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Prosumers and sustainable development: An international assessment in the field of renewable energy

Walter Leal Filho [a,b], Laís Viera Trevisan [c,*], Amanda Lange Salvia [d], Janaina Mazutti [d], Thais Dibbern [e], Salvador Ruiz de Maya [f], Elvira Ferrer Bernal [f], João Henrique Paulino Pires Eustachio [g], Ayyoob Sharifi [h,j], María-del-Carmen Alarcón-del-Amo [f], Iryna Kushnir [i]

[a] Department of Natural Sciences, Manchester Metropolitan University, Chester Street, Manchester M1 5GD, UK
[b] European School of Sustainability Science and Research, Hamburg University of Applied Sciences, Germany
[c] School of Administration, Federal University of Rio Grande do Sul (UFRGS), 855 Washington Luiz St, 90010460, Porto Alegre, RS, Brazil
[d] Graduate Program in Civil and Environmental Engineering, University of Passo Fundo Campus I, Km 171, BR 285, Passo Fundo, RS, Brazil
[e] Department of Science and Technology Policy, University of Campinas, Carlos Gomes St. 250 - Cidade Universitária, Campinas - SP, Brazil
[f] University of Murcia, Faculty of Economics and Business, Marketing Department, Murcia, Spain
[g] Hamburg University of Applied Sciences, Faculty of Life Sciences, Research and Transfer Centre Sustainability & Climate Change Management (FTZ-NK), Ulmenliet 20, 21033 Hamburg, Germany
[h] Hiroshima University, The IDEC Institute & Network for Education and Research on Peace and Sustainability (NERPS), 1-5-1 Kagamiyama, Higashi Hiroshima City, Hiroshima, 739-8529, Japan
[i] Nottingham Trent University, Nottingham Institute of Education, Nottingham, UK
[j] School of Architecture and Design, Lebanese American University, Beirut, Lebanon

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ABSTRACT

The term "prosumers" coined by Toffler, relates to those customers who also engage in the co-creation of products, which they only partly consume, and whose balance is made available to a broader group. But even though the role of prosumers is increasingly relevant as a more comprehensive number of people are engaging in the production of products to be shared by others, there is a need for studies that aim at identifying how widespread they are, and the concrete contribution they are providing to some key area such as, for energy, energy generation and distribution. Based on the need to address this research gap, this paper reports on a study on prosumer behaviour in a sustainable development (SD) context, with a focus on the energy sector. The paper deploys a mixed-methods approach which entails a bibliometric analysis of prosumers from a sustainability perspective - to gain a better understanding of the topic -, a quantitative study of prosumers' behaviour in the field of renewable energy involving respondents from 44 countries, and a set of case studies, supported by the literature, which illustrates current trends. The novelty of this paper resides in the fact that it explores the role of prosumers in an SD context across many countries in the critical area of energy generation and use, outlining the drivers of positive behaviour and identifying some further information needs.

1. Introduction: prosumers and sustainable development

Over the years, researchers have outlined several conceptualisations of prosumers with different contexts. However, the universally accepted definition of prosumers is that of individuals in society with a dual function. They can consume and produce/create value that is intended for self-consumption or consumption by other individuals. In doing so, they may receive several types of incentives from organisations involved in the process/trade/exchange [52].

Research has identified six main types of prosumers. The first type refers to DIY consumers who partake in completing some part of the service by themselves, negating the need to pay others for certain services. Examples include people who grow their food or make their clothes [52]. Self-service consumers perform jobs that eliminate the need for additional workers. This includes those who wholly or partly perform a service alone [12]. Thirdly, customising prosumers exist to

* Corresponding author.
E-mail address: lais.trevisan@ufrgs.br (L.V. Trevisan).

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personalise their own products or services [31]. The fourth prosumer is a collaborative prosumer who provides a service for themselves and others and only benefits from limited cooperation [52]. Monetised prosumers have a similar function. However, companies may benefit from their work without compensation [59]. Lastly, formal incentive consumers may receive value for the activity/service they perform and include prosumers that consume and produce energy [12].

The role of prosumers in sustainable development (SD) has been highlighted in recent times. They have been described as creative agents that can be vital for driving sustainable consumption. This has been attributed to these individuals being involved in business tasks, company-customer relations, and knowledge transfer [56]. The most commonly observed role of a prosumer is seen in the energy sector. Prosumers have emerged in recent years by developing renewable energy (RE) sources, including solar panels and affordable RE alternatives. Sourcing renewable hydrogen supply chains has been another important trend. They are 'vital to enable a sustainable transition' particularly when hydrogen is produced from renewables as in the near future hydrogen will make around 13 % of the total energy mix ([72], p. 1).

Prosumers in the energy industry effectively consume, produce, sell, trade, or store energy, resulting in a more sustainable industry and assisting in meeting the energy goals outlined in the Sustainable Development Goals (SDGs) [30,50]. Furthermore, prosuming entails using smart appliances, electric cars, and battery storage capacities for flexible services [50], and even smart mobility in urban areas [17]. Aside from this, the European Commission defines energy prosumers as active consumers participating in demand response or energy efficiency schemes that do not constitute or fall under their professional work [24]. Prosumers' actions are ultimately desired to lead to the creation of 'smart homes' - home environments that aim to improve user comfort as well as security, along with conserving energy and cost-savings ([65], p. 658), and - on a larger scale - 'smart cities' - cities that are developing on new models of energy conservation ([70], p. 1409) and need to respond better and better to the demand for more efficiency by organisations [68] and individual citizens [18].

In doing so, prosumers are necessary for inflating the growth of the sustainable energy regime [49]. The use of RE sources by prosumers has numerous environmental benefits, in addition to reinforcing social values when sharing that energy with other members of the community [46]. It leads to reduced emissions and thus has downstream effects such as reduced global warming and mitigation/adaptation to climate change. All these benefits positively affect the SDGs and assist in the progression of sustainability [7,49]. In other instances, consumption models have indicated that shifting from consumers to prosumers in urban areas will significantly assist in the further development of smart cities in such areas through the promotion of sustainability. Apart from this shift, the paradigm from consumers to prosumers will assist in both economic and social development in line with the SDGs. It was found that monetary incentives strongly promoted the switch from consumers to prosumers in cities. This was followed by increased social responsibility and an urgency to reduce carbon emissions [35,70].

Furthermore, prosumers were seen to be instrumental in ensuring that the effects of the COVID-19 pandemic were reduced. Seeing that the outbreak was a major threat to sustainability, prosumers in crisis are considered to be sustainability promoters. This was observed in practices such as increased delivery services by people that allowed several businesses to remain open. Aside from this, DIY-prosumers were able to sustain their livelihoods by producing their own food and clothes in times of crisis. Furthermore, many prosumers provided online services that either assisted with mental health or allowed for at-home services (e.g., tutoring, and online fitness classes). Therefore, prosumers were able to reduce adverse impacts on sustainability during the pandemic [52]. Fig. 1 provides an overview of the "benefits loop" of prosumers' behaviour.

In this regard, this study aims to analyse prosumer behaviour with a focus on the energy sector. Therefore, the research objectives of the study are: (1) to identify how widespread energy prosumers are, within the higher education community; (2) to identify prosumers' behaviour in the field of renewable energy; and (3) to outline some of the main drivers of positive behaviour. For that, a mixed-methods approach was

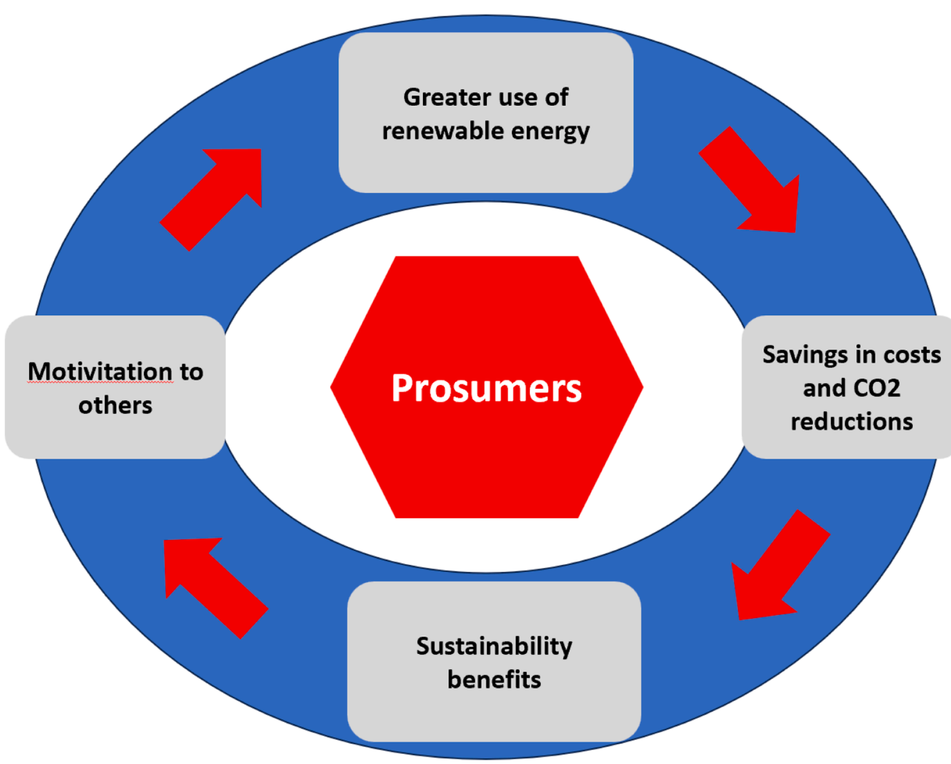

Fig. 1. Overview of the "benefits loop" of prosumers' behaviour.
Source: prepared by the authors (2023).

conducted, based on a bibliometric analysis of prosumers from a sustainability perspective, a quantitative study of prosumers' behaviour in the field of RE, and a set of case studies, supported by the literature, which illustrates current trends. The novelty of this paper resides in the fact that it explores the role of prosumers in an SD context across many countries in the key area of energy generation and use, outlining the drivers of positive behaviour and identifying some further information needs.

2. Prosumers and the energy sector

The increasing demands for energy put pressure on the energy sector to deliver more energy -especially electricity- to consumers. Moreover, there is a well-known pressure for the energy sector to make use of cleaner and more efficient technologies and commit to a low-carbon energy transition. Allied with this, the 2030 Agenda for SD highlights the role of clean and affordable energy in SDG 7 with the aim of "Ensure access to affordable, reliable, sustainable and modern energy for all" [78]. Thus, it becomes fundamental to encourage the self-production of energy, especially RE, to meet the needs of residences, commerce, and industries while also ensuring affordable energy access for all. The so-called "prosumers", in this context, emerge as key partners for a cleaner and more accessible energy transition [10] especially because these actors are contributing to the increase in the use of RE sources [50].

The generation of energy by prosumers is mostly focused on electricity generation, in which the most common form of prosumers is those who generate electricity from solar panels installed on roofs, but it is also possible to find examples such as wind energy, biomass, and hydropower, especially in industries [10,26,63]. In addition, Kotilainen [50] highlights the microgeneration of energy both for cooling and heating, such as geothermal energy.

Bleicher and Gross [8] indicate that key aspects of the drivers for prosumers' energy generation are the wish to contribute to a better environment, as well as energy independence, and their interest in innovative technologies. Similar drivers are pointed out by Ford et al. [30] in the context of both individual and collective prosumers of different sources, including the desire to pursue greener lifestyles, cut carbon emissions, and have greater autonomy and self-empowerment. According to Olkkonen et al. [63], the financial savings (considering the increasingly high tariffs of energy), the possibility of selling the energy to consumers, in addition to the financial incentives in reducing fees, creating better opportunities for prosumers are amongst the main reasons for the adoption of self-generation systems.

On the other hand, several barriers hinder the efforts and intentions of prosumers. As indicated by Streimikiene et al. [77], some aspects that hamper RE projects and the support to prosumers refer to regulations that protect fossil energy companies and lack of attention and support from local government, especially for rural communities. In the context of individual prosumers, commonly reported barriers to include the cost of materials and installation, reliability and compatibility with energy demands, and lack of knowledge and available information [30]. Added to the cost and investment payback period is the lack of business models to support prosumers in the whole process [74]. Related challenges are also seen in the context of collective prosumers, in addition to the need for social cohesion, group commitment, and cost of storage [30].

Despite the challenges, there is increased adoption of this type of energy production. According to the Report *Energy Prosumers in Europe*, prepared by the European Energy Agency [27], in five years (2015–2020) the number of prosumers in the Netherlands has doubled, going from 500,000 to over 1 million. In Portugal, the initial 3000 went to over 30,000 in 2019 and in Eastern Europe, in Poland, the increase was even greater, registering a growth of more than 16 times, going from 51,000 in 2018 to 847,000 in 2021 [27]. Countries such as France, Germany, the Netherlands, and the United Kingdom have favourable frameworks to support collective energy prosumers, while others have yet to shift from restrictive regulations [42].

In North America, Canada has also been observing a significant increase in the number of prosumers and the country expects most of the population to have the option to become prosumers using residential and commercial use of solar panels, district heating, and distributed storage by 2030 [51]. In the United States, the role of prosumers has been increasing since the last decade and tends to continue expanding from rooftop solar systems to microgrids and energy storage [71]. In Latin America, although the considerable potential for deploying the RE prosumption sector, some challenges are seen in aspects associated with the policy framework needed to support this energy transition [20,29].

The transition to a development model guided by the principles of sustainability is demanded globally, and when it comes to the energy sector, a low-carbon, and accessible energy matrix is necessary, especially in a scenario of growing energy demand and insecurity energy in the face of both climatic and geopolitical crises. In addition to a matter of necessity, there is a matter of opportunity linked to the establishment of prosumers. According to Kotilainen [50] and Botelho et al. [9], prosumers in the RE sector contribute to business opportunities, since a community of prosumers can emerge, and thus, traditional, and sustainable-innovative models of production, consumption, share, and sale of energy might also occur.

Furthermore, according to Kotilainen [50], prosumers are also contributors to reducing energy poverty. This form of electricity generation can be viable in rural areas and isolated communities without proper access to the electrical grid in the same way as it occurs in urban areas. The prosumers can then allow reliable energy to reach more places and generate the economic development of more communities [50]. All these factors are components that stand out and help in the behavioural change of citizens in order to favour the flourishing of more prosumers in the energy sector.

3. Methods

In this study, a mixed-methods approach was conducted, based on bibliometric analysis, a survey of prosumers' behaviour in the field of RE, and a set of case studies, supported by the literature. The bibliometric analysis alone would not be sufficient to allow a stock-taking on the subject matter of energy prosumers. Therefore, it was complemented by a survey aimed at gathering first-hand insights from potential prosumers. This, in turn, was complemented by a set of case studies, with examples of initiatives in this field.

The bibliometric analysis can be considered a quantitative research method that can bring relevant insights into exploring several types of publications, such as conference proceedings, books, and scientific articles, through statistical analysis. Researchers usually use bibliometric assessments to identify patterns and research streams in the literature. There are currently several techniques that researchers can adopt in conducting bibliometric analysis, which may be chosen according to the goal of the research, such as understanding the influence of one author or publication on several others, the contribution to a research field, analysing the performance of an academic journal or authors based on several metrics such as citations, number of publications, as well as understanding the patterns of collaborations and other networks of researchers in a specific research field [21].

Moreover, bibliometric analysis can also be very helpful in bringing some light into the several possible research strands of a research field. This is especially true in fertile research areas with a lot of publication interest. From this perspective, for example, researchers may adopt techniques such as the co-citation or co-occurrence techniques, which can be used to map the intellectual landscape of a research field.

In this context, the authors opted to conduct the bibliometric analysis by exploring what the literature has published about prosumers, sustainable development, and RE. The data collection was conducted on the Web of Science, a scientific database known for having comprehensive coverage from various disciplines and high-quality scientific publications [84].

For the data collection stage, the authors created a search string that aimed to identify articles containing terms directly connected to the goal of this paper, whether they appear in the title, abstract, and keywords. The search string was composed of two blocks. The first aims to bring terms related to prosumers, while the second one aims to identify papers that bring terms related to sustainable development and energy. After applying the search string on the Web of Science database, 1549 articles were identified and used to conduct the bibliometric assessment (Table 1).

The bibliometric analysis in this paper identified common strands related to SD, prosumers, and energy. The authors conducted the text mining based on the co-occurrence of terms and used the VOSviewer software to identify the co-occurrence of terms. Both research queries and data collection were conducted in January 2023. The results were presented by a network figure in which the diameter size of each one of the nodes represents the frequency of co-occurrence of each tern, whereas the link width is related to the strength of the connection between two or more terms. Finally, terms that appear close to each other are expected to be connected and generate a thematic cluster represented by different colours in the graph [79–81].

The second approach used in this study was a survey of prosumers' behaviour in the field of RE. The strategy of convenience sampling was employed, and the target population was academic staff from all fields of knowledge. The literature found in the bibliometric analysis supported the development of the questionnaire. Specifically, the questions have been mostly adapted from Horstink et al. [38], who investigated the topic of RE prosumers from the perspective of collective prosumers in the European Union.

The questionnaire covered the following key areas within the scope of the investigation:

(a) Self-identification of prosumers: as informed in the questionnaire to all participants, prosumers refer to citizens that not only consume electricity but also engage in energy production (e.g., generation, storage, and/or self-generated RE electricity sale) [38]. One can be an individual prosumer, such as in households with photovoltaic panels on the roof; or a group of individuals can be considered collective prosumers when households, for example, take a collaborative initiative to install photovoltaic panels on the roof of a multi-family building [27].
(b) For those who identified themselves as prosumers: the survey then continued to explore the energy needs addressed by the prosumer initiative (electricity, heating, cooling, and mobility), the technologies used (e.g., solar photovoltaic, wind energy, heat storage), motivations to become a prosumer, perception of the prosumers' contribution to sustainability, and factors that facilitate or hinder RE energy prosumer initiatives.
(c) For those who have not identified themselves as prosumers: the survey assessed their interest in becoming a prosumer in the future, what would be the motivations for that, and perceived challenges for becoming a prosumer.

Table 1
Search criteria and number of publications on Web of Science.

Database	Search string	Number of documents
Web of science	AK = ((“prosumer*”) AND (“sustainability” OR “Sustainable development” OR "energy" OR "energies")) ***- 467 documents*** *OR* AB = ((“prosumer*”) AND (“sustainability” OR “Sustainable development” OR "energy" OR "energies")) ***- 1411 documents*** *OR* TI = ((“prosumer*”) AND (“sustainability” OR “Sustainable development” OR "energy" OR "energies")) ***- 268 documents***	**1549**

Demographic details to describe the sample were also collected, including country, gender, age group, and area of expertise. A pre-test was applied, and a group of energy and sustainability researchers and academic staff checked the questionnaire for consistency, providing comments on the clarity and organisation of the instrument. The final version was then disseminated via Google Forms.

The invitation to participate was shared amongst the authors' networks, as well as with academic staff associated with the Inter-University Sustainable Development Research Program (IUSDRP) and those registered in academic networks and mailing lists related to sustainability and higher education. The survey collected responses during the first semester of 2023 (29th of March to 02nd of June). It received responses from 44 different countries and the results were analysed using simple descriptive statistics.

Finally, a content analysis of relevant documents on the topic was carried out to identify practical case studies on prosumers and highlight best practices presented in the literature. Therefore, data collection was performed in the Scopus database in March 2023 by using the combination of terms related to prosumers, sustainability, and energy, and the Boolean operators “AND” and “OR”.

The best combination of search strings was the following: (TITLE-ABS-KEY ("prosumer*") AND TITLE-ABS-KEY ("sustainability" OR "sustainable development") AND TITLE-ABS-KEY (energ*). Then, the search was limited from 2019 to 2023 in order to select current documents in the field. The final sample included 85 documents selected for the screening phase. After a deep content analysis of these documents, 15 of them were selected as case studies for this study, based on their relevance in providing practical and real examples of energy prosumers around the world.

The set of case studies does not cater to a cluster between industrialised and developing countries. This is because the latter do not have the same fiscal incentives as the former do. A study of prosumers in developing countries would be required, so as to obtain specific details from developing nations.

4. Results and discussion

4.1. Bibliometric analysis

The bibliometric analysis based on the co-occurrence of terms returned five different clusters that can be considered research streams. Fig. 2 evidences the clusters as well the visual frequency of each one of the terms and how they are interconnected.

The red cluster is the biggest in terms, and it is directly related to RE and policy for sustainability transitions [57,82]. The term RE was mentioned, for example, in more than 1000 articles. Examples of studies in this cluster rely on policy and regulatory frameworks that could contribute to overcoming the challenges related to collective RE prosumers [37]. Another sub-cluster that is also present in the red cluster is the innovation aspect towards sustainability transitions which can contribute to combating climate change [11,45]. Examples of innovation rely on the importance of RE generation and distribution, for example, photovoltaics and wind energy, and the extent to which this could contribute to smart cities [14,23,32].

The green cluster considers the intricate relationship between prosumers, sustainability, and the circular economy within the context of the ongoing energy transition. Prosumers, as active participants in both energy production and consumption, play a pivotal role in reshaping conventional energy paradigms [48]. Their dual role as consumers and producers blur the lines between consumption and production, giving rise to the concept of prosumption. This phenomenon holds the potential to foster a more sustainable energy landscape by redistributing power generation and enabling local energy communities [25]. The circular

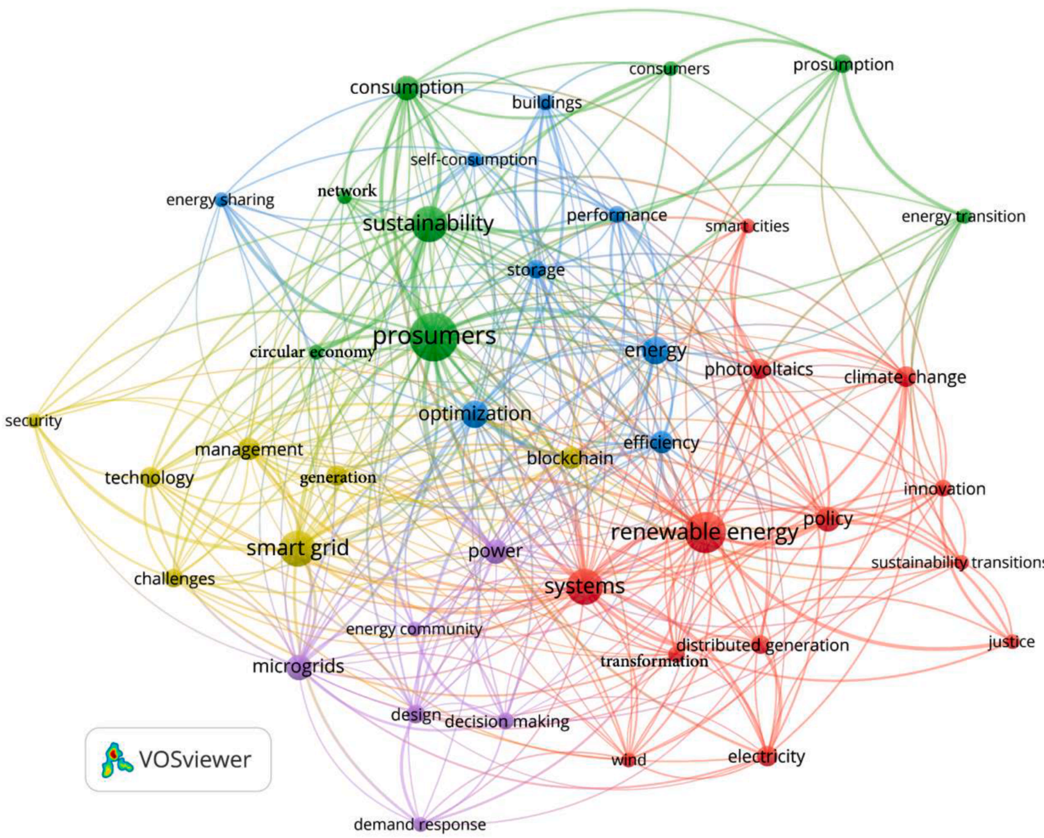

Fig. 2. Co-occurrence of the terms Sustainable Development, Prosumers, and Energy.

economy framework further reinforces these efforts by emphasizing resource efficiency, reduced waste, and the repurposing of energy infrastructure [33]. Networks of prosumers emerge as integral components of this model, facilitating the exchange of surplus energy and promoting community-level resilience [4,39,58]. By engaging consumers as active contributors to the energy grid, a transformative pathway towards sustainable development can be paved, where prosumption becomes a driving force behind the evolution of renewable energy systems [62].

The blue cluster, in turn, brings terms related to energy efficiency and optimation [13,28]. This cluster is related to the relevance of energy consumption of buildings, focusing on performance and efficiency [5]. It is also important to consider that this cluster also brings the term “energy sharing”, which indicates that individuals and organisations play a critical role in creating efficiency by producing energy from several systems and, distributing the excess energy back to the grid, generating energy efficiency and optimisation [41,60]. Moreover, another group of papers also discusses the importance of energy sharing by exploring the contribution of individuals and organisations, contributing to a more sustainable energy ecosystem by helping others to achieve the energy needs of other individuals and organisations that may not have access to RE options [66].

The yellow cluster has as its main term the smart grids and discusses the main challenges to it, especially those related to security and technology management of the generation and transmission of RE [22,43]. This cluster has several strands, such as discussing how technologies such as sensors and communication systems could be deployed to promote energy distribution and consumption efficiency [3,54]. Moreover, other types of technologies can also contribute to the process, such as artificial intelligence and machine learning [2,6,40]. Finally, blockchain technology has become a relevant topic in the field, since it could contribute to optimising how the energy is recorded and tracked by the prosumers involved in the energy generation and transition systems [40]. Examples of this optimisation could be, for example, enabling peer-to-peer energy trading and advancing the security and transparency aspects of how prosumers interplay and return energy to the grid or other consumers.

Finally, the purple cluster embraces the synergy between microgrids, energy communities, and innovative design strategies as catalysts for sustainable development within the realm of renewable energy. Microgrids, characterized by their localized power generation and distribution capabilities, align seamlessly with the concept of energy communities, fostering collaboration amongst prosumers for efficient energy utilization [55,58,69]. The design of such interconnected systems plays a pivotal role in orchestrating power flow and optimizing resource allocation [61]. Through intricate decision-making processes, stakeholders can navigate the complexities of energy management, balancing supply and demand while integrating dynamic demand response mechanisms. This integration enables prosumers to actively engage with the grid, adjusting their consumption patterns in response to real-time signals [1,75,86]. As microgrids evolve from mere energy supply networks into platforms for community-driven energy governance, their design and decision-making structures become instrumental in shaping a sustainable future powered by renewable sources [73].

4.2. Survey on prosumers' behaviour

This study involved the participation of 182 academic staff from 44 different countries. Spain and the United States were the countries with the highest level of participation (20.3 % and 19.8 %, respectively). Regarding the respondents' area of expertise, academic staff from 63 different fields participated in the study, most of the professionals belonged to the “Business, Administration and Law” (19.8 %) and “Social Sciences, Journalism and Information” (17 %) fields. The sample was similarly distributed in terms of gender (53.3 % identified as male) and age ranged from 20 to 83 years old.

Out of the 182 respondents, the majority did not consider themselves RE prosumers (*N* = 118, 64.8 %). On the other hand, 64 participants (35.2 %) identified themselves as prosumers. Within this group, individual prosumers (25.3 %) outnumbered participants involved in collective prosumer initiatives. Concerning the energy needs that the prosumers' initiatives address, only 31.3 % (*N* = 20) of participants reported their initiative addressed a unique need. Electricity emerged as the predominant need in prosumers' initiatives (92.1 %). Additionally, 58.7 % of responses indicated the need for heating, while 44.4 % mentioned the one for cooling and 34.9 % selected the need for mobility.

Within the scope of prosumers' initiatives, the 64 prosumers in our sample reported the use of multiple technologies, most responses referred to solar photovoltaic technologies (85.7 %), followed by storage batteries (19 %) and solar thermal (17.5 %). All the mentioned technologies are outlined in Table 2.

When respondents were asked about their motivations to become a prosumer, "Reducing environmental impact" garnered the highest agreement amongst the motivations, with an average rating of 4.4 (SD = 1.13). This was followed by the motivation to "Feel good about energy decisions" (*M* = 4.35, SD = 0.94) and "Be part of the clean and low carbon transition" (*M* = 4.33, SD = 1.15). But in the top five motivations, with means clearly over 4, we also find another environmental motivation (Tackling the climate change problem) and one related to the cost of energy (*M* = 4.27, SD = 1.16). Means and standard deviations for the items measured are presented in Table 3.

As RE prosumers, participants believed they greatly contribute to sustainable development as a whole (*M* = 4.15, SD = 1.11), the SDGs (*M* = 4.13, SD = 1.02), tackling climate change (*M* = 4.19, SD = 1.06), the creation of an alternative to the energy crisis (*M* = 4.29, SD = 1), and playing a social/environmental role in society (*M* = 4.3, SD = 0.96).

Regarding the drivers that facilitate RE prosumer initiatives, participants considered RE technology options (26.9 %), the ability to use RE technologies (25.3 %), and the information and communication technologies applied to energy production (22 %) are aspects that foster prosumers' actions. In contrast, bureaucracy (18.7 %) was regarded as the most hindering factor.

When it comes to the participants who did not consider themselves as RE prosumers, 56 % (*N* = 102) showcased their interest in embracing prosumption shortly. Results indicate a high level of agreement across the key drivers to becoming prosumers. The mean scores for all items ranged from 3.46 to 4.63. However, respondents expressed the several challenges they face when trying to become prosumers. Approximately 68.8 % of respondents identified access to finance as a major challenge, while 45 % indicated energy infrastructure hindered their ability to become prosumers, and 37.6 % highlighted the obstacle was related to public policies and legislation for RE initiatives. In addition to the predefined response options, some participants provided additional insights on the aspects that confronted them in their quest to become prosumers, respondents highlighted the difficulties they face as tenants: "I am living in a rental apartment. My landlord does not allow solar panels on the balcony. I have no roof"; "Being a tenant and not owning the place I live in"; and "I am living in a rental apartment. My landlord does not allow solar panels on the balcony. I have no roof".

Table 2
Implemented technologies in prosumers' initiatives.

Technologies	Frequency	Participants
Solar photovoltaic	54	85.7 %
Storage in batteries	12	19.0 %
Solar thermal	11	17.5 %
Storage in vehicle batteries	10	15.9 %
Wind energy	7	11.1 %
Biogas or bio-methane (produced from organic waste)	4	6.3 %
Geothermal energy	4	6.3 %
Co-generation (e.g., combined heat and power)	4	6.3 %
Heat storage	4	6.3 %
Biomass (e.g., wood pellets, waste wood)	3	4.8 %
Hydropower	2	3.2 %
Biofuels (e.g., biodiesel)	2	3.2 %
Other	4	6.3 %

Table 3
Motivations for being an energy prosumer.

Motivations	N	Mean *	SD
Reducing the environmental impact	57	4.40	1.13
Feeling good about my energy decisions/being able to practice my values related to energy decisions	57	4.35	0.94
Being part of the clean and low-carbon transition	57	4.33	1.15
Tackling the climate change problem	59	4.31	1.13
Reducing energy costs	59	4.27	1.16
Ethics of climate change	57	4.09	1.23
Achieve energy self-sufficiency	61	3.97	1.22
Ethics of energy production and distribution	56	3.82	1.32
Contribute to innovation in Energy Production	60	3.77	1.32
Decentralising energy production	58	3.59	1.33
Taking advantage of new REs technologies'	60	3.55	1.36
Responding to local demands	61	3.44	1.46
Take advantage of policy incentives	60	3.37	1.44
Improve revenue	59	3.32	1.40
Take advantage of subsidy schemes	60	3.25	1.46
Create a sense of community	56	3.20	1.30
Help tackle energy poverty	57	3.12	1.39
Distrust and/or dislike of large energy companies, especially their history of fossil fuel colonialism	57	3.09	1.48
Religious reasons	57	1.93	1.32

* The scale ranges from 1 to 5, where 1 means 'totally disagree' and 5 'totally agree'.

4.3. *Case studies*

The literature has pointed out that on the path to SD and towards a low-carbon emissions transition, the engagement of consumers in the energy sector is essential [36]. This group of active consumers of energy generation and distribution has been called 'prosumers' and has revolutionised the energy market given its decentralised aspect and its economic, environmental, and social benefits [83]. Nevertheless, the success of this new operational model depends on some political, governmental, organisational, and individual conditions [35]. In this regard, this subsection includes the analysis of 15 case studies selected from the literature to illustrate current trends and examples of prosumers' actions within the energy sector (Table 4).

Some of these studies stand out due to their originality and novelty, as is the case of Li et al. [53]. The authors claim that although it is widely accepted that the installation of household distributed energy resources stimulates electricity consumption, their study found that this kind of system not only facilitates environment protection in terms of limiting emissions but also inhibits electricity usage through a negative rebound effect. Child et al. [15] also present the specific case of Finland, attesting to the possibility of reaching 100 % of RE production by 2050, as long as the prosumer movement supports this transition. Some important elements for the adoption and implementation of these new energy generation systems are highlighted by Pumphrey et al. [67], considering the prosumer movement, such as the ease and automation of the systems, costs involved in the process, and involvement with other actors. These elements affect electricity trading, becoming important for the infrastructure of developed countries.

Moreover, the political and market contexts are explored by some authors, showing the role that governments play in the transition to a sustainable energy system, especially in times of energy crisis such as the one currently faced by humankind. For instance, D'Adamo et al. [16] claim that sustainability cannot be only for the benefit of those with higher incomes, this is why governments need to support photovoltaic systems implementation for less affluent households and provide incentive policies for the population in general. Furthermore, Villena

Table 4
Case studies on prosumers in the energy sector.

Case study	Lessons learned	Reference
Impact of Household Distributed Energy Resources on Residential Electricity Consumption / USA	Household-distributed energy resources (DER) can reduce emissions and decrease electricity consumption, with income and education level affecting the results. The study suggests that policymakers should promote household DER and design strategies to mitigate the rebound effect.	Li et al. [53]
Economic Analysis of Photovoltaic Systems in Sustainable Communities and Collective Self-Consumption / Italy	The profitability of photovoltaic (PV) plants in Italy, under a collective self-consumption (CSC) scheme, is significant with low levels of economic risk. Additionally, the development of sustainable communities and energy communities can contribute to the ecological transition and energy independence, while also providing economic benefits. The study also highlights the importance of policy support and incentives in promoting the development of renewable energy and sustainable communities.	D'Adamo et al. [16]
A Model for Sustainable Urban Energy Transition and Positive Energy Districts / Italy	The study highlights the development of an optimization model specifically tailored for the design and operation of distributed energy networks within urban buildings. This model is geared towards facilitating the transition of urban areas to Positive Energy Districts. A key takeaway is the potential of the decentralization configuration to significantly reduce the reliance on electricity import from the main grid. This reduction aligns with the goals of Positive Energy Districts, emphasizing localized energy production and consumption.	Volpe et al. [83]
A Multi-Periodic Community Development Model Assessing the Impact of Citizen Energy Community Regulation / Germany	This study was carried out in Germany, with 30 households concerning community costs and community emissions with and without Citizen Energy Community regulation proposed by the European Union. It found that Citizen Energy Community regulation consistently reduces community costs and emissions, while heterogeneous distributions of economic and ecological preferences within the community lead to greater gains.	Golla et al. [35]
Empowering Energy Consumers: Insights from Photovoltaic Owners / Denmark	The findings show that photovoltaic (PV) owners consider that they have become more concerned with energy consumption and adjust the time of their daily practices to their production. The study also highlights that technological solutions alone are insufficient, highlighting the need for active consumer participation.	Gram-Hanssen et al. [36]
Interconnected Solar Home System Microgrids and the Role of Smart Energy Management / Rwanda	The study emphasizes the crucial role of a smart energy management (SEM) platform in the interconnection of off-grid systems. The SEM platform is seen as a key enabler for making bottom-up electrification scalable, improving overall sustainability, efficiency, and flexibility of off-grid technology.	Soltowski et al. [76]
Practical Implementation of the Power Cloud Management Model at the University of Calabria / Italy	The results of the experiment show that by adopting this type of system it is possible to obtain significant savings in energy consumption and cost, with major implications for communities and educational institutions. This outcome highlights the practical benefits of implementing such models within communities, particularly in a university campus setting	Giordano et al. [34]
Collective Renewable Energy Prosumers as a Social Movement / Belgium, Croatia, Germany, Italy, Holland, Portugal, United Kingdom	The study discusses the contributions to the transformation of the energy system to produce renewable energy. It also highlights the networking of collective prosumers in prosumer ecosystems, to build social movements towards energy transformation. Building collaborative networks is also highlighted as an important element in engaging prosumer communities.	Wittmayer et al. [85]
Mindset for Citizens in Smart Cities / European Union	Based on a mix of qualitative and quantitative approaches, the analysed case studies validate the research hypothesis, confirming that there is a change in consumers' mentality from consumers to prosumers in EU smart cities. The paper emphasizes the importance of considering citizens' perceptions and new roles or functions within the context of sustainable cities.	Santa (2022)
Functional prosumer-based renewable off-grid direct current (DC) network / Bangladesh	This study shows how prosumers evolved in Bangladesh, a pioneering and developing country. It also demonstrates how the operating system for trading electricity between peers that make up the prosumer network works. The results show that the prosumer movement can increase the quality of life and socioeconomic awareness of the population living in less developed countries.	Khan [44]
Impact of Prosumers on Electricity Distribution Tariffs / Belgium	The results highlight the importance of designing public policies to support the adoption of photovoltaic	De Villena et al. [19]

(continued on next page)

Table 4 (*continued*)

Case study	Lessons learned	Reference
	energy and regulation of the electricity distribution network to facilitate the energy transition to a more sustainable system. The analysis underscores that smart meters contribute to fairer and more sustainable network tariffs. This indicates that, in the long run, advancements in metering technology can enhance the efficiency and equity of electricity distribution systems.	
Barriers and opportunities in the deployment of the residential photovoltaic prosumer segment / Chile	The study shows that without effective policy instruments, high investment costs and low income per family are the main barriers to the implementation of the segment in the country. Therefore, proper promotion of energy policies, regulatory changes, and financing options can accelerate PV deployment.	Osorio-Aravena et al. [64]
The transition of the Finnish energy system / Finland	The results show that it is possible to achieve a 100 % renewable energy system in Finland by 2050, constituting a less costly system, and ensuring greater economic competitiveness in the country. Prosumers can also benefit from this transition process, with several business models supporting the growth of prosumers in Finland.	Child et al. [15]
Consumer perceptions of peer-to-peer energy trading / United Kingdom	This study shows that five factors are important for the adoption of blockchain-enabled peer-to-peer systems because of the increasing probability of consumers and prosumers changing their electricity trading practices: ease and automation, third parties, cost, trust, and image.	Pumphrey et al. [67]
Exploring Residential Energy Storage Modes for Sustainable Energy Practices / Netherlands, Germany, and United Kingdom	The results show that there are five emerging storage modes of which owners can make use and play an important role: individual energy autonomy, local energy community, smart grid integration, virtual energy community, and electricity market integration. The paper emphasizes that these storage modes facilitate new energy practices for householders, including providing grid services, trading, self-consumption, and sharing of energy.	Kloppenburg et al. [47]

et al. [19] highlight the importance of implementing public policies capable of supporting the production of photovoltaic energy, considering the development of regulations that encourage the investment of such technologies.

5. Conclusions

The literature has widely explored the connections between the energy sector and its contributions to sustainable development. Many studies have taken a broad perspective, focusing on the transition of societies towards greater sustainability based on renewable energies. Others have focused on energy efficiency and optimisation, and several works looked at the key challenges such as those related to the interplay between technology and security in producing and using renewable energy.

In this context, over the last decade, we have witnessed the notable growth of a new market player in the energy industry, prosumers. This new market segment not only consumes and produces energy but also sells and stores it, advocating sustainability in the energy sector and significantly contributing to the SDGs. In this era, prosumers drive the surge in renewable energy utilization, emerging as central figures in the transition to cleaner, more accessible energy in modern society.

This study, which included a bibliometric analysis, a survey of prosumers' behaviour in the field of RE, and a set of case studies, supported by the literature, adds a contribution to the sustainability and energy market literature, analysing energy prosumers' behaviour, to better understand their motivations, and illustrate current trends. The paper provides a contribution to theory since it offers an assessment of the current literature on energy prosumers and outlines the emphasis given by the literature on the topic. It also contributes to practice, since it showcases some examples of concrete initiatives involving energy prosumers, and the diversity of approaches used to date.

The bibliometric analysis has shown that the emphasis on prosumer behaviour and publications on energy production-consumption has notably increased in recent years. The benefits of this transition are also documented in various papers. Becoming a prosumer entails personal and societal contributions to alleviate energy poverty, while urban prosumers significantly bolster the smart facet of cities, advancing sustainability and efficient energy distribution. Moreover, prosumers in the RE sector contribute to business opportunities as they support new and sustainable innovative models of production, consumption, and sharing of energy.

The case studies illustrate the fact that the prosumers' role is increasing, partly as part of sustainability-aware societies, focusing on the energy market. They also show how they are changing the concepts of energy generation and consumption, propelled by motivations fostering positive behaviour that can potentially extend to other consumer segments.

As the survey has shown, the distinction between prosumers and non-prosumers offers essential knowledge that can be used to increase the number of prosumers. In this sense, prosumers' main motivations primarily revolve around curbing environmental impacts while also considering energy costs. These motivations encourage prosumer behaviour, catalysed by accessible renewable energy technology and advancements in information and communication technology for efficient energy management. But it is also of interest to consider the challenges faced by non-prosumers as two-thirds of them underscore financial barriers as one of the main difficulties to engage in this field.

The findings of this paper also suggest that modern means to measure and steer energy consumption are needed. For instance, the use of an "energy consumption digital passport" may enhance transparency, accountability and sustainability in energy use, by engaging consumers more closely.

In summary, it is time for policymakers to make decisions that may increase prosumer numbers, given their potential to reshape energy habits and paradigms, and to contribute to the SDGs. As energy resources spread amongst households, consumption drops, and environmental goals thrive, encouraging supportive subsidy policies. Ultimately, a fusion of groundbreaking technologies like blockchain-based trading and energy storage, bolstered by policy and collaborative networks, will play a pivotal role in steering the energy landscape transformation.

This paper has some limitations. The first is related to the fact the bibliometric analysis used a search string associated with energy-related behaviour and did not analyse other variables. Also, The survey obtained responses from 182 academic staff, so it did not have a large sample. Secondly, only 44 countries took part in it. Finally, the fact the survey was undertaken over a short period means that more responses could be obtained. Despite these constraints, the study provides a welcome addition to the literature, since it sheds some light on the views and perspectives of prosumers with a country coverage seldom found in the literature.

There are two main implications of this paper. The insightful exploration of prosumers and their proven impact on the energy landscape opens up promising directions for future research. For instance, research on how community dynamics influence transitions from non-prosumer to prosumer and prosumers' engagement and collective energy solutions. The second implication of the study is that it shows much work is needed, to show to the wider population, the advantages of prosumer behaviours.

Future research may focus on the effectiveness of existing policy measures and regulations in promoting transitions to prosumer roles and involvement and fostering new sustainable energy habits. In addition, future studies may analyse the effectiveness of different incentives such as financial rewards, tax benefits, or community recognition which can help policymakers in their decisions.

CRediT authorship contribution statement

Walter Leal Filho: Formal analysis, Investigation, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Laís Viera Trevisan:** Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Amanda Lange Salvia:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Janaina Mazutti:** Formal analysis, Writing – original draft. **Thais Dibbern:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Salvador Ruiz de Maya:** Formal analysis, Writing – original draft, Writing – review & editing. **Elvira Ferrer Bernal:** Investigation, Writing – original draft. **João Henrique Paulino Pires Eustachio:** . **Ayyoob Sharifi:** Formal analysis, Methodology, Software, Writing – original draft. **María-del-Carmen Alarcón-del-Amo:** Investigation, Writing – original draft. **Iryna Kushnir:** .

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.

Data availability

Data will be made available on request.

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