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Renewable energy source integration into power networks, research trends and policy implications: A bibliometric and research actors survey analysis☆

Emmanuel Hache[a,d,e,*], Angélique Palle[b,c]

[a] IFP Énergies Nouvelles, 1–4 av. de Bois Préau, F-92852 Rueil-Malmaison, France
[b] IRSEM, Ecole Militaire, 1 place Joffre, 75700 Paris SP 07, France
[c] Université Paris 1 Panthéon-Sorbonne, UMR Prodig, France
[d] The French Institute for International and Strategic Affairs, (IRIS), France
[e] EconomiX-CNRS, University of Paris Nanterre, France

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ABSTRACT

This article studies the integration of variable renewable energy sources (RES) into power networks. The main goal is to confront the contents and trends of scientific literature with the eyes and projects of researchers on future topics and issues to be solved, especially in terms of the modeling of electrical systems. The analysis relies on a bibliometric study of the Scopus database on the topic and on an online survey sent to the corresponding authors of the identified papers. The paper analyzes the dynamics of publication, clusters of collaboration, and main topics studied. It then identifies potential research leads, among which unresolved challenges regarding technical aspects, markets and financing issues, and social aspects. The disparity of models and results is still a necessary evil as research is not mature enough to integrate in one model all the very complex parameters of VRE integration into power systems. There is a lack of recurrence, though, such as the impact of emergent technologies or the development of substitute low carbon-emitting technology (other than solar and wind), need to be addressed. The paper also advocates the need for a systemic vision, for both research and policymakers that goes beyond the sole power system.

1. Introduction

The United Nations Environment Programme's (UNEP, 2018) latest report on *Global Trend in Renewable Energy Investment* (2018) in collaboration with Bloomberg New Energy finance (BNEF) recorded an increase in renewable energy (RE) investment of 2% between 2016 and 2017 to about $280 billion, or cumulative amounts since 2010 of about $2.2 trillion (Fig. 1). Nearly 157 GW of new renewable electricity generation capacity was added, representing nearly 70% of new electricity generation capacity. The solar sector (38% of new electricity production capacity) and China (45% of investments in renewable energy) are at the forefront of the changes observed in the global electricity mix. In 2017, solar, wind, geothermal, biomass, waste, marine energy, and small hydro technologies accounted for 12.1% of global electricity generation, compared with 11% in 2016.

For the past two decades, a strong interest has emerged in favor of the integration of renewable energy sources in the energy and electricity mix, both in order to ensure energy security within the framework of energy transition policies and to address climate change consequences. Transitioning toward renewable energy sources seems all the more relevant because they allow the state to earn double dividends, as their diffusion actually reduces the volume of imported fossil energy (Criqui and Mima, 2012). For instance, in France the 2015 law on energy transition imposes a 30% diminution objective in the consumption of fossil energy. This would in turn lead to a 30% decrease in the country's energy dependence (given that France imports 99.9% of its fossil energy), induce a decrease in commercial deficit (and thus, of their financing), and could disrupt certain geopolitical balances or

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* Corresponding author at: IFP Énergies Nouvelles, 1–4 av. de Bois Préau, F-92852 Rueil-Malmaison, France.
E-mail address: emmanuel.hache@ifpen.fr (E. Hache).

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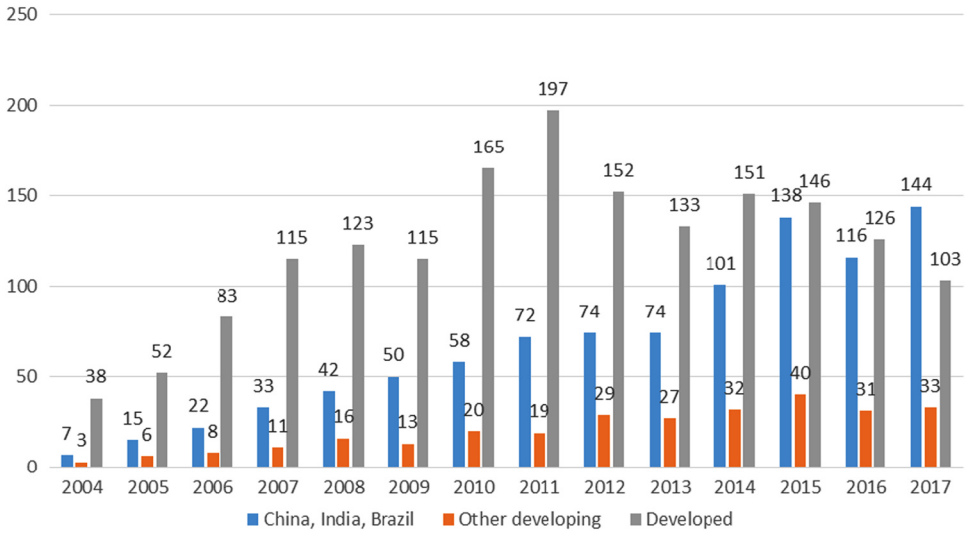

Fig. 1. Global New Investment in Renewable Energy*(Billion $US). * New investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals. Developed volumes are based on OECD countries excluding Mexico, Chile, and Turkey. Details can be found at the following internet address: http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf. Source: UNEP, Bloomberg New Energy Finance

relationships with other importing countries. In order to assess relevant energy policy in this context, governments and states are leading the energy transition scenario, based on different tools such as model, storytelling or expert-based study.

One of the key questions raised by these foresight exercises concerns the evolution of the electricity supply and the conditions for integrating a growing share of variable renewable energy sources (RES) into power networks. This gradual increase must indeed take into account several factors: costs of the different technologies (wind, solar, etc.), public policies supporting variable RES, constraints due to the intermittency of these resources, productions in the network, regulation and political body expectations and evolutions, etc. All society stakeholders (state, company, consumer, non-governmental organizations) are now concerned by these various challenges and the multiple actions undertaken by politicians, citizens' associations, businesses and other institutional and non-institutional actors have led research – whether public or private – to work on the concrete, technical, social or political impacts of the evolution of our energy systems. Both governments and citizens are nowadays associating the fight against pollution and climate change with the development of renewable energy sources.

The profusion of scientific research along with the numerous reports issued by government agencies reflect the interest and the concern of politics and society on this topic. The number of research papers or studies on the integration of variable RES into power networks has grown drastically since the beginning of the 2000s. In these numerous works, hypotheses differ depending on the space and timescale which are studied. The technical and complex aspect of the topic combined with its social and political offshoot often make it difficult to develop a global and synthetic approach to the research carried in this domain. This paper seeks to provide this global synthesis, through a bibliometric and bibliographic approach combined with a survey among actors of the energy research field and especially modelers.

2. Methodology

This article is based on a bibliometric study of the Scopus[1] database on the topic of the integration of variable RES along with a review of the analysis of different government or regulation body reports on this topic. To confront the bibliometric and statistical results of the current and prospective research trends, an online survey was proposed to the researchers of the domain between June and July 2017.

[1] Scopus is the database of academic journal articles and other peer-reviewed publications related to the Elsevier publisher. It covers about 55 million entries.

2.1. Bibliometrics: recent state of the art

Bibliometric analyses are used to explore the research trends and the evolution of researchers' interests in a field. Studying recently published research (2015–2018) we analyzed papers in the field of energy and environment that explicitly referred to the use of bibliometric analysis (Han et al., 2014; Wei et al., 2015; Chen et al., 2016; Gao et al., 2016; Yu et al., 2016; Zhang et al., 2016; Wang et al., 2017a, 2017b; Merigó, Yang, 2017; Zhang et al., 2017; Geng et al., 2017; Chen et al., 2017; Geng et al., 2017; Fabianne de Paulo and Silveira Porto, 2017; Aleixandre-Benavent, et al., 2017; Mao et al., 2018; Tiana et al., 2018). An analytic table of the different papers, their scope and the keywords and methods they use is provided in the appendix. These papers address different topics related to various energy questions: greenhouse gas emissions or climate policy assessment (Geng et al., 2017; Li and Zhao, 2015; Tiana et al., 2018; Wei et al., 2015); low carbon development or technology development (Gao et al., 2016; Fabianne de Paulo and Silveira Porto, 2017; Han et al., 2014; Yu et al., 2016; Wang et al., 2017a, 2017b); carbon tax (Zhang et al., 2016); water footprint (Zhang et al., 2017); deforestation or biomass issues (Aleixandre-Benavent, et al., 2017; Mao et al., 2018) or life cycle assessment (Geng et al., 2017). The two most common methods used are content analysis and citation analysis. Content analysis uses either keyword analysis, which provides stats on the frequency in the literature of some chosen concepts, methods, technical terms, etc., or co-word analysis that searches for the strength of relations between words and by mapping them thus identifies relations and interactions between topics and emerging research trends (Wang et al., 2017a, 2017b). Citation analysis maps the relations between the different parts of the literature – mainly who cites whom – and thus identifies core literature, papers, journals, countries, authors, etc. (Gao et al., 2016). Social network analysis (SNA) using software such as Bibexcel and Gephii, which are the most popular currently in use (five papers over 17 studied mention using both software types), derives from citation analysis and assesses the relation between researchers, institutions or countries exploring the links between them (co-publication, partnerships, co-affiliation, etc.). In most cases, results come out as clusters of relations between concepts, authors, research institutions, etc. Papers usually choose between the two approaches, focusing either on the content of the literature through keyword analysis or studying the publication dynamics, assessing production or collaboration status. Here, we combined the two methods, as we needed both a mapping of production and collaboration statistics to link it to the energy policy led by different countries or regions, and an assessment of the trending research topics to build our online survey.

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