engineering (10%); business, administration, and accounting (6%); and social sciences (5%). Therefore, 75% of the studies belonged to the thematic group of physical sciences, 24% to the social sciences, and only 1% to the life sciences.

Table 2. Publications in the field of RES development—econometric analysis by knowledge area.

Subject Area	Supergroup	Documents
Agricultural and Biological Sciences	Life Sciences	2
Business, Management and Accounting	Social Sciences	16
Chemical Engineering	Physical Sciences	1
Computer Science	Physical Sciences	4
Decision Sciences	Social Sciences	2
Earth and Planetary Sciences	Physical Sciences	4
Economics, Econometrics and Finance	Social Sciences	32
Energy	Physical Sciences	98
Engineering	Physical Sciences	27
Environmental Science	Physical Sciences	70
Materials Science	Physical Sciences	1
Mathematics	Physical Sciences	4
Medicine	Health Sciences	1

Physics and Astronomy	Physical Sciences	1
Psychology	Social Sciences	2
Social Sciences	Social Sciences	15

Source: own elaboration from Scopus database.

4. *Type of source*: Scopus covers various types of sources in order to ensure the maximum research coverage in all fields. It includes serial publications such as journals, commercial publications, book series, and materials or conference proceedings that have been assigned an ISSN (International Standard Serial Number), as well as nonserial documents with an ISBN (International Standard Book Number), such as books, and nonserial documents without an ISBN, such as reports, part of a series of books, procedures, monographs, edited volumes, main reference works, patents, and postgraduate level textbooks. There were 70 literary sources that encompassed the studies of this review—the *Energy Policy* and *Renewable and Sustainable Energy Reviews* were those that have published the largest number of documents, 28 and 19 articles respectively. Table 3 shows the type of source and the number of documents by type of source.

Table 3. Publications in the field of RES development—econometric analysis by type of source.

Type of Source	Documents
Book	11
Book series	4
Conference proceeding	3
Journal	133
Trade publications	2

Source: own elaboration.

5. *Type of document*: within the types of documents that Scopus includes (article, article-in-press, book, book chapter, conference paper, editorial, erratum, letter, note, review, and short review); this review has 118 articles, 19 reviews, 10 books, 5 articles presented at conferences, and 1 book chapter.
6. *Keywords*: Scopus offered the keywords used in the 119 initial documents; however, 34 additional documents were considered important to complete the state-of-the art review. Consequently, each of the 34 additional documents that have been added to this review have been analyzed document by document for the keywords used, which were then included in the database made for the review analysis; with all of them, all keywords have been synthesized following the “document search tips” that Scopus database provides. Changes have been made to synthesize the plural and singular concepts in their singular form and error correction has also been made to avoid duplication in said keywords. With all premises taken into account, there were 210 keywords used by the different authors to reflect the content of the econometric studies on renewable energy sources, with the following being the most frequently used expressions: “renewable energy”, “energy policy”, “economics”, “renewable energy resources”, “investment”, “renewable resource”, “sustainable development”, and “wind power”. Table 4 presents the full list of keywords. From the table above, and grouping the keywords by themes, it can be seen that the most studied topics in the field of the RES development through an econometric analysis were those related to policy such as “climate policy”, “energy policy”, “policy making”, or “public policy”. Others related to the support that renewables received are frequently studied highlighting above all the “feed-in tariff” support or “renewable portfolio standard”. The investment in renewables was also a topic of interest. The sustainability of the energy system has also been frequently studied. In addition, carbon emissions, control emission, and emission trading are also very important issues to the deployment of RES. If we focus on the scope of the analysis, we can observe that most of the publications in the field of RES development have focused on a set of countries (Europe; BRICS, especially China; developing countries; the United States; and countries from the Organization for Economic Co-operation and Development). Regarding the technological scope, most of the studies are focused on RES in

general, but also solar (specially, solar photovoltaic) and wind energy are frequently studied. The methodology used is very varied, highlighting regression analysis, panel data models, cost benefit analysis, choice experiment, and multi criteria decision making.

Table 4. Publications in the field of econometric analysis of RES development by keyword.

Keyword (Number of Documents)	
A	A-carbon (2); Affordability (2); Agriculture (4); Alternative Energy (15); Autoregressive distributed lag (ARDL) (1).
B	Biodiesel (2); Biofuel (5); Biogas (2); Biomass (5); Biomass Energy (2); Biomass Power (2); Brazil (3). Canada (2); Carbon (7); Carbon Dioxide (16); Carbon Dioxide Emissions (2); Carbon Emission (13); Carbon Taxes (2); Chemical Industry (2); China (12); Chinese Companies (2); Choice Experiment (8); Climate change (9); Climate Policy (2); CO2 Emissions (5); Cointegration (2); Commerce (15);
C	Commercialization (2); Company (2); Competition (3); Competition (economics) (2); Complementary sector (1); Conjoint Analysis (2); Consumption Behavior (3); Contingent Valuation (4); Contingent Valuation Methods (2); Convergence (2); Cost Analysis (4); Cost Benefit Analysis (12); Costs (16); Crop Production (2).
D	Data Set (3); Decision Making (7); Demand Analysis (4); Demand-pull (1); Developing Countries (5); Developing World (3); Development stage (1); Diffusion (2); Discrete Choice (2); Dynamics of policy impact (2).
E	Econometric analysis (14); Econometrics (6); Economic Activities (2); Economic Analysis (2); Economic And Social Effects (9); Economic Development (9); Economic Growth (9); Economic Policy (2); Economic Valuation (2); Economics (33); Elasticity (2); Electric Generators (2); Electric Industry (2); Electric Power Generation (4); Electric Power Utilization (3); Electric Utilities (4); Electricity (9); Electricity Generation (14); Electricity grid (1); Electricity markets (1); Electricity Prices (2); Electricity Supply (5); Electricity transmission (1); Electricity-consumption (4); Emerging economies (1); Emission Control (8); Emissions (2); Emissions Trading (4); Empirical Analysis (4); Employment (2); Energy (4); Energy Conservation (8); Energy Consumption (4); Energy Cost (3); Energy economics (1); Energy Efficiency (6); Energy Management (3); Energy Market (10); Energy Planning (9); Energy policy (37); Energy Productions (3); Energy Resource (7); Energy Sector (3); Energy Security (3); Energy Transitions (2); Energy Use (11); Energy Utilization (15); Environment (4); Environmental (2); Environmental Concerns (2); Environmental economics (7); Environmental Impact (6); Environmental Policy (3); Estimation Method (3); Europe (9); European Union (12).
F	Feed-in tariff (13); Finance (4); Financial incentives (1); Foreign Direct Investment (3); Fossil Fuels (9).
G	Gas Emissions (5); Geothermal (1); Global Warming (5); Green energy policies (1); Greenhouse Effect (3); Greenhouse Gas (8).
H	Household Energy (3); Housing (4).
I	Incentive (3); India (1); Induced innovation (1); Industry (3); Innovation (7); Innovation spillovers (1); International trade (1); Invention (1); Investment (26).
J	-
K	-
L	Learning effects (1); Literature review (1).
M	Matching analysis (1); Multi Criteria Decision Making (3); Multi-regime interaction (1)
N	Natural Resources (6); Negative binomial regression (1); Network (1); Nigeria (3); Numerical Model (8).
O	OECD (4); Oil prices (1).
P	Panel cointegration (1); Panel corrected standard error (2); Panel data (14); Panel data models (5); Patents (2); Photovoltaic System (5); Photovoltaics (1); Poland (Central Europe) (3); Policies (1); Policy consistency (1); Policy design (1); Policy effectiveness (1); Policy impact (1); Policy Implementation (3); Policy Making (4); Pollutant emission (1); Power Generation (3); Power Markets (3); Public Policy (10).
Q	-
R	R & D strategy (1); Regional analysis (1); Regional Planning (3); Regression (1); Regression Analysis (6); Renewable (1); Renewable deployment (1); Renewable electricity (7); Renewable energy (61); Renewable Energy Development (6); Renewable energy investments (1); Renewable energy policy (7); Renewable Energy Potentials (3); Renewable energy power (1); Renewable energy promotion (1); Renewable Energy Resources (29); Renewable Energy Source (16); Renewable Energy Technologies (5); Renewable investments (1); Renewable portfolio standard (12); Renewable Resource (22); Research And Development (3); Risk Assessment (4); Rural Areas (3).

Keyword (Number of Documents)	
	Smart Power Grids (3); Social acceptance (1); Solar Energy (3); Solar photovoltaic (4); Solar Power (5);
S	Solar PV (2); Solar technology (1); Spain (5); State electricity policy (1); State policy impact (1); Subsidy (1); Support scheme effects (1); Surveys (8); Sustainability (4); Sustainable Development (17).
T	Tariff Structure (3); Taxation (5); Technological change system (1); Technology-push (1).
U	United States (5).
V	-
W	Waste energy (1); Willingness to Pay (6); Wind (2); Wind energy (3); Wind energy policies (1); Wind power (17).
X	-
Y	-
Z	-

Source: own elaboration.

7. *Author*: the work of 222 authors were included in this state-of-the-art review. Highlights include authors such as C. K. Woo [16–20] and G. Shrimali [21–25] with 5 documents each, and F. Groba [21,25–27] and S. Jenner [21,22,25,27] with 4 publications each.
8. *Author affiliation*: Scopus encompasses three key search concepts in its database: article, author, and affiliation. At this point, Scopus uses 70,000 affiliate profiles, which is an interesting tool for the academic and research field as it meant that we could identify possible relationships between the affiliation body of the authors of the different econometric studies on RES and other different points of this review. The top 15 affiliation organizations of the total 219 are detailed in Table 5.

Table 5. Top 15 author affiliations that publish in the field of RES development—econometric analysis.

Rank	Author Affiliations	Documents
1	Democritus University of Thrace	5
2	Energy and Environmental Economics, Inc.	4
3	German Institute for Economic Research	4
4	Land Policy Institute, Michigan State University	4
5	Swiss Federal Institute of Technology Zurich (ETH Zurich)	4
6	University of Florida	4
7	Covenant University	3
8	Hong Kong Baptist University	3
9	Hong Kong Polytechnic University	3
10	Laboratoire D'Économie Appliquée de Grenoble	3
11	Luleå University of Technology	3
12	Norwegian University of Life Sciences	3
13	Tsinghua University	3
14	Universidad de Castilla-La Mancha	3
15	University of Naples "Parthenope"	3

Source: own elaboration.

9. *Country authorship*: the top countries of origin of the authors of this literature review were the United States, China, Germany, Italy, the United Kingdom, and Spain.
10. *Funding sponsor*: there were 73 organizations that financed part of the studies of this review. It is noteworthy that 7 of the 8 institutions that most frequently funded studies were agencies from China.
11. *Publication language*: the predominant language in econometric research studies concerning the develop of RES was English (150 of the 153 documents of the literary review), and only 3 documents have been prepared in Chinese, French, and Thai.

3. Results

When a large amount of data are used it becomes necessary to apply a bibliometric analysis as a science that uses mathematical and statistical methods to analyze scientific literature and the authors in this field. Most of the articles that performed a bibliographic analysis of the literature used software to make simple graphs of representation with standard statistical software, representing maps with few items [28], so we used the computer program *VOSviewer* created by Van Eck and Waltman for constructing and viewing bibliometric maps in a full detail.

In order to identify the main contents on which the literature of econometric analysis of the development of RES has focused, a co-occurrence map was drawn up, taking into account both the most relevant key words included in the titles and summaries of the 148 publications of the study, and the 210 key words provided in Table 4 (Figure 1, step #4). In total, 1329 key words were processed in this way. The map includes 90 of the 1329 keywords, each of which appeared in at least 5 publications. For each of the 90 keywords, the bibliometric software calculated the total strength of the co-occurrence links with other keywords, and those keywords with the greatest total link strength were selected. Those keywords related to the search strategy of our dataset as “renewable resource”, “renewable energies”, “renewable energy resources”, “renewable energy”, “econometric analysis”, and “econometrics” were deleted since they appeared in most of the publications. The 10 keywords with the greatest total link strength were: “energy policy”, “economics”, “investments”, “electricity generation”, “alternative energy”, “panel data”, “wind power”, “commerce”, “carbon dioxide”, and “cost”. Figure 4 depicts the co-occurrence map.

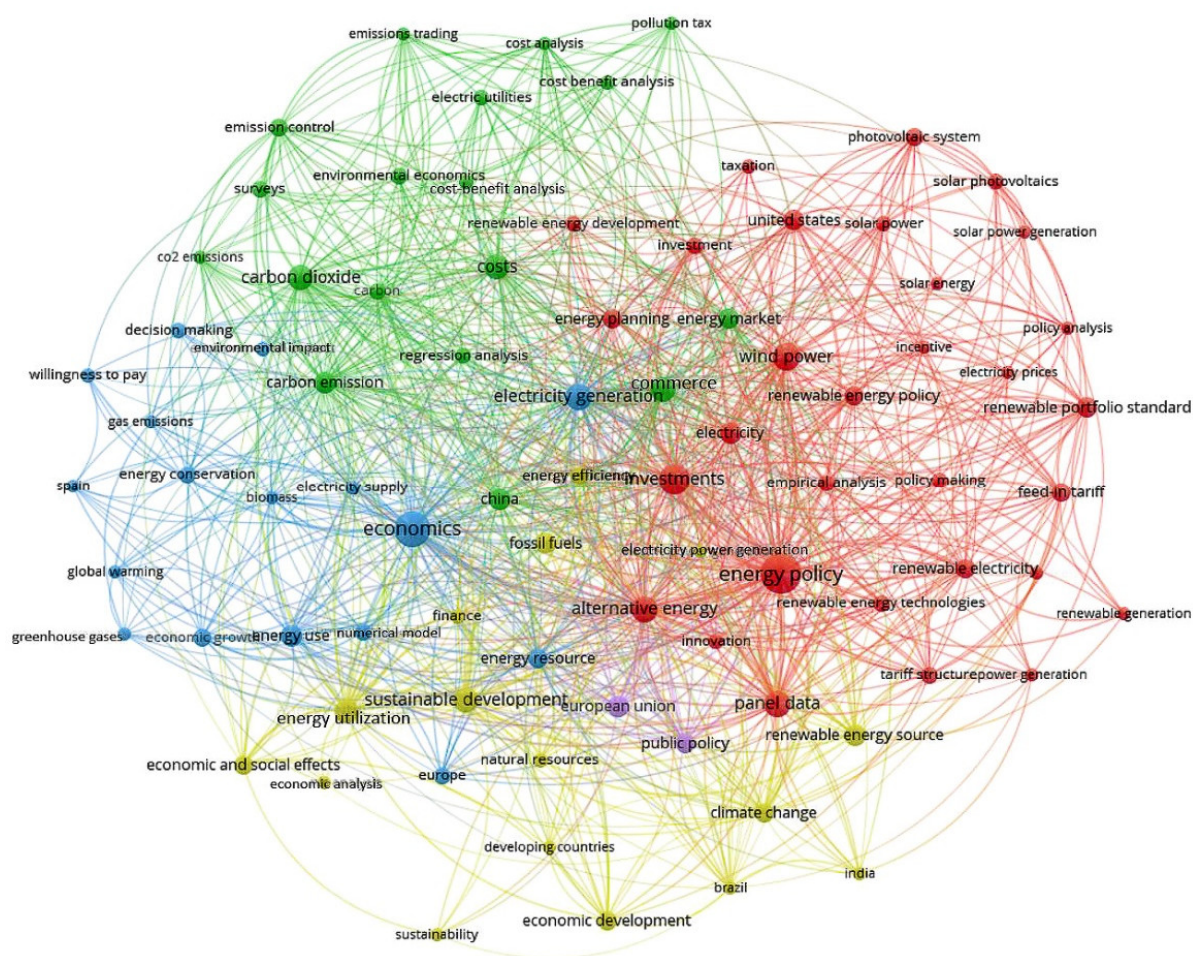


Figure 4. Co-occurrence keyword map in the field of RE development—econometric analysis. A label view.

The structure of the map is quite circular. We identified that there were five clusters created in the co-occurrence keyword map (Figure 1, step #5). Clusters located close to each other in the map indicate closely related fields. Table 6 summarizes the terms included in each cluster.

Table 6. Clusters of the co-occurrence keyword map for the field of RES development and Econometrics.

Cluster	Keywords (Terms)
#1 (Red)	United States.
	Alternative energy, electricity, photovoltaic system, renewable energy technologies, solar energy, solar photovoltaics, solar power generation, wind power.
	Energy planning, Energy Policy, feed-in-tariff, incentive, innovation, investment(s), policy analysis, policy makers, policy making, power generation, renewable electricity, renewable energy development, renewable energy policy, renewable generation, renewable portfolio standard, tariff structure.
	Electricity prices.
	Empirical analysis, panel data.
#2 (Green)	China.
	Electric utilities.
	Carbon dioxide, carbon, carbon emission, CO2 emission commerce, emission control, emission trading,
	Environmental Economics.
	Cost analysis, cost benefit analysis, cost-benefit analysis, cost.
#3 (Blue)	Europe.
	Biomass, electricity generation, electricity supply, energy conservation, energy resource, energy use, energy source, environmental impact, gas emissions, global warming, greenhouse gases.
	Economic growth, Economics.
	Decision making, willingness to pay.
	Numerical model.
#4 (Yellow)	Brazil, India, developing countries.
	Electric power generation, energy efficiency, energy utilization, fossil fuels,
	Climate change, natural resources, renewable energy source.
	Economic analysis, economic and social effects, economic development, sustainability, sustainable development.
#5 (Purple)	Finance.
	European Union.
	Public Policy

Source: own elaboration.

Cluster #1 (red) contains a large number of terms related both to the RES to be developed and to the policy tools to do so. Therefore, the literature corresponding to this cluster focused on the answer to the first question posed in the introduction section: “Which technologies to promote and how?” Specifically, the documents framed in this keyword cluster explored the factors that determine investment in photovoltaic [22,29–35] and wind energy [20,33,35–54] mainly, and especially policy tools such as feed-in-tariffs (FIT) [27,30,36,49,51,55–57] and renewable portfolio standards (RPS) [21,25,51,57–60], although they also considered incentives for innovation, financial incentives, and taxes [23,26,37,38,42,44,61–64]. The scope of these documents was primarily the US [16,20,22,25,48,52,53,59,65–70] and the electricity sector [16–18,20,24,27,29,57,70–81]. It should also be noted that the basic econometric methodology used in this type of contribution was based on the estimation of panel data models [43,46,54,80,82–87]. Finally, it is noteworthy that this cluster evidenced the existence of literature that assessed the impact of the implementation of RES on electricity prices, through the well-known merit order effect or the cost associated with renewable premiums [16,19,39]. Therefore, this part of the literature could contain documents that contribute to

giving scientific support to the question of “Under what conditions?”, which was raised in the introduction.

Precisely, the studies framed in cluster #2 (green) frequently focused on the role played by RES in both energy consumption and energy markets, but from the point of view of their economic impact related to CO₂ emissions [16,17,82,83,86,88–91]. These documents usually provided cost–benefit analyses [92], which attempted to quantify the net impact of investment in renewables in terms of CO₂ emissions avoided by electric generators and, in turn, the savings in emission rights in trading markets and environmental taxation [16]. In this cluster, there was a trend towards studies focused on China [26,61,85,91,93–102] and using tools based on regression analysis [25,38,43,46,50,66,82,103–107]. In other words, the studies included in this cluster contribute to the debate raised in the second question suggested in the introduction: “Why support RES?”

Cluster #3 (blue) includes terms related, mainly, to the consideration of energy as a scarce good and, therefore, from the economic point of view, emphasized the consequences of its generation cycle and use (consumers [75,104,107–109], economic growth [83,86,109–114], and global warming and environmental impact [83,86,90,112–116]). It is worth noting that a large part of these contributions focused on electricity generation [18,20,40,78], and from that point of view they are strongly related to a large part of the contributions that fit into clusters #1 and #2. On the other hand, the documents whose scope was Europe [109,117] stood out. In summary, it can be concluded that the literature framed in this cluster contribute, as that of cluster #2, to answer the question “Why support RES?”, but in a manner less focused exclusively on CO₂ emissions.

Cluster #4 (yellow) contains several terms related to economic and social development and natural resources. The documents framed in this cluster focused on the study of the consequences that the deployment of RES have on the development of economies and societies in a sustainable manner [74,82,88,110,112,115,118–138] and the trade-off that this development entails in relation to the use of fossil fuels [65,122,139,140]. Their scope was frequently developing countries as well as emerging countries [72,74,76,79,82,88,94,107,109,118–120,122,129–134,141], such as India or Brazil, so that, in principle, they contemplated a different reality to that of the EU. Notwithstanding, there were remarkable connections between the terms “sustainable development” and “economic and social effects”, with the term “Europe” in cluster #3.

Cluster #5, with a relatively small number of terms, refers specifically to public policy measures related to the deployment of RES [21–23,25,27,30,34,36,42,46,47,49–59,69,70,79,80,84,87,106,123,125,131,134,142–149]. The scope was mainly the EU and its countries and regions [27,31,33,36–39,41,45–47,49,50,54,56,62,66,73,75,77,81,87,103,106,116,125,127,136,139,143,146,150–164]. This cluster is strongly related to cluster #1 through its links to the term “energy policy” and to the main econometric method applied in the studies (panel data models) [27,44,47,49,55,66,84,86,87,142]. In addition, there is another remarkable link with cluster #4 through the term “sustainable development”. In sum, the documents framed in this cluster can contribute to support both the question of “Why support RES?” and that of “Which technologies to promote and how?”

With the intention of deepening the literature on the analysis of the development of RES by means of econometric techniques, specifically at the EU level, the previous co-occurrence map has been presented from the overlay visualization approach (Figure 1, step #6). In this kind of display, the co-occurrence keyword map shows not only the research structure of the econometric RES analysis, but also the temporal dynamics of this research, since the color of the term indicates the average year in which the publication that includes the term appeared. According to this, Figure 5 depicts the overlay visualization for the item “European Union”.

development of the EU 2020–2030 climate and energy strategic framework related to the development of RES. In fact, conclusions can be drawn from experiences in other scopes to support such implementation. In this sense, Table 1 of this article summarized the main aspects in which the strategic framework referred to RES. Those studies whose geographical scope was exclusively the EU were analyzed in depth. There were 17 studies exclusively from the EU [27,33,37,46,47,49,50,87,103,106,117,125,127,139,143,158,163]; 28 studies from EU countries and regions: Austria [73], Denmark [39], Germany [36,56,73,76], Greece [152,160,161,164], Ireland [41], Italy [38,41,154,155,157,162], Lithuania [159], Norway [77], Poland [150,151,153], Romania [156], Spain [31,54,62,75,81,136], and the United Kingdom [146]; 9 studies from the OECD [30,35,42,84,86,89,138,145,148]; 2 studies for OECD and BRICS countries [79,142]; and 12 studies (world at large) where the EU was included: [34,40,51,55,57,60,63,66,80,83,109,144]. The degree to which the econometric literature covered these aspects can be established, which is the objective of Table 7.

Table 7. Key elements of the EU 2020–2030 climate and energy strategic framework related to the development of RES and coverage of the econometric literature.

WHICH TECHNOLOGIES AND HOW?	
Key Elements	Contributions
RES target: increase 32% by 2030.	[30,33,35–42,46,47,50,51,54–56,60,62,66,73,75,77,79,82–84,87,89,103,117,127,136,139,142–145,150,152–158,160–164]
The electricity system needs to adapt to increasingly decentralized and variable production (solar and wind).	[27,30,31,33–35,37–42,45–47,49–51,54,60,73,77,84,106,117,139,145,151,152,156,161–164]
An improved biomass policy will be necessary to maximize the resource efficient use of biomass.	[35,81,106,136,139,150–152,154,156,157,160–163]
Subsidies for mature energy technologies (including RES) should be phased out entirely in the 2020–2030 timeframe. Subsidies for new and immature technologies with significant potential to contribute cost-effectively to RES volumes would still be allowed.	[31,33–35,39–42,45,46,49–51,55,56,63,73,77,84,143,145,150,156]
Being cost-effective.	[27,30,31,33–42,45–47,49–51,54,57,73,77,81,84,87,109,117,138,139,144,145,150,151,154–156,161–164]
Providing regulatory certainty and transparency for investors in low-carbon technologies.	[27,31,33–40,42,44–47,49–51,55,57,60,63,66,75,77,79–81,84,86,103,106,127,138,139,143–145,150–152,154–156,158,162]
Enhancing policy coherence and coordination across the EU.	[27,30,31,33–35,37,39–41,45–47,49–51,55–57,63,66,77,80,84,87,103,138,139,148,151,152,154–156,158,162,164]

Deployment of smart grids and interconnections between member states to ensure a level of electricity interconnections equivalent to or beyond 10% of their installed production capacity.	[30,34,36,38–40,46,47,49–51,54,55,117,156]
WHY?	
Key Elements	Contributions
RES contribute to achieve GHG emissions target.	[30,31,33–42,46,47,49–51,54–57,66,73,75,77,83,84,87,89,103,117,127,136,138,139,142,144,145,152,154–158,160–164]
RES reduce air pollution.	[30,31,33–42,46,47,49–51,54–57,66,73,75,77,83,84,87,89,103,117,127,136,138,139,142,144,145,152,154,156,157,161–164]
RES promote security of energy supply.	[30,33,35,37,40,42,46,47,49–51,55,56,66,73,87,103,117,138,139,142,144,150,152,154,156,158,163,164]
RES reduce the exposure to volatile prices of fossil fuels.	[30,33–35,39–42,46,47,49,50,55,56,60,66,73,83,87,103,138,139,142,144,150,152,154,156,158,163,164]
Member states must act collectively to diversify their supply countries and routes for imported fossil fuels.	[30,35,37,40,42,47,49,66,77,103,138,139,154,156,158,163]
Diversification of energy imports and the share of indigenous energy sources used in energy consumption over the period up to 2030.	[33,35,38,40,42,46,47,49,50,103,139,150,156,158,161–163]
RES drive growth in innovative technologies.	[30,31,33–35,37–42,45–47,49–51,55,56,60,62,63,73,87,103,145,154–156,160,162]
RES create jobs in emerging sectors.	[33,34,37,40,41,47,51,62,87,136,154–157,162,163]
RES drive technological innovation (R&D expenditure, EU patents, competitive situation on technologies compared to Third World countries).	[30,31,33–35,37–40,42,45–47,49–51,56,60,62,63,73,87,103,139,145,154–156,160,162]
UNDER WHAT CONDITIONS?	
Key Elements	Contributions
Ensuring competition in integrated markets.	[30,33–35,37–40,42,46,47,49–51,77,140,143,155,157,159,163,164]
Exploitation of sustainable indigenous	[30,33,35,36,38–42,46,47,50,51,55,77,139,150,154–158,161–163]

energy sources (RES, domestic reserves of conventional and unconventional fossil fuels (gas natural) and nuclear) according to preferences over their energy mix and within the framework price-integrated market with undistorted competition.	
Competitive and affordable energy for all consumers.	[33,35,37,40,41,46,49,54,56,62,77,81,139,155–158,161,163,164]
Energy price differentials between the EU and major trading partners.	[30,33,35,40–42,46,49,56,139,156,158,162]

Source: own elaboration based on European Commission.

As can be seen in the previous table, there is an abundant volume of econometric literature that supports the guidelines of the EU strategic framework in relation to the question concerning the type of RES to deploy and the public policies to be applied to promote the necessary investment (“Which technologies and how?”). In particular, there are numerous documents that have analyzed the development of certain RES, such as wind and solar photovoltaic and, to a lesser extent, bioenergy. There are also many empirical works that have studied the impact of the different public policies for RES deployment, especially with regard to feed-in-tariffs [27,30,36,49,51,55–57,60,143], the most frequently used and studied tool, and renewable portfolio-standards [51,60]. Kim et al. [145] provided a “way to optimize policies for renewable energy technologies through phases of development maturity” (p.2). There have also been frequent studies that have considered the investment in RES from a cost–benefit point of view [54,161]. However, there is a lack of literature that delves deeper into the necessary investment and transformation in the electricity transmission grid and, in terms of public policies, the effectiveness and efficiency of the application of investment incentives based on competitive mechanisms (auctions).

Regarding the question of the justification of investment in RES (“Why?”), studies have focused on the role of RES in relation to their contribution to reducing GHG emissions [89,127]. Some of them considered CO₂ emissions as not being the main driver [156], others stated “no an outstanding role of renewable energy use in the contribution of CO₂ emissions” [83], increasing energy security as an agent for decoupling energy consumption from imports of foreign energy products, and as a vector for innovation and development in the EU and identifying energy security strategies [158]—all aspects referred to in the EU’s strategic energy and climate framework and linked to the transition to a sustainable development model. The study of the relationship between the deployment of RES and the net generation of qualified employment is suggested as a possible item to be deepened by means of econometric analyses.

Finally, with regard to the conditions under which investment in RES (“Under what conditions?”) should be promoted, the analyzed literature has focused especially on the effect of RES on the functioning of energy markets, especially in the electricity market. However, the volume of existing literature seems to be considerably lower than that included in the two previous questions. Specifically, it would be advisable to go deeper through the use of econometric techniques in aspects such as the assessing of the impact that renewables have on the competitiveness of countries and, from the social point of view, on final electricity prices (net merit order effect of RES).

Table 8 summarizes the main conclusions of the study. For each of the major questions raised in the EU 2020–2030 climate and energy strategic framework, this table lists the topics that have been

frequently addressed by econometric analysis, as well as those topics that require a higher volume of econometric analysis to be used to support policymakers.

Table 8. Topics related to the deployment of RES and the EU 2020–2030 climate and energy strategic framework analyzed by econometric methods.

	WHICH TECHNOLOGIES AND HOW?	WHY?	UNDER WHAT CONDITIONS?
Addressed Topics	Deployment of wind and solar PV technologies.		
	Analysis of the effectiveness of support policies: feed-in-tariffs and quotas.	Assessment of the impact of RES on CO ₂ emissions.	Role of variable RES in liberalized electricity markets.
Topics that Need to be Addressed	Innovation in RES sector.	RES and Economic development.	Social acceptance: willingness to pay.
	Financial resources.		
	Identification of drivers and barriers for RES deployment.		
	Determination of support levels.		
Topics that Need to be Addressed	Electricity generation from biomass.	RES and energy security.	Social acceptance: NIMBY (not in my backyard) effect.
	Deployment of bioenergies.		
	Regional policies for RES deployment.	RES and generation of qualified employment.	RES environmental impacts.
	Electricity grid transformation.	International trade of RES sector.	Effects on retail electricity prices.
	Competitive incentives (auctions).		

Source: own elaboration.

As can be seen in the table above, in general, the greatest contributions of the econometric approach to the literature on the development of RES in the framework of the EU referred to mature technologies (wind and solar photovoltaic) and, in particular, to public policies supporting investment in these technologies. Furthermore, it is worth noting the existence of econometric studies that delve into the factors (in addition to public policies) that influence the development of renewable energies, and the role played, in particular, by innovation and financing mechanisms. On the other hand, there has also been a relatively high number of econometric contributions that justify the development of renewables from the perspective of their contribution to the mitigation of greenhouse gas emissions, and as a driver of economic development. Finally, a large part of the contributions have focused on the role of RES in the electricity market and, particularly, on the analysis of the willingness to pay for more expensive energy in consideration of increasing the weight of renewables in the energy mix.

Nevertheless, the European strategic framework for 2020–2030 involves a huge effort in the deployment of RES under changing conditions, which gives added value to the development of econometric analyses of emerging matters that should be assessed in order to achieve the effective implementation of this framework. This study, based on the analysis of the key elements of the European framework and an exhaustive review of the literature, has identified some of these matters that do not yet have enough econometric literature to support policy makers.

On the question of which RES to support, the EU 2020–2030 climate and energy strategic framework is focusing on wind, solar photovoltaic, and biomass. However, in the econometric literature there is a lower presence of studies on biomass, so it would be recommendable to develop more analyses devoted to the policies and drivers for the deployment of biomass-based energy technologies.

Precisely, in relation to public policies to support the development of RES, the sharp fall in investment costs, together with the high relative cost of support instruments, such as FITs, have led the European Commission to encourage the implementation of new support instruments based on

competition mechanisms, such as capacity auctions. Therefore, this topic requires a greater load of econometric studies that assess the effectiveness of these mechanisms in the deployment of RES.

Similarly, the increase of the weight of RES in the energy mix, and specifically in the case of electricity, implies substantial investment to adapt the electricity grid to a new decentralized system, in which variable energy sources play a key role, and in which interconnections between national electricity systems must be enhanced, as is recognized in the European strategic framework. In contrast, a review of the econometric literature reveals a lack of studies assessing the economic consequences of this transition to a decentralized and interconnected system. Therefore, new studies are necessary to provide evidence on the subject. In addition, in this decentralized system, the incentives for the deployment of RES at the regional level are particularly relevant, so we believe that a greater effort on the analysis at regional level would be a valuable contribution.

In relation to the motivation for supporting the development of RES, most econometric studies have shown the relationship between the deployment of RES and the reduction of greenhouse gas emissions. However, the EU's strategic framework also makes explicit the importance of RES as a provider of energy security by reducing Europe's dependence on Third World countries supplying fossil fuels. The economic assessment of this dimension should be addressed further in the econometric literature. Europe also has a leading RES development sector, which has economic implications in terms of trade and demand for qualified employment. The review of the econometric literature points to a lack of studies quantifying the economic impact of the development of the RES sector from this approach.

Finally, the European energy strategic framework considers the social impact of the deployment of RES. For instance, several studies have assessed the role of these technologies in the electricity market, particularly with regard to their influence on the wholesale price of electricity, known as the "merit order effect". However, only a limited number of econometric analyses assessed the effect of RES on the retail price of electricity, with inconclusive results. Therefore, more contributions are needed in this regard to draw more accurate conclusions in relation to the affordability of the electricity.

Some contributions analyzed the willingness to pay a higher price for energy derived from the use of clean sources such as RES. Nevertheless, the drastic reduction of the costs of RES, combined with the transition towards public support instruments based on competition mechanisms, has made the main RES (wind, solar photovoltaic) competitive, and therefore the study of the willingness to pay is expected to be progressively less relevant.

Contrary to the massive development of RES, from a social perspective, it has given rise, in some areas of Europe, to a feeling of disapproval of their deployment, due to certain externalities, which is known as the not in my backyard (NIMBY) effect. Given that the European strategy sets high growth targets for the deployment of RES in the period 2020–2030, empirical evidence is required on the social impact that RES may entail in terms of externalities.

The critical review of the econometric literature on the development of RES in the EU presented in this study is, to our knowledge, the most comprehensive in terms of number of studies analyzed. There are other papers that have reviewed the econometric literature on the same area (for instance, according to the Scopus classification, [31,38,42,89,139,143,144,152,158,164]). However, we believe that this study is complementary to such reviews, since this study also revised the literature in order to determine which topics may provide support to policymakers for the implementation of the EU energy strategic framework (see as Supplementary Materials), and to identify the lacks in this literature, but it does so from multiple perspectives; whereas the rest of the studies focused on the in-depth review of only certain topics. Finally, as in any research, there are certain points that can be improved in future contributions. In this sense, it is worth noting the improvement of the search engine to obtain a set of studies that are more in accordance with the aim of the study. In addition, we expect to integrate into the study a higher number of documents that were not automatically collected by search engines and to explore other sources of literature. A third improvement will be to exclude other papers from the study which are, in turn, reviews, in order to minimize the risk of committing any sort of bias in the conclusions.

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