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Superconductivity and the Sustainable Development Goals (SDGs): A Challenge for Researchers in Superconductivity

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Abstract: The 17 Sustainable Development Goals (abbreviated: SDGs) for the period 2015–2030 have now just passed the midterm, and thus the efforts of scientists in this direction should be clearly visible. A bibliometric analysis of the papers enlisted in the Clarivate Web of Science (WoS) may enlighten the efforts by researchers in the field of superconductivity. To conduct such an analysis, there are new filters added to the WoS, which classify a given paper via the microcitation topics for the various SDGs. In this contribution, we present a thorough analysis of the field of superconductivity and its applications as well as the performance of selected authors. The results obtained point directly to a big problem that the research on superconductivity is facing: The list of keywords to qualify for SDGs does not represent the field in a way it deserves as most of the papers in the field of superconductivity carry the mico citation topic "critical current density", which is not recognized for the SDGs. This is especially visible when analyzing individual authors, especially those working at companies in the field. Thus, in view of securing the necessary recoginition and research funding, it is obvious that there must be a change to give superconductivity the role within the SDGs it deserves.

Keywords: Sustainable Development Goals; SDGs; superconductivity; levitation; bibliometric analysis

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1. Introduction

In September 2015, the General Assembly of the United Nations adopted the 2030 Agenda on Sustainable Development (UN 2015), which comprises 17 Sustainable Development Goals (SDGs) forming the kernel of this agenda. These 17 SDGs—although all these are not legally binding—define a framework to implement sustainable development worldwide to improve global sustainability by 2030 [1]. These 17 SDGs cover the three dimensions of sustainable development: environmental protection, social inclusion and economic growth [2]. Additionally, they are made up of 17 goals with 169 targets and include 300 indicators covering all aspects of sustainability. The 17 goals are given in Figure 1 together with a description or highlight following Fonseca et al. [3]; the ones being most important for superconductivity are indicated by a blue color. Thus, the SDGs are an ambitious step towards actionable targets for sustainable development covering all aspects of sustainability as well as all sectors of society [4]. The SDGs represent a framework for governments and organizations but also individuals to work towards sustainable development [5]. Action is needed from every country in the world or every institution/organisation, no matter which level of development they have reached. All 193 countries who sit in the UN General Assembly adopted the SDGs and agreed to take action to implement the SDGs in their own countries [6]. However, from the side of the UN, there were no basic rules issued, and no associated compliance mechanisms were installed, leaving these tasks to each local government to develop its own approach based on the local needs and politics [7,8]. All this, of course, also applies for the various institutions/organizations in Science.

Now, we have passed the year 2023, which corresponds to the half-way milestone of the agenda, and so the efforts taken worldwide should be already clearly visible. A view of the progress towards sustainable development was provided by Soergel et al. [9], where the authors quantified climate and SDG outcomes but also found several important gaps remaining.

Meschede [10] performed a literature search in the Clarivate Web of Science core collection as well as in Scopus with the search term "Sustainable Development Goals" as the topic in the timespan 2015–2019. The small number of papers found (3237 papers from WoS were collected for the analysis after removing duplicates) led to the conclusion that many authors do not yet link their research to the SDGs. The findings further infer that most research, which directly refers to the SDGs, stems from the research areas Life Sciences and Biomedicine (2261 articles) and Social Sciences (1960), whereas from the category Technology, 850 entries were obtained and, from the category Physical Sciences, only 121 articles. This directly confirms the hypothesis that scientists do not consider the SDGs very well. Consequently, it was found that SDG 03 (*Good Health and Well Being*) is the best represented goal, whereas SDG 11 (*Sustainable Cities and Communities*) was barely represented in the dataset. This finding may have important consequences for future research funding, so it is essential to find the reasons for the relatively bad performance of Physical Sciences/Technology towards the SDGs.

Various publications [11–14] have discussed the challenges caused by the SDGs, their inter-relations and the relations between the SDGs and energy or the circular economy. Sachs et al. [11] presented an action agenda for Science but also pointed out that "important knowledge gaps exist in designing pathways and strategies for each transformation, implementing them and monitoring results". The key issue is that integrated efforts are required, combining scientists and engineers as well as policy specialists together to be effective to reach the goals set by the SDGs. Thus, the current time is well suited to analyze the performance of a given scientific field, in the present case, the field of superconductivity and its applications. Superconductivity, providing the loss-less transportation of electricity, should play an important role within the SDGs, especially concerning the goals 07, 09, 11 and 13. Other SDGs may be targeted as well considering the applications of superconductivity, e.g., magnetic resonance imaging (MRI) magnets [15] and magnetic drug delivery [16] for SDG 03 (*Good Health and Well-Being*), levitation demonstration [17] for SDG 04 (*Quality Education*) and magnetic separation technology [18] for SDG 06 (*Clean Water and Sanitation*) or SDG 12 (*Responsible Consumption and Production*). In this sense, one would expect that papers on superconductivity may play a good role among the research towards the SDGs. The current worldwide efforts to implement a hydrogen economy [19,20] in order to reduce the production of CO_2 provides now unique chances for the field of superconductivity, especially the high-T_c superconductivity (HTSc) with superconducting transition temperatures well above 20 K. This was first described in 2004 by Grant [21] and is now followed by many authors several years later [22–27].

SDG	Icon	Highlights	"supercond*" 73,372	"supercond*" AND "application" 7,265
01 No poverty		End poverty in all its forms, everywhere.	2,136	92
02 Zero hunger		End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.	29	7
03 Good health and well-being		Ensure healthy lives and promote well-being for all at all ages.	10,689	1,535
04 Quality education		Ensure inclusive and equitable quality education and promote life-long learning opportunities for all.	208	19
05 Gender equality		Achieve gender equality and empower all women and girls.	83	5
06 Clean water and sanitation		Ensure available and sustainable management of water and sanitation for all.	772	179
07 Affordable and clean energy		Ensure access to affordable, reliable, sustainable and modern energy for all.	31,401	2,586
08 Decent work and economic growth		Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all.	3,136	137
09 Industry, innovation and infrastructures		Built resilient infrastructure, promote inclusice and sustainable industrialization, and foster innovation.	15,171	1,656
10 Reduced inequalities		Reduce inequality within and among countries.	97	13
11 Sustainable cities and communities		Make cities and human settlements inclusive, safe, resilient and sustainable.	6,894	645
12 Responsible consumption and production		Ensure sustainable consumption and production patterns.	765	91
13 Climate action		Take urgent action to combat climate change and its impacts.	1,645	237
14 Life below water		Conserve and sustainably use the oceans, seas and marine resources for sustainable development.	279	48
15 Life on land		Protect, restore and promote sustainable use of terrestrial ecosystems, sustainable manage forests, combat desertification, and halt and reverse land degradation, and halt biodiversity loss.	58	9
16 Peace, justice and strong institutions		Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and built effective, accountable and inclusice institutions at all levels.	3	---
17 Partnerships for the goals		Strengthen the means of implementation and revitalize the global partnership for sustainable development.	---	---

Figure 1. The 17 Sustainable Development Goals (SDGs) and their icons. The ones relevant for the field of superconductivity are written in blue, and other targeted ones (as deduced from the literature search) are written in green. The column Highlights is given following Fonseca et al. [3]. Goal 17 plays no role for the field of superconductivity. The last two columns give the results obtained in the WoS searches with the topics "supercond*" and "supercond* AND application" and the WoS SDGs filter applied.

Liquid hydrogen serves as an energy carrier, but, at the same time, it could be a coolant for superconductors (the boiling point of liquid hydrogen, LH_2~20 K). Thus, the HTSc as well as superconductors like MgB_2 (T_c~38 K) or some of the Iron-Based Superconductors (IBSs) with T_c~38–50 K are especially well suited for this synergetic operation in LH_2 [24–27], which should strengthen the role of superconductivity even more.

In this context, the Clarivate Web of Science (WoS; [28]) has introduced a new filter in the advanced filter system, allowing the papers included in the database to be tagged by the various SDGs. This enables the efforts in various scientific disciplines concerning the SDGs to be directly visualized, and thus the performance in a given scientific discipline can be elucidated.

In a recent review [29] entitled "Bridging Ceramic Superconductors with UN Development Goals: Perspectives and Applications", we considered the role of the applications of superconductivity towards the SDGs and performed a thorough bibliometric analysis on two datasets, one on superconductivity and applications spanning the period 1980–2023, and a second one for the same topic but employing the WoS-SDGs filter for the SDGs in the timespan 2015–2023. Here, we could identify the most productive countries, the most relevant institutions/organizations and the respective interactions. Furthermore, we identified the most relevant sources and articles, including the dynamics of the author-provided keywords and the research trending topics during the SDG stage. Although these all represent important results for the field of superconductivity, the SDG tagging mechanism and the role of individual researchers was not yet investigated in detail.

The present paper now discusses the SDG tagging for papers dealing with superconductivity and presents some detailed analysis considering several topics of active research in superconductivity and the respective SDG tagging. Furthermore, the results obtained for some selected researchers in the field are presented to obtain a better impression how the SDG tagging works. From the various results obtained, several important conclusions are drawn, which have importance for individual researchers as well as for the entire field of superconductivity.

This paper is organized as follows: Section 2 presents the methodology applied to obtain the data from WoS, Section 3 presents the results obtained from the bibliometric analysis, firstly considering the general analysis of superconductivity and its applications (Section 3.1), followed by an analysis of the most cited papers in the field of Superconductivty (Section 3.2) and an analysis of the top-5 authors working in the field, the two Nobel laureates for HTSc and the authors who had discovered $YBa_2Cu_3O_{7-\delta}$ (YBCO), MgB_2, the IBS and the nickelates (Section 3.3). Appendix A gives some more additional comments to the bibliographic analysis and an introduction to the Appendices B–F. Appendices B and C present the bibliographic data obtained before December, 2025, to enable a comparison with the data of the main article. Appendices D–F present the analysis of several members of the Editorial board of the journal *Superconductivity* (Appendix C), of several selected researchers in the field of superconductivity (Appendix D) and of researchers affiliated with large research centers and companies (Appendix E). The results obtained are then further elucidated in Section 4 considering properties of the WoS SDGs filter and the topic "supercond* AND levitation" in detail. Finally, Section 5 presents the conclusions that can be drawn from the bibliometric analysis.

2. Methodology

In this contribution, we used bibliometric analysis of the data collections from Clarivate Analytics Web of Science (WoS) [28]. For a general overview, we employed the topic search terms "supercond*" as well as "supercond* AND application" with the "*" denoting a wild card to include all words starting with the term "supercond". Since 2022, the WoS has provided a filter tool named "Refine by Sustainable Development Goals", which enables one to perform a refinement of the data obtained from a topic or author search. The underlying tool for this filter is category-to-category mapping, where the SDGs are mapped to sets of related microcitation topics. The first mapping to microcitation topics was carried out in January 2022, and in April 2024, the citation topics clustering has been updated [30]. On this base, all the papers included in WoS may receive an SDGs tag according to SDG 01–17, not only such ones written after the publication of the SDGs in the year 2015. Here, it is important to note that the SDGs mapping is possible for all documents contained in WoS. The accessible timeframe is depending on the university's subscription, so in most cases, starting from 1945. Combining the search terms "supercond* AND application" practically limits the timeframe to the range 1960–present, but, for a proper analysis, the incomplete years 2024 and 2025 were omitted in our searches. Figure 2 shows the schematic approach to obtain the bibliometric data from the Web of Science core collection for the general search and the author-based search.

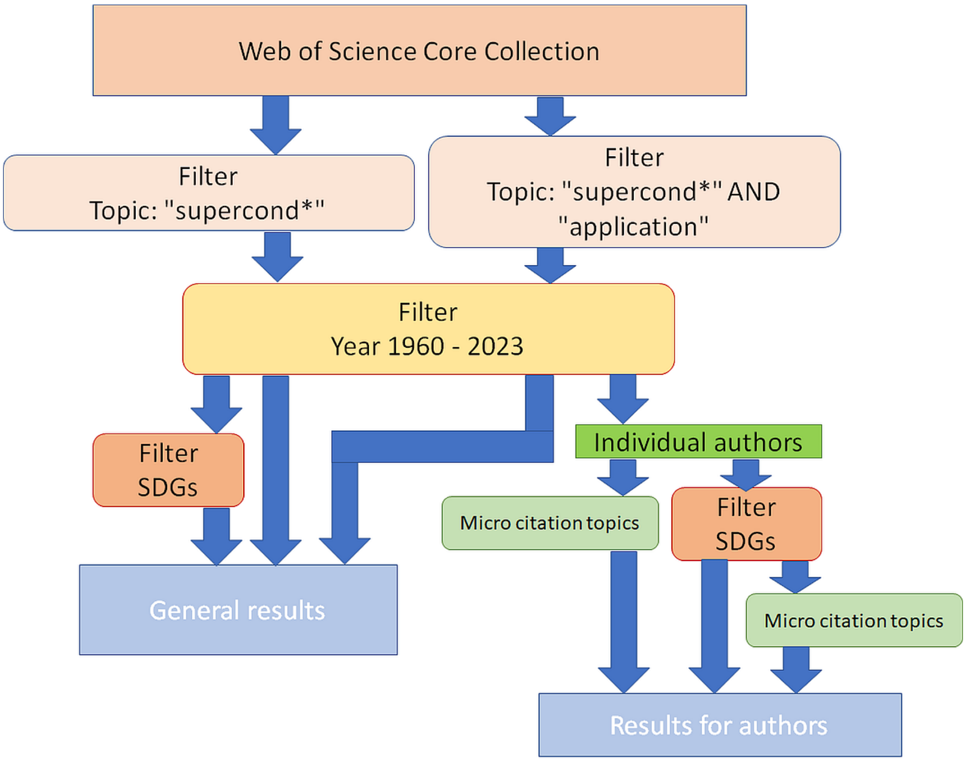

Figure 2. The approach applied to obtain the bibliometric data from the Web of Science Core Collection.

The author search in WoS can be troublesome for authors with quite commonly used names (e.g., "Müller", "Berger" or "Tanaka"), which do not allow an unambiguous identification. In this case, it was necessary to try the author identifiers (i.e., the WoS number given to an author or the ORCID number). In doing so, most of an author's contributions could be identified, but, in some cases, there exist more than one author identifier for a given author in WoS, no unregistered ORCID number or even multiple people (e.g., with the same initials) may be registered on one identifier. This situation is also quite common for Chinese or Japanese authors. In such a case, only an author search combined with the respective affiliation(s) or with the topic (e.g., "supercond*") may help to properly identify the selected author by identifying a paper in the field, and, on this base, a decision about which approach may work best can be made.

To analyze the detailed microcitation topics that lead to an SDGs tag (as performed in Section 4 below), we performed multiple filtering steps. In the first step, the topic was selected, e.g., "supercond* AND levitation", and then, the SDGs filter was applied. Following this step, a refinement for each SDG was made and then filtered for the microcitation topics.

All data collections presented here were last updated on 15 December 2024, and the document types covered were articles, proceedings papers, reviews, or meeting abstracts.

3. Bibliometric Results

3.1. WoS General Analysis

Let us first start with a simple search on the WoS core collection with the keyword "SDG" as topic. As a result, 12,161 papers are found. Searching now for the combined topic "SDG AND supercond*", no result is obtained. Searching for "SDGs AND supercond*" yields in total only three (!) results. Immediately, we learn here that SDG is not an unique abbreviation, but it is used differently in various fields, e.g., "Secoisolariciresinol diglucoside (SDG)", "subdural hygroma (SDG)", "Small diameter gravity sewers (SDGS)", "synchronous distributed generation (SDG)" or "simultaneous distributed generation (SDG)". This directly implies that the search for "SDGs" gives better results as the simple keyword "SDG".

These three results are given below:

- (1) Sadeghi, Mohsen; Abasi, Mahyar [31]
  Optimal placement and sizing of hybrid superconducting fault current limiter for protection coordination restoration of the distribution networks in the presence of simultaneous distributed generation.
  Electric Power Systems Research, vol. 201, 107541 (2021)
  DOI: 10.1016/j.epsr.2021.107541
  Research Areas: Engineering
  Citation Topics:
  4 Electrical Engineering, Electronics & Computer Science
  4.18 Power Systems & Electric Vehicles
  4.18.1055 Fault Location
  Sustainable Development Goals:
  07 Affordable and Clean Energy

- (2) Mato, Takanobu; Noguchi, So [32]
  Microplastic Collection With Ultra-High Magnetic Field Magnet by Magnetic Separation.
  IEEE Transactions on Applied Superconductivity, vol. 32, 3700105 (2022)
  DOI: 10.1109/TASC.2021.3135796
  Research Areas: Engineering Physics
  Citation Topics:
  3 Agriculture, Environment & Ecology
  3.60 Herbicides, Pesticides & Ground Poisoning
  3.60.2078 Microplastics
  Sustainable Development Goals:
  14 Life Below Water

- (3) Watanabe, Tsuneo [33]
  The review of international forum on magnetic force control IFMFC activity from 2010.
  Progress in Superconductivity and Cryogenics, vol. 24, 1–6 (2022)
  DOI: 10.9714/psac.2022.24.3.001
  Research Areas: Physics
  Citation Topics:
  1 Clinical & Life Sciences

1.6 Immunology
1.6.487 FOXP3
Sustainable Development Goals:
03 Good Health and Well-being

Although this seems to be a quite poor result, we can learn here that all papers were published in the timespan 2015–2023, i.e., the time of the SDGs. None of the papers mentions the SDGs in the title, but two of them (1, 2) in the abstract, and two of them (2, 3) are written by Japanese authors. In Japan, the SDGs are even promoted in schools and in many locations like on station platforms as well as in special-outfitted commuter trains. We also see that WoS groups the papers into three levels of citation topics: "Web of Science Categories", "Meso citiation topics" and "Micro citation topics". These "Micro citation topics" by WoS are finally the key to the SDG tagging; the importance of which we will see later on in Section 3.3. Paper (1) does use the term "SDGs" in the abstract but, as already mentioned, for the term "simultaneous distributed generation", which is not necessarily related to superconductivity. Nevertheless, the paper received an SDGs tag (*07 Affordable and Clean Energy*). Also interesting is the fact that only one paper (1) received a link to SDG 07; (2) is linked with SDG 14 and (3) with SDG 03. According to the hypothesis mentioned in Section 1, this result does not fit the expectation.

Searching the WoS with the topic "Sustainable Development Goals" (like in Ref. [10]) AND "supercond*" yields exactly two results. One of them is also included in the previous search (2). The other one is given below:

- (4) Fukuyama, Hidetoshi [34]
  "More Is Different" and Sustainable Development Goals: Thermoelectricity.
  Annual Review of Condensed Matter Physics, vol. 15, 1–15 (2024)
  DOI: 10.1146/annurev-conmatphys-032922-114143
  Research Areas: Physics
  Citation Topics:
  5 Physics
  5.33 Semiconductor Physics
  5.33.329 Quantum Hall Effect
  Sustainable Development Goals:
  08 Decent Work and Economic Growth

This paper (4) has, however, not much to do with current research in superconductivity but is linked to the basic theory of superconductivity via the discussed transport and thermodynamic properties of Bloch electrons in magnetic fields and the Green's function formalism. Another interesting result is that papers (2), (3) and (4) also appear in the result list when searching for "magnet*" AND "SDGs", which demonstrates the strong interlinking between the research fields of superconductivity and magnetism.

Superconductivity, and especially its applications with loss-free carrying of electric currents, should have a well-established position in the SDGs as such applications clearly contribute to the reduction in CO_2 and reduced energy comsumption. This assumption is, however, not true. When searching the WoS for "supercond*" or "supercond* AND application", one finds that only a small number of papers has received an SDGs tag. The search with the topic "supercond*" results in 239,368 papers (limited to the years 1960–2023), and 41,669 of them have received an SDGs tag, corresponding to 17.4%. From the 21,084 papers obtained for the search topic "supercond* AND application", the SDGs filtering yields 3885 papers, which corresponds to 18.4% of all papers dealing with superconductivity and its applications. The distribution of these papers to the SDGs is shown in the last two columns of Figure 1. Only SDG 17 is not covered by any paper dealing with superconductivity.

For the following analysis, we consider only the articles found applying the topic search "supercond*" and limit the search to the years 1960–2023. The year 1960 marks the beginning of applications of superconductivity, and 2023 represents the last and complete year. If there is a deviation from this rule, it will be mentioned in the respective graph.

Figure 3 illustrates the number of papers that received an SDGs tag for the two searches mentioned above; all papers in *Superconductivity* are shown by the blue bars, whereas the papers dealing with superconductivity and applications are indicated by the red bars. We can learn here that the SDGs 07, 09 and 03 are the most important SDGs in the research on superconductivity, followed by Nos. 11, 08, 01 and 13, which all received more than 1000 counts (see also Figure 1). All the other SDGs are covered by considerably smaller amounts of papers, and only SDGs 16 (three counts for the search "supercond*") and 17 (no count in both searches) play a minor or no role in superconductivity research.

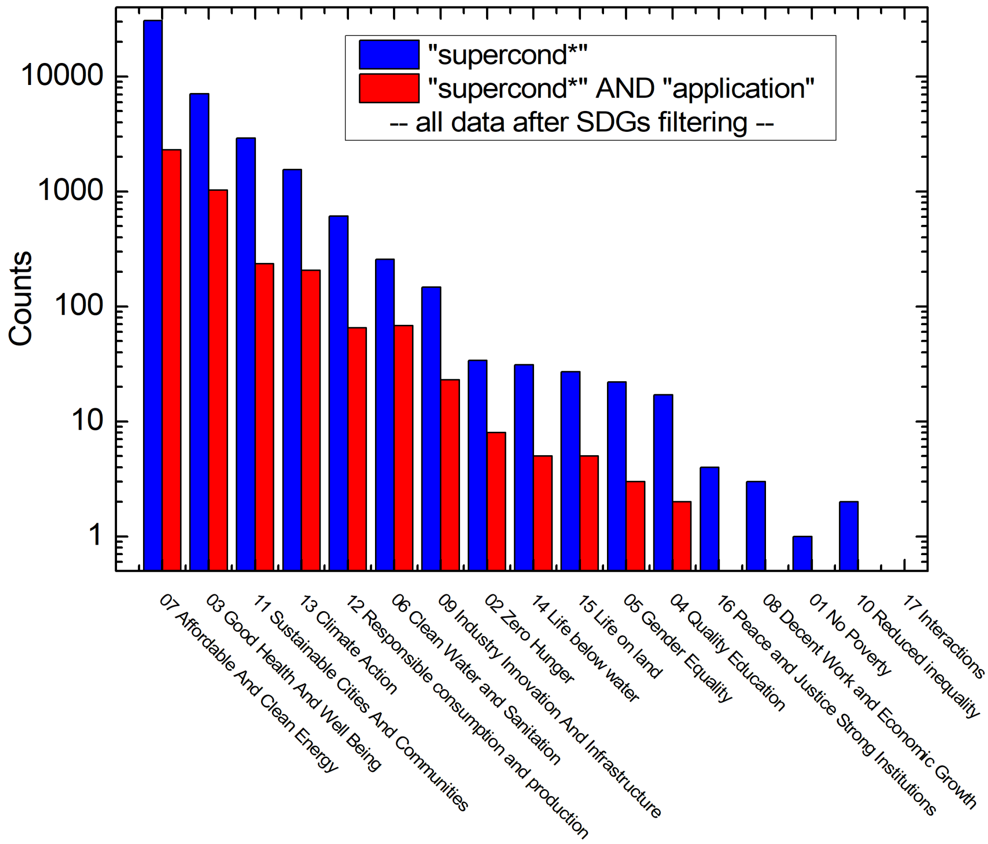

Figure 3. The number of papers tagged for the SDGs by the WoS SDGs filter for the search topics "supercond*" (blue) and "supercond* AND application" (red). Note the logarithmic scale of the *y*-axis, which is necessary to properly show all the results.

Another interesting point is the SDGs tagging of papers dealing with superconductivity as function of time. Thus, we look at the time evolution of the SDGs tagging for the four most important SDGs, No. 03, 07, 11 and 14, in the entire timeframe spanning from 1960 to 2023 in Figure 4a–d. In 1960, the first papers appeared dealing with possible applications of superconductivity, and the development of the alloys NbZr, NbTi and slightly later, Nb_3Sn, enabled the building of superconducting coils to produce high magnetic fields. Thus, SDGs tags are also given to these papers, even though their number per year does not exceed 5. In the graphs, we placed a red-dashed line (- - - -) at the year 1987, indicating the discovery of the high-temperature superconductors (HTSc). Of course, the onset of the research on the applications of the newly found HTSc took some time until 1990, but then an immediate increase in the number of papers, which received an SDGs tagging, is clearly visible in all four graphs. A second, green-dashed line (- - - -) at the year 2008 marks the discovery of the Iron-Based Superconductors (IBSs), which caused again a push-up of the number of papers. Remarkably, the finding of MgB_2, the metallic superconductor with the highest transition temperature [35–37], in the year 2001 did not cause a similar increase in the number of papers. This point is very important and will be discussed in detail later on. Finally, the full, orange line (——) marks the announcement of the SDGs. Again, all the four graphs reveal an increase in the SDGs-tagged papers towards the year 2023. Only the data for SDG 07 (see Figure 4b) reveal a steady increase, whereas the other SDGs (SDG 03, SDG 11 and SDG 13) see some scattering of the data, especially in the last years.

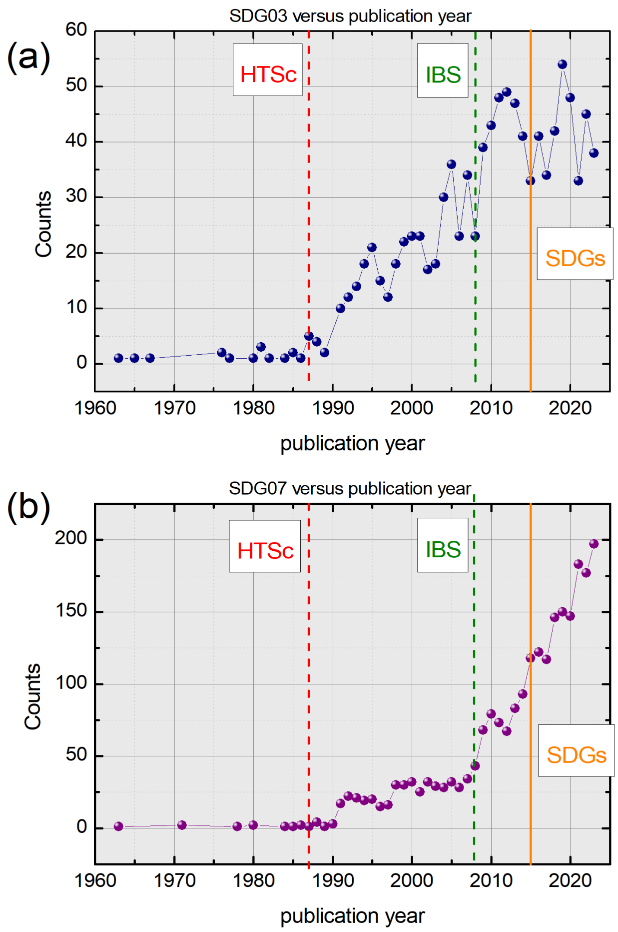

Figure 4. The 4 most important SDGs for the field of superconductivity as a function of the publication year in the timeframe 1960–2023. (**a**) SDG 03, (**b**) SDG 07, (**c**) SDG 11 and (**d**) SDG 13. In each plot, the dashed red line (- - - -) marks the upcoming of the HTSc, the dashed green line (- - - -) indicates the discovery of the Iron-Based Superconductors (IBSs), and the solid orange line (——) marks the announcement of the SDGs in the year 2015.

Papers for SDG 03 normally deal with applications of superconductivity in the medical field, i.e., magnetic resonance imaging (MRI) or magnetic drug delivery. As consequence, the number of papers for SDG 03 is fairly limited, reaching to about 40 papers/year in 2023 with a maximum of 54 papers in 2019. The curve also suffers from data scattering.

In contrast, SDG 07 is the most important SDG for the superconductivity research, having practically with 200 papers/year more than double the number of papers for SDGs 03, 11 or 13. This curve nicely reflects the effects of the finding of the HTSc and the IBS as well as the announcement of the SDGs as each event pushed up the number of papers counting for this tag.

The time evolution for SDG 11 is presented in Figure 4c, reaching to about 25 papers/year in 2023. Overall, the amount of papers for this SDG is only about a tenth of SDG 07 (b). The first datapoint stems from 1980, and the amount of papers for this tag increases from 1990 onwards.

The time evolution for SDG 13 is shown in Figure 4d. The amount of papers classifying for this tag ranges between 1 and 17 (in the year 2023). There is an increase in the papers with time, but a large scatter of the data is also clearly visible. However, one could have expected many more papers that classify for the tag SDG 13 as affordable and clean energy represents a direct goal of superconductivity research, so the ∼200 papers/year in 2023 is a quite small number when regarding the total number of papers in the entire field of superconductivity.

All graphs of Figure 4 demonstrate clearly the effect of the discovery of the HTSc, which is followed by a strong increase in the amount of papers, but also the discovery of the IBS may show an influence. This symbolizes that the research field is a quite active one, and one may expect a further increase in the amount of papers driven by the finding of new superconducting materials (e.g., room-temperature superconductivity and nickelates) or new fabrication technologies (e.g., coated conductors, infiltration growth, and high pressure synthesis).

To summarize this part, we can say that the field of superconductivity has an obvious problem to have the efforts recognized with the SDGs as only about 18% of the papers are tagged by SDGs. Hardly any paper dealing with superconductivity mentions the SDGs and their goals, so only four papers can be found in the search "supercond* AND SDGs". Considering the importance of superconductivity for the low-loss transport of energy, the field is clearly underrepresented in this analysis.

3.2. Most Cited Papers in the Field of Superconductivity

This Section analyzes the top-5 most cited papers in the field of superconductivity (topic search "supercond*" and year limit 1960–2023) and their performance towards the SDGs, which was not carried out before. Among these papers, we expect to find important review articles as well as articles describing new discoveries that play an important role for the further research in the respective field. Furthermore, one may expect that these significant articles are also recognized by the SDGs tagging.

- (1) Hasan, M.Z. and Kane, C.L. [38]
  Colloquium: Topological insulators.
  Rev. Mod. Phys., vol. 82 (4), pp. 3045–3067 (2021)
  DOI: 10.1103/RevModPhys.82.3045
  15,751 citations
  Research Areas: Physics
  Citation Topics:
  5 Physics
  5.30 Superconductor Science
  5.30.755 Topological Insulators
  Sustainable Development Goals:
  none

- (2) Bednorz, J.G. and Müller, K.A. [39]
  Possible High-T_c Superconductivity in the Ba-La-Cu-O System.
  Zeitschrift für Physik B—Condensed Matter, vol. 64 (2), pp. 189–193 (1986)

DOI: 10.1007/BF01303701
11,705 citations
Research Areas: Physics
Citation Topics:
5 Physics
5.30 Superconductor Science
5.30.187 Cuprates
Sustainable Development Goals:
none

- (3) Qi, X.L. and Zhang, S.C. [40]
  Carbon nanotubes—the route toward applications.
  Rev. Mod. Phys., vol. 83 (4), pp. 1057–1110 (2011)
  DOI: 10.1103/RevModPhys.83.1057
  11,339 citations
  Research Areas: Physics
  Citation Topics:
  5 Physics
  5.30 Superconductor Science
  5.30.755 Topological Insulators
  Sustainable Development Goals:
  none

- (4) Baughman, R.H.; Zakhidov, A.A. and de Heer, W.A. [41]
  Topological insulators and superconductors.
  Science, vol. 297 (5582), pp. 787–792 (2002)
  DOI: 10.1126/science.1060928
  9212 citations
  Research Areas: Chemistry
  Citation Topics:
  2 Chemistry
  2.76 2D Materials
  2.76.23 Carbon Nanotubes
  Sustainable Development Goals:
  none

- (5) Kamihara, Y.; Watanabe, T.; Hirano, M. and Hosono, H. [42]
  Iron-based layered superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05–0.12) with T_c = 26 K.
  J. Am. Ceram. Soc., vol. 130 (11), pp. 3296–3297 (2008)
  DOI: 10.1021/ja800073m
  7100 citations
  Research Areas: Chemistry
  Citation Topics:
  5 Physics
  5.30 Superconductor Science
  5.30.1620 Iron-Based Superconductors
  Sustainable Development Goals:
  07 Affordable and Clean Energy

Here, it is remarkable to note that it is *not* the Nobel-prize winning article of Bednorz and Müller that is found in place (1) but an article on topological insulators, followed by another article on toplogical insulators and superconductivity in place (4). The article of Bednorz and Müller is found in rank (2). Place (3) goes to an article on the application on carbon nanotubes, which only mentions superconductivity as a keyword, not in the title or the abstract. Thus, in the article itself, there is only a single sentence saying that superconductivity was found only at low temperatures (up to ∼5 K in 0.5 nm diameter single-walled carbon nanotubes). Place (5) is taken by the first paper on the IBS materials of Hosono's group. Thus, only two articles of those describing new classes of superconducting materials are found in the top-5 most cited papers; the ones claiming superconductivity in YBCO (5798 citations [43]) and in MgB_2 (5681 citations [35]) are listed in rank (10) or just miss the top-10 in rank (11), respectively. A notable point for our further analysis is the fact that articles (1)–(4) have not received any SDGs tagging, only the paper (5) on the IBS materials counts for SDG 07. This fact clearly indicates that there is something wrong with the SDGs tagging for superconductivity articles.

The year limit applied for the above misses one very important paper from 1957, which deserves to be mentioned here as well: the article "Theory of Superconductivity" [44], which earned the authors the Nobel prize of 1972.

Bardeen, J.; Cooper, L.N. and Schrieffer, J.R.
Theory of Superconductivity.
Phys. Rev., vol. 108 (5), pp. 1175–1204 (1957)
DOI: 10.1103/PhysRev.108.1175
10,138 citations
Research Areas: Physics
Citation Topics:
5 Physics
5.30 Superconductor Science
5.30.187 Cuprates
Sustainable Development Goals:
none

Very striking is the microcitation topic given to this article. It is surely right that this paper was often discussed after the discovery of the Cuprate-HTSc, but it is questionable how this paper written 30 years *before* the discovery of the cuprate-HTSc could receive this quite specific microcitation topic.

3.3. Selected Researchers

To address potential biases and provide a more comprehensive overview of the field, we employed multiple targeting strategies in our bibliometric analysis. Specifically, we examined (i) the most prolific authors, to ensure a broad sample of active contributors; (ii) the Nobel Prize laureates, as representatives of seminal work; (iii) the most cited authors, to account for recognized impact; and (iv) selected researchers affiliated with universities as well as with industry, to incorporate an applied perspective. This multi-faceted approach was designed to mitigate the limitations of focusing solely on citation counts, which often emphasize either pioneering studies or review articles. As demonstrated in our analysis, despite the different selection criteria, the findings consistently converged, reinforcing the robustness and representativeness of our results. The items of (iv) are presented in the Appendices A–E to this article.

In the first part of this Section, we analyze the performance of the top-five authors of the field, ranked by the number of articles published in our dataset, identified through the topic search terms "supercond*" (see Figure 5). This analysis aims to explore the complex relationships between the general Web of Science (WoS) microcitation criteria and the criteria employed by WoS for tagging articles with Sustainable Development Goals (SDGs). Furthermore, our conclusions were validated using a training set of five influential authors in the field of superconductivity, external to the dataset. Specifically, this set included two (2) Nobel laureates and four (4) authors pivotal to the discovery of YBCO, MgB_2, the iron-based (IBS), and nickelate superconductors, which were used solely for external validation.

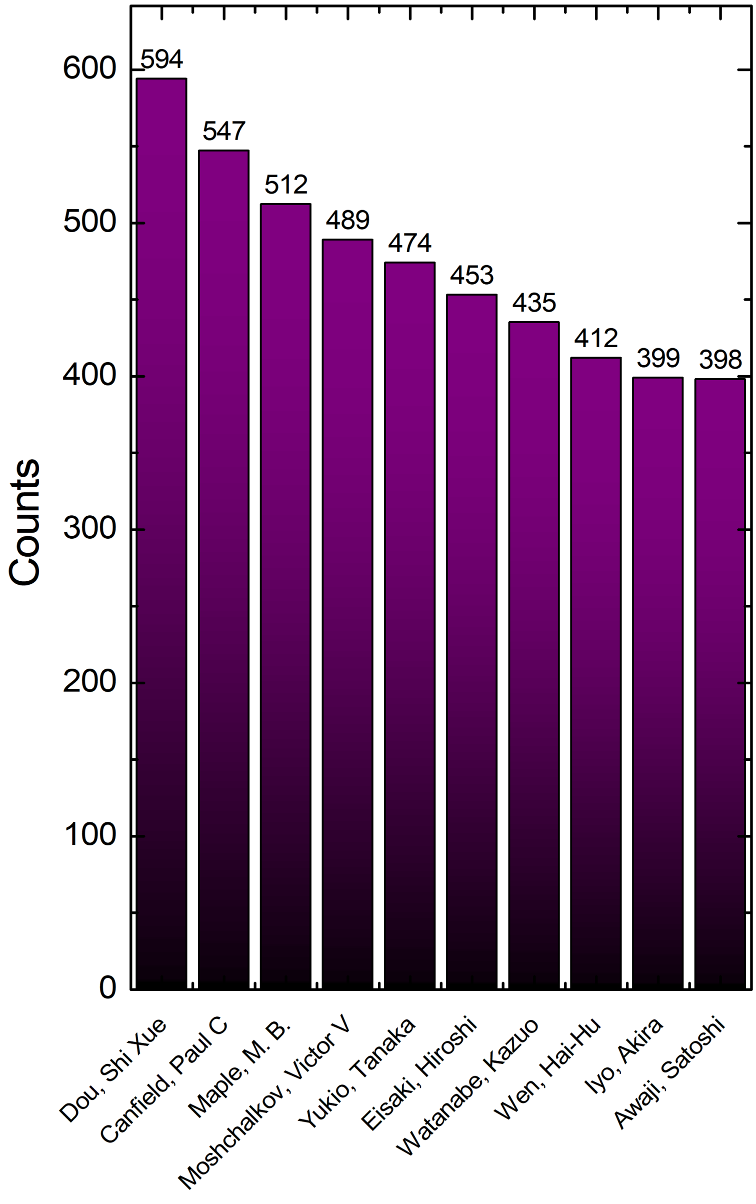

Figure 5. The number of publications of the top-10 authors, following a search with "supercond*" in the titles, abstracts and authors' keywords.

Considering the physical and technical complexity of the superconductivity field, Figure 5 demonstrates that all authors within the top-10 show a high rate of academic production in this area, with more than 400 articles published (NA $>$ 400). For a more focused discussion, we provide here the most critical information for the top-5 authors (see below):

(1) Dou, Shi Xue (Web of Science ResearcherID: D-5179-2012);

(2) Canfield, Paul C. (Web of Science ResearcherID: H-2698-2014);
(3) Maple, M. Brian (Web of Science ResearcherID: FKV-1378-2022);
(4) Moshchalkov, V. V. (Web of Science ResearcherID: I-7232-2013);
(5) Tanaka, Y. (Web of Science ResearcherID: F-4140-2012).

The author with the highest amount of publications in the field of superconductivity is Dou, Shi Xue (WoS ResearcherID: D-5179-2012, see Figure 6 for further details), who scored a total of 594 articles and 16 microcitations in WoS. Among these, the top-3 microcitations are "Critical Current Density", representing 74% of the total (431 articles); "Cuprates", accounting for 13% (77 articles); and "Iron-Based Superconductors", contributing 7% (39 articles) as shown in Figure 6a. In contrast, Figure A1 of the Appendix B presents his full publication score, covering also various other research fields. However, when applying the SDGs filter to the data above, there remain 41 results (i.e., 6.9% of all articles), and only three (3) microcitation topics are identified: "Iron-Based Superconductors" (39 articles), "Magnetic Nanoparticles" (1 article), and "Solid Oxide Fuel Cell" (1 article). Figure 6b reveals that these articles are primarily linked to SDG 07 (*Affordable and Clean Energy*), accounting for 95% (40 articles), and to SDG 03 (*Good Health and Well-being*), which represents approximately 5% (2 articles).

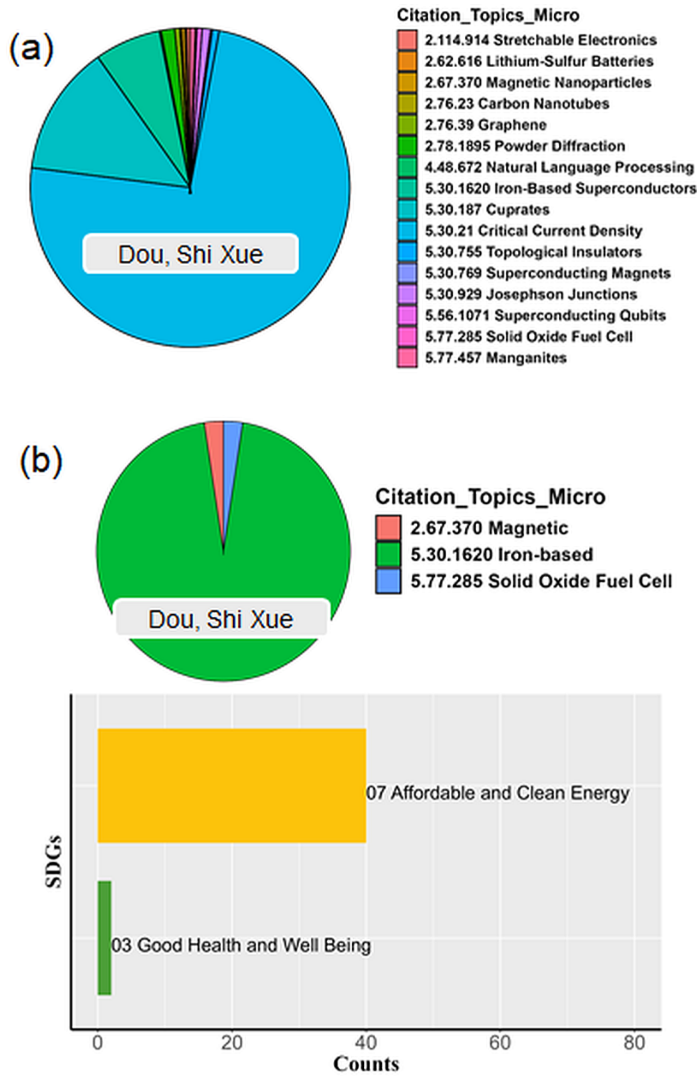

Figure 6. First top author—Dou, Shi Xue. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

From this, it is clearly visible that the SDG microfilters in WoS omit certain critical terms relevant to the field of superconductivity, such as "Critical Current Density" and "Cuprates". The term "Cuprates" refers to a class of materials analogous to "Iron-Based Superconductors", which are included in the SDG microfilters. This omission underscores a potential limitation in the current SDG tagging system. Consequently, the discrepancies involving critical superconductivity-related terms and their implications for other authors and microcitations will be examined in detail throughout this article.

For Canfield, Paul C. (Figure 7a), there are 547 results and 15 microcitations in WoS. The top-3 microcitations are "Iron-Based Superconductors", which corresponds to 46% (251 articles), "Kondo Effect", which corresponds to 35% (193 articles) and "Critical Current Density" (67 articles), which corresponds to 12%. However, when considering the SDGs, there are left 41 articles and 5 microcitations (Figure 7b), "Iron-Based Superconductors" (56.2%, 251 articles), "Kondo Effect" (43.2%, 193 articles) and "Bulk Modulus", "Vanadium Dioxide" and "Magnetocaloric effect" for each corresponding to 0.2% (i.e., 1 article). Among these articles, 99% (446 articles) are related to SDG 07, while 1% (1 article) corresponds to SDG 13.

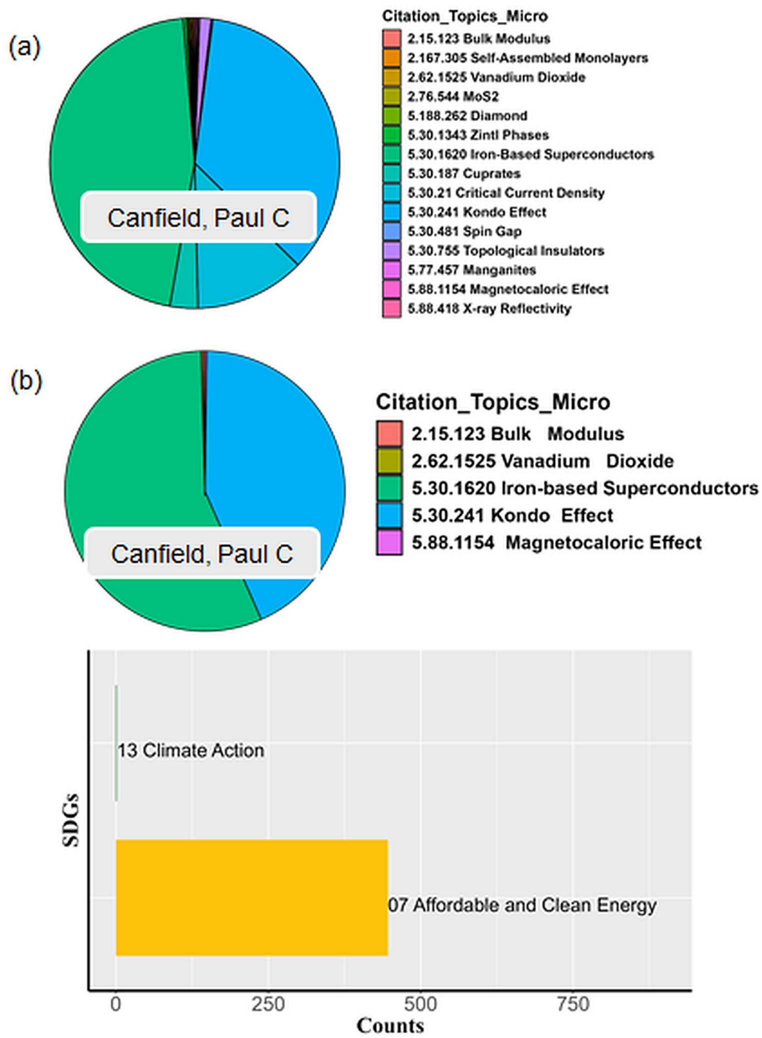

Figure 7. Second top author—Canfield, Paul C. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

The author Maple, M.B. (WoS ResearcherID: FKV-1378-2022, see Figure 8a) has 512 publications and 19 WoS microcitations. The top-three microcitations are "Kondo Effect" (273 articles, 55%), "Cuprates" (117 articles, 24%) and "Critical Current Density"

(38 articles, 8%). However, when filtered using SDGs criteria according to WoS (Figure 8b), there are 303 articles remaining, and only five SDG-linked microcitations were identified. The Top-3 SDGs topics were "Kondo Effect" (273 articles, 90%), "Iron-Based Superconductors" (25 articles, 8%) and "Bulk Modulus" (3 articles, 3%). Of these, 302 articles (97.7%) were associated with SDG 07, while only one article (0.3%) was linked to SDG 11.

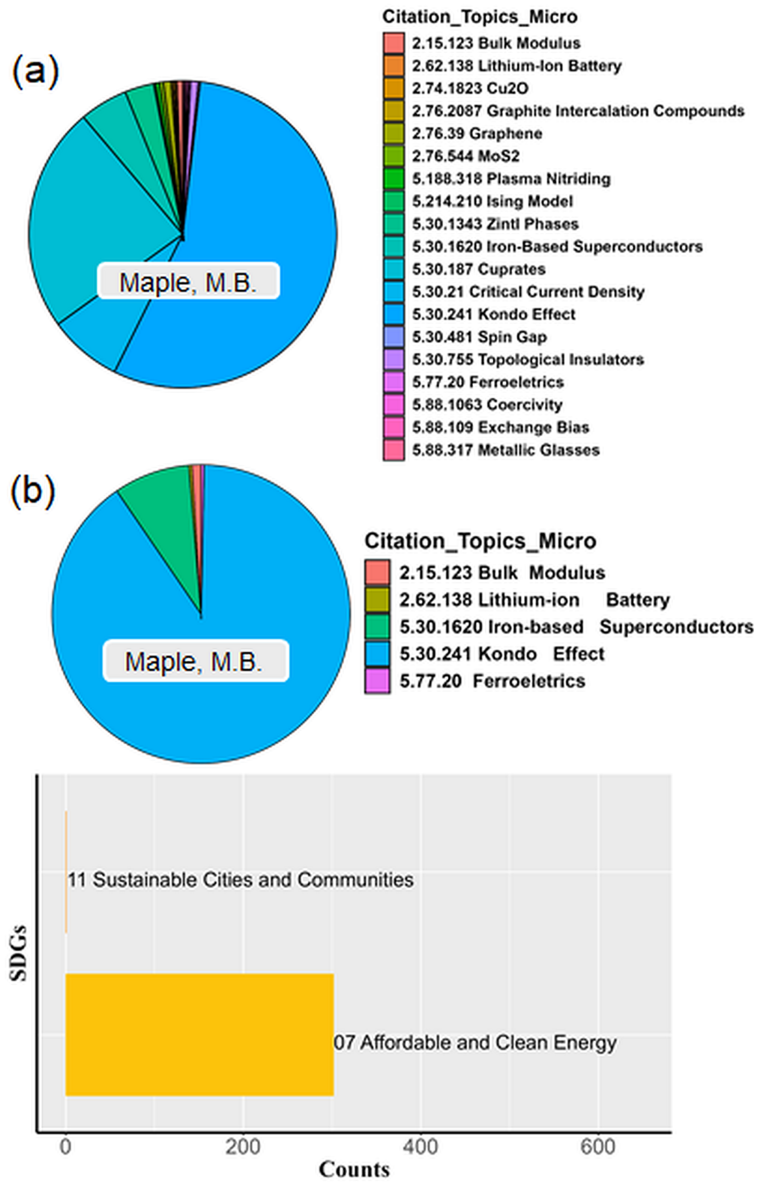

Figure 8. Third top author—Maple, M.B. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

According to WoS, the author Moshchalkov, V. (WoS ResearcherID: FKV-1378-2022, see Figure 9a) has 489 publications and 19 microcitations. The top-three microcitations are "Critical Current Density" (347 articles, 73%), "Cuprates" (47 articles, 10%) and "Kondo Effect" (19 articles, 4%). After applying the SDGs filter (Figure 9b, the top-three SDG-linked microcitations identified are "Kondo Effect" (19 articles, 54%), "Iron-Based Superconductors" (13 articles, 37%) and "Bulk Modulus" (3 articles, 9%). Notably, only 35 of these articles received an SDGs tag, and all were associated with SDG 07.

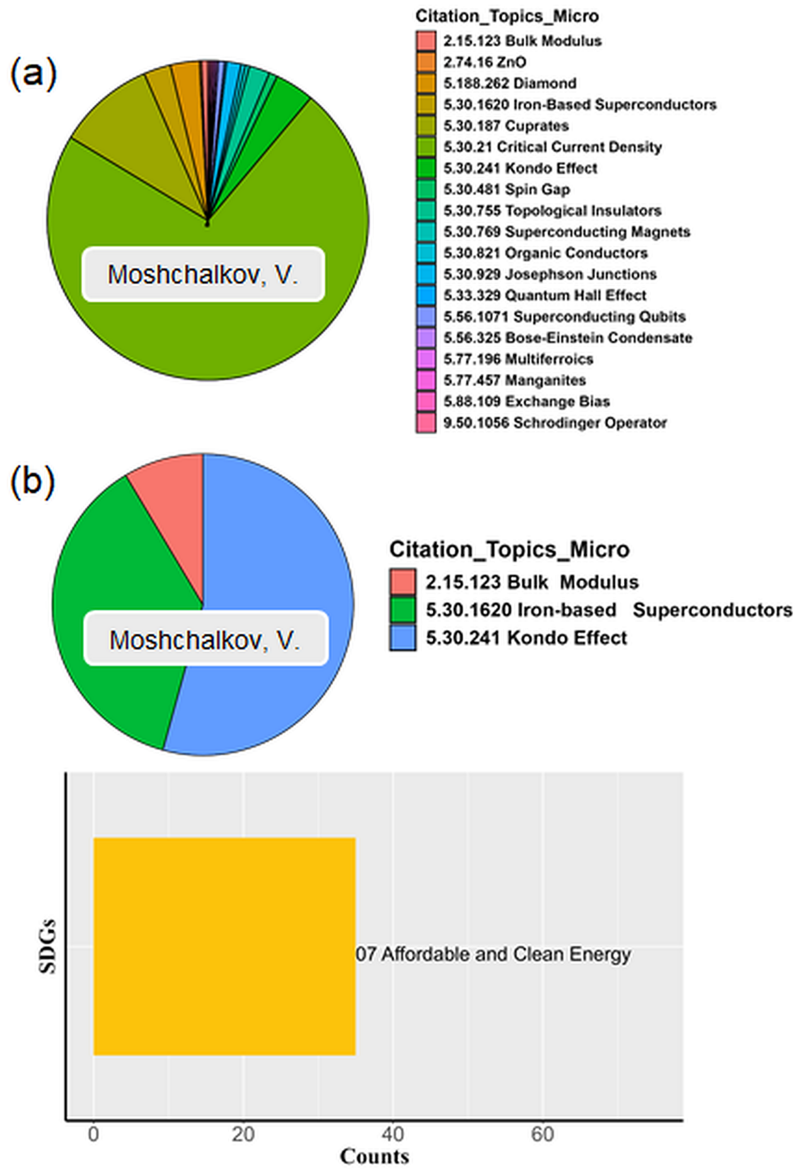

Figure 9. Fourth top author—Moshchalkov, V.V. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

For Tanaka, Yukio (Figure 10a), there are 474 results and 13 microcitations. The top-three microcitation are "Topological Insulators" (79%, 375 articles), "Cuprates" (8%, 37 articles) and "Iron" (5%, 25 articles). When considering the SDGs (Figure 10b), there are 16 articles and 4 microcitations, "Iron-Based Superconductors" (50%, 8 articles), "Kondo Effect" (38%, 6 articles), "Bulk Modulus" (6%, 1 article) and "Ferroeletrics" (6%, 1 article). Among these articles, 94% (15 articles) are related to SDG 07, while 6% (1 article) corresponds to SDG 03.

Practically, the analysis of all the top-5 researchers working in the field of superconductivity reveals the same basic feature, they all have articles associated to SDG 07 and some links to SDGs 03, 11 and 13. However, it is worth noting here that some microcitation topics are not linked to the SDGs microfilter. For example, "Cuprates" refers to a type of material, similar to "Iron-based superconductors", which is associated with SDG 07. Additionally, "Critical current density", which is in the top-3 microcitation topics for the first four authors, also does not align with the SDGs microfilter.

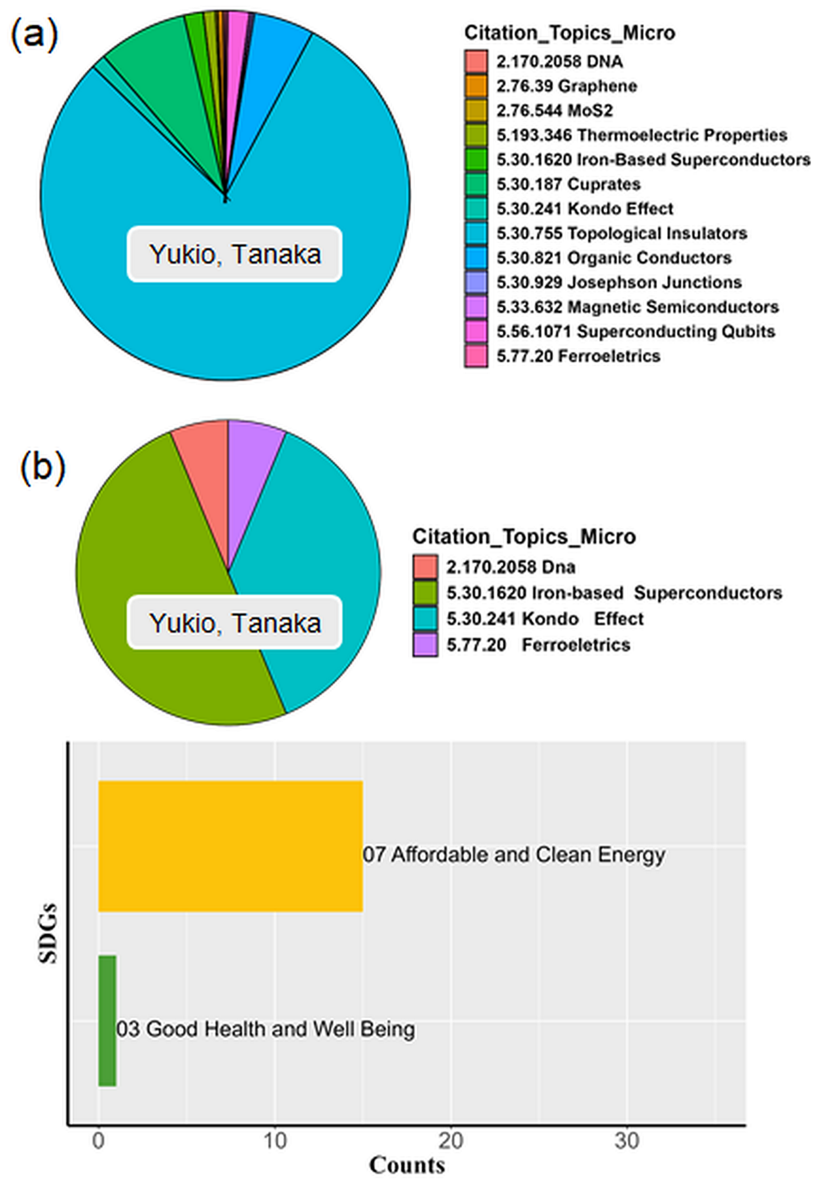

Figure 10. Fifth top author—Yukio, Tanaka. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

The bibliographic data for the two Nobel Prize winners for discovery of the HTSc, K.A. Müller (†2023) and J.G. Bednorz are presented in Figures 11a,b and 12a,b.

Prof. K. Alex Müller (Web of Science ResearcherID: DHX-4488-2022) is listed in WoS with 223 papers. The graphs covering all his scientific papers are given in the Appendix C He had worked on several different research topics during his career, but two topics were the most important according to WoS: "Cuprates" (66 articles) and "Ferroelectrics" (66 articles). He had intensively worked on perovskite materials like $SrTiO_3$, which finally led to the development of the perovskite HTSc, so these two topics are very much describing his work. The application of the topic filter "supercond*" yields 68 papers only. Figure 11 shows the corresponding four microcitation topics, "Cuprates" (53 articles, 77.9%), "Critical current density" (11 articles, 16.2%), "Manganites" (1 article, 1.5%) and "Homogenization" (1 article, 1.5%). Interesting to find is the topic "Critical current density" given for 11 papers, all of which were written just after the discovery of the HTSc, dealing with the very important topics like the irreversibility line, the vortex relaxation and the glassy state. However, all these papers do not count for any SDGs. Thus, the Nobel laureate is not all recognized by the SDGs tagging. Now, it could be argued that all his work on the HTSc would be too academic or theoretical, but when looking at all the works of Müller (see Figure A4 of the Appendix B), it is clear that the papers on "Ferroelectrics" (5.77.20 Ferroeletrics) count well for the SDGs, which is in stark contrast to the articles on superconductivity.

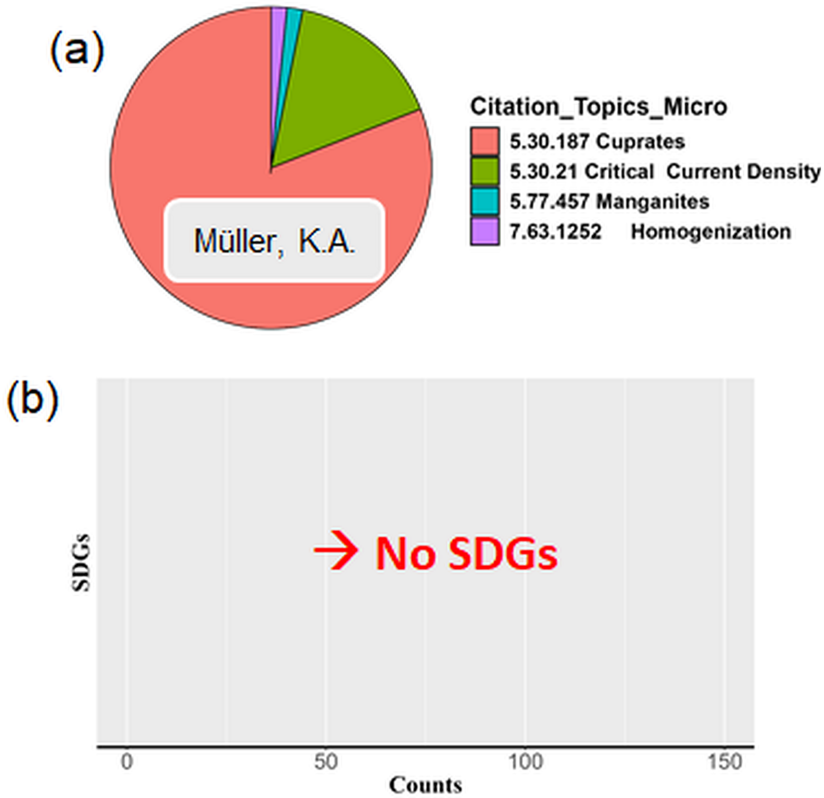

Figure 11. Author Müller, K.A. (**a**) General microcitations and (**b**) microcitations related to the SDG tags. No SDGs tags were given for the 4 microcitation topics.

For J.G. Bednorz (Web of Science ResearcherID: CFR-8278-2022, WoS: 124 documents), there are 65 papers dealing with superconductivity, and six microcitation topics can be identified (see Figure 12a,b). Like for Müller, the microcitation topics "Cuprates" (40 articles, 61.5%) and "Critical current density" (11 articles, 16.9%) are the most important ones. However, Bednorz got three SDGs tags (SDG 07) for the work on superconducting Nb-doped $SrTiO_3$ (5.77.20 Ferroeletrics) and one for SDG 11 (titanium and niobium oxides, 2.78.1729 Pyrochlore). Also for him, the graphs covering all his scientific papers are given in the Appendix C.

Next, we consider the work of the authors who discovered YBCO, C.W. (Paul) Chu ([43], Web of Science ResearcherID: B-1705-2015), MgB_2, J. Akimitsu ([35], Web of Science ResearcherID: J-3489-2013), the Iron-Based Superconductors (IBSs), Hideo Hosono ([42], Web of Science ResearcherID: J-3489-2013), and the Nickelates, Harold Y. Hwang ([45], Web of Science ResearcherID: CUG-4586-2022). For this analysis, we focus solely on their advancements in the field of superconductivity. The search was conducted using the keyword "supercond*" within the title, abstract, and author keyword fields.

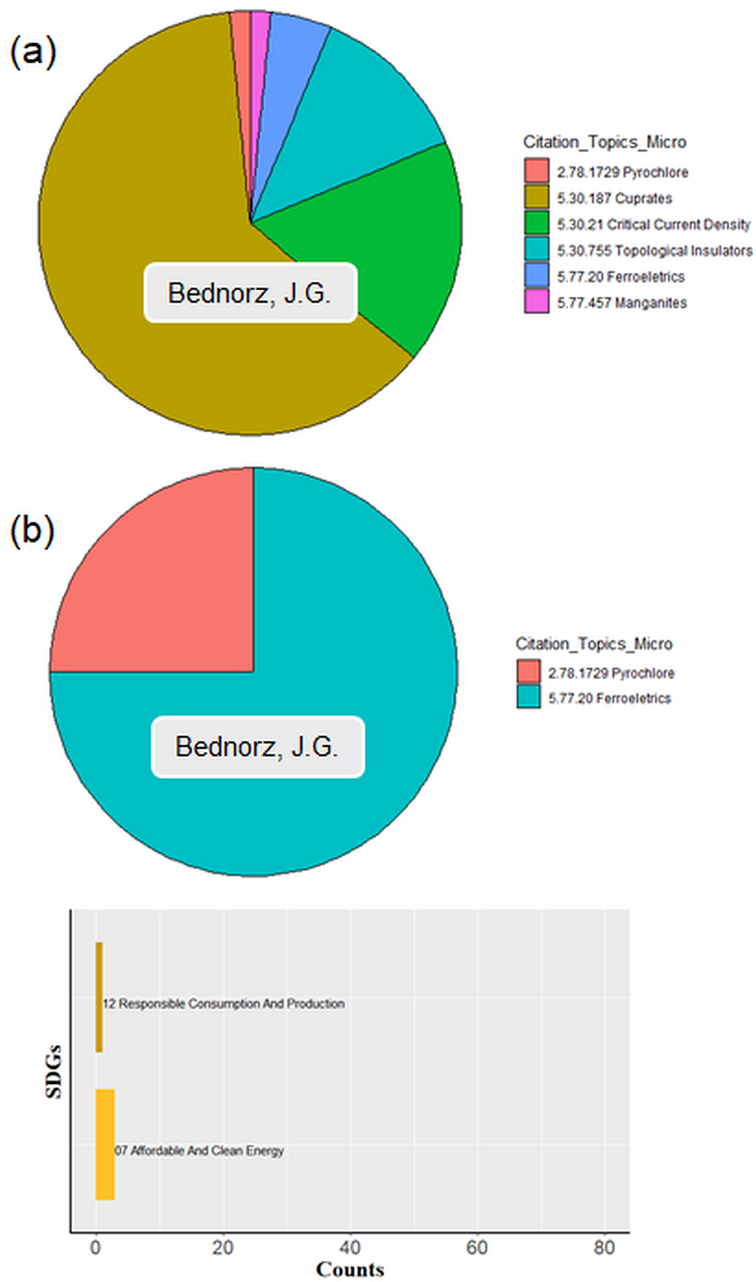

Figure 12. Author Bednorz, J.G. (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

For C.W. (Paul) Chu (Figure 13a), there are 276 results and 23 microcitations in WoS. The top-three microcitations are "Cuprates", which corresponds to 32% (87 articles), "Iron-Based Superconductors", which corresponds to 18% (50 articles), and "Critical Current Density", which corresponds to 14% (37 articles). When considering the SDGs (Figure 13b), there are 84 results and seven microcitations, "Iron-Based Superconductors" (60%, 50 articles), "Kondo Effect" (17%, 14 articles) and "Bulk Modulus" (8%, 7 articles). Among these articles, 85% (71 articles) are related to SDG 07, while 15% (13 articles) correspond to SDG 03.

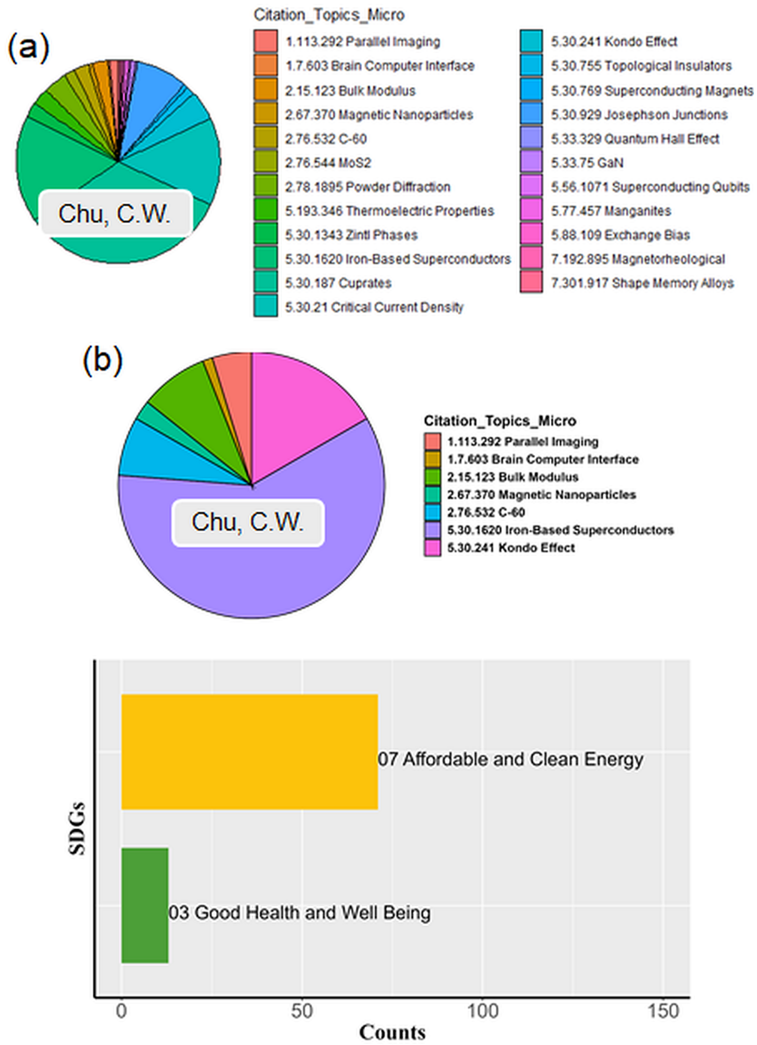

Figure 13. Author Chu, P., with the search for "supercond*". (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

For Akimitsu, J. (Figure 14a), there are 284 results and 22 microcitation topics in WoS. The top-three microcitations are "Cuprates", which corresponds to 23.9% (68 articles), "Spin Gap", which corresponds to 21.8% (62 articles), and "Critical current density", which corresponds to 18.7% (53 articles). When considering the SDGs (Figure 15b), there are 65 results and six microcitation topics, "Kondo effect" (80%, 52 articles), "IBS" (12.3%, 8 articles) and "Bulk Modulus" (3.1%, 2 articles). Among these articles, 95.4% (62 articles) are related to SDG 07, while 3.1% (2 articles) correspond to SDG 03 and 1.5% (1 article) to SDG 03.

For Hosono, H. (Figure 15a), there are 244 results and 13 microcitation topics in WoS. The top-three microcitation topics are "Iron-Based Superconductors", which corresponds to 83.6% (204 articles), "Solvated Electrons", which corresponds to 5.3% (13 articles), and "Cuprates", which corresponds to 4.1% (10 articles). When considering the SDGs (Figure 15b), there are 226 results and six microcitation topics, "Iron-Based Superconductors" (90.4%, 204 articles), "Solvated Electrons" (5.8%, 13 articles) and "Kondo Effect" (2.7%, 6 articles). Among these articles, 94% (212 articles) are related to SDG 07, while 6% (14 articles) correspond to SDG 03.

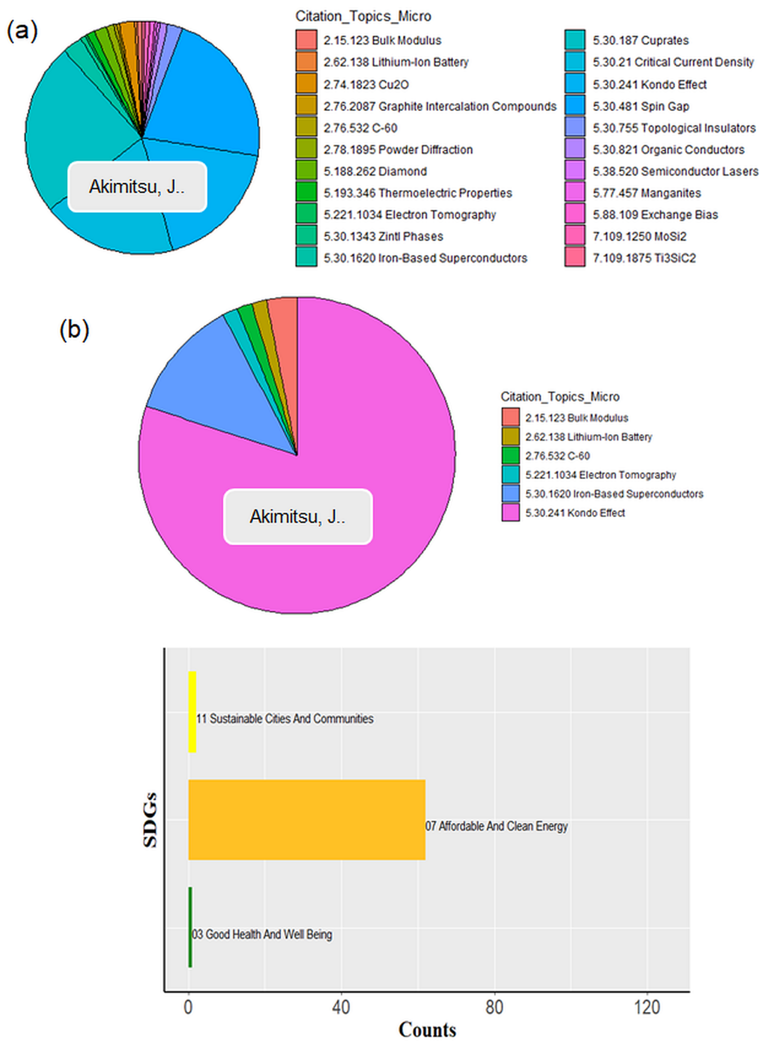

Figure 14. Author Akimitsu, J., with the search for "supercond*". (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

For Hwang, H.Y. (Figure 16a), there are 55 results and 10 microcitations in WoS. The top-three microcitations are "Maganites", which corresponds to 45.5% (25 articles), "Ferroeletrics", which corresponds to 27.3% (15 articles) and "MoS_2", which corresponds to 7.3% (4 articles). When considering the SDGs (Figure 16b), there are 19 results and 4 microcitations, "Ferroeletrics" (78.9%, 15 articles), "Iron-Based Superconductors" (10.5%, 2 articles), and "C-60" (5.3%, 1 article). Among these articles, 95% (18 articles) are related to SDG 07, while 5% (1 article) corresponds to SDG 03.

Similarly, the top-5 authors in the field of superconductivity and the ones who discovered YBCO, MgB_2, the IBS and the nickelates have their articles associated with SDG 07 and SDG 03. Regarding microcitations in the field of superconductivity, the microcitation "Critical current density" is notably significant, although it appears with a small percentage in Paul Chu's works and an even lower percentage in those of the other authors.

Furthermore, a visible deficiency is observed in the linkage between microcitations and the SDG microfilters. For instance, when categorizing materials like "Iron-based superconductors", the classification fails to include "Cuprates". Another notable observation is the presence of materials such as "C-60" in H.Y. Hwang's microcitation topics, which underscores that the microcitations in SDG microfilters do not fully encompass consistent material classifications.

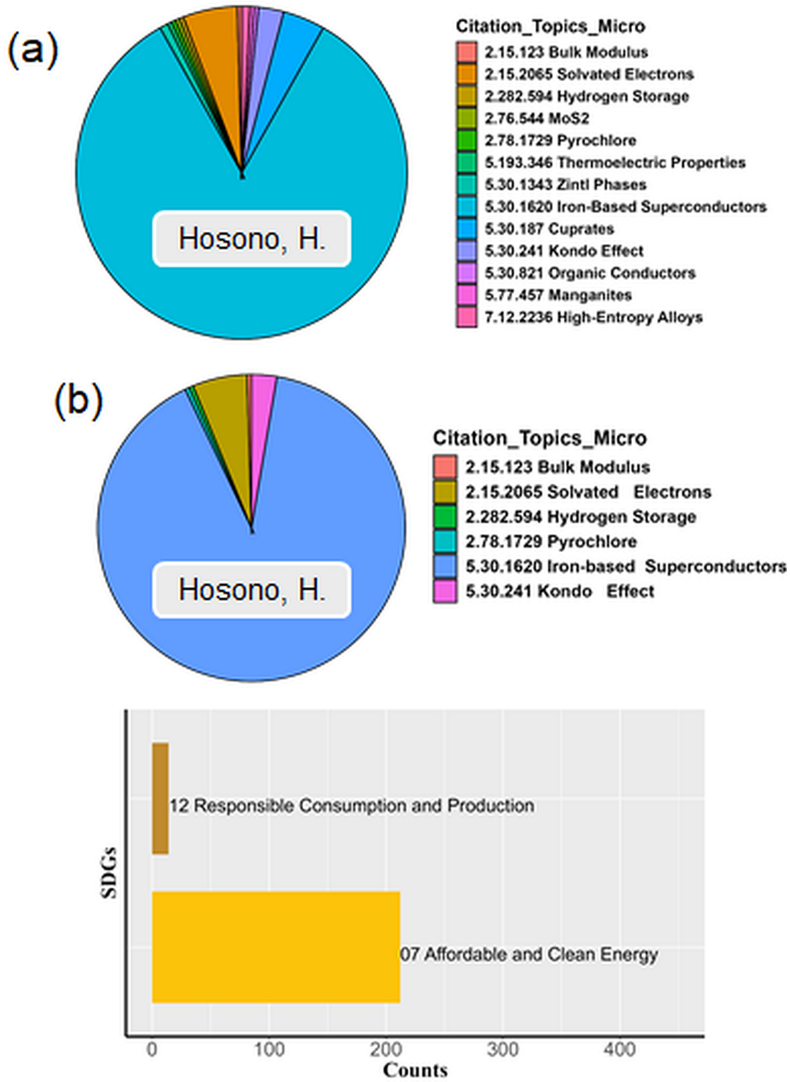

Figure 15. Author Hosono, H., with the search for "supercond*". (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

Additional to the materials presented here, the Appendices B–F (Figures A1–A33) contain an analysis of the microcitation topics and the resulting SDGs tagging for the top-5 authors in the field of superconductivity (Appendix B, Figures A1–A3), the Nobel prize laureates Bednorz and Müller (Appendix C, Figure A4), the discoverers of YBCO, MgB_2, the IBS and the nickelates (Appendix C, Figures A5 and A6), selected members of the Editorial Board of the journal *Superconductivity* (Appendix D, Figures A7–A12), some more selected authors in the field of superconductivity (Appendix E, Figures A13–A26) and researchers affiliated with companies, CERN and *Applied Superconductivity* (Appendix F, Figures A27–A32). Differently to the analysis presented in the main paper, the searches in the Appendix F were performed only for the authors, not limited by the topic or by the publication years. All this covers in total 63 authors in the field of superconductivity, which provides a conclusive picture of the current situation concerning the SDGs tagging for superconductivity.

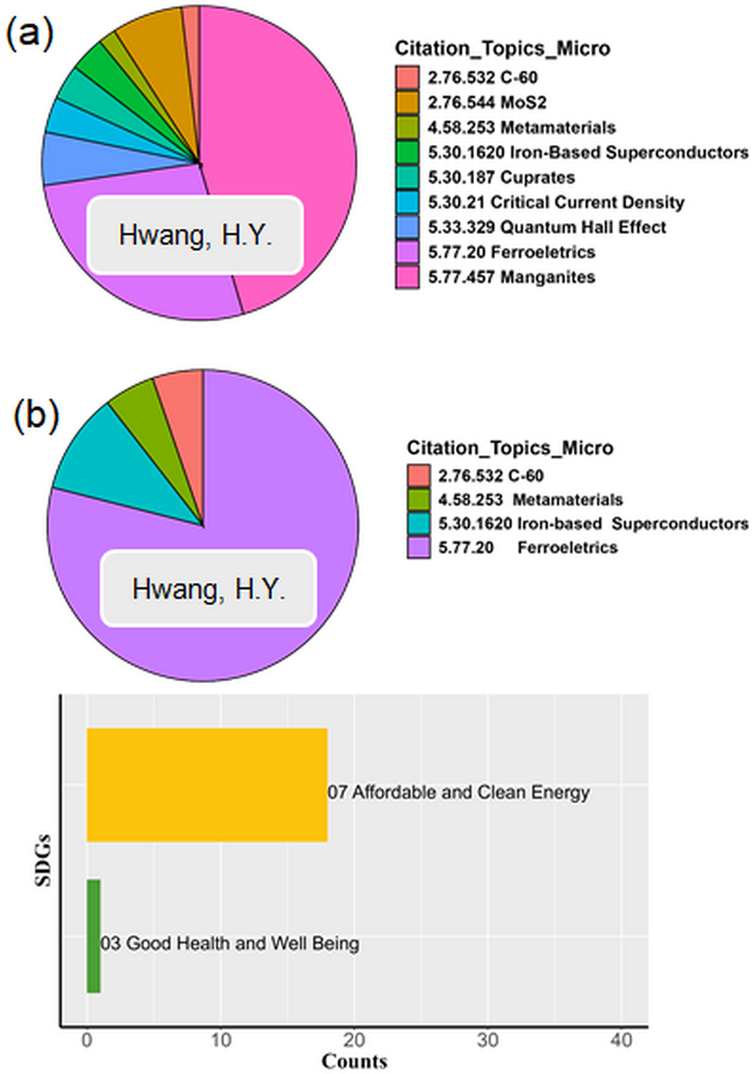

Figure 16. Author Hwang, H.Y., with the search for "supercond*". (**a**) General microcitations and (**b**) microcitations related to the SDG tags.

4. Discussion

To start the discussion of the results obtained here, we must look in detail how the WoS SDGs filter works. In WoS, there is an Excel file provided entitled SDG_2024.xls, which gives a list of the microcitation topics counting for the various SDGs. This file can be downloaded at [30]. The distribution of the microcitation topics to the various SDGs is very inhomogeneous as illustrated in Figure 17.

Looking closer at this file, we can find that SDG 03 has in total 1153 microcitation topics, whereas SDG 13 has 143 ones as the second largest one; all other topics range between 88 and only 8 (!) topics. This is a direct proof for the finding of Ref. [10] that SDG 03 is the dominating SDG and that the field life sciences and biomedicine is the most important. The SDGs important for superconductivity, SDG 07, 09, 11 and 13 are among the higher-valued SDGs (i.e., more than 40 microcitation topics, except SDG 09 with only 34 topics), but the numbers of topics are only 5–10% of SDG 03. This clearly demonstrates that here some action is highly demanded to include more microcitation topics to this conversion file in the future for a better representation of the work in superconductivity.

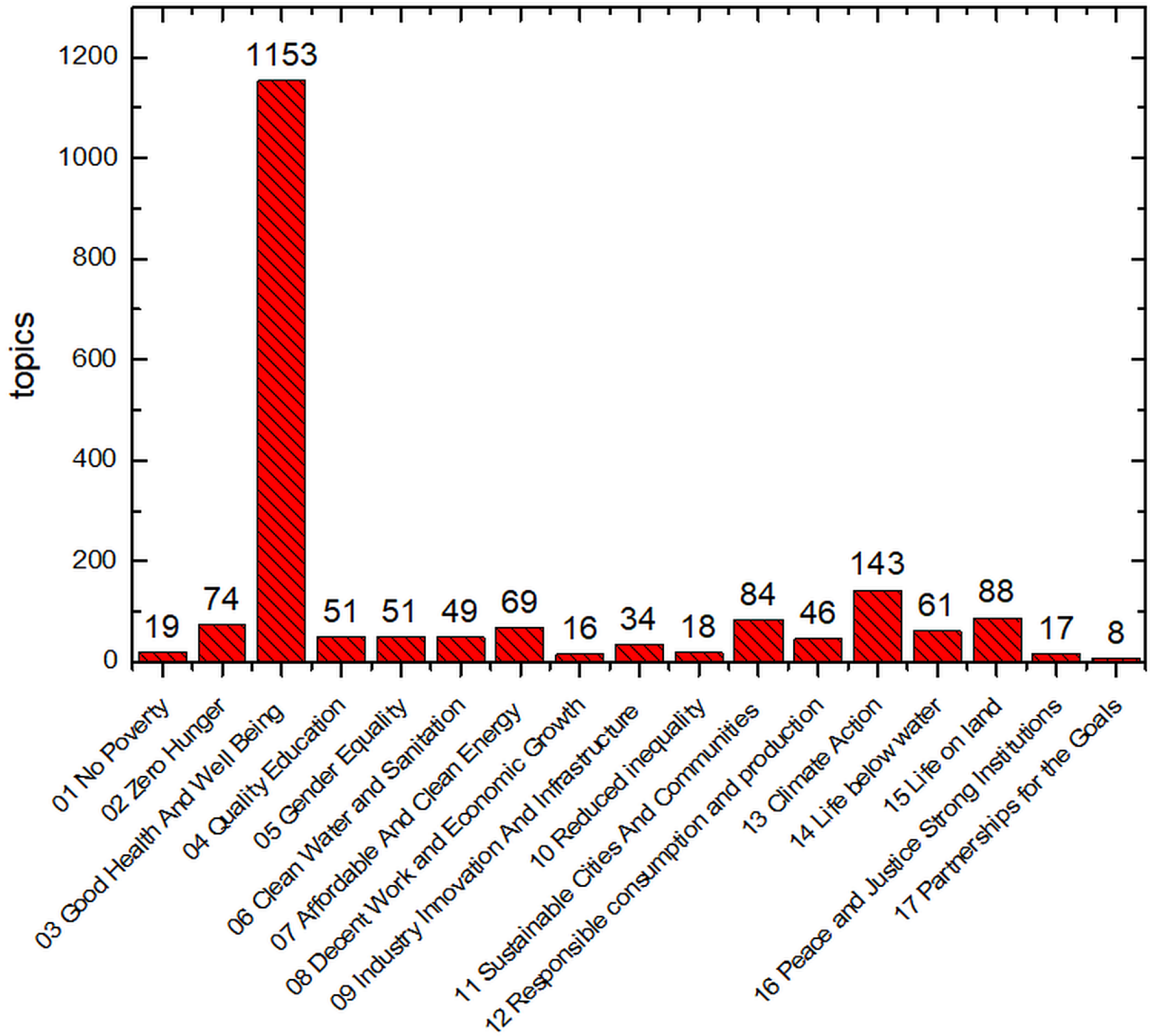

Figure 17. Diagram of SDG-2024.xls, showing the number of microcitation topics for each SDG.

When going through the file (the file with marked sections is included in the Appendix F), it is further not possible to find many direct connections to superconductivity—except the microcitation topic 5.30.1620 Iron-Based Superconductors for SDG 07. The topic 5.30.769 Superconducting Magnets counting for SDG 09 cannot be found in the file, and the same applies for 5.302.1765 Avogadro Constant. Thus, the interaction between the SDGs and the microcitation topics must be somewhat more complicated.

To obtain a better insight to the way the SDGs tagging works, we select here a single topic, which plays an important role in superconductivity research: the levitation.

Superconducting levitation is one of the key features for bulk superconductivity, and has several different kinds of applications. Searching WoS for levitation papers (in general) via the keywords "supercond* AND levitation" yields 2185 results (papers published in the timeframe 1960–2023), which is not bad for a single topic when considering the 239,368 papers for the keyword "supercond*" alone (see Section 3.1). There are in total 88 microcitation topics for this search, and the vast majority of the articles (1665, corresponding to 76.2%) is counted with "Critical current density". Among these microcitation topics are also quite interesting ones like "Physics Teachers" (that is, papers dealing with levitation experiments, e.g., Ref. [46]) or "Atomic force microscope", where locally the

London penetration depth was measured [47] or the levitation of a ferromagnetic cantilever on a Pb disc [48].

The result of the SDGs tagging of the papers dealing with levitation is somewhat problematic as only 291 of these articles received an SDGs tag, corresponding to just 13.3%, which is even less than the result of the general search (see Section 3.1). The three papers just mentioned before did not receive an SDGs tag, even though one could have imagined SDG 04 for the first one.

This is a strong reason to look here closer at some examples, starting with some highly cited papers in this subfield.

(1) "Review of maglev train technologies" (highly cited paper with 572 citations) [49]

Research Areas: Engineering and Physics
Citation Topics: 7 Engineering and Materials Science
7.192 Testing & Maintenance
7.192.1197 Wheel–Rail Contact
Sustainable Development Goals:
09 Industry, Innovation and Infrastructure.

This paper surely deserves an SDGs tag, but the microcitation topic 7.192.1197 Wheel–Rail Contact is somewhat obscure as the levitating trains are just avoiding a wheel–rail contact. Obviously, the word "train" was here the key for this citation topic.
Now, we look at the next papers in the list of WoS results:

(2) "Superconducting bearings" (439 citations) [50]

Research Areas: Physics
Citation Topics: 5 Physics
5.30 Superconductor Science
5.30.21 Critical Current Density
Sustainable Development Goals:
none

(3) "The first man-loading high temperature superconducting Maglev test vehicle in the world" (427 citations) [51]

Research Areas: Physics
Citation Topics: 5 Physics
5.30 Superconductor Science
5.30.21 Critical Current Density
Sustainable Development Goals:
none

(4) "Superconductor bearings, flywheels and transportation" (388 citations) [52]

Research Areas Physics
Citation Topics 5 Physics
5.30 Superconductor Science 5.30.21 Critical Current Density
Sustainable Development Goals:
none

(5) "Superconductively levitated transport system: The SupraTrans project" (321 citations) [53]

Research Areas: EngineeringPhysics
Citation Topics: 5 Physics
5.30 Superconductor Science 5.30.21 Critical Current Density
Sustainable Development Goals:
none

For articles (3) and (5), the keyword "train" did not appear in the title or abstract, and so the result is quite predictable as these papers are tagged like most other papers in superconductivity for the microcitation topic 5.30.21 "Critical Current Density" and, hence, have no SDGs tag. Typically, papers like "Recent Developments in High-Temperature Superconducting Magnet Technology (Review)" [54], "A Full Scale Superconducting Magnetic Levitation (MagLev) Vehicle Operational Line" [55] or "Superconducting Light Rail Vehicle A Transportation Solution for Highly Populated Cities" [56] describing clearly the application of levitation to build new transportation systems end up with the microcitation topic notorious for superconductivity, "Critical Current Density", which is practically the same for all other papers discussing the properties of levitation, including the stability/stiffness or measurements of levitation forces.

Looking at the list of the 291 papers that have received an SDGs tag, one can find paper (1) also on top of this list. The list further corroborates the importance of the keyword "train" as a total of 43 papers mention it. In contrast, position (2) is occupied by a paper "The superconducting gravimeter" (174 citations [57]) tagged with SDG 13. So, a paper dealing with the use of a superconducting levitator to levitate cells or proteins may come up with an SDGs tag (i.e., SDG 03)), and the same applies for work with microgravimeters or microgravity. This observation clearly manifests the importance of specific applications of superconductivity to obtain an SDGs tagging.

After we now followed the SDGs tagging of some highly cited papers in this field, we can now have a closer look on other papers dealing with superconducting levitation. To obtain a better idea what is going on, we selected one important topic for superconductivity (here, the search "supercond* AND levitation" as shown in Figure 18a), checked the answer(s) of the WoS SDGs filter, performed a refinement of the WoS output and then applied the microcitation topic filter, which finally yields the pie charts shown in Figure 18b.

Figure 18 presents a detailed analysis of the SDGs distribution for the search "supercond* AND levitation". The upper graph (a) gives the number of papers tagged for the various SDGs. In total, 10 different SDGs can be found for our search, the most important one being SDG 11 with 141 papers (37.3%), closely followed by SDG 03 with 119 papers (31.5%). SDGs 09, 07 and 13 are the next ones, but with only 48 (12.7%), 34 (9%) and 22 papers (5.8%), and the remaining SDGs (12, 02, 06, 01, 14) are covered with only 1 (0.3%) and up to 10 papers (2.7%). We also note that SDG 04 (*Quality Education*) is not given to any paper dealing with levitation.

The pie diagrams shown in Figure 18b present the various microcitation topics for the five most tagged SDGs, i.e., 11, 03, 09, 07 and 13 (from highest to lowest, respectively). Here, it is important to note that all the microcitation topics listed now are *only* for the papers having received an SDGs tag.

For SDG 03, we see that the largest topic counting for the SDGs with 65.5% is protein crystallization, and the other main topics are spaceflight (11.8%), magnetic nanoparticles (8.4%) and AFM (3.4%) as well as electromagnetic fields (2.5%). SDG 07 contains prominently the Iron-Based Superconductors (IBSs) with 11.8%, and also the keyword "Kondo effect" plays some role for superconductivity, especially concerning the heavy-fermion superconductors [58]. SDG 09 has two main parts, 50% for Superconducting Magnets and 45.8% for Avogadro constant, and two small contributions with 2.1% for Bose–Einstein condensate and 2.1% for high-spin states.

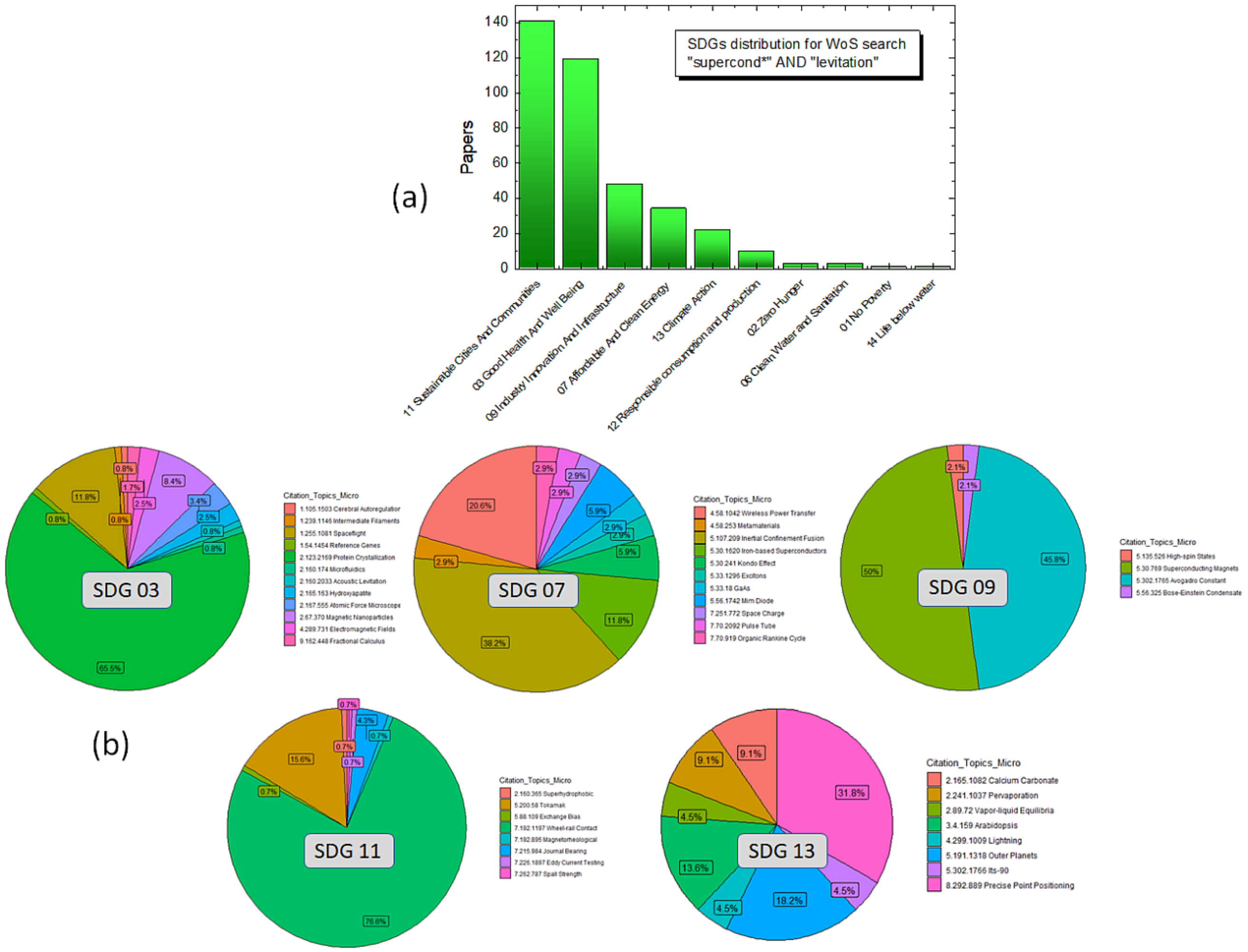

Figure 18. Detailed analysis of the SDGs distribution for the search "supercond* AND levitation". The upper graph (**a**) gives the number of papers for the various SDGs, and the pie diagrams (**b**) present the various microcitation topics for the 5 most given SDGs, i.e., 11, 03, 09, 07 and 13 from highest to lowest.

SDG 11 is governed by the topic wheel–rail contact with 76.6% (in fact, it is the goal to avoid this contact when levitating), and 15.6% by the topic Tokamak, which is a more understandable application for superconductors. Interestingly, the topic is only covered by 4.3% of the papers.

For SDG 13 (*Climate Action*), only the topic ITS-90 (the international temperature scale [59], 4.5%) may be directly related to Climate Action, but precise point positioning (31.8%) concerning superconducting gravimeters is surely also an important issue to better understand our planet. In contrast, the topic "Outer planets" deals with a possible superconducting origin of Saturn's ring formation, the topic "Lightning" with the measurement of an infinitely long helical solenoid and the topic "Arabidopsis" with the growth of a species of cells in microgravity, created by superconducting levitation.

Thus, the closer look on the microcitation topics that lead to an SDGs tag clearly reveals that the SDGs tags are only given to papers dealing with (very) specific applications of superconducting levitation and not for levitation in more general aspects like stability, stiffness or control. All research dealing with materials or material properties for levitation will end up with the microcitation topic "Critical current density", as we have seen already before.

Based on the analysis of the microcitation topics and the corresponding SDGs tagging for more than 50 researchers in the field of superconductivity, we can summarize our findings as follows:

(i) The field of superconductivity is not well represented in the efforts towards the sustainable development goals as only ∼18% of all papers receive an SDGs tag in WoS.
(ii) The SDGs tagging is based on the WoS microcitation topics. Most papers in the field of superconductivity receive the microcitation topic "Critical current density", which is consequently the dominating sector in the individual pie diagrams of the microcitation topics presented here.
(iii) The only direct relation of a superconducing material class and the SDGs exists for Iron-Based Superconductors and SDG 07. Thus, all papers dealing with IBS are tagged for SDG 07, even theoretical ones performing DFT calculations, not experimental work. Via the keyword "Zintl phases", also the Chevrel superconductors are prominently recognized for SDG 03, and via the topic "Kondo effect", the heavy-fermion superconductors are recognized as well. However, no other superconducting materials (HTSc, C-60, nickelates, hydrides, magic-angle bilayered graphene, MgB_2, Nb_3Sn, NbTi, HEA, 2D superconductors and borocarbides, see, e.g., Ref. [60]) are recognized in the same manner.
(iv) SDGs tags are given only for quite specific applications of superconductors and not for general properties of a superconducting material or its application.
(v) Up to now, only three (!) papers can be found in WoS when searching for "supercond*" AND "SDGs" and one more for the spelled-out keyword "Sustainable Development Goals", which implies that authors in the field should mention the SDGs being aimed at, either in the title, the abstract or the keywords of the paper. This would help to secure more importance of superconductivity among the SDGs.

Point (i) is a quite obvious problem, recognized already by several authors [9,10]. Research in fields like biology or medicine plays a much more important role for the SDGs, which is also manifested by the content of the file SDG_2024.xls (Ref. [30]) in WoS.

Point (ii) represents a characteristic problem for the research in superconductivity. The situation is extremely bad for the company researchers: Mostly, they may have only one microcitation topic, the "Critical current density". For some of them, this is even more striking as they may have works with SDGs tagging, but this stems from their pre-company time at the university (see Figure A33 of the Appendix F). For all other reseachers, to cover 5–6 different SDGs is a very good achievement. Only some of the researchers investigated here cover more SDGs, e.g., S.X. Dou (7 SDGs), P. Seidel (7 SDGs), T.H. Johansen (8 SDGs), V. Moschchalkov (8 SDGs), H. Hosono (8 SDGs), P. Badica (9 SDGs) and V.M. Vinokur (11 SDGs).

Point (iii) covers a big misunderstanding of the work carried out in superconductivity. All the efforts to bring the HTSc materials to the market are simply disregarded for the SDGs by the choice of materials, and the same applies to the research on MgB_2. Both the IBS and the Chevrel phases do not entirely represent the research carried out in superconductivity but are more like "niche" topics producing, however, interesting results (high upper critical fields, interesting physics).

Point (iv) manifests the need to devise new applications of superconductivity, which may play a role in daily life or lead to better understanding of problems related to the key ideas of the SDGs (i.e., sustainability, (in)equality, poverty, health and no hunger).

Only point (v) can be easily addressed by the authors of papers in the field of superconductivity, while point (iv) represents a challenging task. Whereas everyone, theorists or experimentalists involved in superconductivity research knows about the importance of control and optimization of the critical current density in view of technological applications, this may not be recognized in other disciplines, by politics or funding organizations. Thus, the awareness of the SDGs should not only be important when writing project applications but should be a goal of every researchers' work in the present situation of global warming and its challenges and, thus, also be included in the scientific articles. We may state here that the superconducting community needs to think more widely about their research, giving a social meaning for their works. With this, naturally, or organically, superconductivity will gain a better place towards the SDGs. For a field like superconductivity, it is essential to be counted to work towards the SDGs—this will ensure a stable funding of the research in the following years, and receiving SDGs tagging will not only improve the general recogition but also improve the relations towards other scientific disciplines like, e.g., (electrical) engineering.

In contrast, the points (i), (ii) and (iii) require concerted efforts of organisations representing the research in superconductivity so that the WoS microcitation topic file could be corrected in favor of superconductivity.

5. Conclusions

To conclude, we have presented here a bibliographic analysis of the research in the field of superconductivity in relation to the UN Sustainable Development Goals (SDGs). Combining the new filters in WoS with the search on a given topic or on individual authors, we established a relation between the research in superconductivity with the Sustainable Development Goals. Our analysis reveals that only three papers include the keyword "SDGs" directly in the title or abstract. Furthermore, only about 18% of the papers in the field of superconductivity have received an SDGs tag by the WoS filter, which is a much smaller ratio as compared to other scientific fields like biology or medicine. In the case of the selected sub-field "Levitation", only 13.3% of the articles received an SDGs tag, which is even worse. The further analysis of individual researchers working at universities, research centers or companies (in total, the microcitation topics and the corresponding SDGs tagging of 63 researchers were investigated) demonstrates that most of the work in superconductivity to improve the performance of the materials is classified with the microcitation topic "Critical current density" or "Cuprates" and, thus, does not count for an SDGs tagging. Thus, the field of superconducvity is in a quite bad situation concerning the recognition of the work done, which may have consequences to obtain future research funding. From all bibliographic data obtained, we indentify four important issues that require attention by the scientific community as well as by individual authors in order to give the research in superconductivity the place it deserves concerning the worldwide efforts demanded by the UN SDGs.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available from the authors upon reasonable request.

Conflicts of Interest: Authors Michael Rudolf Koblischka, Diana Michaela Koblischka and Anjela Koblischka-Veneva were employed by the company SupraSaar. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A. Introductory Comments

The Appendix presents the analysis of the microcitation topics and the resulting SDGs tagging by the WoS filter for several individual authors in Figures A1–A33.

First of all, we must note here that all WoS searches shown in the Appendices B–F were carried out for the respective authors (identified either by name, affiliation, WoS identifier or ORCID number). In some cases, a combination of the identifiers were necessary. No topic search was applied in contrast to the data shown in the main paper, and all found articles were counted (no year limit was applied).

In this Appendix, we present the analysis of the microcitation topics (pie diagram and list) identified for each author and the resulting SDGs tagging (bar diagram with fixed colors for each SDG) for (Appendix B) the top-5 authors in the field of superconductivity, (Appendix C) the two Nobel prize laureates for the discovery of the high-temperature superonductors (HTSc), K.A. Müller and J.G. Bednorz, followed by the discoverers of YBCO, MgB_2, the IBS and the nickelates. All these data enable a direct comparison to the data present in the main article. Then, we consider the data of several selected members of the Editorial Board of *Superconductivity* (Appendix D), and the Section (Appendix E) gives a set of other well-known researchers in the field of superconductivity. Finally, Appendix F presents the same data for company researchers, and researchers affiliated to CERN and *Applied Superconductivity*.

In the following, always the data of two researchers are presented together in one figure, with the exception of S.X. Dou due to his large amount of articles found. Overall, we include here data for 53 individual researchers in our analysis to obtain a conclusive survey.

Figures A1–A3 give the bibliographic data for the top-5 authors in the field of superconductivity, and Figure A4 gives the data for the HTSc Nobel prize laureates, K.A. Müller and J.G. Bednorz. Figures A5 and A6 present the data for the discoverers of YBCO, MgB_2, the IBS and the nickelates. These data enable a direct comparison to Figures 6–16 in the main text, where the search was limited to papers in *Superconductivity* only (topic search: "supercond*"). Then, Figures A7–A12 give the microcitation topics and the score of the SDGs for selected members of the Editorial board of the journal *Superconductivity*, including some comments to the data.

Appendix B. Top-5 Authors

Here, a comparison with Figure 6a,b of the main text becomes possible. He has a large number of papers (1719) that deal with superconductivity as well as with batteries, energy harvesting, photocatalysis, etc. This leads consequently to a large number of microcitation topics (in total 61) with contributions to 7 SDGs.

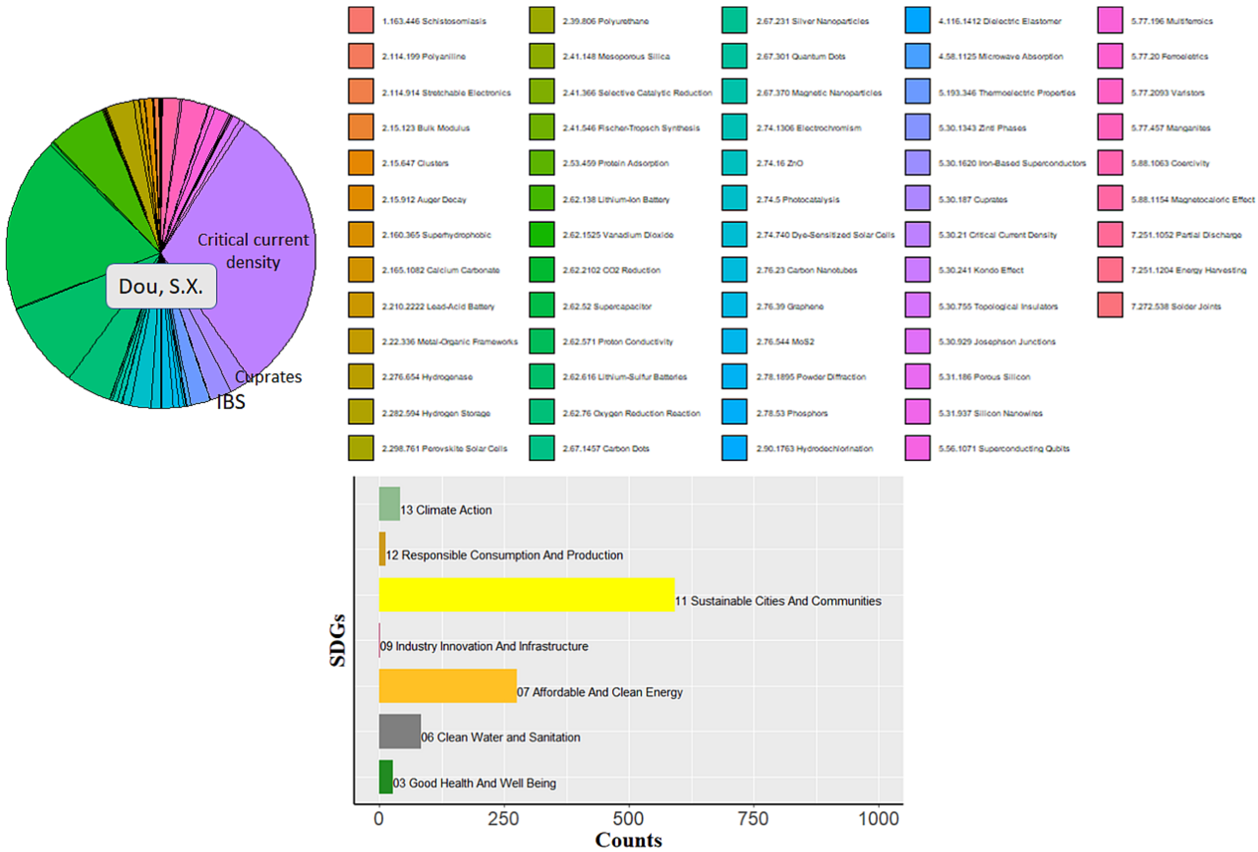

Figure A1. Personal data for the Top-1 author Dou, S.X. obtained from a search using the author identifier and the affiliation University of Wollongong.

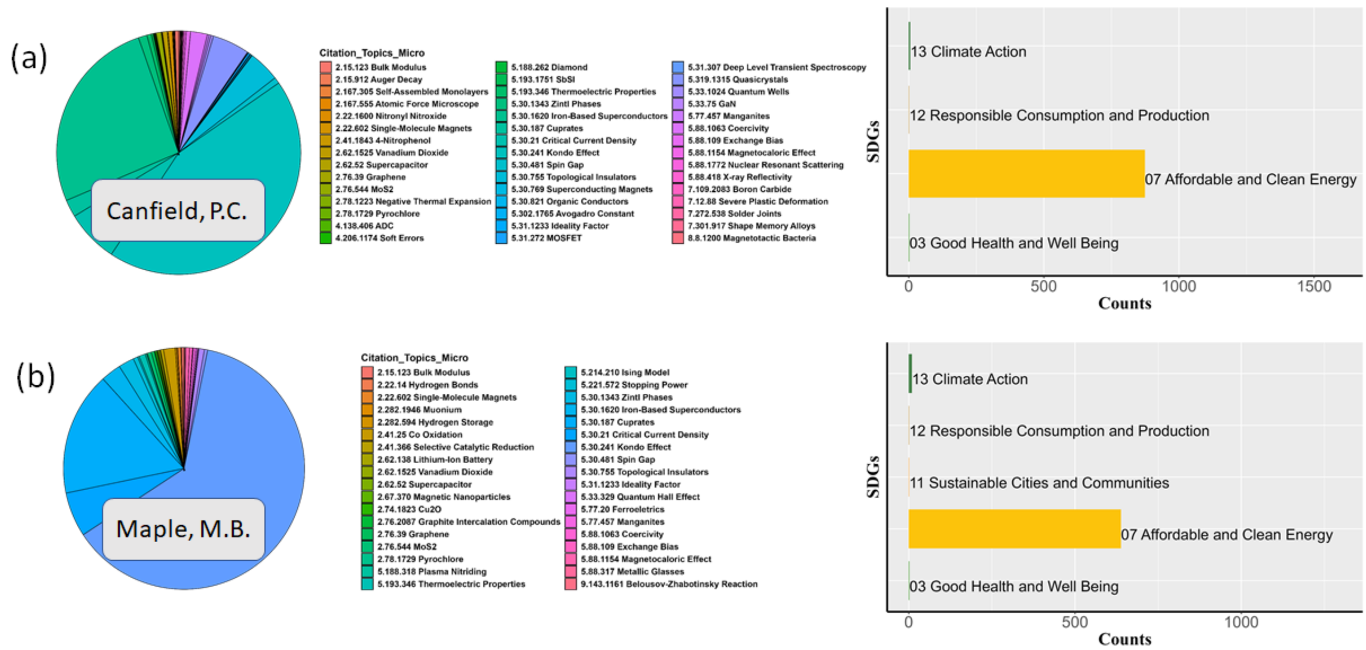

Figure A2. Personal data for (**a**) Canfield, Paul C. and (**b**) Maple, M.B.

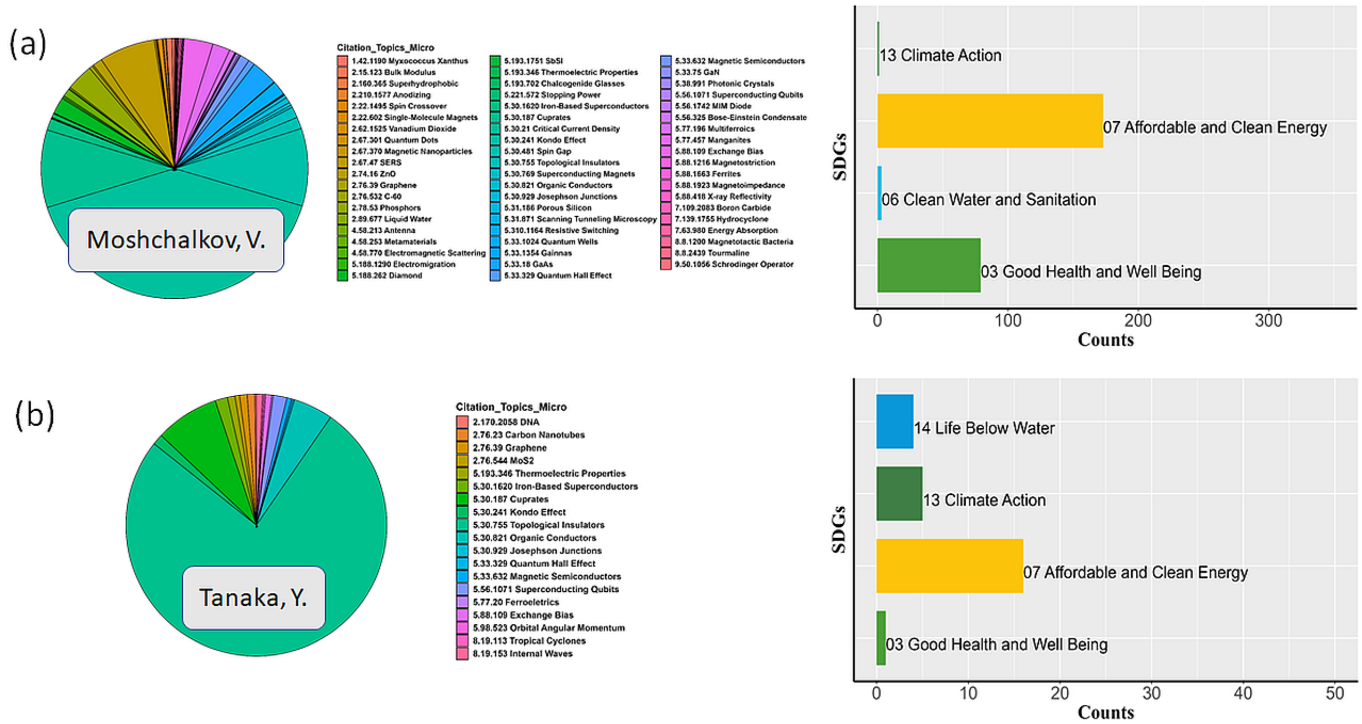

Figure A3. Personal data for (**a**) Moshchalkov, V. and (**b**) Tanaka, Yukio.

Appendix C. Nobel Prize Laureates and the Discoverers of YBCO, MgB_2, IBS and Nickelates

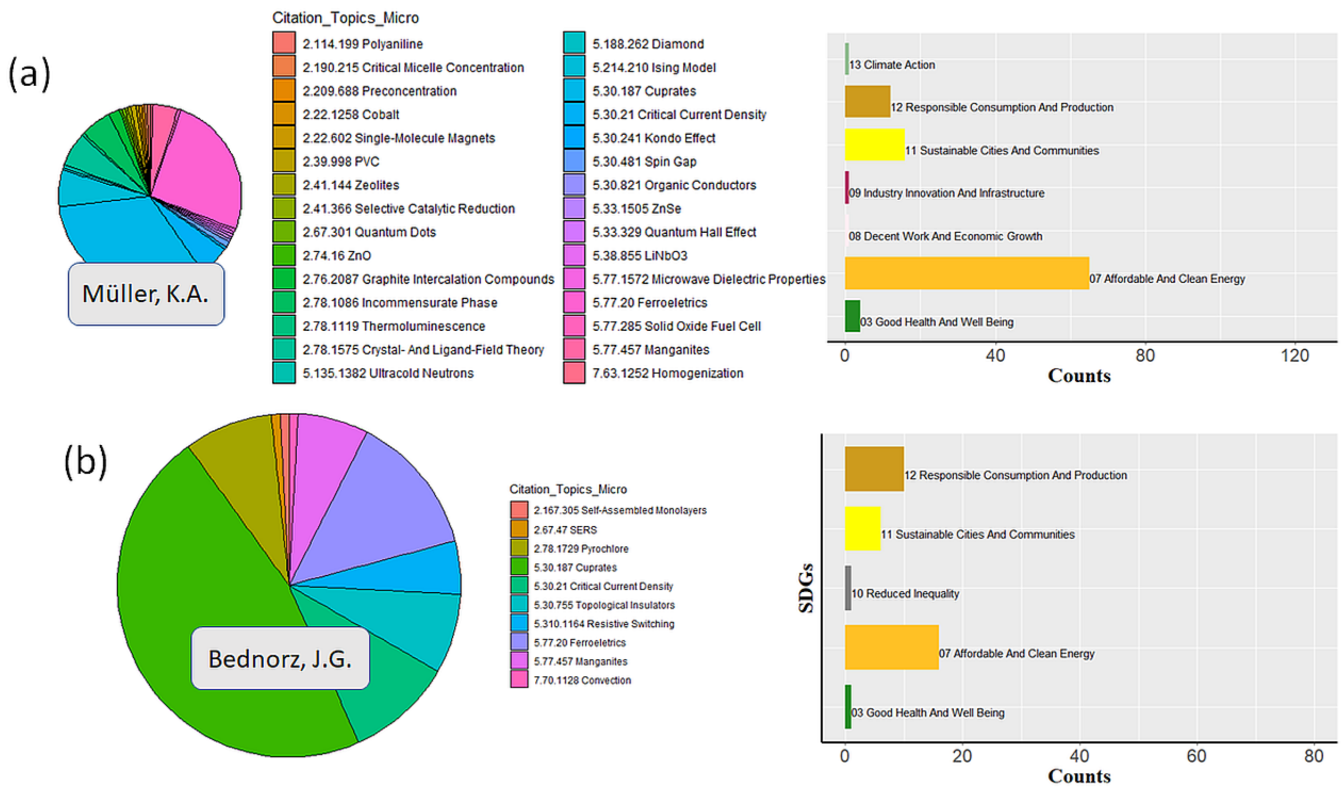

Figure A4. Personal data for (**a**) Müller, K.A. and (**b**) Bednorz, J.G.

Prof. K. Alex Müller is listed in WoS with 223 papers, and J.G. Bednorz has 124 documents in WoS. In contrast to the search limited to works in *Superconductivity*, both researchers have much more microcitation topics (Müller 30, Bednorz 10). Very interesting is it now to see that many works of both qualify for SDGs tagging without the limitation to the field of superconductivity.

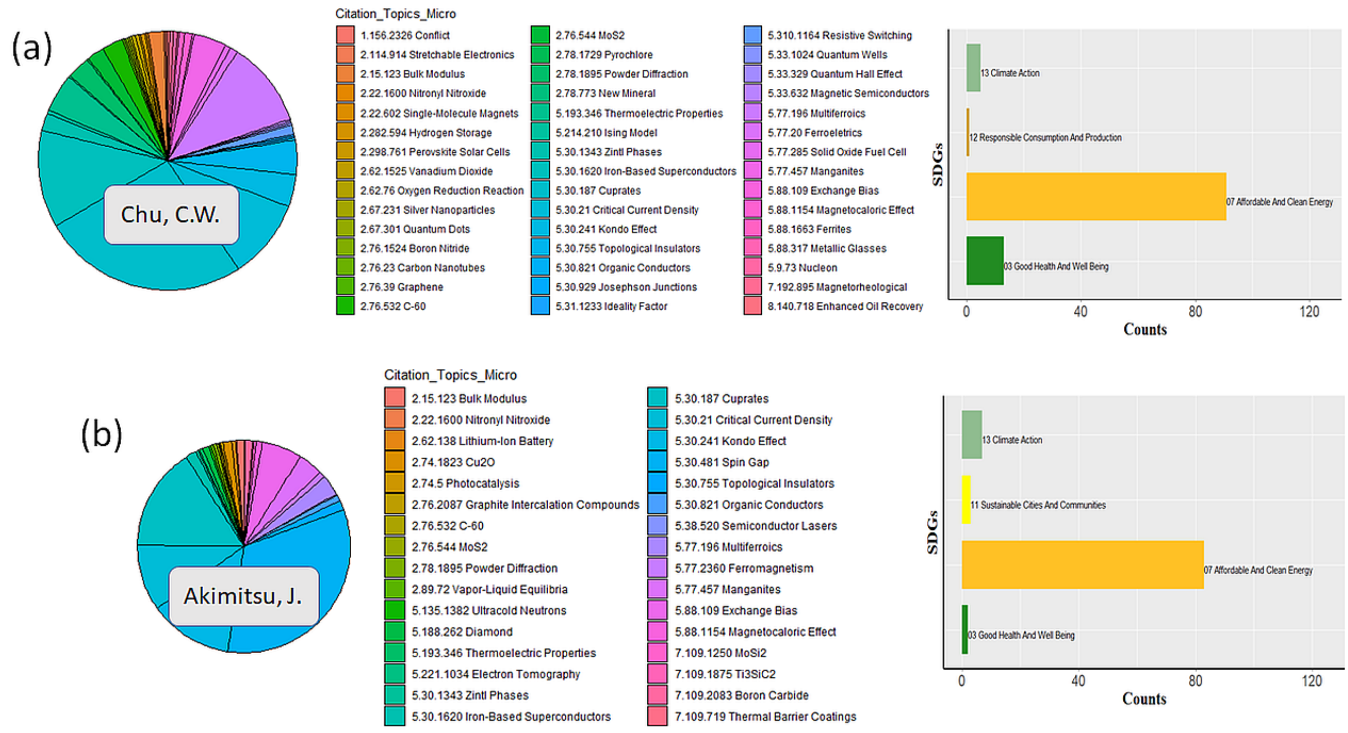

Figure A5. Personal data for (**a**) Chu, C.W. and (**b**) Akimitsu, Jun.

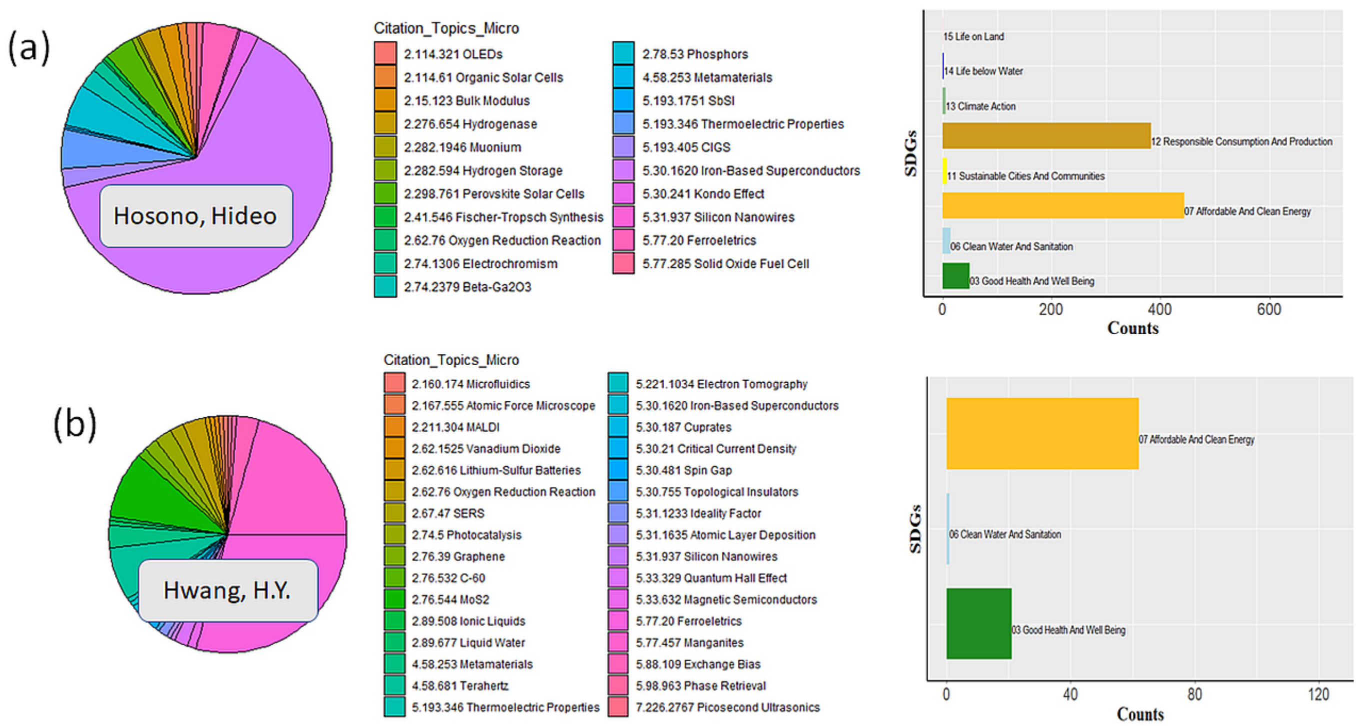

Figure A6. Personal data for (**a**) Hosono, Hideo and (**b**) Hwang, H.Y.

Appendix D. Selected Members of the Editorial Board of *Superconductivity*

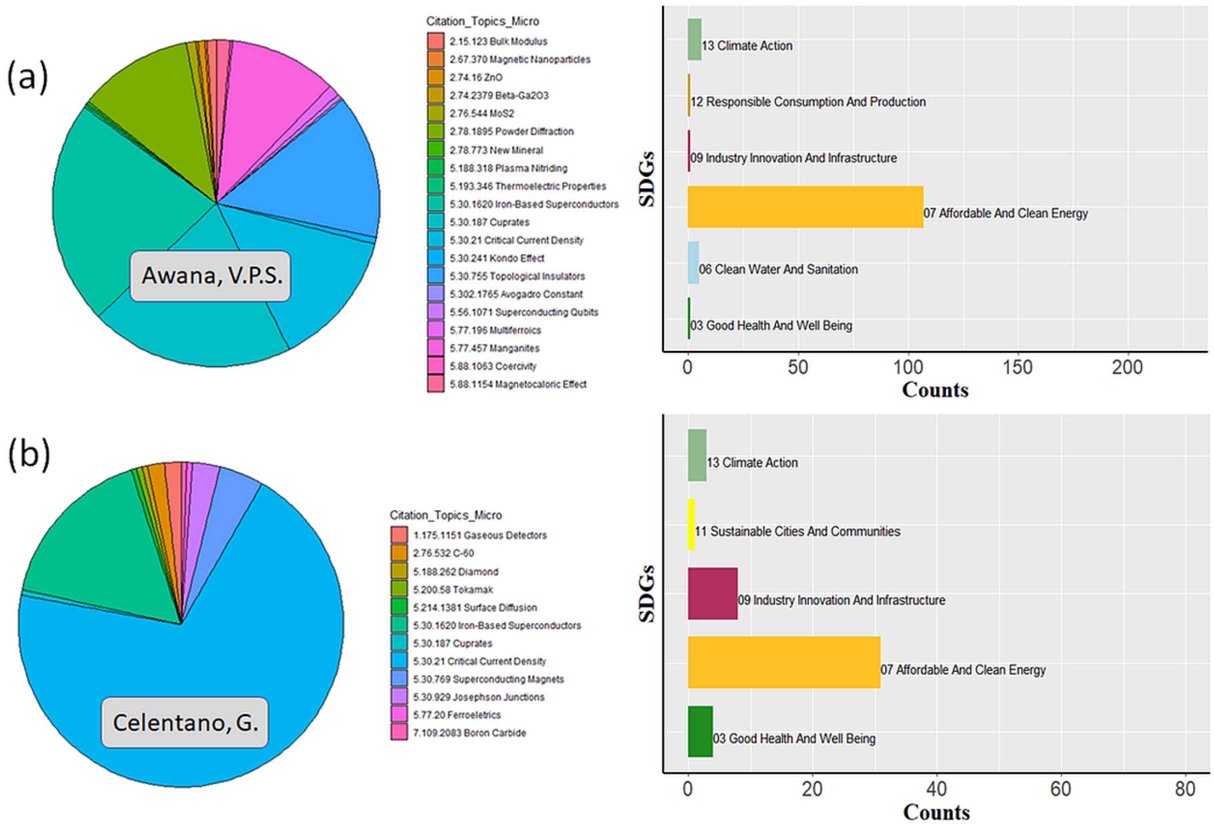

Figure A7. Personal data for Editorial board members of *Superconductivity*. (**a**) Awana, V.P.S. and (**b**) Celentano, G.

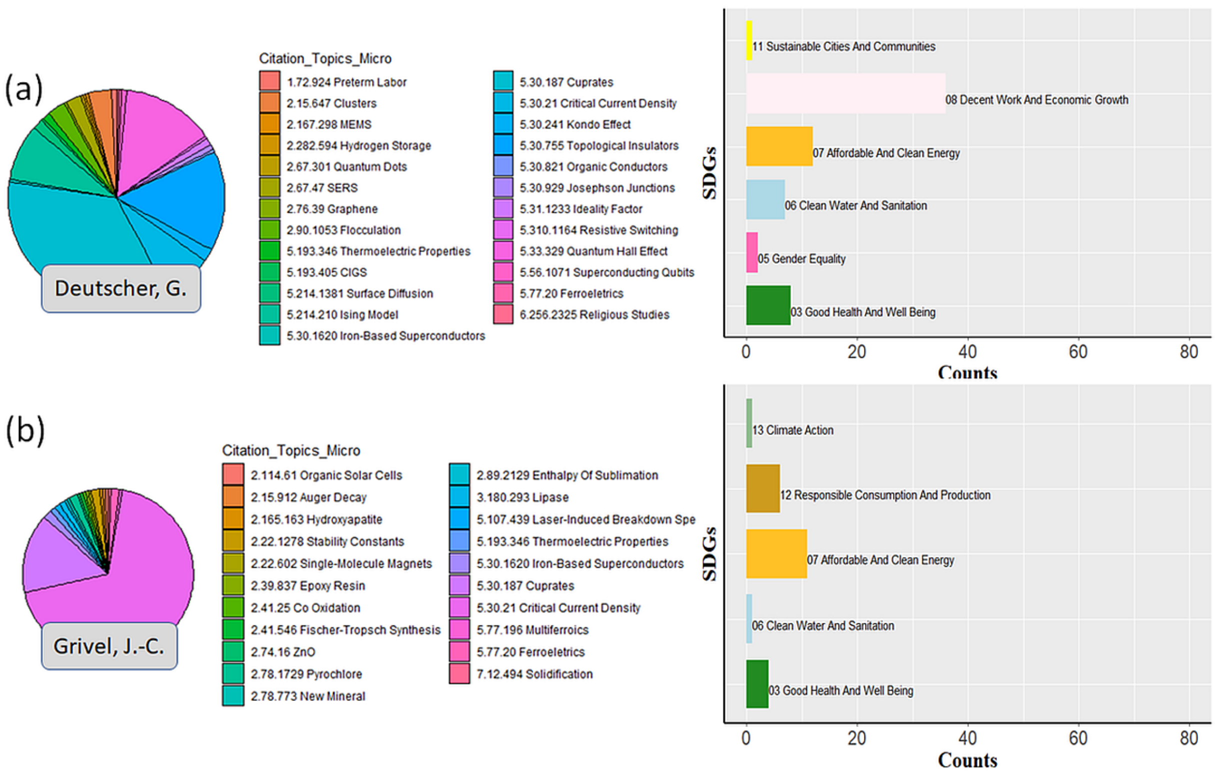

Figure A8. Personal data for Editorial board members of *Superconductivity*. (**a**) Deutscher, G. and (**b**) Grivel, J.-C.

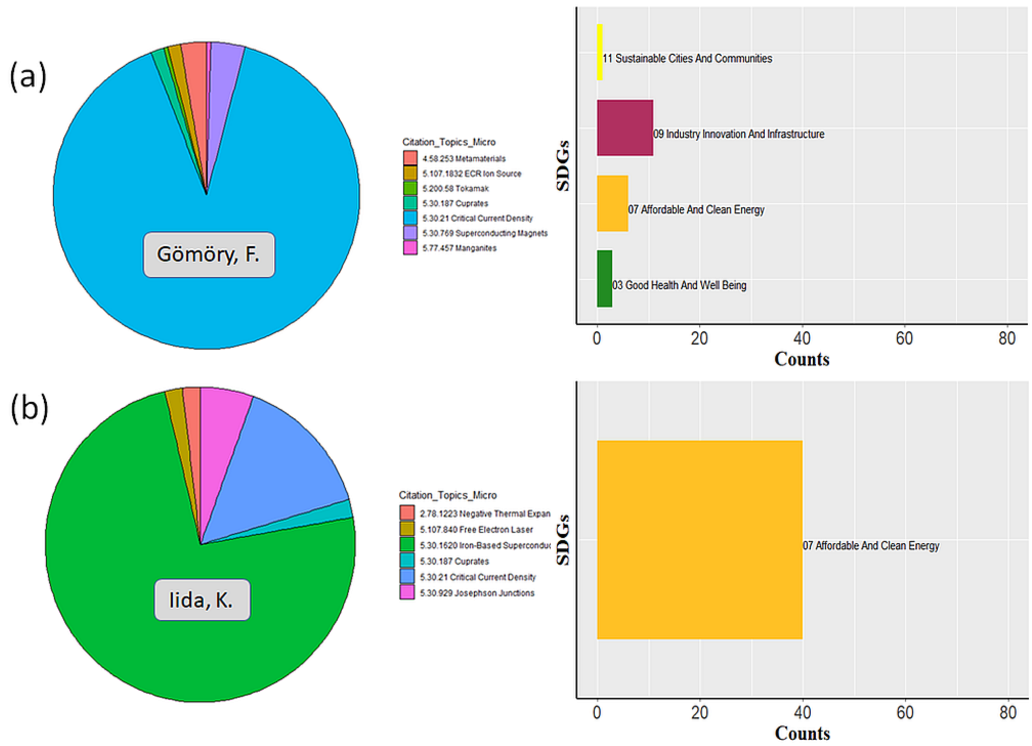

Figure A9. Personal data for Editorial board members of *Superconductivity*. (**a**) Gömöry, F. and (**b**) Iida, K.

Gömöry working at Institute of Electrical Engineering, Slovak Academy of Sciences, has lot of application-related work, but only the work on magnetic cloaks and metamaterials counts for the SDGs besides an analysis of coated conductors for ISTTOK, which received the keyword "Tokamak".

In contrast, Iida had carried out a lot of research on *RE*BCO bulks, but only the more recent work on IBS superconductors does count for the SDGs.

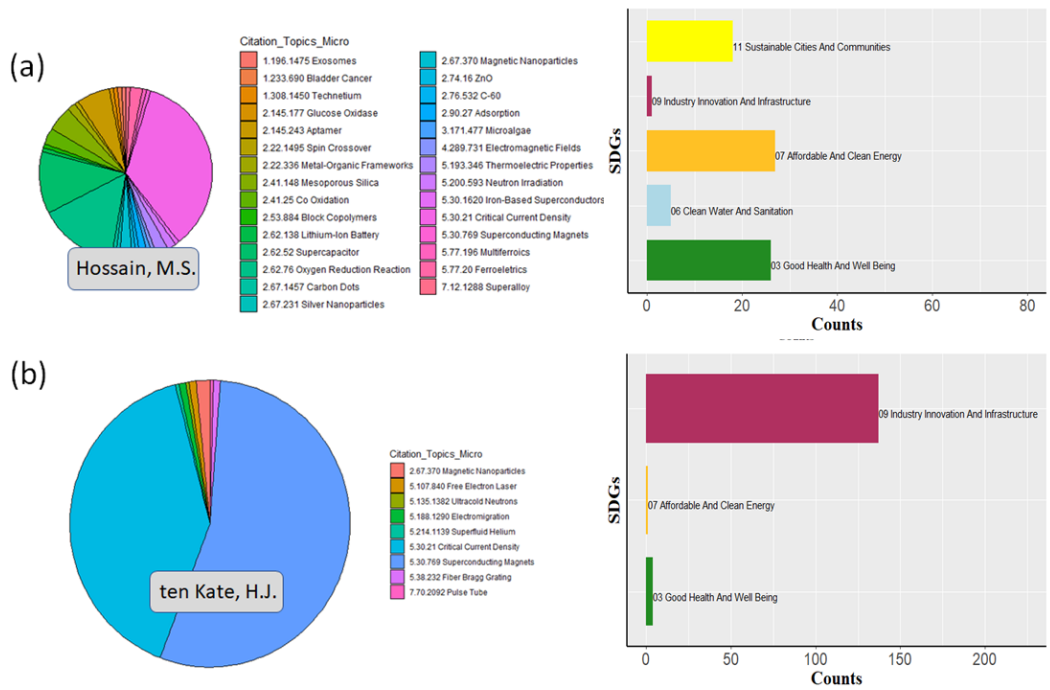

Figure A10. Personal data for Editorial board members of *Superconductivity*. (**a**) Hossain, M.S. and (**b**) ten Kate, H.J.

For H.J. ten Kate, one must note the large bar for SDG 09, which directly reflects the amount of his work on the topic "Superconducting Magnets" (especially work on Nb_3Sn).

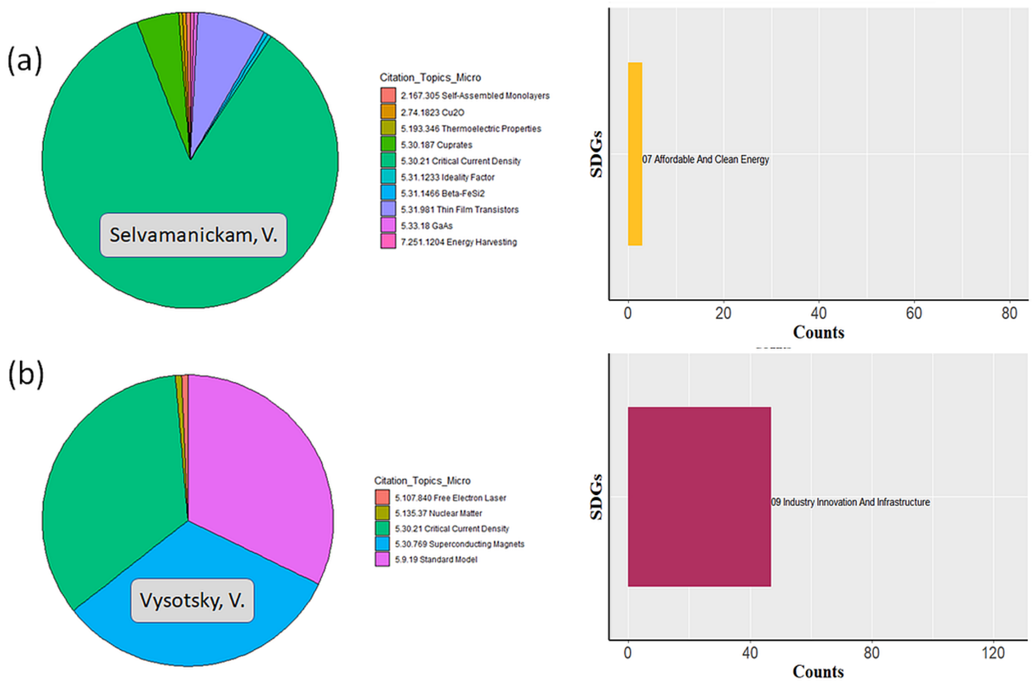

Figure A11. Personal data for Editorial board members of *Superconductivity*. (**a**) Selvamanickam, V. and (**b**) Vysotsky, V.

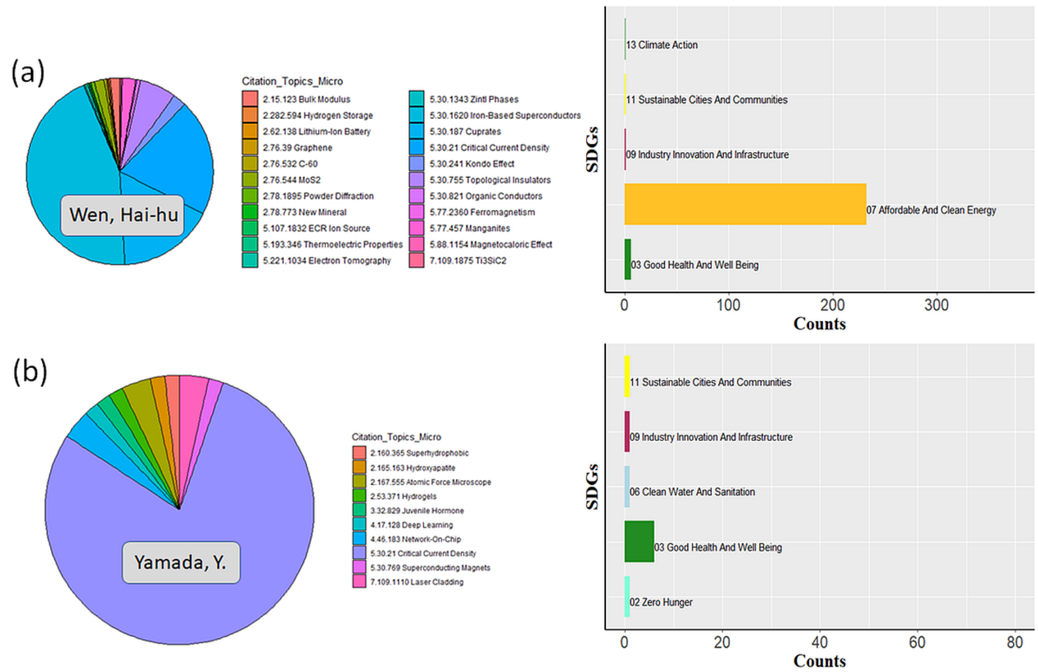

Figure A12. Personal data for Editorial board members of *Superconductivity*. (**a**) Wen, Hai-hu and (**b**) Yamada, Y.

Overall, we can learn from these graphs that all authors working in the field of superconductivity and high-temperature superconductors have in their pie diagrams a very large section for the microcitation topic "Critical current density" and/or "Cuprates". The data for ten Kate and Vysotsky (Figure A11a,b), working on superconducting magnets (typically with materials like NbTi or Nb_3Sn), accordingly exhibit a large section for the microcitation topic "Superconducting magnets", and, as result from this, many articles were qualifying for SDG 09 (*Industry Innovation and Infrastructure*).

Appendix E. Other Selected Researchers

Figures A13–A26 give the data for selected researchers in the field of superconductivity. Additionally, some comments to the data obtained are given, highlighting some interesting and remarkable papers.

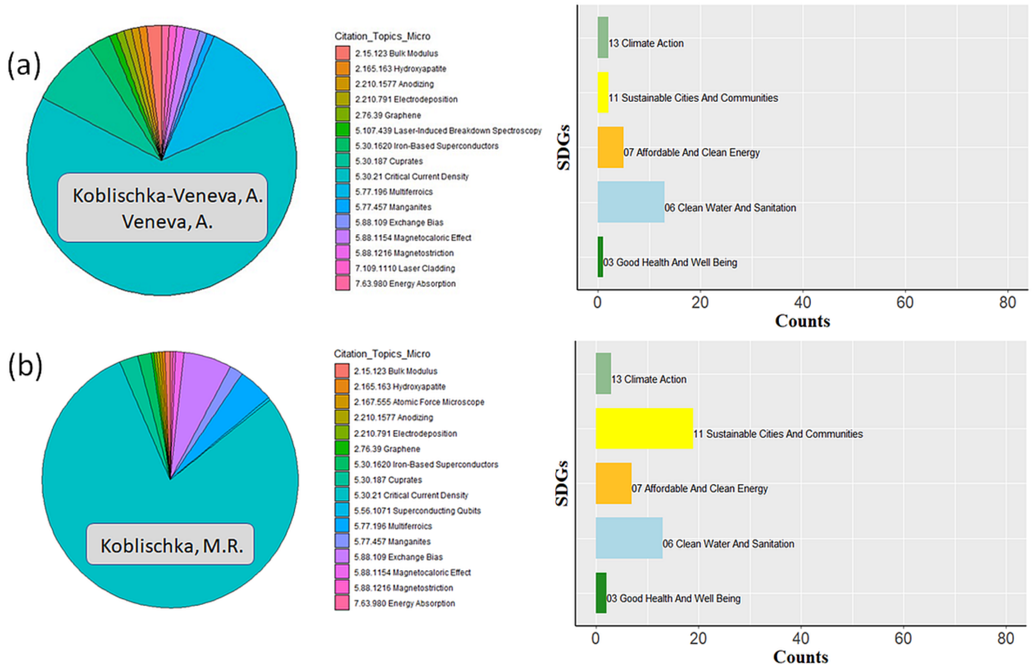

Figure A13. Personal data for selected authors. (**a**) Koblischka-Veneva, A. and (**b**) Koblischka, M.R.

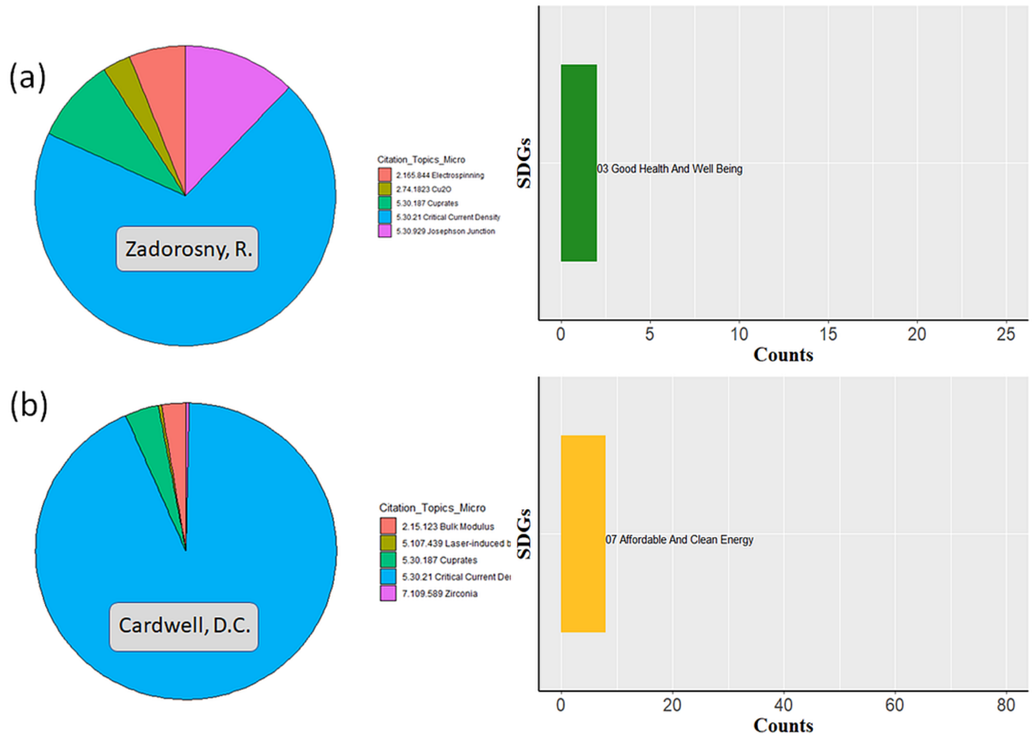

Figure A14. Personal data for selected authors. (**a**) Zadorosny, R. and (**b**) Cardwell, D.C.

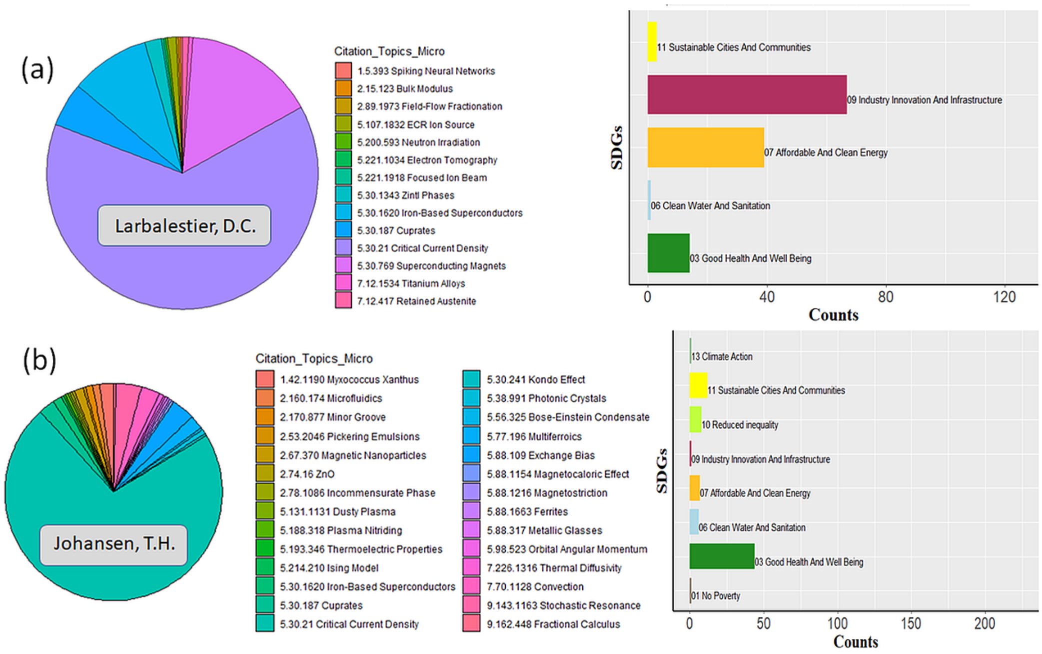

Figure A15. Personal data for selected authors. (**a**) Larbalestier, D.C. and (**b**) Johansen, T.H.

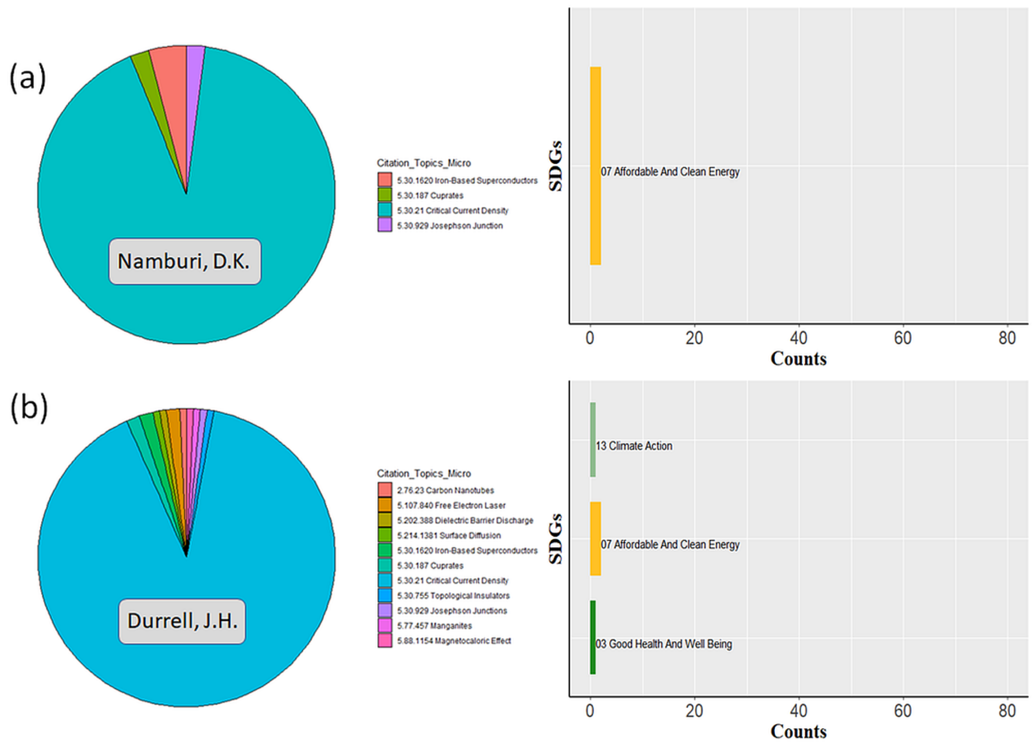

Figure A16. Personal data for selected authors. (**a**) Namburi, Devendra K. and (**b**) Durrell, J.H.

Then, we consider the work of the authors of the present contribution, A. Koblischka-Veneva (former name A. Veneva), M.R. Koblischka (Figure A13) and R. Zadorosny, shown together with the data for D.A. Cardwell (Figure A14). The left side of each figure shows the microcitation topics found in WoS for the selected author, and the diagram on the right side presents the number of papers that received an SDGs tag and the corrsponding SDG number. Here, it is directly obvious that for all four researchers there is a very large sector in the pie diagram for the microcitation topic "Critical current density", and all other microcitation topics make up only small contributions. This implies directly that all the papers dealing with superconductivity are classified as "Critical current density", which does not qualify to get an SDGs tag. This is a quite astonishing result, as one would expect that work intending to improve the performance of any superconducting material is well within the aims of SDG 07 (Affordable and Clean Energy).

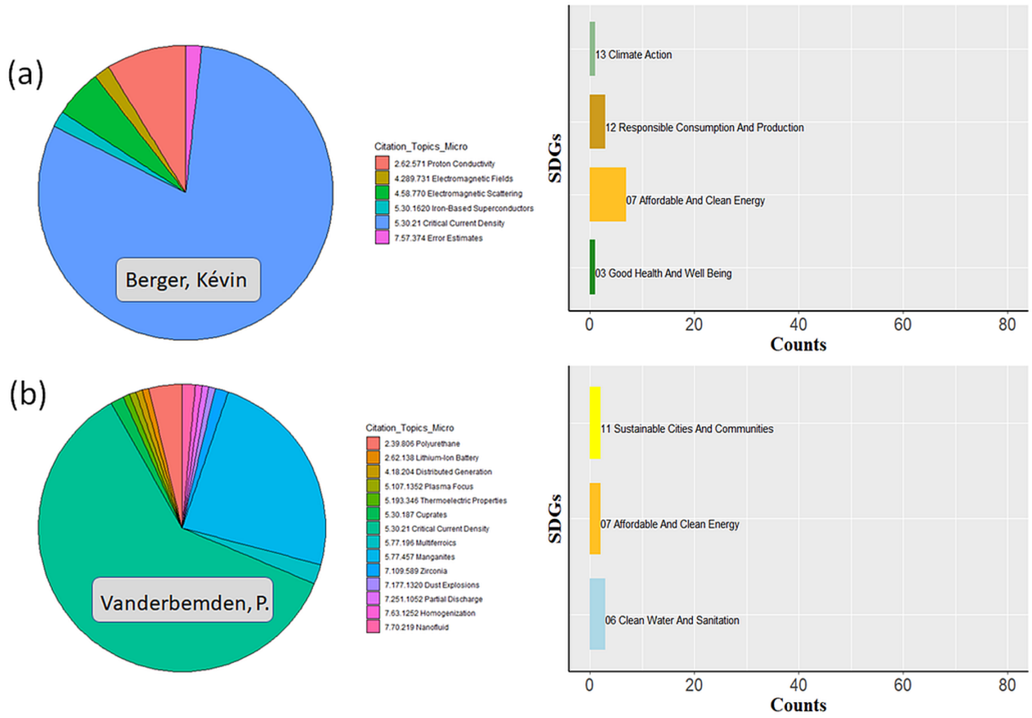

Figure A17. Personal data for selected authors. (**a**) Berger, Kévin and (**b**) Vanderbemden, P.

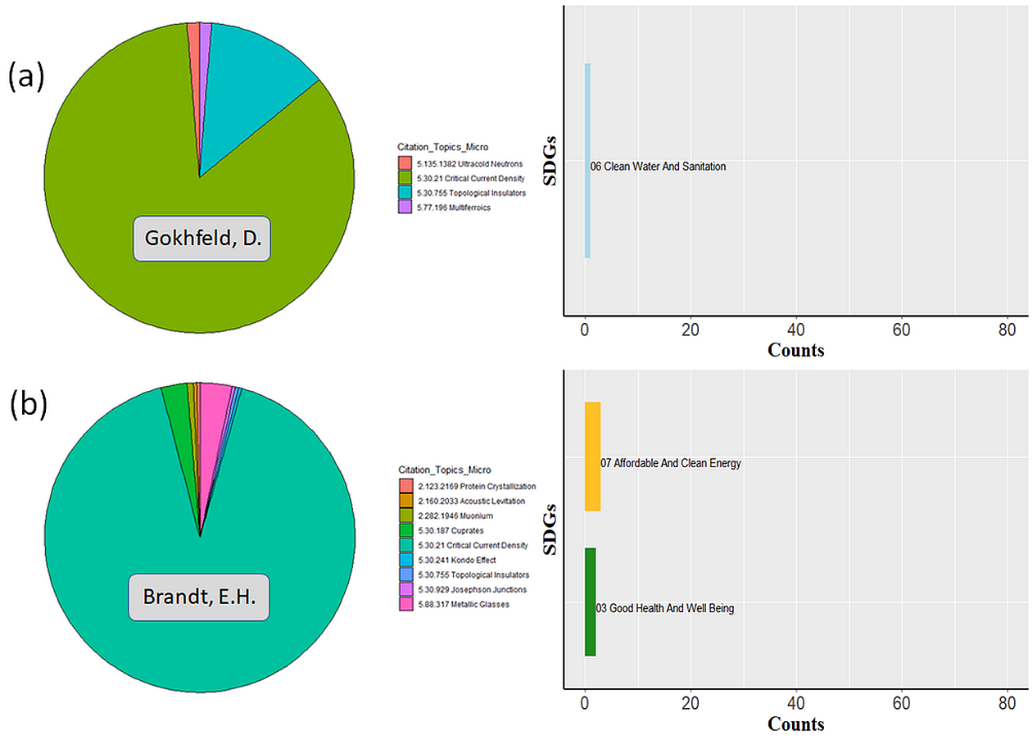

Figure A18. Personal data for selected authors. (**a**) Gokhfeld, D. and (**b**) Brandt, E.-H.

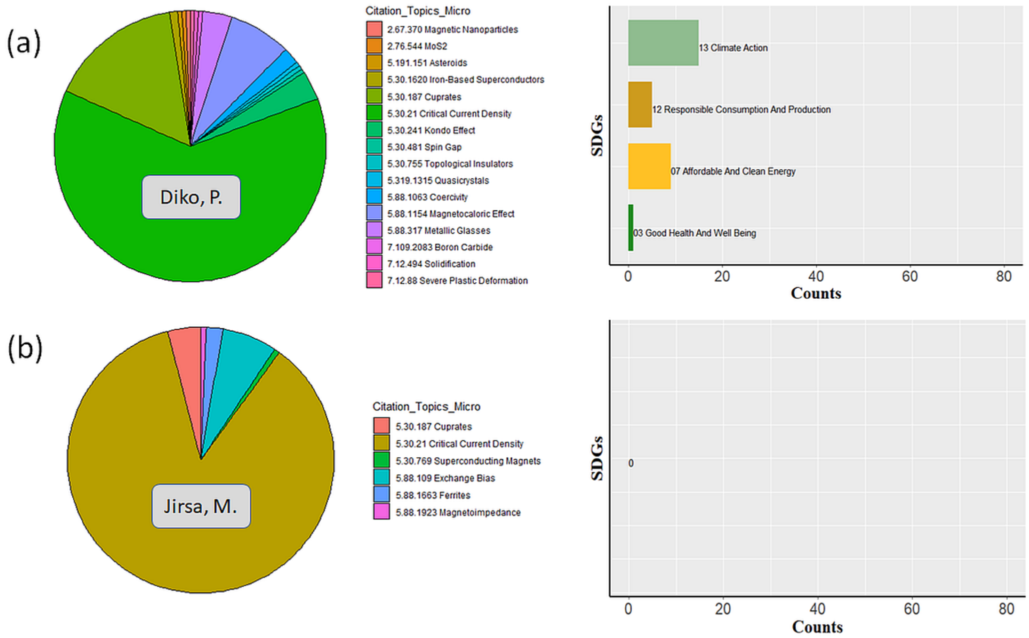

Figure A19. Personal data for selected authors. (**a**) Diko, P. and (**b**) Jirsa, M.

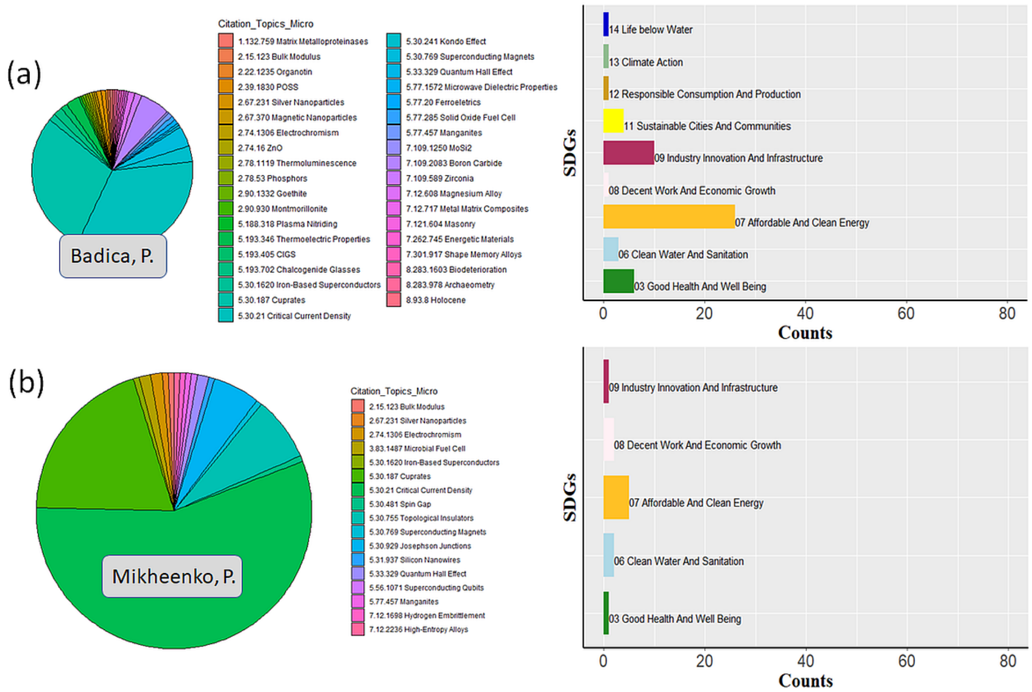

Figure A20. Personal data for selected authors. (**a**) Badica, P. and (**b**) Mikheenko, P.

For A. Koblischka-Veneva (Figure A13a), there are 110 results in WoS. From these papers, 71 are listed with the topic "Critical current density", which corresponds to 64.5%. The topic "Multiferroics" has 13 counts, the topic "Cuprates" 9 counts, and all other topics are ranging between 1 and 3 counts. Only 23 of 110 papers have received an SDGs tagging, and among them is no paper dealing with superconductivity.

For M.R. Koblischka (Figure A13b), 223 papers are listed with the topic "Critical current density", which corresponds to 75.9% of all papers listed (294). As a consequence of the dominating microcitation topic "Critical current density", from the 294 papers listed in WoS only 44 works (=15%) count for the SDGs. So, when now refining the search in WoS to these works, one can learn that there are papers on the Iron-Based Superconductors (IBSs), but practically all work dealing with magnetic force microscopy (MFM), high-frequency MFM and harddisks (SDG 11), with various magnetic materials like metal foams, permalloy, NiMnGa (SDG 06) and the MCE effect (SDG 13) as well as biological materials, which qualifies for SDG 03 (keyword "hydroxyapatite"), are counted for the SDGs. The only exception among the papers on superconductivity from the microcitation topic "Critical current density" are some papers on nanowires (keyword "electrospinning"—no SDGs tag) but, interestingly, not all of them. As an example, the most recent paper on nanowires [61] is classified as

Research Areas: Physics
Citation Topics: 5 Physics 5.56 Quantum Mechanics
5.56.1071 Superconducting Qubits,

which also does not receive an SDGs tag. This classification is also remarkable for itself as this does not really fit the intention of this work. It is also notable that the SDGs diagrams for A. Koblischka-Veneva and M.R. Koblischka look very much similar to each other, with only some small differences in the counts, and only the counts for SDG 11 are clearly different due to M.R.K.'s work on MFM/HF-MFM.

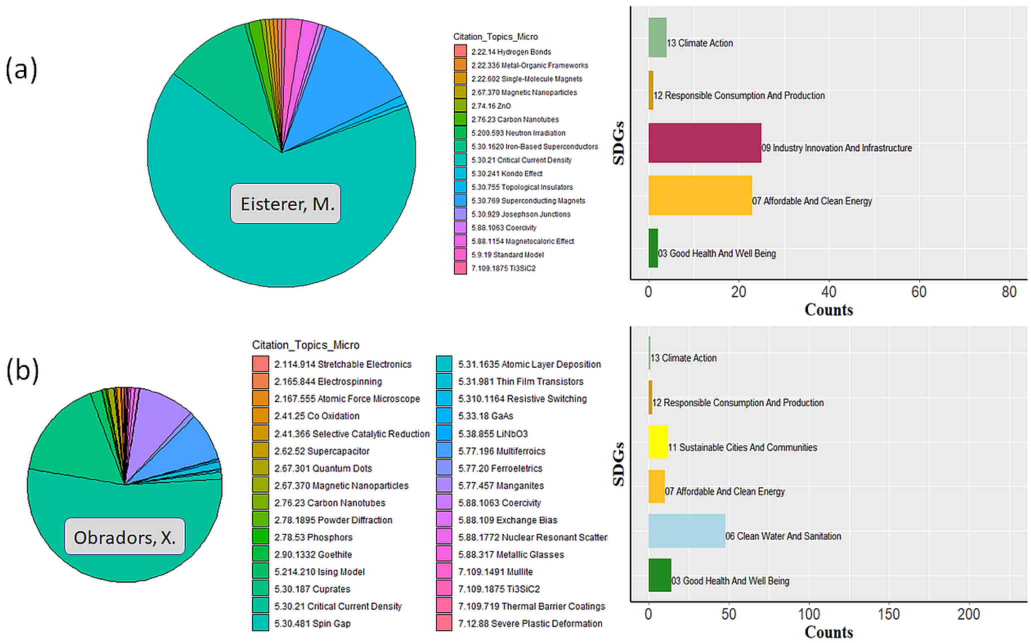

Figure A21. Personal data for selected authors. (**a**) Eisterer, M. and (**b**) Obradors, X.

R. Zadorosny (Figure A14a) has 33 papers listed in WoS, two of them (=6.1%) qualify for the SDGs with the research area/citation topics:

Research Areas: Materials Science
Citation Topics: 2 Chemistry 2.165 Nanofibers, Scaffolds & Fabrication
2.165.844 Electrospinning,

and so are counted for SDG 03 (*Good Health and Well-being*). In total, 23 papers are given the topic "Critical current density", which corresponds to 70% of all papers listed. The rest received topics like "electrospinning", "Cuprates" and "Josephson junctions", which do not qualify for an SDGs tag.

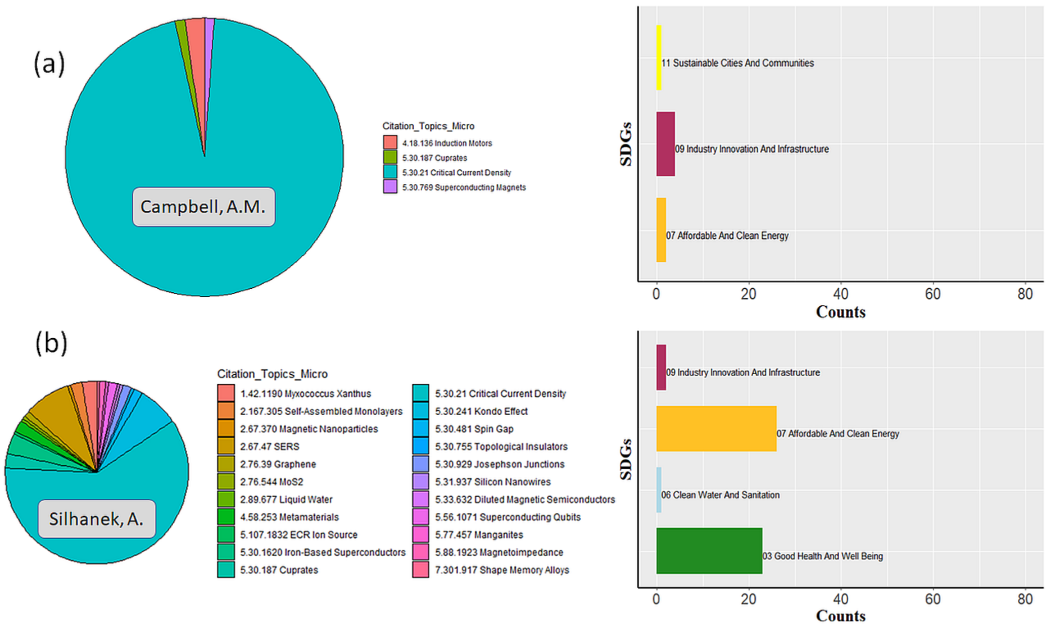

Figure A22. Personal data for selected authors. (**a**) Campbell, A.M. and (**b**) Silhanek, A.

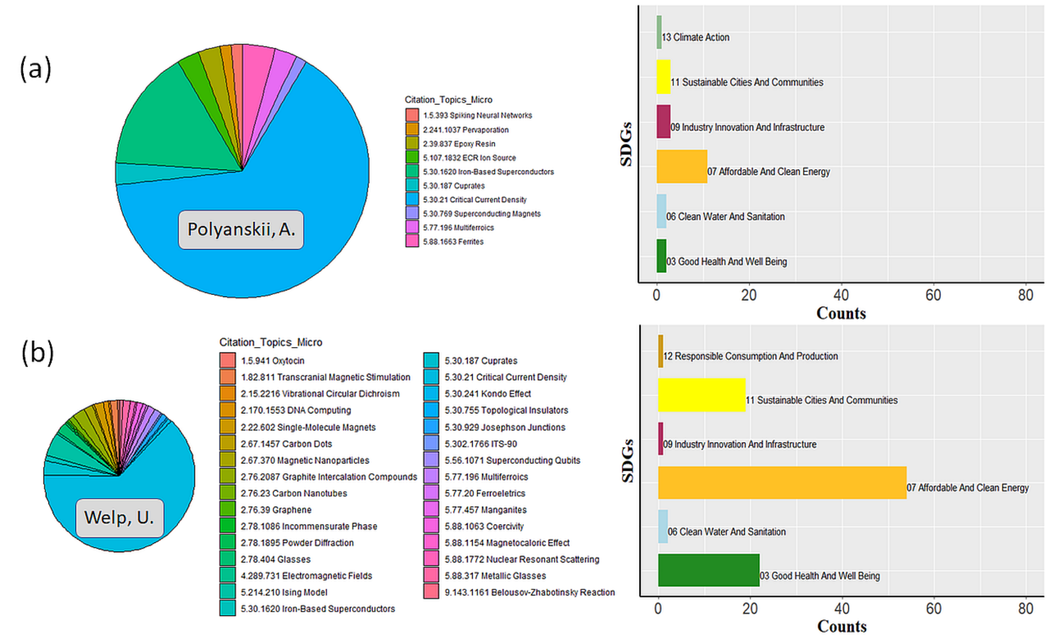

Figure A23. Personal data for selected authors. (**a**) Polyanskii, A. and (**b**) Welp, U.

D.A. Cardwell (Figure A14b) has 304 papers listed in WoS of which 283 ones have the microcitation topic "Critical current density". This corresponds to 93.1%, which is an extremely high number. So, the Leader of one of the most respected groups in the field of superconductivity has only eight (!) papers with an SDGs classification (SDG 07 *Affordable and Clean Energy*). This is, however, not for superconductivity but for Compton scattering experiments on various materials, stemming from his master's or PhD work in the 1980s. This will be demonstrated in Figure A33 below.

Research Areas: Physics
Citation Topics: 2 Chemistry   2.15 Physical Chemistry   2.15.123 Bulk Modulus.

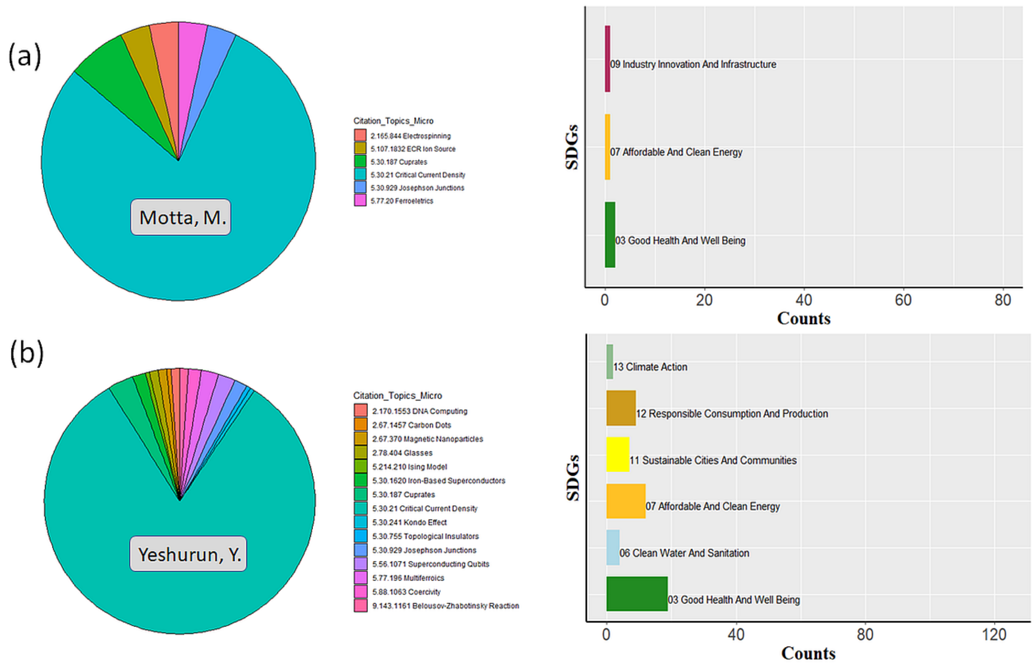

Figure A24. Personal data for selected authors. (**a**) Motta, M. and (**b**) Yeshurun, Y.

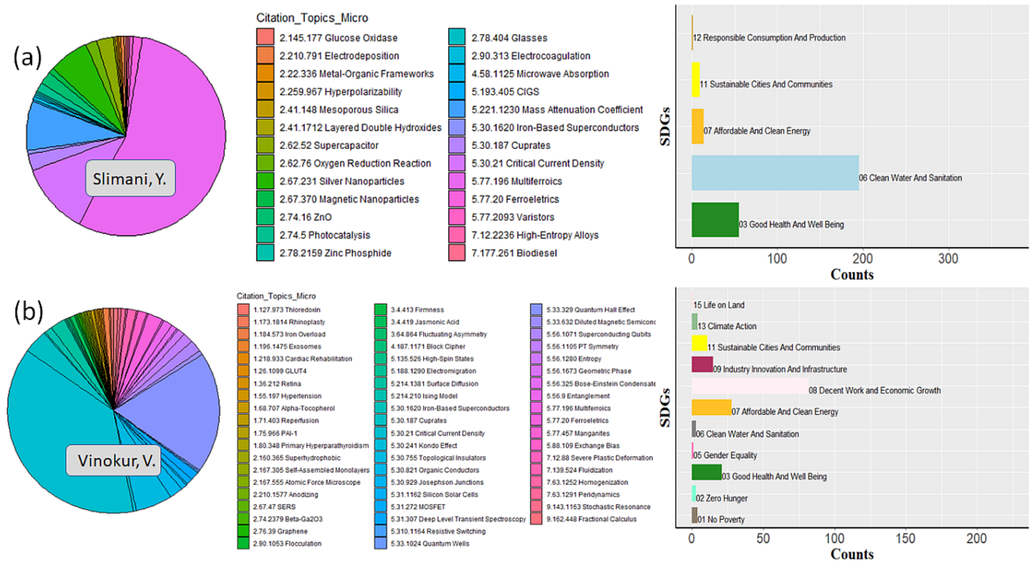

Figure A25. Personal data for selected authors. (**a**) Slimani, Y. and (**b**) Vinokur, V.

The same analysis is continued in the following for several other authors like D.C. Larbalestier, T.H. Johansen (Figure A15), D.K. Namburi, J.H. Durrell (Figure A16), Kévin Berger, P. Vanderbemden (Figure A17), D. Gokhfeld, E.H. Brandt (Figure A18), P. Diko, M. Jirsa (Figure A19), P. Badica, P. Mikheenko (Figure A20), M. Eisterer, X. Obradors (Figure A21), A.M. Campbell, A. Silhanek (Figure A22), A. Polyanskii, U. Welp (Figure A23), M. Motta, Y. Yeshurun (Figure A24), Y. Slimani, V. Vinokur (Figure A25) and P. Seidel, A. Gencer (Figure A26) in the following figures.

D.C. Larbalestier (Figure A15a) has 418 results in WoS and 124 papers tagged with SDGs, which corresponds to 29.7% of all papers listed. Larbalestier's 67 papers dealing with Nb_3Sn, cables and strands for SDG 09 are well counted, but all these are all for Nb_3Sn and its development from the 1980s onwards! This also applies for the 14 counts for SDG 03 and the 3 counts for SDG 11. The one paper [62] tagged for SDG 06 is a review article written in 1984 mentioning the keyword "superfluid", which received the citation topic

Research Areas: Physics
Citation Topics: 2 Chemistry 2.89 Ionic, Molecular & Complex Liquids 2.89.1973 Field-Flow Fractionation,

which is somewhat difficult to be understood.

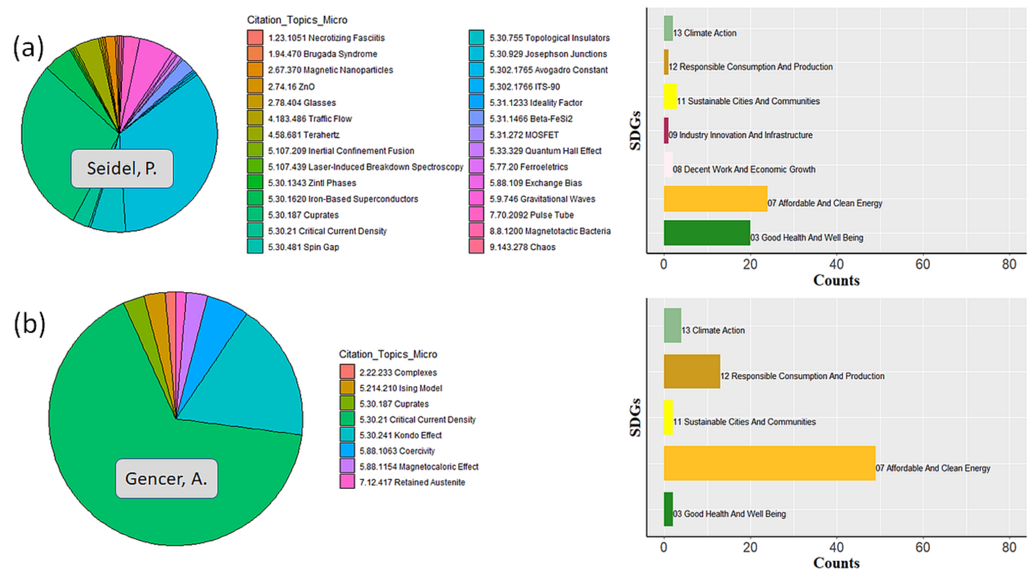

Figure A26. Personal data for selected authors. (**a**) Seidel, P. and (**b**) Gencer, A.

For T.H. Johansen (Figure A15b), 332 results are obtained from WoS from which 52 (=15.6%) are tagged for SDGs. Among them, there are 17 papers for SDG 03 dealing with the trapping of magnetic beads or nanoparticles between magnetic domain walls, which may have manifold applications [63]. In total, 203 papers (=62.3%) received the topic "Critical current density", which includes all the papers on superconductivity and magneto-optic imaging as well as the superconducting levtiation. The papers tagged for SDG 10 deal with magnetic bubble memories, and the papers for SDG 07 are works on IBS. So, his review on magnetostriction [64] is included in the majority of the papers with the common topic, and no SDGs tag.

The authors D.K. Namburi and J.H. Durrell (Figure A16a,b) show a situation similar to D.A. Cardwell as the majority of their papers are classified as "Critical current density", which does not qualify for the SDGs. For D.K. Namburi, only two papers on IBS, one on Josephson junctions and one on Cuprates, are listed, so only the two IBS papers make up to SDG 07. In the case of J.H. Durrell, 136 papers are listed among which 123 got the topic "Critical current density" (=90.4%). Again, only the two papers on IBS (SDG 07), one paper on the MCE effect (SDG 13) and one paper on sputtering/plasma (SDG 03), count for the SDGs.

Figure A17a,b show the data for Kévin Berger and P. Vanderbemden. Both of them belong to Electric Engineering, so their work is much more application-oriented. However, this does not change the picture very much. For K. Berger, 46 of 52 papers (=88.5%) show the topic "Critical current density", and only 12 papers (23.1%) received an SDGs tag. P. Vanderbemden has 134 papers, from which 81 got the tag "Critical current density" (=60.4%), and so seven papers (=5.2%) obtained an SDGs tag.

In Figure A18a,b, two theoreticians are analyzed. Figure A18a presents the data for D. Gokhfeld, where 66 of his 78 papers (84.6%) got the topic "Critical current density". Only one paper received an SDGs tag for SDG 06 [65]:

Research Areas: Physics
Citation Topics: 5 Physics 5.77 Applied Physics 5.77.196 Multiferroics,

dealing with direct and inverse magnetoelectric effects in orthorhombic $DyMnO_3$.

Figure A18b shows the data for Ernst Helmut Brandt (†2011), who was working as theoretician mainly in the field of superconductivity. Overall, WoS lists 304 papers for him, and so the only works of him counting for the SDGs (5(!), corresponding to 1.6%) come from his contributions to levitation but remarkably *not* the superconducting levitation. Here, it is an invited viewpoint article on acoustic levitation [66] and a paper in *Physics World* entitled "Theory catches up with flying frog" [67], which makes his work count for SDGs. The levitating frog counts for SDG 03 with the microcitation topic 2.123.2169 Protein Crystallization. The other works deal with muon spin resonance and count for SDG 07. This directly implies that all his work on the flux line lattice, flux pinning, etc., is all enlisted in WoS with the topic "Critical current density" and, thus, does not count for any SDGs. His case also symbolizes the fact that even authors who had not known about the SDGs may receive SDGs tags in WoS.

P. Diko and M. Jirsa (Figure A19a,b) reveal a similar picture. In total, 62.3% of Diko's papers are classified with the microcitation topic "Critical current density", and even 86% for Jirsa are "Critical current density". Even though Jirsa has also works dealing with magnetism, he has not received any SDGs tag.

The pie dagram for P. Badica (Figure A20a) reveals a high number of microcitation topics (in total 37). So, although also his sections for "Critical current density", "Cuprates" and "IBS" make up more than 50%, his works qualified for nine different SDGs.

The data for both M. Eisterer and X. Obradors (Figure A21a,b) show again large sections (>50%) for the microcitation topics "Critical current density" and "Cuprates", but the work on "Superconducting magnets", "Neutron irradiation" or Magnetism leads to a respectable SDGs score.

Figure A22a,b present the analysis for A.M. (Archie) Campbell and A. Silhanek. Nearly all the work (=95.5%) of Campbell is tagged for the microcitation topic "Critical current density", and so no SDGs are counted. Only the work on superconducting magnets and induction motors does coult for the SDGs. A. Silhanek shows a much wider research spectrum including topics of magnetism, nanoparticles, graphene and shape memory alloys, which is well recognized in the SDGs. However, also for him, 60% of the papers are tagged for "Critical current density".

A. Polyanskii and U. Welp (Figure A23a,b) work both at research institutes like NHMFL and Argonne National Lab. This enables them to work on a variety of topics with the result of having scores for six different SDGs. M. Motta and Y. Yeshurun (Figure A24a,b) and Y. Slimani and V. Vinokur (Figure A25a,b) are university researchers working on a large variety of topics, so they have achieved up to six SDGs taggings. For theorists, it seems somewhat easier to be involved in much broader research efforts, which may cover several different topics. Thus, V. Vinokur has the highest SDGs score covering in total 11 SDGs.

The data for P. Seidel and A. Gencer are presented in Figure A26a,b. P. Seidel is mainly active in the field of superconducting thin films, Joesphson junctions and cryoelectronic applications. As a result, his work covers seven different SDGs. The data for A. Gencer reveal the typical diagram for a university researcher working in the field of superconductivity, with the microcitation topic "Critical current density" dominating the pie diagram. Nevertheless, the work on the magnetocaloric effect (MCE) and on topics in magnetism helped to score five different SDGs.

Appendix F. Company Researchers, Researchers Affiliated to CERN and Applied Superconductivity

Next, we consider company researchers in superconductivity in Figures A27–A32, i.e., the data for M. Rikel, U. Flögel-Delor, W. Prusseit, W. Reiser, J. Plechacek, S. Elschner, R. Semerad, G. Grasso, C. Scheuerlein, R. Flükiger, B. Seeber, and M. Noe. From these figures, it is clearly visible that all the company researchers all have a dominating microcitation topic "Critical current density" in their diagrams, which manifests their work to further improve the performance of the superconducting materials. This section may even be covering all their papers as in the case of U. Flögel-Delor (ATZ) and W. Reiser (VESCSuperbar). The graphs for M. Rikel (Figure A27a); worked with Nexans, Deutsche Nanoschicht GmbH, S-Innovations and W. Prusseit (Figure A28a); work at THEVA show that these researchers may have also other microcitation topics, but, in both cases, these topics were covered during their diploma or PhD work and so does not measure their work for the company.

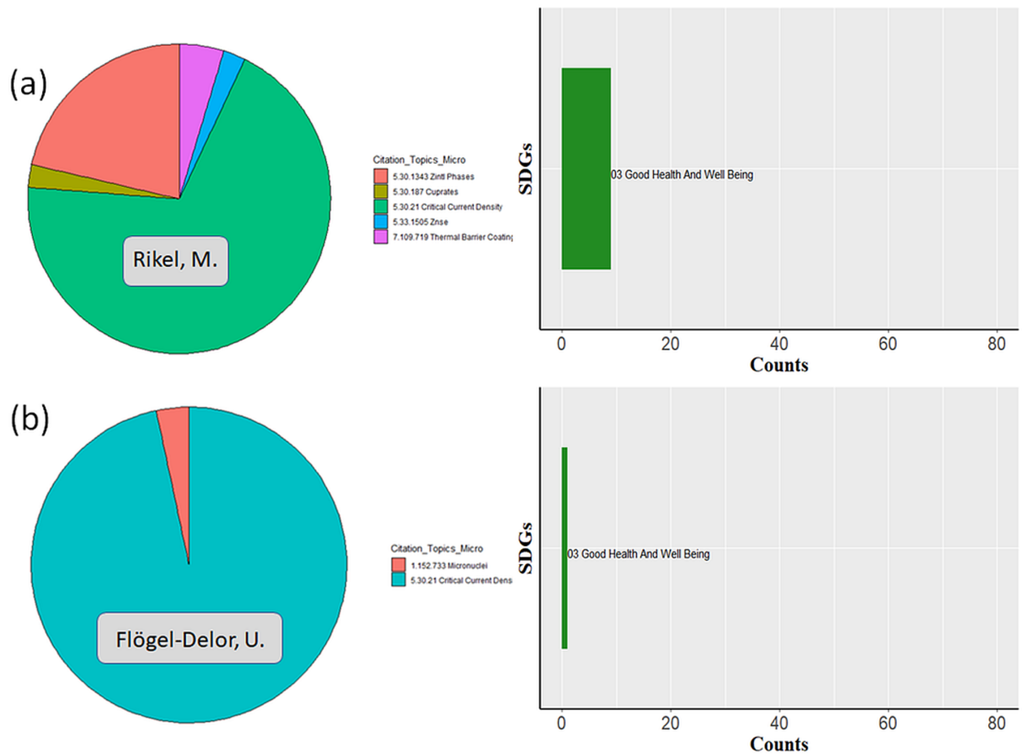

Figure A27. Personal data for selected authors. (**a**) Rikel, M. and (**b**) Flögel-Delor, U.

J. Plechacek (CAN Superconductors s.r.o.) and S. Elschner (Hoechst) shown in Figure A29a,b are both company researchers. As consequence, there is only very limited SDGs tagging to their work; as for J. Plechacek, there is only work with the microcitation topic "Critical current density", which yields no SDGs tag, and S. Elschner does have articles tagged for SDG 07 but for the work on "Solid Hydrogen" not the HTSc.

Figure A30a,b give the data for R. Semerad (CERACO) and G. Grasso (Columbus, ASG Superconductors). For R. Semerad, there are about 50% of his papers in the section "Critical current density" but also seven other microcitation topics from which several (Avogadro Constant, Quantum Wells, Solid Oxide Fuel Cell) do count for the SDGs. G. Grasso has 97 papers in WoS, and the majority of his papers with the topic "Critical current density" (91%), plus a section section "Cuprates" (6%) originating from his PhD work on Bi-2223 tapes. This makes a total of 97% papers in these two topics. However, he also has microcitation topics like Micronuclei or Tokamak, stemming from papers with other researchers using the MgB_2 wires for applications (coils), which count well for the SDGs.

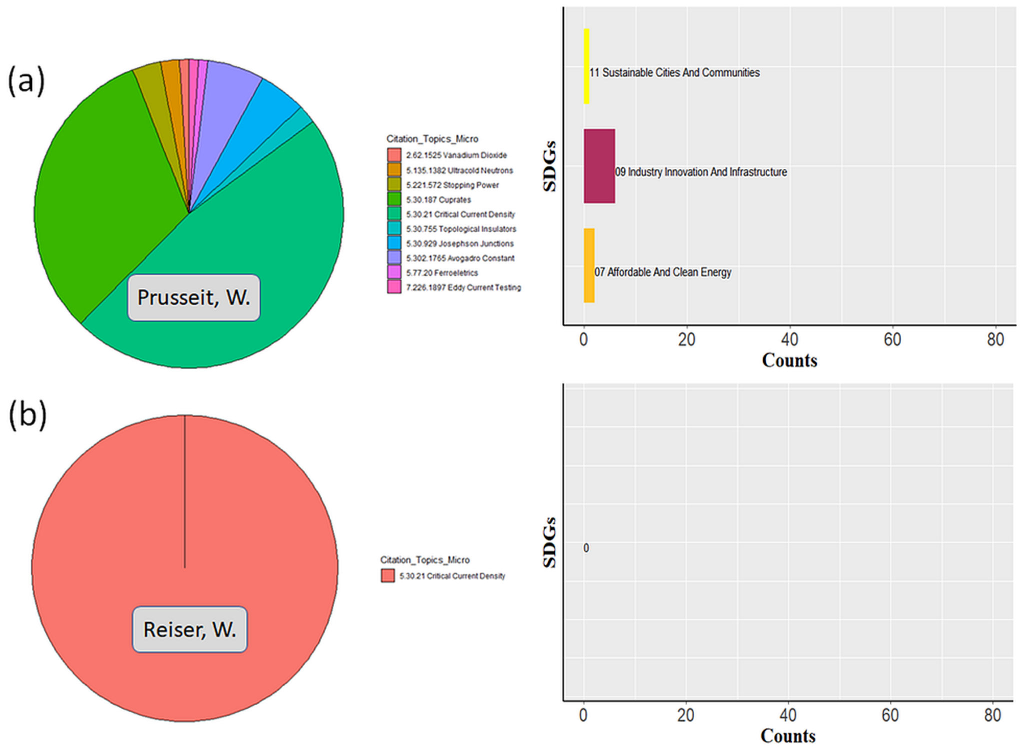

Figure A28. Personal data for selected authors. (**a**) Prusseit, W. and (**b**) Reiser, W.

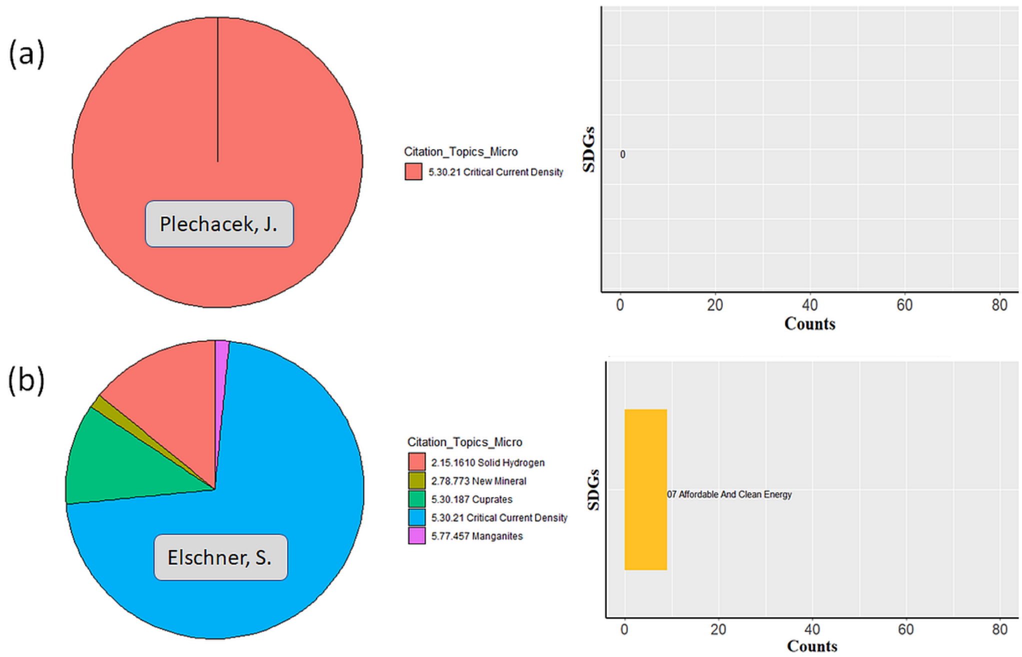

Figure A29. Personal data for selected authors. (**a**) Plechacek, J. and (**b**) Elschner, S.

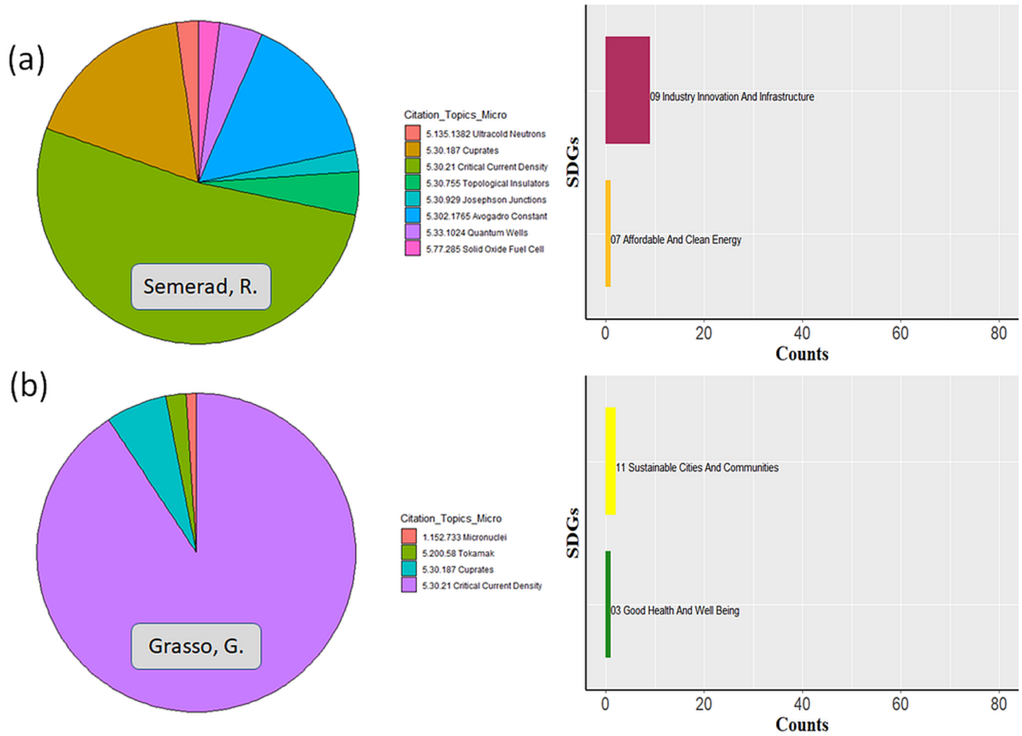

Figure A30. Personal data for selected authors. (**a**) Semerad, R. and (**b**) Grasso, G.

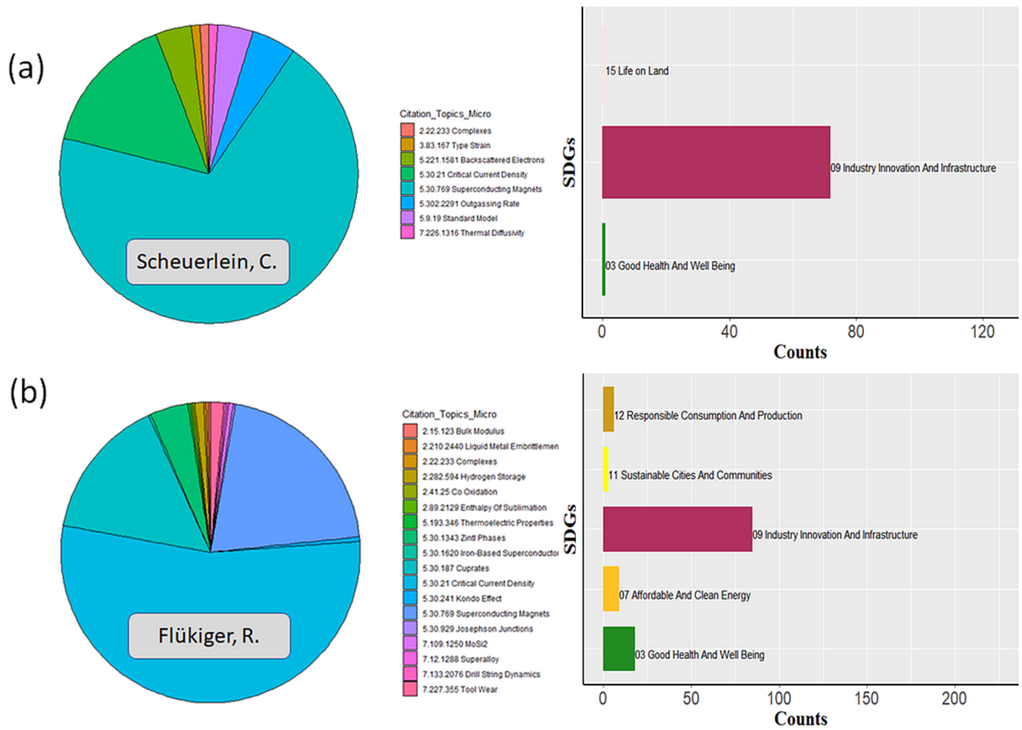

Figure A31. Personal data for selected authors. (**a**) Scheuerlein, C. and (**b**) Flükiger, R.

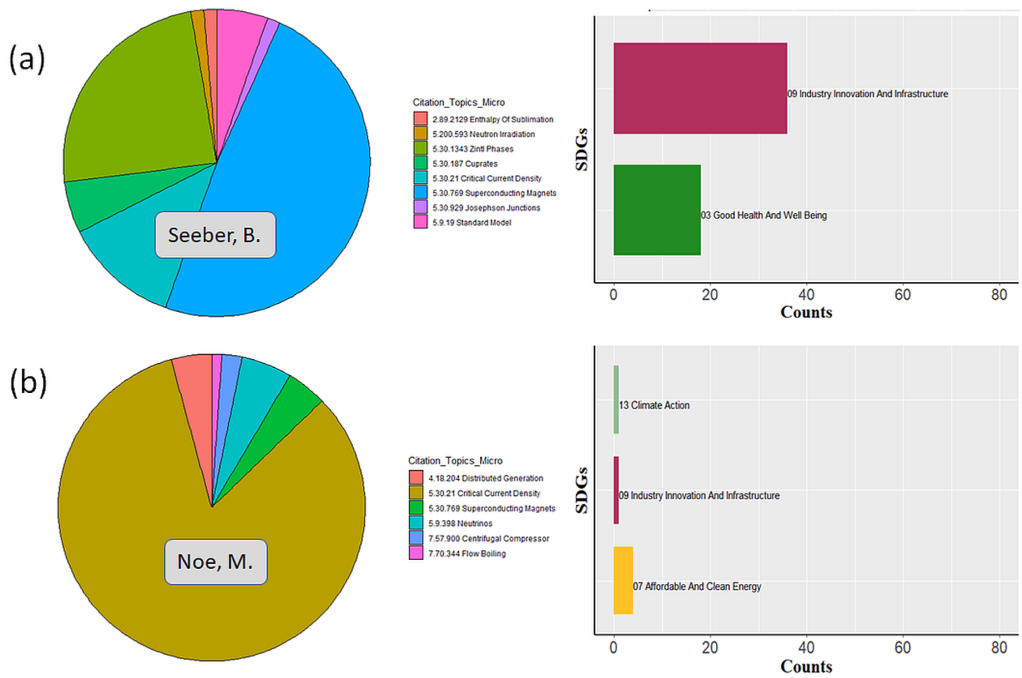

Figure A32. Personal data for selected authors. (**a**) Seeber, B. and (**b**) Noe, M.

For C. Scheuerlein (104 entries to WoS, Figure A31a), the largest section of the microcitation topics is—as expected from a researcher working at CERN—the microcitation topic "Superconducting Magnets" (72 articles, 72 counts for SDG 09), and the second largest is again "Critical current density" (16 articles). Furthermore, we show here the analysis for R. Flükiger (Figure A31b), who worked for the development of superconducting magnets at the university, as well as at CERN, but also on the development of various materials, superconducting and non-superconducting ones. He has in total 438 entries to WoS, with 121 entries qualifying for SDGs, alone 85 ones counting for SDG 09, which concern chiefly the work on Nb_3Sn for superconducting magnets, e.g., at CERN. Also, in his case, the largest microcitation topic is "Critical current density", and the topics "Superconducting Magnets" and "Cuprates" are the next big ones, whereas other topics only play a minor role.
Remarkable is the following paper with the title:
Impact of the Number of dpa on the Superconducting Properties in HiLumi-LHC and FCC Accelerators [68].
The first words of the abstract are as follows:
The aim of this paper is to estimate the change of the superconducting properties T_c, $J(c)$, and B_{c2} in the quadrupoles of the future accelerators HiLumi-LHC and FCC, submitted to irradiation by multiple high-energy sources.
The result of the WoS tagging is as follows:

Research Areas: Physics
Citation Topics: 5 Physics 5.30 Superconductor Science 5.30.769 Superconducting Magnets
Sustainable Development Goals: *09 Industry, Innovation and Infrastructure*

So, this paper, including also C. Scheuerlein, is counted for the topic "Superconducting Magnets"; even the title and the abstract directly suggest the classification "Critical current density". Obviously, writing in the title the formula symbols J_c instead of the full wording helps so that the mentioning of "future accelerators" leads to the final classification. However, more importantly, the work on conventional superconductors including the microcitation topic "Zintl Phases", which includes the Chevrel phase superconductors with

the generic formula $M_x\text{Mo}_6X_8$ (with M describing one of more than 25 different elements that are mono-, di- or trivalent, $x = 1 \ldots 4$ and X denoting usually one of the chalcogenides (S, Se or Te)), counts for the SDGs, as well as the work on IBS, but no other superconducting material systems like Bi- or Tl-based superconductors he had worked on. This can be directly checked with the following paper:
Improvement on $J(c)$ transport of the quaternary $Pb_{0.6}Sn_{0.4}Mo_6S_8$ Chevrel phase wire [69].

Research Areas: Physics
Citation Topics: 5 Physics 5.30 Superconductor Science 5.30.1343 Zintl Phases
Sustainable Development Goals:
03 Good Health and Well-being

Checking several other papers on Chevrel phase superconductors (e.g., Refs. [70–72]) enables the conclusion that the Chevrel superconductors are the second superconducting material besides the IBS, which is recognized for direct tagging with SDG 03. Noteable is here that there are still no real applications of the Chevrel superconductors.

The work of B. Seeber (Figure A30a), the Editor of the book *Applied Superconductivity* [73], shows a large section for "Zintl phases" in the pie diagram, which leads to several entries for SDG 03. Practically, the half of his pie diagram is for "Superconducting Magnets", and so he obtained 35 entries for SDG 09.

M. Noe from KIT Karlsruhe (Figure A30b) is known for the work in *Applied Superconductivity*, but most of the work is counted in the microcitation topic "Critical current density". As a result, there is only limited SDGs tagging for SDG 07, SDG 09 "Superconducting Magnets" and SDG 13.

For all researchers studied up to now, the collected data yield all the same outputs by a dominating sector "Critical current density" in the respective microcitation topics pie diagram. Thus, we can say that all the efforts to develop new and better performing superconducting materials end up with the same microcitation topic, which does not qualify for an SDGs tag. Only in the case that the new or improved materials are directly applied to the design or construction of an apparatus or magnet system, then the SDGs tagging is possible. However, this is only a possibility as, e.g., no paper on bulk, trapped field magnets has received an SDGs tag, even though the title may have carried information like "Development of MgB_2-Based Bulk Supermagnets" [74] or "Flux Pinning Docking Interfaces in Satellites Using Superconducting Foams as Trapped Field Magnets" [75] to mention only two papers of M.R. Koblischka as examples. Both papers are tagged with the microcitation topic "Critical current density". Interestingly enough, the literature research also revealed the existence of an opposite case as exemplified by a paper of R. Semerad [76]: "Large critical currents and current steps in shunted bicrystal Josephson junctions at liquid nitrogen temperatures".

Research Areas: Physics
Citation Topics: 5 Physics 5.302 Instrumentation 5.302.1765 Avogadro Constant
Sustainable Development Goals: *09 Industry, Innovation and Infrastructure.*

This is again quite difficult to be understood as the "Critical currents" are here even the first two words in the title.

Figure A33 shows the counts for the SDGs as function of the publication year for several authors, Koblischka M., Cardwell D.A., Rikel, M. and Prusseit, W. The works with SDGs tag for D. Cardwell were all carried out during his PhD work, and all work conducted on superconductivity did not earn any SDGs tag. A very similar situation is obtained for the two company researchers, M. Rikel and W. Prusseit. In contrast, the work of M.R.

Koblischka recieves SDGs tagging since 2004 when extending the research work at the university towards MFM and magnetic materials.

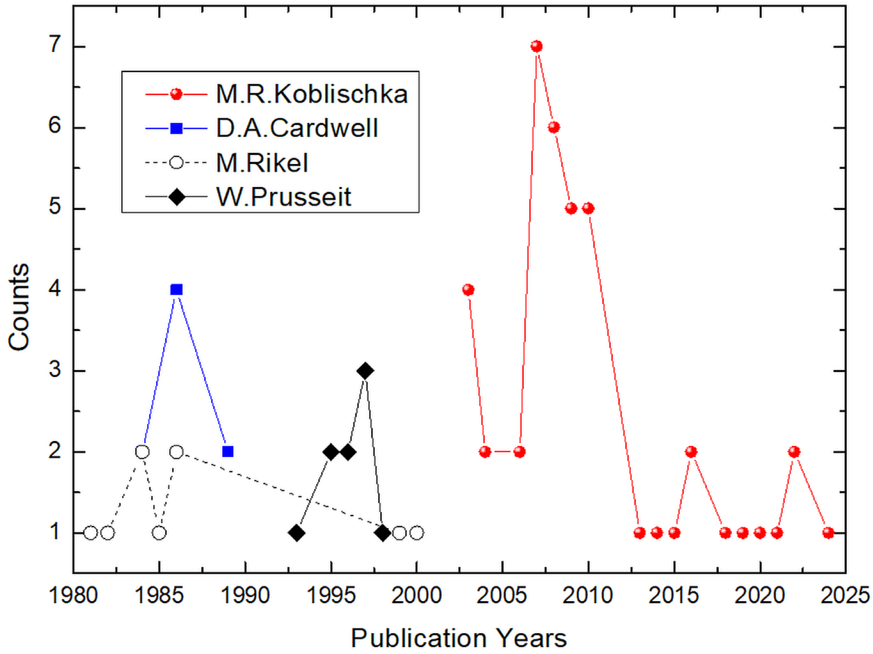

Figure A33. SDGs tagging as function of the publication year for 4 selected authors.

The information collected from Figures A1–A33 fully corroborates the findings seen from the data presented in the main text. It is obvious that researchers working at universities or research institutes have more freedom of their research, covering often not only superconductivity but also topics in magnetism, ferroelectricity and energy and also very specific applications of superconductivity like the zero-G environment by levitation or the growth of bacteriae or algae in such an environment. In contrast, the works by company researchers and the researchers at institutions like, e.g., CERN, are much more limited to the direct goals, and so the works are more narrowly focused, and only some SDGs may be covered.

Practically, the analysis of all the researchers working in the field of superconductivity reveals the same basic feature—the microcitation topic "Critical current density" is by far the largest section governing the pie diagram of the authors' WoS microcitation topics, and so the SDGs tagging results only in a minor amount of papers receiving an SDGs tag. For the company researchers, the microcitation topic "Critical current density" may even be the only entry in their pie diagrams, and so no SDGs tagging results. However, for all authors, the work on the Iron-Based Superconductors does count directly for SDG 03; otherwise, it is mainly the work in neighboring fields like magnetism, ferroelectricity, biologic materials, etc., which does count for the SDGs. Only some of the authors have papers dealing with superconductivity counting for SDGs 09 or 11, which is the case for magnet development or applications of thin films, like Josephson junctions and SQUID sensors.

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