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The woman's researcher tale: A Review of Bibliometric Methods and Results for Studying Gender in Science

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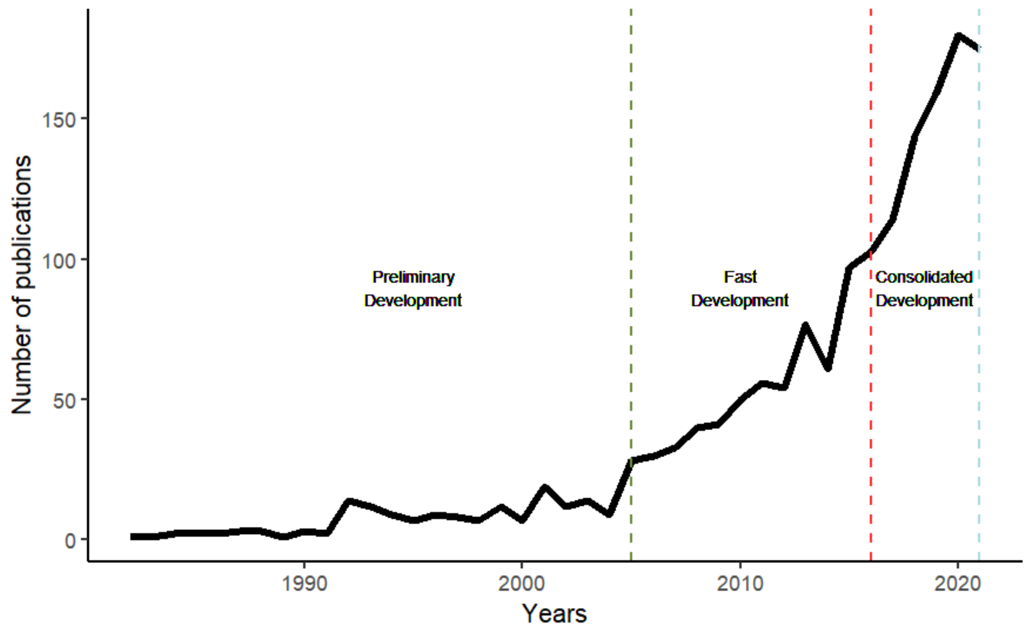
1. Introduction

Gender self-identification plays a crucial role in the opportunities and choices scholars make, shaping their academic life (Beddoes & Pawley, 2014). Women [1] perceive how their careers are hindered, while the image of the scientist as a man is socially elevated (Boekhout et al., 2021). This situation has led to an increasing demand for "solid quantitative support to what is intuitively known" (Larivière et al., 2013), which is reflected in the number of publications dealing with gender within the field of Bibliometrics (Figure 1). We observe three different stages in the evolution of research on gender differences: a preliminary development (1980-2003), a fast development (2004-2015) and a consolidated development since 2016. The scale and gender assignment methods employed in these studies have become more refined over time, as well as the methodological design which ranges from basic descriptive analyses to more intricate investigations aimed at identifying underlying causes behind gender disparities. The aim of this paper is to summarize such findings both, in terms of methodological improvements, as well as explanatory evidence.

Figure 1.

Publications including the term 'gender' or 'sex' in title, abstract, author keywords and keywords plus, assigned to the micro topic Bibliometrics in Web of Science Core Collection (1982-2021).



There have been targeted literature reviews covering the broad umbrella of gender and Bibliometrics from approaches that aim at identifying "gender and analyze the bibliographic data'' (Halevi, 2019) to the study of specific elements such as funding (Cruz-Castro et al., 2022) or gendered specialties during education (Alers et al., 2014). Some research carried out meta-analysis, drawing conclusions from literature on gender in science (Astegiano et al., 2019; Ni et al., 2021). However, there has not been a comprehensive literature review on the use of bibliometric methods to study gender differences in science and their results. This review differentiates itself from previous analyses as it provides a holistic and updated view of the topic. Though every piece of research has its limitations, our goal is to identify and address them in a systematic manner providing a valuable resource for anyone who seeks to gain a comprehensive understanding of the subject.

Studies on gender inequality is a highly politicized and extremely hard to grasp topic given the dynamic nature of the object of study. These barriers are overcome in various ways, some more controversial than others. We find cases in which gender differences are not acknowledged, or simply denied. A well-known case is the Strumia study that hints at biological differences as the reason for found gender gaps (Strumia, 2021; Andersen et al., 2021). The struggle of generalization within bibliometric research does not help with this issue. Data limitations, contradicting reports based on specific country or field specific case studies demonstrate these difficulties. Most studies focus on Western countries, providing little evidence from other regions (Prozesky & Beaudry, 2019), and there are disciplinary biases, as most studies focus on STEM. Still, there is a consensus that gender differences are present in most aspects in academia but causes behind such differences are not clear.

This review is structured into four sections. The first one focuses on methodological approaches used to analyze gender differences in science: gender identification, units of analysis and assumptions of methods employed to address causality. The second part describes the main findings these studies report: gender differences attached to specific research activities, underlying mechanisms behind such differences, and the overall effects of gender inequality. Then, the discussion provides an overview of the literature review, and the last section highlights limitations and builds a future research agenda.

2. Methodological approaches

Gender inequality studies face a series of methodological challenges that are crucial to interpret their findings, such as gender identification based on metadata, selection of the unit of analysis and methodological design in explanatory studies.

2.1. Gender identification

2.1.1. Metadata. Data on gender are usually unavailable in bibliographic metadata, thus studies infer them from indirect metadata based on four basic approaches.

The most common approach employs the author's name in combination with the affiliation data. Thanks to the introduction in bibliometric databases of full names, the researcher gender can be estimated, and we can see the probability that a gender is usually assigned a name. For instance, Web of Science introduced this linkage in 2007 (searchable since 2011) and Scopus included author full names in May 2022. A second technique uses given names as input to search for pictures in search engines (Kong et al., 2022), or retrieve individuals' image from their own personal or institutional website (van den Besselaar & Sandström, 2017) to infer gender.

Both approaches, however, assume a relation between names, facial characteristics, and gender. Moreover, they take a binary stance of the researcher's gender: man, woman, or unknown, if the information is not clear enough, which might hide other gender realities leaving no room for self-identification.

To overcome this limitation, a third approach, although less common, is based on pronouns used by authors for self-identification that are not available in bibliometric databases but in external data sources, such as personal websites or social media (e.g., Twitter, LinkedIn). Maliniak et al. (2013) and Azoulay & Lynn (2020) used this data to assign and/or validate gender.

Other approaches are more direct but not commonly used given their time-consuming nature and do not ensure ending up with a complete dataset. Here researchers are surveyed and asked for their gender (Zheng et al., 2022). For instance, when the researcher's gender was not clear, Amering et al. (2011) asked colleagues who knew the investigators in question.

2.1.2. Methodological approaches for gender assignment. Most methods for gender identification focus on given names as their primary means for assignment. These methods involve matching names against a pre-existing database containing a comprehensive collection of names associated with assigned genders or probabilities thereof.

Refinements to this approach often incorporate geographical information derived from affiliation metadata allowing a more nuanced understanding and avoiding overgeneralizations. A common example is the name 'Andrea' generally assigned to women except for Italy, in which it is common among men. The inclusion of last names enhances accuracy in some regions, such as Slavic countries and some algorithms include a temporal dimension, recognizing that gender-name relationships change throughout time (Blevins & Mullen, 2015).

Many studies use third-party algorithms (i.e. GenderAPI, Genderize.io) but only a few develop their own method to match name and gender, starting from specific-lists of names assigned to men or women in different countries (using i.e., the US census). While some algorithms provide binary stances (man/woman), most of them will provide the probability of a given name being assigned to a given gender. Table 1 shows a non-comprehensive list of some of the most used gender assignment services and algorithms.

Table 1

Non-comprehensive list of gender identification services.

Algorithm	**Information used (type of result)**	**Access**	**Regular Updates (last update)**	**Data sources**	**Size**	**Link**
Gender API	Name (Percentage)	Private	Yes	Publicly available data, governmental data and manual additions/corrections	6,084,389 (190 countries)	https://gender-api.com/
Genderize.io (Ozan Soft)	Name (Percentage)	Private	Yes	Open to the general public government sources	4.079.646 (188 countries)	https://genderapi.io/ http://cran.nexr.com/web/packages/genderizeR/vignettes/tutorial.html
Gender Guesser (NamSor)	Name (Percentage)	Private	?	?	9 billion (249 countries)	https://gender-guesser.com/
Gender-guesser (gender.c)	Name (Unknown, androgynous, female, male, mostly_female,	Public	No (2016)	Nam_dict.txt	44.568 names	https://pypi.org/project/gender-guesser/

	mostly_male)					
NameAPI (Optimaize)	Name (Percentage)	Private	Yes	Phone books, national government publications, websites on the subject, local freelancers	590.000 (55 countries)	https://www.nameapi.org/
Gender-detector (Open Gender Tracking)	Name (Binary)	Public	No (2015)	Social Security Administration (USA) Office of National Statistics (UK) Northern Ireland Statistics and Research Administration (UK) Scotland General Register Office (UK)	125.000 (2 countries)	https://pypi.org/project/gender-detector/
Sexmachine (Python)	Name (Androgynous, male, female, mostly_male, mostly_female)	Public	No (2013)	Nam_dict.txt	44.568 names	https://pypi.org/project/SexMachine/#description
Gender (CRAN)	Nam (Percentage)	Public	No (2011)	First names and dates of birth using historical datasets (U.S. Social Security Administration, the U.S. Census Bureau (via IPUMS USA), and the North Atlantic Population Project)	339,967 (from 1789-1930) 91,210 (from 1930 onwards)	https://cran.r-project.org/web/packages/gender/

Genni + Ethnea for the Author-ity 2009 dataset	Name (two methods: binary and Androgynous, male, female, mostly_male, mostly_female)	Public	No (2018)	Sex-machine data and US Social Security Administration	9,300,183 names	https://databank.illinois.edu/datasets/IDB-9087546
World Gender Name Dictionary	Name	Public	Yes	34 groups of national databases (full detailed list available on their Github)	25,000,000 names (195 countries/territories)	https://github.com/IES-platform/r4r_gender
Wiki-Gendersort	Name (Masculine, Femenine, Unisex, Initials, Unknown)	Public	No (2018)	Wikipedia (English) first names	694 376 names	https://github.com/nicolasberube/Wiki-Gendersort
Genderchecker	Name (Male, Female, Unisex)	Private	No (2011)	2001 and 2011 UK census data.	102,240 names	https://genderchecker.com/
Face++	Face (Binary)	Private	?	?	?	https://www.faceplusplus.com/

2.1.3. Limitations and solutions. There are issues with the binary stance most studies assume as gender is not a binary category (Lindqvist et al., 2021). The She Figures 2021 report stated the need for an effort to consider non-binary gender data (European Commission, 2021) and, since last decade, researchers are becoming more aware on how a binary conception of gender can bias their findings and of the limitations of gender identification algorithms (Halevi, 2019).

Some of these approaches do not work well in some Asian and Sub-Saharan Africa countries and others such as Brazil (Andersen et al., 2019; Larivière et al., 2013). Thus gender identification lists are not inherently global and Karimi et al. (2016) suggests using separate gender identification models for each language. Moreover, the current affiliation of the researcher may not be their country of origin nor origin of their name (Boekhout et al., 2021).

Many gender assignment algorithms are privately-owned, updated regularly and work relatively well, but they lack transparency and accessibility for many researchers (González-Salmón & Robinson-Garcia, 2023). Alternative and open methods tend to use smaller databanks, centered in English-speaking countries (i.e. Gender-detector, Genderchecker) or end up being abandoned (i.e. OpenGenderTracking Project, SexMachine).

Then, databases used by the algorithm are crucial for their accuracy. For instance, Wikidata information may suffer from biases translated from Wikipedia, biased towards men (Tripodi, 2023; Zheng et al., 2023). Although gender self-identification seems the most accurate approach (Van Buskirk et al., 2022) it is also the least exhaustive and most resource-intensive. Some authors propose a self-declared gender identification database for each journal (Ribarovska et al., 2021), while others include disclaimers stating that the notion of "gender" used in their research does not refer to the authors self-identification (Kong et al., 2022).

Lastly, some studies combine different approaches to overcome the inherent limitations of each of them (El-Ouahi & Larivière, 2023) which may be the most robust way to gain higher precision and exhaustivity in gender assignment (Karimi et al., 2016).

2.2. Unit of analysis

Results vary depending on the unit of analysis used, that is, depending on "the objects or sampling units in the performance of science which may be described by variables and about which inferences can be made." (McGrath, 2005, p. 263). The unit of analysis will determine, to some extent, the focus of the study (e.g., differences on citation, productivity, career gaps) being radically different from one another. This could explain partly why many studies present contradictory conclusions (Ceci et al., 2014; Nygaard et al., 2022). In many studies the unit of analysis is not clear or there is more than one unit of analysis (González-Alvarez & Sos-Peña, 2020).

2.2.1. Publications. When the unit of analysis is the research paper, its operationalization changes throughout investigations (Sugimoto & Larivière, 2023). Some research looks at first authors to create a categorical variable to determine that a paper was written/led by women when the first author is a woman, and vice versa (Caplar et al., 2017). There can also be more variables: male-male, female-female, male-female and female-male, by combining two first authors who contributed equally (Broderick & Casadevall, 2019), or when looking at patents: all female teams, majority female teams, minority female teams and all male teams (Koning et al., 2021). Other approaches count papers more than once assigning as many genders to papers as there are authors on it (Kong et al., 2022); determine a percentage looking at number of men and women in the author byline (Ruggieri et al., 2021) or create a woman-to-man authors ratio by publication (Demaine, 2021).

2.2.2. Authorship. Another unit of analysis is authorship. For instance, the CWTS Leiden Ranking uses it and, by assigning gender to each authorship, ranks universities' gender diversity and generates different types of indicators: the total number of authorships of a university, the number and proportion of authorships belonging to women and men and the number of authorships whose gender is unknown (Van Eck, 2019). Others look at the gender composition of each authorship position (West et al., 2013), sometimes focusing on the key positions of first, last and corresponding authorship (Bendels et al., 2018).

2.2.3. Individual researchers. Researcher as unit of analysis implies carrying out an author name disambiguation as to group an individual researcher's outputs and information (Tekles & Bornmann, 2020) for analyzing researchers' productivity (Cameron et al., 2016), citations (Chan & Torgler, 2020), careers (Boekhout et al., 2021; Spoon et al., 2023) and collaborations (Holman & Morandin, 2019; Mihaljević-Brandt et al., 2016), amongst other aspects.

2.3. Causality, biases and differences

Most bibliometric studies tend to be purely descriptive while others attempt at looking into causality or inferring factors contributing to gender inequality (Potthoff &

Zimmermann, 2017). The most used method is regression analysis. While gender differences are influenced by multiple factors (Ceci et al., 2014), studies tend to focus on specific causes while controlling for other variables. This approach can be problematic, as control variables may not be fully independent, limiting the capacity of such analyses to "uncover mechanisms that produce the gender disparities" (West et al., 2013), and masks potential mediation effects between different variables (Zheng et al., 2022). These studies try to uncover if gender differences are related to biases, discrimination, etc. (Boekhout et al., 2021). A contested ground since differences may not always lead to biases or disparities, and not all differences may necessarily represent unfairness (Traag & Waltman, 2022).

In any case, most analyses depart from understanding causality in terms of structure, whether they do this explicitly or not. They assume that social structure is inherently causal and that each social group experiences a different social structure, constraining its individuals, and limiting individuals' influence capacity on the structure (Ross, 2023). Hence, changes on the social structure will change the conditions of the population and, therefore, some causality is assumed and accepted.

3. Findings

Next, we group papers around the differences studies find, factors that explain these differences and what are the consequences of such differences.

3.1. Differences

Firstly, research asks itself where do gender differences take place in academia. Most studies reviewed below delve into this issue. Others try to go deeper and after confirming such differences, they try to locate how deep down they are entrenched in academia. Here we find studies looking into differences in the social structure of science, which may influence what we later observe.

3.1.1. Authorship. Authorship order decisions are entangled in social relationships and present gendered characteristics. Many studies report substantial gender differences in authorship (Demaine, 2021; González-Álvarez & Cervera-Crespo, 2017). This situation has not changed with the increasing presence of women in different fields such as Economics (Boschini & Sjögren, 2007), Pediatrics (Fishman et al., 2017) or Medicine (Jagsi et al., 2006). Oppositely, an increase of women in academia has been related to an increase in their overall authorship in other areas such as Dermatology (Feramisco et al., 2009).

Research shows that overall, women's underrepresentation as first authors has decreased in the last decades (Broderick & Casadevall, 2019; Colwell et al., 2020; Sidhu et al., 2009), although there are significant differences by field. There is an overrepresentation of women in first authorship positions in medical fields such as Neuroscience, Neurology or Psychiatry (Marescotti et al., 2022) and an underrepresentation in others such as Entomology (Walker, 2020). Moreover, countries with a higher overall proportion of women as first authors, tend to have sharper first-authorship differences between fields, leading to a "gender equality paradox" (Thelwall & Mas-Bleda, 2020).

Differences are also observed in corresponding authors. Even when women are in first position, they are less likely to be corresponding authors (Chinchilla-Rodríguez et al., 2024; Fox et al., 2018; Morillo et al., 2024). In difficult circumstances, such as the COVID-19 pandemic, men assumed a greater role as corresponding authors than women (Bell & Fong, 2021). However, studies here are limited and tend to be field-specific. This is not the case with last authorship, where there is abundant and uncontested evidence pointing towards a disproportionate number of men over women (Bendels et al., 2018; González-Alvarez & Sos-Peña, 2020; West et al., 2013).

Authorship position is a critical factor of success for research career prospects (Milojević et al., 2018). Collaborative papers with mixed authorship tend to be first authored by men (Broderick & Casadevall, 2019), while women's presence in the byline increases the chance of having a higher number of women co-authors (Aakhus et al., 2018; González-Alvarez & Sos-Peña, 2020; Sugimoto & Larivière, 2023; Zettler et al., 2017). For instance, in Ecology and Zoology journals in Latin America, the presence of women in the byline depends strongly on the gender of the last author (Salerno et al., 2019).

There are further constraints for women regarding authorship as they are more likely to experience authorship disagreements and men are more likely to determine authorship unilaterally (Ni et al., 2021). Besides, women are less credited than men with authorship for the same type of contributions (Ross et al., 2022) having a higher "time-to-credit payoff" resulting in fewer publications during PhD stages (Feldon et al., 2017). The dissatisfaction perceived by authorship attributions bears relation with the rank and gender of authors (Smith et al., 2020). As the motivation to work in research teams may depend on the perceived risks and gains (Feng & Kirkley, 2020), this devaluation of women's work creates cumulative disadvantages in scientific careers, especially for early career researchers (Fleming, 2021).

3.1.2. Citations. Citations are one of the most controversial areas. Citation differences vary by field and much attention has been paid to citations in STEM disciplines. In Physics, papers authored by women are under-cited, while those authored by men tend to be over-cited (Teich et al., 2022), which might be related to men starting to publish earlier in their careers (Kong et al., 2022). In Astronomy, papers written by women receive less citations than expected if written by men (Caplar et al., 2017).

There is a less clear image in the Life Sciences. Andersen et al. (2019) found almost no differences between women and men in citations in Medicine when adjusting for other variables. On the contrary, articles written by women published in high-impact journals were less cited than those of men (Chatterjee & Werner, 2021). Although gender bias in citations is less common among younger scientists, it still keeps making women's research less visible (Zhou et al., 2024). Less research has been done on Social Sciences, Humanities and Arts. However, there is evidence that women are under-cited in fields such as International Relations (Maliniak et al., 2013) and Communication (Wang et al., 2021).

Citation behavior seems to vary depending on the gender of citing authors, field and journal (Teich et al., 2022). In the field of Communication in Germany, men cite other men more than women cite women (Potthoff & Zimmermann, 2017). Men's citation practices seem to be the reason for an under-citation of women (Dion et al., 2018; Dworkin et al., 2020). Gender homophily in citations have been found in all scientific fields (Ghiasi et al., 2018), and tend to rule in every discipline when excluding self-citations and career gaps (Cameron et al., 2016). Given that men are more productive, this could lead to an uninterrupted disparity (Ghiasi et al., 2018).

Other variables into consideration are geography and productivity. Thelwall (2020) analyzed gender differences in six English speaking countries showing that "it is rare for field citation advantages to be dominated by one gender in a country". Chan & Torgler (2020) studied 21 fields in 43 countries concluding that amongst top scholars, citation inequality was higher than productivity inequality. Concerning 'elite authors', results are somewhat contradictory: there are less citation differences amongst the most productive researchers according to Aksnes et al. (2011), while significant citation differences amongst top-cited authors were found by Ioannidis et al. (2023).

The role played by self-citations is also contradictory. Some studies found that men self-cite more than women (King et al., 2017) while others claimed the opposite (Caplar et al., 2017). Others report no differences (Mishra et al., 2018) or have not found a positive impact of self-citations on career outcomes given gender (Azoulay & Lynn, 2020). At the same time, there are those who encourage women to self-cite more (Cameron et al., 2016), while others believe that this will not necessarily translate into scholarly gains (King et al., 2017).

3.1.3. Productivity. Women are less productive than men (Abramo et al., 2009; Astegiano et al., 2019; Campbell & Simberloff, 2022; Ceci et al., 2014; Huang et al., 2020; Nakhaie, 2008; van den Besselaar & Sandström, 2016; Xie & Shauman, 1998). This difference is confirmed across most studies, it is field-specific (Duch et al., 2012) and usually appears from early career stages (Symonds et al., 2006). In this line, Borrego et al. (2010) showed that the median number of papers published after obtaining a PhD tends to be lower for women than for men.

Specialization impacts productivity (Zeng et al., 2019). Women tend to publish in a wider range of topics (Leahey, 2006), to exhibit different publication patterns (Mayer & Rathmann, 2018) and carry out a wider range of tasks: they do more teaching and administration tasks than men and volunteer twice as often to carry out non-promotable tasks (Vesterlund et al., 2014). This is known as the "academic housework"

(Heijstra et al., 2017). This leads to a double discrimination in universities' recruitment processes (Brommesson et al., 2022) by which firstly women are expected to carry out more teaching and administration tasks and then these activities are considered less valuable during evaluations.

3.1.4. Contributorship. Research looks directly into author contribution statements to investigate women's role in research teams (Allen et al., 2019) but contributor role taxonomies are not a widely spread practice (Hosseini et al., 2023). Macaluso et al. (2016) found that women tend to do experiments more than men, and this remains constant throughout the whole scientific career. Besides, women are more likely to carry out technical work and to write the original draft, while men are more likely to review and edit the manuscript, acquire funding, provide resources and supervise projects (Larivière et al., 2021; Sugimoto & Larivière, 2023).

Such differences in the distribution of roles by gender may lead to the higher dropout rates for women especially at the beginning of their careers (Haeussler & Sauermann, 2020) and affect women's prospects, since the early career stage is the time when research finds a larger gender gap in task distribution (Robinson-Garcia et al., 2020). Gender inequalities observed among authors who made equal contributions also raise concerns about women not receiving proper credit for publications and suggest a need for journals to request clarity on the method used to decide author order (Broderick & Casadevall, 2019). Similarly, Paul-Hus et al. (2020) found that women are heavily underrepresented in the acknowledgement section.

3.1.5. Academic status. There is the assumption that gender parity in every academic aspect will arrive as the number of women increases (Sugimoto & Larivière, 2023). However, the number of women going from tenure to full professorship has not "kept pace with their rise in numbers in academia" (Bonawitz & Andel, 2009). This is known as the "leaky pipeline" (Corona-Sobrino et al., 2020; Mihaljević-Brandt et al., 2016; Spoon et al., 2023) by which women tend to drop out of the academic career as they progress, not reaching senior positions (Aramayona et al., 2022). This is observed in Italy where women scholars have a lower probability of becoming associate and full professors

(Filandri & Pasqua, 2021) or in Spain (Chinchilla-Rodríguez et al., 2024), and differences cannot be explained in terms of productivity (Marini & Meschitti, 2018).

Academic status is usually studied focusing on either collaborative patterns or evaluative practices in promotion (Fox, 2020). Collaboration affects men and women's career prospects differently. For women, their co-authors' gender influences their probability of receiving tenure, but does not affect men equally (Sarsons, 2017). When discussing evaluative practices, the picture is not so clear: a higher presence of women in evaluation panels led to a higher success rate for women applying for full professors (Zinovyeva & Bagues, 2011). However, Williams & Ceci (2015) found the opposite in men dominated fields, where women had a greater chance for promotion.

3.1.6. Journals. Gender differences exist in journals, even in fields dominated by women (Squazzoni et al., 2021). Women are underrepresented in high impact journals (Mauleón et al., 2013; Shen et al., 2018), as they often engage in topics which receive less attention by these outlets (Light, 2013). Women's representation is also alarmingly low within journal editors, key actors in the scientific communication system (Kennedy et al., 2001). This low presence extends to editorial boards in many disciplines (Aiston & Jung, 2015; Liu et al., 2023; Metz & Harzing, 2009). For instance, for most Psychology and Neuroscience journals, more than half of editors were men in 2019 (Palser et al., 2022). In the case of top-ranked medical journals, women were 15.9% of the editors-in-chief (Amrein et al., 2011), and women in editorial boards are less likely to be editor-in-chief, and more likely to carry out administrative work (Burg et al., 2022). The "leaky pipeline" alone does not explain these differences, since the proportion of women editors is lower than their representation in senior faculty positions (Fishman et al., 2017).

3.1.7. Conferences. Women are underrepresented in scientific gatherings such as conferences and workshops (Santosa et al., 2019) where the presence of the so-called "manels'' is still common. Women do not present their work in conferences as much as their counterparts, regardless of their work being of higher quality (Housri et al., 2008). However, there is an improvement in terms of overall parity (Ruzycki et al., 2019). The presence of women within the organization or panel of speakers in an event increases the proportion of women participants (Casadevall & Handelsman, 2014; Nittrouer et al., 2018; Sardelis & Drew, 2016; Zaza et al., 2021). However, even when there is overall parity, men tend to gather more attention in terms of participation than women: they ask more questions (Carter et al., 2018), take more time in their interventions (Jones et al., 2014), and men's lectures received higher attendance (Aufenvenne et al., 2021). Furthermore, women preferred presenting posters instead of talks, while it was the opposite for men (Isbell et al., 2012).

3.2. Explicative factors

Literature also tries to identify factors explaining such differences. This section is organized around the following concepts: gendered preferences, gender roles, and gendered life-work balance.

3.2.1. Gendered preferences. Science shows gendered preferences. These preferences either show a gender homophily or a preference of men over women.

Research looks for gender homophily in various ways. Firstly, in the choice of collaborators. It has been found, regardless of variables of seniority or proportion of women, in sub-fields of Life Sciences (Holman & Morandin, 2019); in some cases, women show a greater gender homophily than men (Jadidi et al., 2018) and, women tend to collaborate with men and women alike while men tend to collaborate more with other men in Poland (Kwiek & Roszka, 2021). Secondly, research studies homophily in peer review done by journals such as *eLife* (Murray et al., 2018), *Frontiers* (Helmer et al., 2017) and *American Political Science Review* (König & Ropers, 2022): men and women peer-reviewed more positively research done by researchers of their same gender. Hence, mixed groups of peer reviewers are recommended as they showed the lowest gender bias (König & Ropers, 2022). Thirdly, gender homophily in citations may be related to gender differences in research areas and subject content of the research (Potthoff & Zimmermann, 2017). Lastly, we found gender homophily in women's presence at scientific gatherings (see 3.1.7).

In other cases, both men and women prefer men or regard their work as being of higher quality. Regarding collaboration preferences, Biotechnology patents show that both men and women tend to collaborate more with men (Whittington, 2018). Men are more attractive as collaborators when they publish in men-typed topics, and vice versa (Knobloch-Westerwick et al., 2013). These differences vary greatly within sub-disciplines (Yamamoto & Frachtenberg, 2022; Zeng et al., 2016).

Regarding research quality, women doctoral students are perceived as less committed than men to their work (Ellemers et al., 2004). Gendered preferences lead to assuming that men wrote the work we read: women scholars are ten times more likely than men to be miss-cited as part of the opposite gender (citing them as "he" instead of "she") (Krawczyk, 2017). This is also seen in peer review processes. In a large-scale analysis of 145 scholarly journals from different disciplines, Squazzoni et al. (2021) found that women are less included in peer review in most disciplines. In Ecology, women receive less favorable peer review scores (Fox et al., 2018), while articles produced by gender-mixed teams are perceived to have a higher quality (Campbell et al., 2013).

Gendered preferences also exist in grant evaluation processes although results are not conclusive. Cruz-Castro et al. (2022) reviewed gender and funding literature concluding that it is not possible to grasp the full global picture. However, a meta-analysis based on 21 studies showed that men have a higher probability of approval than women by around 7% when using peer review (Bornmann et al., 2007). Marsh et al. (2009), analyzed the data used in Bornmann et al. (2007) and found no significant gender differences at all.

Research shows a preference for men in evaluators in country-specific analysis. For instance, men candidates are more likely to be more successful in Italy (Bagues et al., 2014; Jappelli et al., 2017); from age 38 onwards, women receive less funding than men in Quebec (Larivière et al., 2011) and PI women are being treated less favorably in evaluations on Canadian Institutes of Health Research (Witteman et al., 2019).

3.2.2. Gender roles. Gender roles in science show that women are directed towards teaching and administrative tasks, while men reserve more time to research (Filandri & Pasqua, 2021). They also show a gender bias in teaching evaluations from students that rate men higher (MacNell et al., 2015; Mengel et al., 2019; Miller & Chamberlin, 2000). In this sense, an over emphasis on publications during evaluations makes other practices such as teaching or administrative tasks less valuable, thus hindering women's careers (Hatch & Curry, 2020; van den Brink & Benschop, 2012). Moreover, research on scientific profiles along with an analysis of gender and archetypal differences found that women are less likely to be leaders during early and mid-career stages (Robinson-Garcia et al., 2020).

3.2.3. Gendered work-life balance. Considerable research tries to explain differences within researchers' work-life balance (Kyvik & Teigen, 1996; O'Brien & Hapgood, 2012). The main idea is that women carry out more domestic chores, take care of children and the elderly and, consequently, have less time for research (Kalra et al., 2023). This is known as the "parenting penalty" (Derrick et al., 2022), which affects women's productivity (Hunter & Leahey, 2010). Although "productivity penalty" is decreasing (Morgan et al., 2021), parenthood is still perceived as a factor influencing more negatively women's career prospects than men's (Zheng et al., 2022). Even when parents self-declare an equitable division of tasks, women researchers engage more on most parenting activities (Derrick et al., 2022). Oppositely, other research states that the presence of children increased both men and women's productivity (Fox, 2005), and that the higher productivity in women with children may be due to a "positive self-selection effect", by which only the most productive women are both researchers and mothers (Joecks et al., 2014).

This gendered work-life balance has mobility consequences (Lubitow & Zippel, 2014; Tower & Latimer, 2016): women are less mobile than men (Jöns, 2011; Sugimoto & Larivière, 2023), tend to move geographically closer to their home (Moguérou, 2004) and to a lower range of countries (Zhao et al., 2023). Underrepresentation of women in international mobility happens in every discipline, especially in Physical Sciences (Momeni et al., 2022) and women tend to move internationally when their caring responsibilities are lower (Cañibano et al., 2016). Parenting is not the only reason, moving with partners may be harder than with children (Zippel, 2011) and having a partner may have stronger effects for women (Rivera, 2017; Uhly et al., 2015). Consequently, some research contests the idea of "gender-neutral policies'' and calls for "gender-aware" policies (Burch et al., 2023).

This lower international presence has collaborative consequences: men tend to collaborate more internationally than women (Aksnes et al., 2019; González-Álvarez & Cervera-Crespo, 2017), and women rely more on national funds and receive less international funding (Ruggieri et al., 2021). In Italy, these differences are reduced for highly productive authors (Abramo et al., 2019).

In this sense, COVID-19 pandemic seems to have only accentuated the already existent gendered work-life balance (Andersen et al., 2020; Bell & Fong, 2021; Ribarovska et al., 2021), although some research hinds towards no gender differences in publication during the pandemic (Abramo et al., 2022; Jemielniak et al., 2022).

3.3. Consequences

This review identifies a nuanced picture that has many consequences, which we group in two different categories: career diversity and the scientific workforce and the knowledge generated.

3.3.1. Career diversity and scientific workforce. Every element discussed here ends up creating a vicious circle that affects women's careers (Aiston & Jung, 2015; Freund et al., 2016; van den Besselaar & Sandström, 2017), producing an accumulation of disadvantage known as the Matilda effect (Rossiter, 1993) and leading to different career trajectories, successes and transitions (Filandri & Pasqua, 2021; Jagsi et al., 2011; Lerchenmueller & Sorenson, 2018). Women experience more difficulties to enter informal networks within the scientific community, being "workplace climate" one of the top reasons for women to leave academia (Spoon et al., 2023), related to the existence of daily "micro-inequities" (Aiston & Fo, 2020).

Women's careers are generally shorter and there are more gaps in women's publishing careers than in men's. The reason can be found in diverse career length (Huang et al., 2020), although differences in productivity could not be only explained by career length or stage, but by the number of men and women starting a career as researchers (Boekhout et al., 2021).

These restrains to gender diversity are also affecting the scientific workforce as a whole, since diversity (whether gender, ethnic or geographical diversity, amongst others) allows for more novel research, is better for problem-solving (Nielsen et al., 2017b), generates higher impact (Yang et al., 2022) and receives more citations (Powell, 2018).

3.3.2. Knowledge generated. The literature highlights two main elements related to gender and the knowledge generated. First, women and diverse teams tend to include variables of sex and gender in their research more than all-men teams (Key & Sumner, 2019). This is relevant since sex inclusion, sex analysis and sex reporting can change the conclusions of an investigation (Sugimoto et al., 2019), and extrapolating data from one sex to another is dangerous (Klein et al., 2015). For instance, patents made by teams composed solely by women were 35% more likely to focus on women's health (Koning et al., 2021), and there is a strong positive correlation between women's authorship and the probability of a study including gender and sex analysis (Nielsen et al., 2017a).

Second, some disciplines and topics are dominated by a specific gender and there tends to be homophily between authors' demography and the topics they research (Sugimoto & Larivière, 2023). Kozlowski et al. (2022) develop the idea of "privilege of choice", by which the choice of a particular topic is rooted in that person's gender and race. Overall, in the US, men tend to study STEM topics, whereas women study topics more related to Gender-Based Violence, Families, Learning, LGBT Studies and Nursing (Kozlowski et al., 2022). Stereotypes are considered to be more important than discrimination within some fields, and they may be the reason women are not present in some disciplines, since they do not enter them in the first place (Ceci et al., 2014).

Moreover, when women have entered previously fields denominated by men, some research has found a "reconfiguration" of segregation (Acker, 2006). For instance, when entering a field dominated by men such as Medicine, women tend to specialize in Pediatrics, Gynecology and General Practice, but not in Surgery, which is still dominated by men (Acker, 2006; Alers et al., 2014).

4. Discussion

In this paper we provide a comprehensive literature review of gender inequality in science. Unlike other reviews, we focus on research using bibliometric methods focusing on two aspects: methodologies used and the findings of the literature, which we divided into three elements: differences, explicative factors, and consequences.

Regarding methodological aspects, we found an elaborated but not yet perfected range of techniques for identifying gender of researchers. We also identified the different units of analysis, publications being the most used. Lastly, we commented on the causality issue. We will delve further into these issues in the following section, when analyzing gaps in the literature.

We found gender differences in almost every aspect of academia. This is not unexpected, given that science is a social activity, and it reflects social inequalities found outside the research world. Nevertheless, research on citations is somewhat contradictory and gender gap evidence on contributorship is still too scarce.

Albeit establishing causality is not an easy enterprise, research tries to find possible explanations for gender differences. There is evidence of gender homophily within academia and of a general preference for men and men's work, coming from men and women alike. Literature is also considerably clear on the existence of gender roles within science and on the gendered work-life balance.

The consequences of a gender gap are numerous and probably extend far beyond what we currently know about the scientific workforce and the knowledge that is accepted and created. That is why most studies combine bibliometric methods with other interdisciplinary approaches. These consequences mainly relate to career diversity and the scientific force and the knowledge that is created.

5. Towards a future agenda

Here we organize the gaps observed in the literature and we propose a novel research agenda for future studies (Table 2).

Table 2

Connections between the gaps and the new research agenda proposed

Gap	New research agenda
Methodological limitations (in general; gender identification in particular)	Devote greater attention to methodological issues and limitations.
Lack of a global view	Encompass a global vision on research and carry out more literature reviews and meta-analyses
Imbalance of topics of research	Attempt at researching new topics
Confusion of concepts	Guidelines on correct use of concepts

Firstly, there are methodological issues. Gender identification algorithms are not always satisfactory as they reflect a binary vision of gender and assume that gender can be obtained from names. Moreover, gender assignment processes do not work well with every country of origin and/or language, leading to inaccurate reporting and hindering reproducibility. A collaborative effort is needed to reduce the challenges, whether through the creation of open approaches, self-declared databases, or other.

A second gap is the lack of generalization. Given the localized nature of data, research tends to focus on a few variables on particular study cases: the same geographical areas (Europe, USA, and Canada), in English and in STEM. Thus, instead of a coherent body of literature there is a patchwork of ideas and conclusions. Although this limitation comes from lack of normalized data, there have not been many attempts at exploring the global structure of knowledge, not allowing for a global comparison nor for a holistic understanding of the situation of women in science. Hence, we highlight the value of meta-analysis and systematics reviews to have a global vision and infer conclusions.

A third gap is the imbalance of research topics. The unit of analysis studied in research tends to be publications and most research focuses on authorship, citations, evaluations, and work-life balance, with fewer research aiming at exploring new and/or diverse topics (contributorship, networking or impact on the knowledge that is created). There should be a balance of the topics studied to be able to connect and analyze the new knowledge generated from studying those topics to the already existing research.

The use of different concepts corresponds to the fourth gap. Different research does not understand the concepts of “man/woman” and “male/female” in the same way, and there is no discussion nor written consensus on how to tackle these issues ethically and correctly within Bibliometrics. Although nowadays research usually clearly distinguishes the differences between sex and gender, and gender is now the most used concept (Fox et al., 2022), some bibliometric studies are strikingly behind in this distinction or seem to have only substituted one word for the other. Using sex leads to the idea that differences are natural and unchangeable, whereas when focusing on gender, we allow for change, given its cultural creation. Thus, a novel research agenda would not be complete without a guideline that carefully explains how to use certain concepts related to gender properly and systematically within the field.

We are aware of the challenging nature of these research agenda. Data is usually not ideal, and it is not always possible to establish causal inference. However, we believe it is more an issue of a lack of imagination when using Bibliometrics. Time alone will not fix things, and to fight the “gender fatigue” (Kelan, 2009), we must conduct a re-consideration of these issues and develop critical reflection on them. This could not only result in solutions currently unimaginable, but it is a socially responsible act that we must perform to produce a more beneficial and nuanced research.

[1] Throughout this literature review, we use women/men to refer to gender and rather than female/male. Quoted articles are not modified, therefore some of them may not follow this guideline.

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