Technology in Society 69 (2022) 101955

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

Open and collaborative innovation for the energy transition: An exploratory study

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ARTICLE INFO

Keywords:
Innovation
Energy transition
Business model
Open movement
Collaboration
Energy sector

ABSTRACT

This work aimed at investigating how electricity sector companies have adapted their approaches to innovation in response to calls for openness and the participation of new actors. It combined results from academic and grey literature as well as real-world initiatives to identify companies' strategies to innovation. A systematic literature review was conducted, aided by the development of an ontology of collaborative and open approaches to innovation. These approaches were associated with four main aspects: open innovation, business model innovation, non-producer innovation, and the open movement. Among the main findings, it can be highlighted that, although partnerships, alliances, and co-development are now quite common, electricity sector companies have just started to participate in open data and open-source initiatives. Outbound innovation is less common compared to inbound practices. Co-creation, co-design, and crowdsourcing reflect the inclusion of communities in the ideation of transition pathways, even though in a limited manner. The inclusion of civil society is also emphasized in the development of alternative partnerships and user innovation. Challenges that accompany the implementation of collaborative and open approaches to innovation are varied and contingent on local circumstances, which emphasizes the relevance of international partnerships for the energy transition.

1. Introduction

The energy transition requires huge shifts in power generation, distribution, and consumption. Technological, social, and organizational innovations are at the core of these changes. Technological because new or improved technologies are necessary for, e.g., energy generation, efficiency, and storage, social as users and communities commence to play new roles as producers and funders of local energy transitions, and organizational because companies must adapt their business models (BMs) to take advantage of market opportunities and reduce financial risks. Therefore, new BMs and Business Model Innovation (BMI) have been mentioned as fundamental for the energy transition due to the need to meet climate change and incorporate digitalization and decentralization trends [1,2], which can be a particularly difficult task for electricity utilities. This is because, until the mid-1990s, utilities were often owned or controlled by the state operating as quasi-monopolies, especially in Europe [3]. Additionally, innovation was not seen in the same way it is today, "*as a tool for competitive differentiation*" [3], p. 352, but rather as a mean to provide customers with reliable energy supply. Since then, the electricity industry has experienced widespread liberalization [4], which resulted in deep changes in the strategies adopted by energy utilities, including strategies for innovation and collaboration. The 'open movement' and governance shifts have also modified consumers' needs and expectations towards energy services [5]. Therefore, in addition to liberalization and new entrants to the energy market, calls for openness, the growth of digital tools (e.g., blockchain [6]), the financial crisis of 2008 [7], and the advancement of renewable energy (RE) have put power companies under pressure to innovate their BMs.

Without adapting BMs, utilities are at risk of not absorbing or capitalizing knowledge that is external to the organization, which is dependent on firms' absorptive capacity [8]. The ability to access and take advantage of external knowledge is directly related to open innovation (OI) [9], which can be particularly relevant for areas in which a large amount of resources is necessary for technological development, as it is the case of the energy transition. As stated by Ref. [10], "*technology actors may bring about new technological innovations, challenging the incumbent players and disrupting the existing regime, but at the same time, must also endeavor to collaborate with the incumbents and communities*", p. 99. Therefore, large collaboration networks have been developed and formalized through different agreements such as strategic alliances,

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https://doi.org/10.1016/j.techsoc.2022.101955
Received 5 November 2021; Received in revised form 22 February 2022; Accepted 24 February 2022
Available online 4 March 2022

co-development, joint research and development (R&D), and partnerships [11]. Although partnerships between government, industry, the community, and the research community are not exactly new, their broad incorporation in a traditional sector, i.e., the electricity sector, can be a game-changer in case it reduces the investments and time necessary to address the urgent issue of climate change and decarbonization. From this background, the present work aims at identifying if and how companies in the electricity sector have incorporated open and collaborative innovation into their practices and BMs. It does so by applying a perspective in which influences from OI, BMI, non-producer innovation, and the open movement are considered.

On related works [5], identified the key drivers that motivate firms in the power and energy sector to embrace OI. In 2017, the authors proposed a fuzzy cognitive map to evaluate the involvement of government, academia, customers, and suppliers into OI practices in power and energy firms. As a main benefit of OI, they highlighted the possibility of companies sharing costs and risks, which is particularly relevant for a sector that is not traditionally attracted to radical (and risky) innovations. Nevertheless, the authors pointed that, even though collaborating with other actors, especially universities, firms in the power and energy sector are still more attracted to develop incremental and low-risk innovation [5]. The work of [12] proposed a "new framework to evaluate energy organizations on openness of their structure", in which energy companies are seem as strongly dependent on external factors due to the highly regulated nature of the industry and the heavy influence of government and large corporations. Lastly [13], evaluated what the authors called the "paradox of openness" in energy and transport-related companies, underscoring the danger of overly deterministic research as every firm has its own approach to innovation. The latter work also highlighted that conflicts among stakeholders are a downside to openness and larger collaboration networks due to increased complexity [13]. BMs changes and BMI have also been largely addressed in the literature and applied to the energy sector in certain cases [14–16].

The literature on innovation research is vast, and many other works could be cited herein, e.g., related to user innovation [17] and crowdsourcing [18]. Nevertheless, differently from previous works, this paper discusses the responses of companies aided by the creation of an ontology of collaborative and open approaches to innovation based on four main aspects: OI, BMI, non-producer innovation, and the open movement. To do so, a systematic literature review was performed and complemented by evidence gathered from real-world initiatives. From the knowledge of the authors, this is the first work to investigate the response of electricity sector companies' approaches to innovation from this perspective. In other words, we aim at answering the following research questions: "How have electricity sector companies adapted their innovation practices and BMs to respond to increasing cooperation levels?" and "Has the call for openness and transparency from the 'open movement' influenced the innovation practices and BMs of electricity sector companies?". If yes, "what are the 'open movement' effects on electricity sector companies?". Because time and resources are crucial aspects of the current transition, the contribution of this research relates to exploring how increasing collaboration levels and the 'open movement' have supported and can (potentially) speed the energy transition through the activities developed by electricity sector companies. The systematic literature review and the gathering of information from companies allowed the authors to identify gaps in the literature and recommend lines for future research.

The next sections are organized as follows. Section 2 introduces the concepts used to identify and discuss collaborative approaches in the energy industry, namely the open movement, OI, non-producer innovation, and BMI. It also brings some general and practical examples of each concept. Section 3 presents the methodology, starting with the development of an ontology of collaborative and open approaches to innovation, followed by the establishment of research questions, objective, and hypothesis, and the systematic literature review. Section 4 addresses more explicitly the initiatives taken up by energy companies according to the presented ontology. This work concludes with main findings, limitations, and recommendations for future research in Section 5.

2. Theoretical background

2.1. The open movement

The pace and nature of technological innovations have had an essential role in shaping society by altering the ways by which people and organizations interact with each other. The ability to receive instantaneous feedback and data from all over the world allowed unprecedented levels of collaboration among communities, which had remarkable impacts, especially on science. As a result, scientific production has experienced huge growth since the 90s, through increased access to information, rising competition across nations, and new ways of collaborating [19]. This is related to the birth of the "open movement", which calls for increased transparency and participation of a wider and more diverse actor network for creating and disseminating knowledge [20]. Some authors believe the open movement is causing a revolution in the way science is made [20,21], while others doubt its validity and hidden motivations [22,23]. Academic culture, where scientific knowledge has thrived, has been characterized by its openness since the 16th century at least, but new information and communication technologies (ICTs), and tools have expanded the possibilities [20]. According to Ref. [24], the term "open science" captures an expanded notion of openness within a scientific community that shares results almost immediately and with a wide public. It is also linked to new ways of measuring the impact of science, publicly available research, collaboration tools and platforms, specific intellectual property rights, open data, open source, and open access [24].

In response to the increasing demand for research that is freely and readily available online, several initiatives have been developed around the world to enable the reuse, redistribution, and reproduction of research. In the European Union (EU), examples are the Budapest Open Access Initiative [25] and the Project FOSTER - Fostering the practical implementation of Open Science in Horizon 2020 and beyond [26]. The concept of open access, according to the Budapest initiative, can be understood as an instrument of open science in regards to offering online and free access to peer-reviewed scientific publications without most of the limiting copyright and licensing restrictions [25]. Civil society's ability to participate in innovation development is also promoted from an open perspective. By making data available to the public, the government's transparency and accountability are increased, as well as citizen participation and engagement [27]. For researchers and decision-makers, it facilitates research development and gives information for more robust decision-making [28]. As stated by Ref. [29], open data refers to data that can be accessed online, with no charge, and can be used, reused, and distributed without restrictions. Examples of open data initiatives are the Latin American Open Data Institute, or Instituto Latino Americano de Datos Abiertos (ILDA) [30], and the North American Data.gov [31]. From an open perspective, there are specific advantages of making models and data open: (i) reproducibility of research, transparency, traceability, and peer-reviewed works; (ii) more effective collaboration between academia and government; and (iii) time and resources savings by avoiding unnecessary duplication of work and higher levels of collaboration among academics, which would cause a steep increase in the learning curve [32].

Nevertheless, joint open initiatives are not new to the software development industry as it is the case of open-source software (OSS). OSS has its source code made freely available for adaptation and dissemination and is built jointly and voluntarily by software developers [33]. Well-known examples of open source are Linux and Android operating systems [34]. In general, volunteers might participate in open source initiatives seeking learning opportunities, skills development, or personal interest [35]. Companies, on the other hand, have economic incentives for the adoption of OSS such as cost reduction in the development phase [36]. According to Ref. [37], OSS is also more creative, cheaper to produce, presents higher quality, and errors are found and fixed more rapidly. Its time-saving aspect is quite relevant for developers, who can reuse and adapt software components to their necessities [24].

2.2. Open innovation

One of the most popular concepts to emerge in innovation management in the 21st century was the concept of "open innovation" [38], which was developed by Chesbrough, in 2003, pointing to an overall shift in the innovation process, from closed to open. OI is a "*paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms seeks to advance their technology*" [9], p. 24. Therefore, it is no longer assumed that a company and its R&D team, for example, are in the best position to innovate on internal matters, as it is assumed in a closed perspective. Users, retailers, suppliers, competitors, universities, research labs, and individual researchers outside the organization are acknowledged as capable and valuable collaborators in the innovation process. This type of innovation, when the company opens up to external inputs and contributions, is known as outside-in or inbound OI [39]. Examples of inbound innovation are acquisitions, merges, licensing-in, minority equity investments, and R&D contracts [40]. Inside-out or outbound OI, on the other hand, is less common and happens when the organization allows internal ideas to go outside and be used by others [39], such as licensing-out, divestments, and spinning off [41]. Other strategies that have been associated to OI are linked to collaboration and joint initiatives between different actors, mainly private companies, i.e. coupled processes [41]. Nevertheless, these coupled processes are also linked to BMI and companies' adaptation to increased levels of collaboration, which are further discussed in Subsection 2.4.

When OI is applied to profit-oriented businesses, it is assumed that many if not most experts and innovative potential are placed outside the company. This, however, does not abstain the company from investing in its internal R&D since "*the lack of internal R&D resources may limit an organization's ability to explore new knowledge domains*" [8], p. 243, which is translated into its absorptive capacity [42]. Nonetheless, R&D capacity was not the only factor for the development of OI. Workforce mobility, more capable universities, start-ups' access to venture capital (VC), the Internet, ICTs, among other socio-technical factors, have augmented the importance and feasibility of OI [39]. Policies propitious for knowledge dissemination and the adoption of open concepts by governments, academia, and private corporations have also contributed to OI and the development of new technologies and BMs [39,43].

2.3. Non-producer innovation

Although innovation by firms has been at the center of economic dynamics, non-producer innovation may also have an important role to play in the energy transition. According to Ref. [44], "*it has been assumed that the most important designs for innovations would originate from producers and be supplied to consumers via goods and services that were for sale*", p. 1399. In other words, profit-oriented BMs have been in a better position to innovate thanks to their inherent motivation and higher available funds for innovation research. However, this is not necessarily true, as argued by Hippel [45]. During the energy privatization in the UK in the 1980s, for example, R&D responsibilities were transferred from the public to the private context, which caused many issues because of "*incompatibilities between short-term and profitability-led investment objectives of the private sector and the more long-term, efficiency-based and sustainable demands of energy services*" [46], p. 883. Mismatched profit and time scales are a common concern for profit-oriented businesses, especially when incorporating sustainability and efficiency requirements.

The main idea behind non-producer innovation is mobilizing individuals' tacit knowledge towards innovation [33]. It encompasses initiatives that come from the civil society, as users (e.g., user-led innovation) and communities (e.g., grassroots innovation, common innovation, and social innovation) [33]. Users are defined as "*firms or individual consumers that expect to benefit from using a design, a product, or a service*" [47], p. 3, while producers expect to benefit from the profit of selling a product or a service. Essentially, users are solving their own problems when innovating [48], because, by accustoming a particular product or technology to their specific reality, users may obtain more efficient outcomes. That is why, in some contexts, users can be seen not only as a source of ideas but drivers of the innovation themselves [47].

There are two main concepts related to non-producer innovation: crowdsourcing and co-creation [49]. Crowdsourcing refers to a company presenting a challenge to the public, who comes up with ideas and solutions [50]. It is also known as closed collaborative innovation, as the public influence is limited to offering ideas in a one-way process [44]. Co-creation, on the other hand, is a more collaborative process than crowdsourcing as it relies on the "*active involvement of end-users in various stages of the production process*" [49], p. 1335. Both approaches have been applied to the energy sector. Crowdsourcing, for instance, can be an effective way of obtaining data for energy models by making use of observations from community members [50], whereas co-creation with citizens and stakeholders can be linked to social innovation (SI), as it supports participative governance models [49]. Examples of SI in the energy context are RE cooperatives, e.g. Ref. [51], and community-owned energy storage systems e.g., Ref. [52]. When stakeholders actively participate in the knowledge-acquiring or decision-making process, they are prone to increase effectiveness and reduce conflicts by taking ownership of outcomes [53]. Thus, in addition to access individuals' tacit knowledge, citizen participation in innovation, whether through user-led or community-based initiatives, has a positive network effect on innovation diffusion [54,55].

2.4. Business model innovation

According to Ref. [56], a BM can be understood as the design of value creation, value delivery, and capture mechanisms of a business. In other words, it is how a company creates value for itself while delivering products or services for customers. BM frameworks can be represented by different elements related to value propositions, customers, revenue streams, resources, cost structure, key activities, and key partnerships [57], for example. Considering the need for sustainable practices in a low-carbon economy context, companies have to think not only about how environmentally friendly their products or services are. They must also consider how the company interacts with this emerging sustainable highly digitized and fast-changing market and its actors. As stated by Ref. [58], "*enhanced sustainability or circularity requires changes in the way companies generate value, understand and do business […] moving from a firm-centric to a network-centric operational logic*", p. 199. Government, regulatory bodies, competitors, suppliers, consumers, researchers, universities, and end-users, for example, are part of this network of stakeholders [59]. From an innovation perspective, innovation sourcing must be aligned with other components of the BM [9]. If a company decides to adopt OI practices, it implies different approaches to licensing and intellectual property, commercialization, and profit-making channels, i.e., an appropriate BM.

BMI consists of "*a change in the configuration of either the entire business model or individual elements of it, either as a reaction to opportunities or challenges in the organization's environment or as a vehicle for diversification and innovation*" [60], p. 405. That is to say that a business must adapt itself to respond to new technologies, new habits of consumption, and market trends. One way of innovating the BM that has seemed very effective is through co-development partnerships in which two or more parties agree to develop jointly a new technology, service, or product [61]. Co-development can significantly reduce R&D expenditure, increase efficiency and quality of research, and even open up new markets [9]. Nevertheless, the parties involved in the energy transition have developed a diverse range of partnerships and alliances that are further discussed in Subsection 4.4.

3. Methodology

3.1. Ontology: collaborative and open approaches to innovation

Based on the presented theoretical background and the variety of related terms, it is useful to establish an ontology, which comprehends domain assumptions and the researcher's view of the nature of reality [62]. It has been proposed, for instance, in Ref. [17] for user innovation and [63] for software engineering. Herein, the ontology is captured in the form of hierarchical conceptual relationships, which were derived from Section 2, and depicted in Fig. 1. In other words, collaborative and open approaches to innovation are analyzed as a product of OI, BMI, non-producer innovation, and the open movement (blue arrows). These four main parent concepts are further split in subcategories (black arrows). This conceptual mapping helped delineate the coding processes within the literature review and derive lines of discussion.

Furthermore, it is necessary to define what is meant by "electricity sector companies". In this case, it includes companies that work with electricity generation, i.e., electricity utilities, electricity providers, and grid operators, and companies related to smart grid planning and modeling. As this work aims at identifying how electricity sector companies have adapted their innovation practices and BMs to respond to increasing cooperation levels and calls for openness from other actors, it is also useful to define what is meant by "open and collaborative approaches to innovation". It refers to responses of private companies as means to adapt their BMs, R&D, and innovation strategies to increasing participation and collaboration of other actors and their calls for openness.

3.2. Research questions, objectives, and hypothesis

Following recommendations regarding rigor and appropriateness provided by Ref. [64], research questions, objectives, and methods are presented in this section. In essence, this is a qualitative research based on a systematic literature review and examples from the energy industry, which are used to answer the research questions below.

- How have electricity sector companies adapted their innovation practices and BMs to respond to increasing collaboration levels?
- Has the call for openness and transparency from the 'open movement' influenced the innovation practices and BMs of electricity sector companies? If yes, what are the 'open movement' effects on electricity sector companies?

Accordingly, the following research objective can be stated: "to identify if and how companies in the electricity sector have responded to increasing collaboration levels and calls for openness". Evidence was gathered through the research method described below to address the research hypothesis: increasing collaboration levels among actors and calls for openness have influenced electricity sector companies' innovation practices and BMs.

3.3. Literature review process

For the systematic literature review, the first step consisted of determining the search string according to the presented ontology. After

Table 1
Search string structure.

Main concept	Fields	Terms included in the search string
Innovation	Title, Abstract, and Keywords	innovation AND
Open initiatives	Title, Abstract, and Keywords	("user innovation" OR "crowdsourcing" OR "co-creation" OR "co-design" OR "citizen engagement" OR "open data" OR "open source" OR "open platforms" OR "triple helix" OR "joint research and development" OR "open innovation" OR "collaborative innovation" OR partnership OR venturing OR alliances OR "spin off" OR "mergers and acquisitions" OR "M&A") AND
Electricity sector companies	Title, Abstract, and Keywords	(energy OR electric OR electricity) AND (utility OR provider OR company)

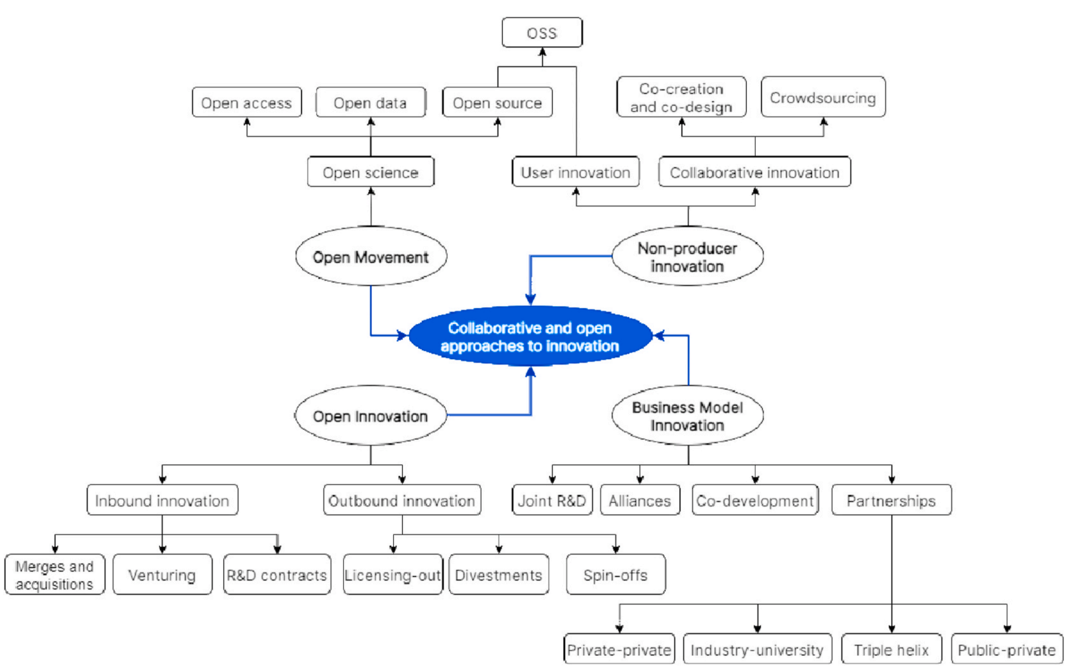

Fig. 1. Mapping of concepts related to collaborative and open approaches to innovation.

a series of combinations (40 in total), the authors ended up with the terms presented in Table 1 that yielded a total of 164 results on the Web of Science (WOS) database on January 9, 2022.

From the 164 results, records that (i) were not written in English (n = 6), (ii) had been published before 2002 (n = 12), and (iii) did not consist of conference, research, or review papers (n = 2) were excluded before screening. Therefore, of the 164 records, n = 144 records had their titles and abstracts screened. Afterwards, n = 80 records were excluded because they did not fit the scope of research, i.e., they were deemed not useful to answer the research questions. From the 64 records left, n = 4 could not have their full texts accessed. After accessing the full text of the remaining 60 articles, 35 records were included in this review. Specific reasons for excluding n = 25 papers at the full-text screening stage can be abridged under two main reasons: (1) they did not focus on electricity sector companies (n = 17) or (2) they did not focus on companies' approaches to innovation (n = 8). The identification process from WOS database is illustrated in Fig. 2.

The records included in the review are displayed in Table 2. Concerning the publication type (PT), n = 10 works are conference papers (C), and n = 25 are journal articles (J). Most works were published in 2017 (n = 9) and 2018 (n = 8). Works were also classified according to the main categories established in the ontology (Fig. 1): BMI, OI, non-producer innovation (NPI), or open movement (OM). Particularly, in the BMI category, n = 16 works address partnerships of which nine report partnerships with universities. As it can be seen, no works could be found in relation to the open movement, so the need for looking for references, i.e., companies and initiatives, outside the WOS database.

Besides the evidence gathered from the afore described literature review, the authors also included additional references for partnerships that involved unconventional actors and/or purposes and searched for initiatives from the electricity sector by looking at companies' activities and open initiatives online. This proved especially relevant for coding categories the literature search did not yield significative results, i.e., open movement. Companies, partnerships, and initiatives included in the review are summarized in Table 3.

4. Collaborative and open approaches to innovation in electricity sector companies

Following the concepts presented in the adopted ontology (Fig. 1) and the coding process, this section explores cases and unfolds a discussion around the responses of electricity sector companies to the Open Movement (subsection 4.1), OI (subsection 4.2), non-producer innovation (subsection 4.3), and BMI (subsection 4.4).

4.1. Reactions to the open movement: open data and OSS

As said before, there are several advantages of making data open, in particular operational and management transparency and synergies between industry and academia [32]. Our search for companies outside WOS database showed that these advantages might have been recognized by electricity sector companies, as some of the largest electricity utilities in Europe have embraced open data initiatives. Among them, EDF, the biggest producer and distributor of energy in France but also strongly positioned internationally, offered datasets on daily river flows at EDF Hydropower plants in France containing 60 years of flow measurements, along with information on nuclear and thermal units in France, and other operational and managerial aspects of the company [92]. EDP, the largest producer, distributor, and supplier of electricity in Portugal [89], has made part of its projects' data open, enabling its reuse by universities, startups, and interested people. Now, data for their SunLab project, an on-field laboratory that tests solar panels performance under different settings, and one of their wind farms are available for authenticated users [112]. Similarly, Engie, a services provider, energy producer and distributor, has made available data from La Haute Borne wind farm [113]. Other examples include the DataHub from REN the Portuguese operator of the main transport infrastructure and overall manager of the national electric system and the national natural gas system [95] and the REData for the REE [98]. Besides open data, 'open source' has also been included in energy utilities innovation approaches. According to Ref. [18], "*from the perspective of a utility firm, this (open source) is a potential source of available assets that can provide value to the firm at no direct cost*" [18], p. 63. This has been already recognized by some companies, as the work of [74] shows. The latter presents information on the French "Linky by makers" project, an attempt to bring university, a public industrial company, and community together in an open source collaboration context to develop smart meters in France [74]. In addition, two other works [18,74] mentioned "open source" to develop open platforms directed towards increasing collaboration among stakeholders.

Particularly, the energy industry has been incorporating OSS for energy modeling. Energy modeling is key for governments' development and integration plans and is also pivotal for energy decisions based on future scenario analysis. Energy modeling initiatives count on large

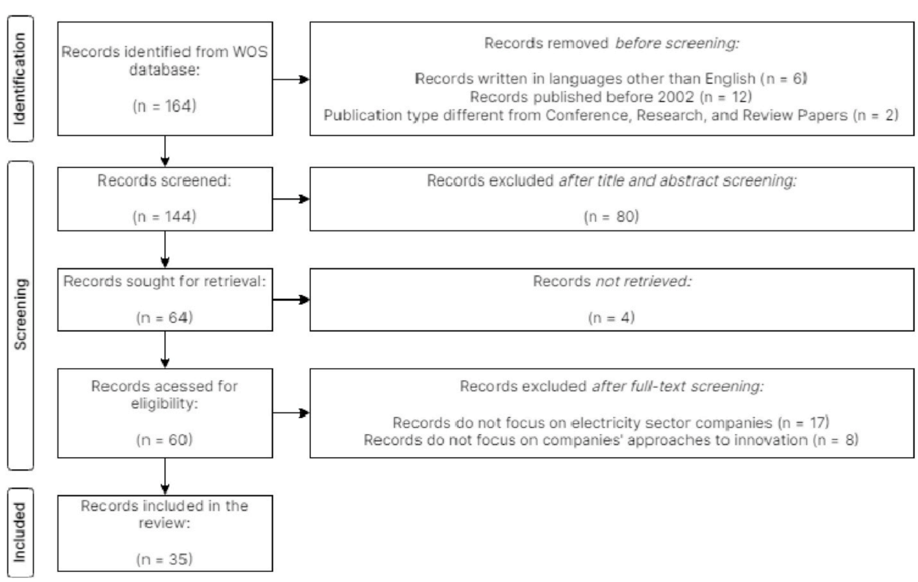

Fig. 2. Systematic literature review diagram flow. Source: Adapted from Ref. [65].

Table 2
List of works included in the systematic literature review.

Ref.	Publication title	PT	Year	Categories
[17]	Evolution of User Driven Innovation	C	2010	NPI
[66]	Renewable Energy Innovation and Governance in Wales: A Regional Innovation System Approach	J	2012	BMI
[67]	Stimulating Energy Technology Innovation	J	2012	BMI
[68]	New Venture: A New Model for Clean Energy Innovation	J	2012	OI, BMI
[69]	Nuclear electricity generation in South Africa: a study of strategic innovation for sustainability	J	2013	BMI
[70]	International Knowledge Networks in Sustainable Energy Technologies: Evidence From European Projects	C	2013	BMI
[71]	Smart Energy: Competitive landscape and collaborative business models	C	2015	BMI
[72]	The role of international business in clean technology transfer and development	J	2015	BMI
[73]	Design Driven Innovation in Clusters	C	2016	OI, BMI
[12]	Open organizational structures: A new framework for the energy industry	J	2016	OI
[8]	Can supplier innovations substitute for internal R&D? A multiple case study from an absorptive capacity perspective	J	2017	OI
[74]	Collaborative Innovation Projects Engaging Open Communities: a Case Study on Emerging Challenges	C	2017	NPI
[75]	From “living lab” to strategic action field: Bringing together energy, mobility, and Information Technology in Germany	J	2017	OI
[76]	Innovative Microgrid Solution for Renewable Energy Integration within the REIDS Initiative	C	2017	BMI
[77]	Joint business model innovation for sustainable transformation of industries – A large multinational utility in alliance with a small solar energy company	J	2017	BMI
[13]	Navigating the “paradox of openness” in energy and transport innovation: Insights from eight corporate clean technology research and development case studies	J	2017	OI, BMI
[5]	Open innovation in the power & energy sector: Bringing together government policies, companies’ interests, and academic essence	J	2017	OI, BMI
[78]	The Mexican Center of Innovation in Geothermal Energy, CeMIE-Geo: Challenges and Opportunities	C	2017	BMI
[79]	Venture Capital and Cleantech: The wrong model for energy innovation	J	2017	OI
[80]	Exponential Technologies and Innovation Ecosystems	C	2018	OI
[81]	Innovation intermediary challenging the energy incumbent: enactment of local socio-technical transition pathways by destabilization of regime rules	J	2018	OI, NPI
[11]	Network impact on business models for sustainability: Case study in the energy sector	J	2018	BMI
[46]	Rethinking the continuum between public and private actors in electricity policy in the context of the UK Energy transition	J	2018	BMI
[82]	Shareholder value and open innovation: evidence from Dividend Champions	J	2018	OI
[16]	Smart electricity distribution networks, business models, and application for developing countries	J	2018	BMI
[83]	Sustainable Campus Model at the University of Campinas-Brazil: An Integrated Living Lab […]	C	2018	OI, BMI
[10]	Typology of future clean energy communities: An exploratory structure, opportunities, and challenges	J	2018	NPI
[18]	Better together—Harnessing motivations for energy utility crowdsourcing activities	J	2019	NPI
[84]	Managing ecosystems for service innovation: A dynamic capability view	J	2019	OI, BMI
[85]		J	2020	OI

Table 2 (*continued*)

Ref.	Publication title	PT	Year	Categories
[86]	A new approach for detecting open innovation in patents: the designation of inventor Patterns for International Cooperation between Innovation Clusters. Cases of CFAA and ruhrvalley	C	2020	BMI
[15]	Smart energy driven business model innovation: An analysis of existing business models and implications for business model change in the energy sector	J	2020	BMI
[87]	Current Innovation Sources Driving The Spanish Electric Power Sector	J	2021	OI
[88]	How governments, universities, and companies contribute to renewable energy development? A municipal innovation policy perspective of the triple helix	J	2021	BMI
[14]	Sustainable energy systems in the making: A study on business model adaptation in incumbent utilities	J	2022	BMI

Table 3
Electricity sector companies and open initiatives included in this work.

Electricity sector companies	Open Initiatives	Partnerships
Energias de Portugal (EDP) [89]	Open Source Energy Modeling System (OseMOSYS) [90]	Public-private partnerships (PPP) [69,91]
Électricité de France (EDF) [92]	Global Innovation Exchange (GIE) [93]	Public-private-people partnerships (PPPP) [94]
Redes Energeticas Nacionais (REN) [95]	LF Energy [96]	Philanthropic-crowdfunding-partnership (PCP) [97]
Red Eléctrica de España (REE) [98]	PyPSA Africa [99]	Fuel Cells and Hydrogen Undertaking (FCH JU) [100]
Camus Energy [101]	Free Electrons [102]	European Hydrogen Alliance [103]
ENEL [15]	Plug and Play [104]	Pro-poor public-private partnership (5P) [105]
E.ON [106]	Energy Future [107]	
Equatorial [108]	Open Energy Modelling Initiative (Openmod) [109]	Renewable Energy and Energy Efficiency Partnership (REEEP) [110]
Ørsted [111]		

amounts of data and robust software to simulate energy landscapes that are complex and dynamic by nature. These features will be further reinforced by renewables’ deployment due to RE’s intermittency and decentralized energy generation and storage. Concerning energy modeling, emphasis can be given to the Openmod initiative, which was founded in 2014 to “*better coordinate the further development of open models and data*” [109], p. 64. It consists of a platform that enables researchers from all over the world to interact and cooperate in ways that allow reproducibility of research and coordinate efforts toward similar goals. Several benefits arise from it, such as increased quality of research, reduced duplication of works, and availability of free tools and data to researchers and policy-makers deprived of funding [109]. Moreover, OSS can contribute to energy analysis because “*open modeling efforts can improve the utility and accessibility of energy models and also lower the cost of data collection and management*” [50], p. 150. As an example, the OseMOSYS, an OSS for energy modeling, has a modular construction that allows for customization according to context and data availability, as well as extensions of its applicability [90]. Initially designed for Europe and being currently extended to Africa, PyPSA Africa is an open-source energy system model that has been built in collaboration by several universities, public and private organizations [99]. The initiative aims at building an open-source model to cover the whole continent, enhancing the potential of African capabilities and the community while offering opportunities for international collaboration.

4.2. Open innovation: outside-in or inside-out?

In [5], it is stated that power and energy sector companies face several R&D challenges not only in technological but also in financial terms, which is used be the authors as a favorable argument towards the employment of OI in the sector. On the other hand [13], suggests that there are downsides to openness and inclusion. For offshore wind, their study revealed "*conflicts about in-house versus outsourced research and who ought to control private research*" [13], p. 244, arguing that "*nascent technologies appear to benefit from openness and involvement of different stakeholders whereas those already commercialized may experience more closedness*" [13], p. 244. In agreement with this statement [85], concluded that three quarters of wind energy patents in Europe are developed by companies that use exclusive closed innovation models. Furthermore, OI can be further split into inbound and outbound innovation. In this matter, inbound innovation is dominant over outbound processes as electricity sector companies are more likely to allow external knowledge to come in than the opposite. This process, however, can compromise companies' success, especially when internal R&D capacities are lagging market requirements. This is endorsed by Ref. [8] that suggested that supplier innovations can even substitute internal R&D as long as absorptive capacities and network management are aligned to do so.

4.2.1. Inbound innovation

4.2.1.1. Mergers and acquisitions. As a consequence of the liberalization of electricity markets, an intense wave of mergers and acquisitions (M&A) took place in Europe, through which market players readjusted their production and distribution capacities [4]. M&A integrate different firms into one [14]. If in the past, companies in the electricity sector performed M&A due to cost efficiency, access to foreign expertise, and distribution networks [4], nowadays, the reasons are different. According to Ref. [114], there are four main aspects driving M&A: (i) geographic diversification, which is in line with internationalization trends [3], (ii) business diversification, (iii) balance sheet strengthening, and (iv) innovation into new lines of business, particularly digital innovation. Focused on inbound innovation [14], analyzed 756 boundary-spanning transactions, i.e., M&A, joint ventures, and strategic alliances of European utilities (including electricity utilities) from 1990 to 2019. The authors found that utilities have preference for integrating new activities through M&A, assuming they can reinforce the "*efficiency and lock-in of their traditional business model*" [14], p. 1. Apparently, M&A with a focus on decarbonization, increasing RE capacity, and enhancing the business-customer interface have increased recently [115,116]. The rapid expansion of digital applications in the energy sector has enabled small and new players, such as startups, to enter the game, which induces and promotes VC programs.

4.2.1.2. Venture capital programs and open challenges. Corporate VC programs have become a common practice among electricity sector utilities as "*collaborating with startups is recognized as a means to innovate and keep leadership in a changing industry*" [117], p. 38. The technology and knowledge exchanges between corporations and startups play a key role in reducing resources needed for innovation [118]. Therefore, if such strategic partnerships are so beneficial, the challenge is to bring together the most suited partners among thousands of energy startups worldwide. The company EDP, for instance, has a VC arm, called EDP Venture that invests in startups in the early stages of development [119]. In association with their VC investments, they also roll acceleration programs, hackathons and challenges, conferences, and summits that intend to enhance networking and connect startups and enterprises to EDP [120]. From the startup's point of view, associating with a large company represents privileged access to crucial complementary assets which can be fundamental to a successful market entry. Moreover, engaging incumbents "*provides a pathway to leverage the unique scale of capital that corporates can provide, […] a natural exit opportunity once commercial scale economics are proven*", and "*helps commercially de-risk projects*" [68], p. 57. However, "*public markets do not tend to get excited about the risk profile of projects that have not yet demonstrated commercial-scale economics*" [68], p. 57, especially when studies such as [79] demonstrate that VC invested in clean technologies posed higher risks and yielded lower results than medical and software investments.

Nevertheless [81], discussed a case of success between an incumbent in the electricity sector and a smaller intermediary in Finland. Through local experimentation, the incumbent Helen Ltd., fully owned by the city of Helsinki, collaborated with an innovation organization FVH in a R&D program for a smart grid pilot. This collaboration resulted in new actors being engaged, i.e., residents, startups, large and small companies. According to the authors, "*local experimentation was found to be a way to bring together innovation champions from incumbent companies, startups and civil society, thus enabling changes in their cognitive frames and assumptions*" [81], p. 1465. Conversely [14], asserts that when utilities venture they do so to "*reinforce the traditional utility business model [BM] which is based on a vertical integration and centralization of electricity generation and supply*", p. 15. A challenge that remains for both sides is, first, how to get in contact with each other, and second, how to efficiently cooperate.

One way to put startups in contact with larger companies is through online platforms and open challenges. For instance, the GIE, "*a global development technology platform for innovations,* funding, *and insights*" that started in 2017 and went offline in September 2021, was not limited to energy-related innovations but supported social innovations in the energy sector, ranging from clean cooking to energy policy and regulations [93]. On the other hand, the platform Plug and Play has built a network with startups, world-leading corporations, VC firms, universities, and government agencies across multiple industries, in a more capital-led initiative [104]. They run several accelerator programs for startups, corporations, and venture capitalists around the world, one of them directed to solve energy challenges through innovation in renewable and distributed energy resources, smart home and IoT, hydrogen, grid-scale storage, e-mobility and EV charging, cybersecurity, retail and customer engagement platforms, among other areas [104]. Examples of open platforms dedicated to energy only are Energy Future [107] and Free Electrons [102]. Both platforms bring startups and energy utilities together through accelerator programs (e.g., Ørsted's open challenge on wind turbine coating technologies [111] and the Equatorial 365's open challenge that looks for technological and social innovations to promote energy accessibility to a Brazilian city [108]). Nevertheless, as highlighted by Ref. [121] when investigating General Electrics' endeavor towards an open challenge, it is common to exist a mismatch of technological scale and revenue between startups' solutions and large firms' needs, which asks for close management and clear long-term business strategies from the latter in order for investments to pay off.

4.2.2. Outbound innovation

In the reviewed literature, no work exclusively addressed outbound practices. The work of [15] analyzed the BMs of 175 energy firms and highlighted the presence of spin offs as an alternative to third-party partnerships. A spin off is a company created from a parent company through the sales or distribution of new shares of the latter, process known as a type of divestiture and outbound innovation. This separation of the company into relatively autonomous business areas has to do with several factors such as the need for different technological and marketing competencies and practices that facilitate management, either by a process of corporate structuring and consolidation, or due to political and legal factors. In other words, among the reasons to create a spin off, there is the possibility of taking advantage of a segment that has been constrained within the parent company's activities, establishing an ancillary service, and reducing the necessity of more diversified resources as the parent company can focus on its core needs. Spin offs have surged in the energy industry as companies attempt to accelerate their ability to adapt and innovate in a changing and competitive market. Since it can be challenging for utilities to operate in both the traditional and renewable sectors, "green energy" spin offs focused on RE generation have been created. As an example, in 2007, the EDP Group established the subsidiary company EDP Renewables (EDPR), a spin off that operates the RE assets of EDP [122]. The same happened to E.ON, one of the first spin-off from a large utility in Germany, addressing the trends in decentralized renewable energy and smart grids, and to Uniper focused on conventional energy [106]. Other examples include Enel, who has "*bundled its smart energy-related innovation activities in the spin-off Enel X*" [15], p. 7.

4.3. Non-producer innovation: benefits from users and community participation

In the energy sector, inventive users can "*speed up the development and proliferation of distributed renewable energy technologies*" [123], p. 499. The reasons for so are, first, the alternative designs that fine adjust technology to users' particular circumstances (i.e., climate vulnerability and available energy technology), and, second, the knowledge shared with other users and producers, which increases users' awareness and engagement and saves time and resources in the product development process for producers [123]. Research has also pointed out the link between user innovation and energy communities (e.g., Refs. [124,125]). In addition to improvements in physical energy products and systems, users can also innovate in the virtual domain, especially in energy modeling. In other words, "*there are plenty of informed energy users who could serve as lead users and work with energy related companies to promote innovation in the sector*" [17], p. 5.

Considering the high costs involved in energy data acquisition and management for modeling initiatives [50], also point to the particular importance of OSS and crowdsourcing, in which users provide new ideas and feedback as observers and reviewers. This practice can be even more relevant in developing countries, where governments are prone to experience a lack of funding for energy analysis and data gathering (e.g., PyPSA meets Africa [99]). Moreover, it lowers the barriers to innovation at national levels, which has the potential to cause positive changes in society, for example, by lessening energy poverty and reinforcing democracy [50]. Camus Energy, a company based in San Francisco, CA, is building an OSS platform to enable the future Distribution Service Operator (DSO) [101]. It believes that going open source will benefit both the company and customers through faster development processes by combining external and internal expertise, enabling broad adoption by making it easy and affordable for grid operators to adopt their technology, stimulate the creation of a community where companies and research institutions develop their own solutions on a common platform and enhancing security and reliability through greater transparency [101].

A similar open approach is supported by LF Energy, a Linux Foundation project [96]. They believe that the energy transition can be accelerated by open-source modeling and open data initiatives that maximize flexibility, agility, and interoperability [96]. LF Energy OpenEEmeter, for example, is an "*open source toolkit for implementing and developing standard methods for calculating normalized metered energy consumption (NMEC) and avoid or minimize energy use*" [126]. This approach is related to smart grids, smart meters, and demand-side management, which are considered key for reducing energy consumption and avoiding grid instability in the future. Besides the key advantage of an open-source company's agility to respond to an increasingly dynamic energy market, OSS can even pose a threat to commercial software [36] because the former has no development costs, since it is developed openly and free of cost by volunteer programmers around the world [127].

As citizen engagement and participation increase in the energy sector not only through the generation, storage, and consumption of energy but also through participatory processes, energy companies also need to adapt themselves to a new class of customers and partners. The core assumption of these cooperative approaches is that the engagement of clients and civil society helps companies to deliver better services in terms of quality and stability [128]. Within crowdsourcing, utility operators can receive valuable input from customers for planning and innovation activities [18]. Research has also shown that citizens are ready to incorporate crowdsourcing in some aspects of service provision in smart cities [129]. Co-creation and co-design have demonstrated their relevance for local transformations in the energy system (e.g., Refs. [130,131]). For those that argue in favor of co-designing solutions with local communities, end-users must be included in the design process for the simple fact that they know better their daily needs and realities [132].

4.4. BMI for collaboration in the energy sector

According to Ref. [7], when analyzing the emergence of new BMs in the energy industry, most of the emerging digital green BMs can be divided into three categories: 1) distributed energy, 2) broad customer-centric models and 3) smart grids. The first category introduces the concept of prosumer [133], in which the consumer can also have the role of producer. The second category is related to smart home developments. Both categories challenge the usual customer interface, but the second involves a multifunctional management platform and several different and interconnected technologies [7]. Smart grids, the third category, expand from households to the management of supply chains and include energy producers, distributors, storage, and consumers [7]. Additionally [3], on strategic choices of European utilities, identified two major tendencies: first, a transition to Utilities 2.0, a concept which implies providing service solutions, and second, expansion of their business models towards international markets. When adopting a Utility 2.0 posture, a company can specialize in the management of decentralized assets, the management of information, or both [3].

In developing nations, however [16], called attention for the challenges faced by BMs of the power distribution sector in terms of governance and technology. Therefore, the authors proposed a smart BM, in which an open platform provides small players the opportunity to participate in the power sectors through an open market for electricity, which spills over on other sectors such as ICTs and education and training and leads to economic growth. Similarly [72], discussed BMs alternatives for less-developed economies, as the latter tends not to match electricity sector companies' interests when looking for profit in international markets. Because of that, the author suggested the development of targeted public policies and sources of funding, as well as public-private and non-profit partnerships for increasing international investment in less-developed markets. Besides, "*the local entrepreneurship that has emerged in renewable (off-grid) energy in developing countries might be helped through partnerships and linked to multinationals and potential sources of* funding, *knowledge, and expertise from business, government agencies or NGOs*" [72], p. 174.

4.4.1. Partnerships

Thanks to the importance of energy access and stability for socio-economic development, the magnitude of investment that is required for energy projects, and the presence of the state as a regulator and sometimes the owner of electric utilities, partnerships are common in the energy sector. Nevertheless, as pointed by Ref. [84], "*firms need to identify and select cooperation partners based on a systematic analysis, to set up clear structures, roles, and processes within the network and within the firm itself, and to regulate and evaluate cooperation activities continuously*", p. 515. In other words, firms must find the best suited partners (e.g., universities, private companies, public organizations) and closely monitor the partnership development. Public-private partnerships (PPP) can be understood as a form of cooperation among governments (public) and profit-oriented (or non-profit) companies aiming at providing better public services [134]. In PPP, public and private parties share risks and responsibilities in what can be short or long-term contracts. In the energy sector, growing energy requirements and infrastructure gaps may lead governments to seek private capital and expertise. For instance Ref. [91], concluded that PPP were facilitators of RE deployment in some countries. Nonetheless, the work of [69] highlighted the challenges of establishing PPP for the case of nuclear electricity generation in South Africa through a partnership involving Eskom, the main supplier of electricity in the country [69]. The project faced many issues including technology gap, poor stakeholder management, and lack of financing that led to its failure [69].

Moreover, when it comes to new technology development, traditional financing channels (e.g., banks) tend to avoid risk exposure, which requires energy companies and projects to look for new sources of capital including the public sector and civil society. Therefore, the collaboration between public and private sectors in association with people has emerged through public-private-people partnerships (PPPP). According to Ref. [94], who evaluated how PPPP could enhance the diffusion of solar photovoltaics (PV), PPPP have a big potential to overcome limited funding and risk uncertainty "*by dividing the high initial costs into more affordable sums, facilitating the information flow among different sectors, and involving all three sectors to create new incentives*" [94], p.1. Another promising way to overcome limited funding within energy projects is co-ownership or financial citizen participation [135], in which individuals are allowed to contribute to energy projects or infrastructure development.

Still considering innovative partnerships [97], analyzed how a philanthropic-crowdfunding-partnership (PCP) model could reduce socioeconomic inequalities in the development of solar farms in Turkey. Essentially, a PCP would raise capital through the public by favoring individuals and small and medium enterprises over large companies [97]. Additionally, in relation to vulnerable communities that struggle over energy poverty [105], defended the adaptation of PPP to the 5P model, or the "pro-poor public-private partnership" model, in which BMs are adapted and social concerns embedded in projects' development, since common PPP tend to neglect poor communities because of high risk-exposure. The REEEP, an international partnership focused on improving energy conditions in low and middle-income countries [110], has developed initiatives that employed 5P features when establishing funds for increasing energy access in remote and poor communities [136]. Initiatives that have a prominent social aspect have received more attention and financing in pursue of an inclusive energy transition.

4.4.2. Co-development, joint R&D, and alliances

In addition to (or within) PPP and its variations, energy utilities have been reaching out to other private companies for joint R&D and co-development in private-private collaborations such as the one between ENGIE and Schneider Electric, who have made a partnership for developing solutions related to electricity, mobility, and clean cooking within a microgrid demonstration on Semakau Island as part of the Renewable Energy Integration Demonstration-Singapore (REIDS) initiative [76]. When universities are included in research initiatives in association with the private sector, industry-university partnerships take place [137]. In the power sector, such developments are quite common and considered to bring benefits to all parties involved (see Ref. [5]). Examples of industry-university partnerships involving electricity sector companies are highlighted in Refs. [5,66,67,82,83] within the reviewed literature. A common characteristic of these partnerships is their low-risk and symbiotic nature. The public sector can also collaborate with universities in academia-public sector partnerships, as described by Ref. [74] for smart electricity distribution in France. Independent research from universities can also spin out to form startups that can be further acquired by private companies or continue solo operations.

When the government also gets involved in research along with corporations and universities, a tripolar model is implemented, the triple helix, where government, industry, and academia work together toward solving a particular problem [138]. The triple helix was approached in Refs. [46,70,75,78,86,88] within the reviewed literature. One live example of the triple helix is the FCH JU, which comprises research, technological development, and demonstration initiatives around green hydrogen and fuel cells, that has three main poles: the European Commission (government), fuel cell and hydrogen industries (industry), and the research community (universities), in which energy utilities such as Enel and EDF collaborate [100]. Similarly, since technological development around green hydrogen could imply a sustainable and economic path for decarbonization especially in the industrial sector, European energy utilities, such as the company EDP [89], have decided to take part on the European Clean Hydrogen Alliance [103].

Initiatives presented in this section 4 are synthetized in Table 4, which indicates the parent concept, the relative subcategory and its short description, and the initiatives and examples found within the electricity sector.

5. Conclusion

In response to the first research question, "how have electricity sector companies adapted their innovation practices and BMs to respond to increasing collaboration levels?", we have identified that companies have collaborated with public and private sectors, universities, and more recently with civil society through different types of associations. Joint R&D, partnerships, alliances, and co-development have become a common approach to deal with the resource requirements of the energy transition. Industry-university partnerships are particularly common as both sides are likely to benefit in a relatively low-risk agreement. The partners benefit from the relative low-cost knowledge resources and R&D capacity of the academia, while universities benefit from the financing and real-world problems presented by the industry. Inbound OI, M&A, venturing, and open platforms have brought knowledge from the outside and enhanced electricity sector companies' ability to connect with startups, take advantage of new markets, and respond to internationalization and utility 2.0 trends [3]. Open challenges and platforms are a way for startups to access learning, scaling up, and financing opportunities, whereas for electricity sector companies, they represent an opportunity to access new ideas and solutions while taking advantage of startups' ability to capitalize from small markets. Despite being less common, outbound innovation has taken place through companies' spin offs, which gives subsidiary companies the chance to tap opportunities in other sectors, such as software and RE, while allowing inside-out flow of knowledge, people, and technology.

Concerning the second research question, "has the call for openness and transparency from the 'open movement' influenced the innovation practices and BMs of electricity sector companies?", the answer is yes, as electricity sector companies have started to respond to the open movement by releasing data, embracing open data initiatives, and reaching to OSS to develop and provide services related to smart equipment and grid management. Even though born within academia, the 'open science' effects rebound in industry through open data and open-source initiatives. Energy researchers have been collaborating globally through platforms to develop open energy system models. These open energy system models can be an alternative to closed-source models for industry and research and be used by policy makers, researchers, and governments to envision energy transition pathways The quality of being open can be particularly relevant for developing and less developed countries, where the lack of resources may hamper energy planning and appropriate policies development. It can also motivate the participation of the community for financing and envisioning energy developments. The inclusion of civil society has contributed to the development of alternative partnerships (e.g., PPPP, PCP, 5P) and user innovation. Non-producer innovation has facilitated OSS development for private and non-profit organizations, user-led innovation in both digital and

Table 4
Synthesis of main open initiatives found in the energy sector.

Parent concept	Subcategory	Description	Initiatives and Examples in the Energy Sector
Open movement	Open data	Data that is made available online and allowed to be reused and reproduced [27]	Open Data initiatives of EDP [112], EDF [92], ENGIE [113], REN [95], and REE [98]
	OSS	Software that has its source code made freely available for adaptation and dissemination and is built jointly and voluntarily by software developers around the globe [33]	OseMOSYS [90], Openmod [109], and PyPSA [99]
OI	Inbound innovation	The company opens up to external inputs and contributions, allowing knowledge and technology transfer from the outside to the company [39]	M&A [14], EDP Venture [119], Free Electrons [102], Plug and Play [104]
	Outbound innovation	It happens when the organization allows internal ideas to go outside and be used by others [39]	Spin offs, e.g., EDPR [122] and E.ON [106]
Non-producer innovation	User innovation	It mobilizes user innovation towards technology improvement and adaptation.	Physical and digital user-led innovations, e.g. [17,124,125],
	OSS	Software that has its source code made freely available for adaptation and dissemination and is built jointly and voluntarily by software developers around the globe [33]	Camus Energy open-source DSO [101], LF Energy OpenEEmeter [126]
	Crowdsourcing	Crowdsourcing refers to a company presenting a challenge to the public, who comes up with ideas and solutions [50]	Crowdsourcing, e.g. [18,129],
	Co-creation and co-design	Co-creation relies on the active participation of end-users, in many cases the civil society, in the ideation and design of products and or/projects [49]	Co-creating cities and energy realities, e.g. [130,131],
BMI	Partnerships	There are various types of partnerships including actors from the academia, public and private sectors, as well as the civil society (see Subsection 5.4)	PPP for RE in developing countries, e.g. Refs. [69,91], PPPP for solar development [94], PCP [97], 5P facilitating energy access [105], REEEP [110]
	Joint R&D, co-development, and alliances	Actors from all sectors agree to develop or improve in tandem a technology and/or service	FCH JU [100], Triple helix [46,70,75,78,86,88], Joint R&D [8,73,76,81], the European Clean Hydrogen Alliance [103]

physical domains, and collaborative innovation mainly through co-creation and co-design of energy pathways and crowdsourcing for private companies.

Our research hypothesis has been confirmed, as increasing collaboration levels and calls for openness have indeed influenced electricity sector companies' innovation practices and BMs. Nevertheless, there are several challenges when embracing more collaborative and open approaches to innovation, among which figure network management [11], intellectual property [85], and financial investment issues [79]. Moreover, in developing countries, more traditional resolutions and centralized electricity provision may encumber the participation of new actors. Next to this, it might stand the lack of experience, R&D capacities, and capital (e.g., Ref. [69]), which reinforce the importance of BMI and international partnerships not to substitute underdeveloped innovation skills, but to foment in-house expertise.

Among the main limitations of this work, we could cite the risk of employing a systematic literature review for investigating a broad topic such as innovation. The English-only inclusion criteria as well as the search string can be a source of bias as well. Nevertheless, considering the focus on electricity sector companies and the extensive testing of search terms, we believe that the most relevant literature has been included in the review. We could also identify an underrepresentation of works, companies, and initiatives outside Europe, which can indicate bias on the inclusion criteria and search string and/or relative few works focusing on other continents, especially less-developed ones. Even though the relationships between OI, BMI, non-producer innovation, and the open movement (Fig. 1) could be described and interpreted in other manners, the produced ontology allowed us to answer the research questions within these domain assumptions. Nonetheless, other perspectives over the subject could lead to a different discussion from the one presented herein.

Therefore, our exploratory research showed that open and collaborative approaches may have the potential to speed the power transition as long as collaborations in the electricity sector develop in a symbiotic way. However, this claim has to be supported by quantitative evidence, as endorsed by the following recommendations for future research:

- Evidence from grey literature shows that private companies are employing OSS into their BMs. Therefore, it would be interesting to evaluate how many companies in the energy sector are following this OSS-trend, their location, and what are the impacts on (a) social perception of the energy transition and (b) private companies' financial performance.
- Since most OI practices are inbound and not outbound, a quantitative analysis comparing the background and performance of electricity sector companies' M&A and spin-offs could provide reasons for the prevalence of the former. Additionally, considering the urgency of achieving a low-carbon economy, it would be valuable to evaluate if and how outbound innovation could impact the pace of the energy transition without affecting profit-oriented business' position in the market.
- Considering the call for decarbonization and the limited resources and time for doing so, perhaps the energy industry could benefit from sharing more openly technology developments and data with other actors. This goes back to the open movement effects and the importance of performing a quantitative evaluation of its (potential) effects on research development, digitalization trends and data privacy issues, and its geographical uptake. This proves especially pertinent due to the lack of papers retrieved in the subject during our literature review.

Declaration of competing interest

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

Acknowledgment

This work was supported by FCT – Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

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