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## From the Rise and Fall of Quantum Radar to Proposed Improvements of Research Assessment

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**Abstract.** It appears that many researchers and scientific journalists wish to ignore the Chinese proverb “If what you say doesn't improve the silence, don't say it”. Hence, it is more and more difficult to distinguish the constructive and reliable results and methodologies of scientific and technological research from a lot of useless, misleading and deceptive content within a vast and growing sea of information. In the publications world, this very critical situation is coped with the predatory eco-system to which most researchers are subjected and with the damaging effects of the widespread misuse of bibliometric indexes.

Our analysis starts from the particular research area of radar theory and techniques, well known to us. Through a generalization process, the exemplary case of Quantum Radar (QR) allows us to study in detail the effects of the aforementioned general situation on the research and development, on the assessment procedures and on the evaluation of results. Our conceptual contribution to research assessment and evaluation is resumed as follows. (a) At least a case of important failure of research assessment is demonstrated “beyond reasonable doubt”. Therefore, one may logically deduce that many other do exist. (b) Publications show an increasing quantity coped with a decreasing quality. (c) The assessment based on bibliometric indexes is a more and more critical process; the same applies to the assessment based on peer review. Hence, effective evaluation strategies are needed.

The main conclusion of our analysis is that the present situation – and its trends – call for new research assessment and evaluation procedures at the international level. In this frame, (im)possible proposals, which include the regulations of scientific publications and a related international agency, are presented.

**Keywords.** Quantum Radar; Public and Private Research; Assessment; Evaluation Team; Hype; Reviews.

### 1. Introduction

Unluckily, the celebrated sentence attributed to Abraham Lincoln (1858) “*You can fool all the people some of the time, and some of the people all the time, but you cannot fool all the people all the time*” does not always apply in our – increasingly busy and complicated – scientific/technological world.

In fact, only a few experts hold a deep knowledge of a specific, difficult field and are able to debunk fake news or hype in that field. If those experts do not spend significant efforts on

debunking, the unfortunate case arises when *all the people is fooled all the time* (or at least, for a long time).

Such a situation applies very well to the difficult, vast, counter-intuitive and sometimes *oversold* field of Quantum Mechanics and of its technologies and applications.

Radar systems are the focus of the scientific interests and of a practical experience for the authors of this paper, due to many years of full-time research at the University and within the Industry. Hence, Quantum Radar is taken here as an exemplary case of “*fooling people for a long time*”, showing a specific example of *unfit research assessment*. Unfortunately, there are signs that many other, economically bigger, representative cases do exist, as recalled hereafter.

Quantum technologies, proposed since about 1990 as a key development drive, include different applications. Some of them have demonstrated a clear and worldwide success, e.g. the measurement (Giovannetti, et al. 2004) of physical quantities such as time, gravitation, electromagnetic fields (Brooksby, et al. 2025) arriving, in metrology (Callegaro, 2023), to the redefinition of the international system (SI) based on quantum experiments.

In other cases, valuable results are still to be assessed, as for Quantum Communications and Quantum Computation. Finally, the failure of Quantum Radar (QR) deserves a careful analysis as, in spite of a noticeable and long-lasting hype, QR did not lead (and, by all means, cannot lead) to any successful result because of underlying physical laws (Daum, 2020a), (Daum, 2021), (Sorelli, 2022).

From the sociological point of view, Quantum Radar can be considered and analyzed in the frame of the “*falsification theory*” due to Karl R. Popper (1902-1994), (Popper, 1959), (Popper, 1962). Of course, the ensuing discussion does not negate the importance of investigating quantum-mechanical systems, models and techniques with studies aimed to produce significant results in some specific areas (first of all, the aforesaid measurement techniques and the metrology).

Summing up, the ultimate scope of this paper is to propose a way to withstand the “*fooling*” and the related human weaknesses in the research assessment context.

To this aim, we exploit the representative example of Quantum Radar on which knowledge and worldwide information are fully available to us. Of course, other Authors might consider in detail other “*quantum-related*” examples such as Quantum Computation or Quantum Cryptography, or, maybe, even the more and more publicized alleged quantum-mechanical aspects of the brain and the consciousness problem. Some of these topics are quickly mentioned in the following.

## 2. Case study: Quantum Radar

### 2.1 Origin and overview of Quantum Radar research

Nature and operation of radar, both *conventional* (i.e. classical) (Skolnik, 2000) and *quantum*, are described in Appendix A and in (Pavan, Galati, 2024), for the interested reader. An early analysis of quantum effects on radar is due to two DARPA (Defense Advanced Research Projects Agency) Scientists (Steinhardt, 2003). Subsequently, the Quantum Illumination concept is found in two 2008 papers, (Lloyd, 2008) and (Tan, et al. 2008), as well as (with a description of a possible *embodiment*) in a (never implemented) USA patent by the Lockheed Martin Corporation (USA Patent, 2008) where Quantum Radar (QR) is proposed as a microwave implementation of the Quantum Illumination concept.

The history of QR research can be divided into four, partly overlapped, periods.

- Proposals (2008-2011). The forerunner is the book “*Quantum Radar*” (Lanzagorta, 2011). In its Introduction we read: “*As such, quantum radar offers the possibility of detecting, identifying and resolving stealth targets ...*” (a stealth target is a target

(aircraft) built with technologies that make it imperceptible, or barely perceptible, to radar or other tracking devices) and “... *the effective visibility of certain targets is increased if observed with a quantum radar*”.

These false claims are discussed in (Galati, et al. 2025) *inter alia*. Seth Lloyd, with his paper (Lloyd, 2008), was one of the early proponents of Quantum Illumination and one of the main actors of *quantum fever*. Lloyd’s biography is available at [https://en.wikipedia.org/wiki/Seth\\_Lloyd](https://en.wikipedia.org/wiki/Seth_Lloyd) (accessed on 09/01/2026); other Lloyd’s publications are the book “Programming the Universe” (Lloyd, 2006) [https://en.wikipedia.org/wiki/Programming\\_the\\_Universe](https://en.wikipedia.org/wiki/Programming_the_Universe) (accessed on 09/01/2026) and (Lloyd, 2012); for further information see also the paragraph 2.2 of Section C of (Supplementary Information, 2025).

- Early papers production and hype (2011-2017). More works by Lanzagorta appear with neither data nor supporting analyses. In most of early papers production started after Lanzagorta’s book and in (Lanzagorta, 2015), experimental data are absent, as well as quantitative evaluations of the basic feature known as *Range* (i.e. the maximum distance at which a Radar can reliably detect a target – see Appendix A and (Skolnik, 2000)). This is a clear case of *publication bias*, i.e. one of the many unfortunate biases affecting research (see for instance <https://www.scribbr.com/category/research-bias/>, accessed on 09/01/2026).
- Mass papers production (2018-2022). A peak in the literature production on Quantum Radar characterizes this period. Papers containing both relevant SWaP (Size, Weight and Power) considerations and quantitative evaluations of the Range, finally appear: (Brandsema, 2018), (Daum, 2020a,b,c; 2021), (Daum et al., 2021), (Sorelli et al., 2022), (Cho, 2020), (Brandsema, 2018), (Brandsema et al., 2020), (Jonsson et al., 2020), (Jonsson, Ankel, 2021) and (Sorelli, 2021). They clarify that implementing a QR for medium-long range targets detection (order of km or ten of km) is an impossible task (for the technical details see Appendix A and (Pavan, Galati, 2024)).
- Disillusionment and endurance (2022-2025). Finally, some QR papers recognize that the laws of physics make it impossible to implement a long-range QR and propose the use of QR technology for new – improbable because of SWaP limitations – applications in the medical and biological area (Luong, et al. 2021; 2020). In the 2023/2024 scientific production, we find again endurance papers like (Karakoç et al., 2024), (Farina et al., 2023), and finally (Yu-Cheng Lin Tsung et al., 2024) where we read, once again, the *fake new* about stealth targets: “*Quantum radar systems ... extend their capabilities ... encompassing the detection and identification of RF stealth platforms*”.

The “*enduring groups*” of some researchers show examples of: (i) continuing publications (and trying to get more research funds) on useless and hopeless topics, and (ii) preventing other groups to publish contrasting results and negative considerations.

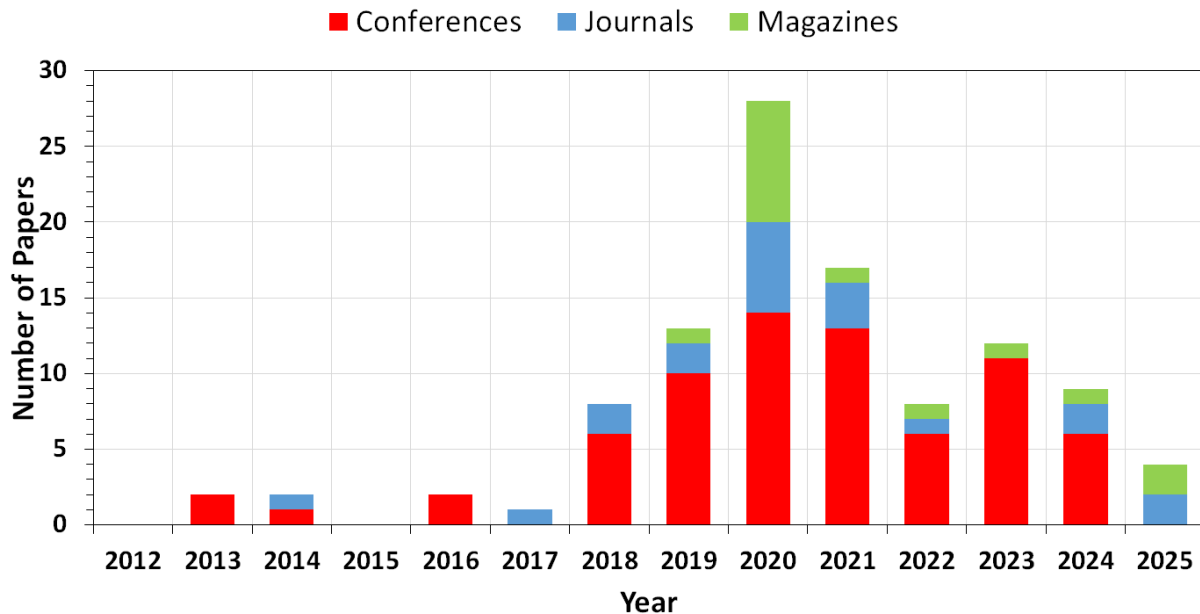
Examples of (i) and (ii) (with their complete documentation) are available in Sections H and K of (Supplementary Information, 2025).

The loss of interest in Quantum Radar after 2024 was not as large as 100%, and even in 2025 a paper (Sangwoo et al., 2025) describes the *astonishing capabilities* of QR. Moreover, in an IEEE lecture (Livreri, 2025), the Abstract of the presentation ends as follows: “*The proposed technology paves the way to the first X-band long-range microwave quantum radar*”.

Summing up, the title of (Cho, 2020): “*The short, strange life of quantum radar*”, tells us, once again, that, while it is generally difficult to *find a solution for a non-trivial problem*, it may be even harder to *find the correct problem for a given, sometimes improbable, solution*.

## 2.2 Literature and Evaluations on Quantum Radar

A search for quantum radar on IEEEXplore (the database of the Institute of Electrical and Electronic Engineers, <https://ieeexplore.ieee.org/Xplore/guesthome.jsp>, (accessed on 09/01/2026) yielded the results shown in **Figure 1**. They amount to 106 papers (in 2012-2025) distributed on Journals (20), Magazines (15) and Conference Proceedings (71). The search was carried on by the presence of the words “Quantum” followed by “Radar” in the title. A manual check allowed us to avoid the inclusion of papers not really related to the QR.



**Figure 1.** Papers on Quantum Radar year by year, from 2012 to 2025, referenced in IEEEXplore (<https://ieeexplore.ieee.org/Xplore/home.jsp>).

The years 2020 and 2021 show the maximum interest concerning QR, as pointed out in **Figure 1**. This interest decreases in 2023 – 2025, as confirmed by the scientific programs of the most relevant International Radar Conferences post-2023. Details on QR literature are in (Pavan, Galati, 2024), (Galati et al., 2025) and Section C of (Supplementary Information, 2025).

A representative sample of *low-value* or *non-research* outputs, within the area of Quantum Radar, is analyzed within the aforementioned 106 QR papers listed in IEEEXplore. Having reviewed all of them, we find that for 90% of those published papers our (simulated) suggestion to an (ideal) Editor are either *Reject* or *Major changes*. Within this limited sample, such a result denotes a large percentage of confused, misleading and/or wrong contributions thus suggesting the potential presence of important assessment failures in the scientific literature.

### 3. Diagnosis of assessment failures

#### 3.1 Foreword

The so-called *second quantum revolution* (Jaeger, 2019), aimed to exploit the possibility of addressing and controlling single quantum entities, is forty years old, as its origin may be date back to the publication of the cryptographic protocol BB84 based on pairs of photons (Bennett, Brassard, 1984). The related hype is well present, for example, in many documents widely using the keywords “*superimposition*” and “*entanglement*”, as well as in the book (Jaeger, 2019).

Some, really surprising, quantum-related *New Age* claims appear in recent literature such as (Faggin, 2024), (Mann, 2017), (Schwartz et al., 2005), (Tegmark, 2000), (Neven et al., 2024), (Adams, Petruccione, 2020), (Fisher, 2015), (Abdyssagin, 2024) and (Swayne, 2025).

It may be interesting to view the second quantum revolution in the historical frame of technical and industrial developments since the (first and second) Industrial Revolution, when the main technical and scientific developments – mostly, “unpromised” – have been conceived and implemented according to a real “problem solver” approach. For example, from the first quantum revolution, they include microelectronics, laser, LCD and LED monitors, rubidium/cesium clocks, GPS and Galileo system and powerful diagnostics tools (NMR, PET and more).

On the other side, some of the recent research and development efforts in the quantum-related technical developments appear to belong to the reverted paradigm of “*a solution calling for a problem*”. Note that this – often, misused – paradigm is not always damaging. Valuable scientific and technical knowledge may arise in the absence of a precisely posed problem and/or of a clear need. Sometimes these developments rise thanks to a political or social push: a well-known historical example is the Apollo program (due to a strong political decision by John F. Kennedy) which landed the first humans on the moon in 1969 and produced important technical results.

The aforementioned, deeply analyzed, Quantum Radar is a “*solution calling for a problem*” (see also Supplementary Information, 2025)). Its noticeable hype mainly originated from the fear of the aforementioned *fake news* concerning detection and location of *stealth targets* by an opponent such as China.

#### 3.2 Literature and Evaluations on Quantum Computer

An interesting example of “*solution calling for a problem*” is the Quantum Computer (QC) as discussed in (Accardi, 2010), (Accardi, 2023), (Dyakonov, 2019), (Dyakonov, 2020) and <https://www.linkedin.com/pulse/quantum-computing-one-dumbest-ideas-last-40-years-alan-shields-kbave> (accessed on 27/01/2026), which concludes as follows: “*Quantum computing isn't the future of computation. It's a fascinating dead end that survives on prestige and hope. And the sooner people see that clearly, the sooner we can stop pouring resources ...*”.

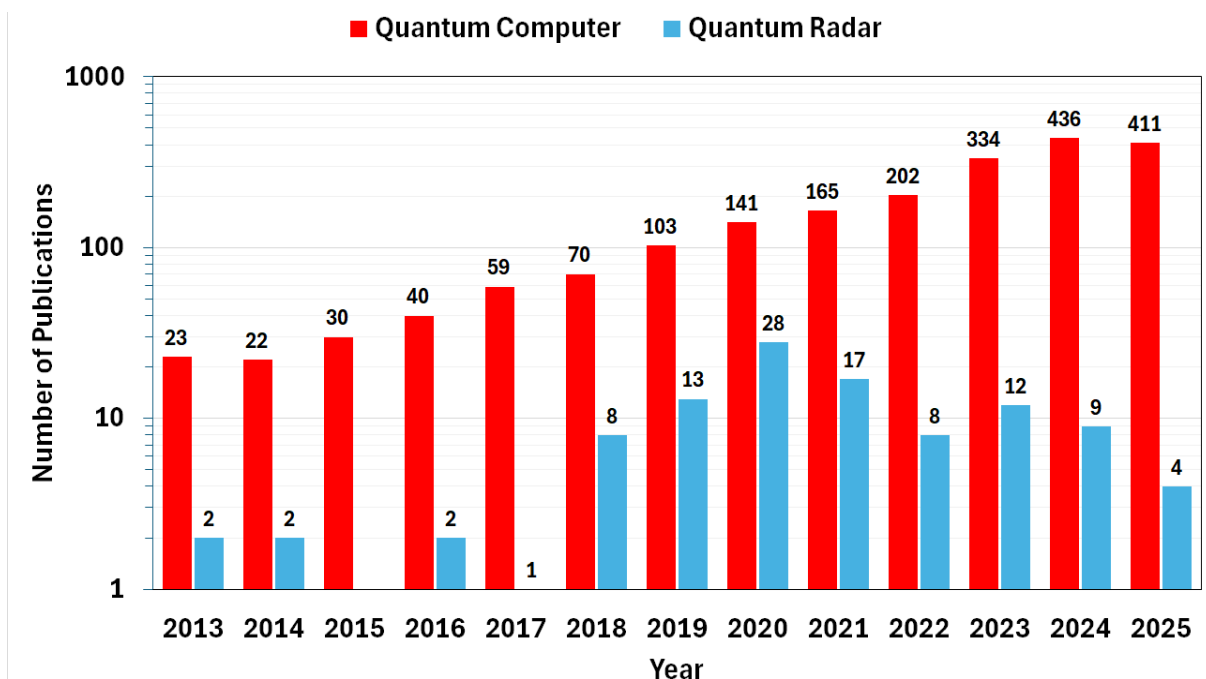
The feature of QC as “*solution calling for a problem*” is clearly (and indirectly) confirmed by one of the main private QC financers, that is, Google. The Google-GESDA-XPRIIZE (<https://www.xprize.org/prizes/qc-apps>, accessed on 09/01/2026) is a five million dollars global competition for defining quantum computer applications to solve real world problems: difficult not to see in it the paradigm of a *solution calling for a problem*.

From the operational point of view, Quantum Computer is allegedly forty years old (Editorial, 2022), (Benioff, 1980), (Feynman, 1982) and still not a single, general, usable set is on sale. In fact, after the theoretically unwarranted fanfare about the quantum algorithm for Shor's factorization in 1994 and after some attempts with optimization methods, no much more algorithms with similar potential were found, see also, in (Supplementary Information, 2025),

Sections F and F1. (Interestingly, Section F1 shows a reply by a QC proposer accepting the critics about QC research and development).

A large contribution to the QC hype is due to the alleged threat to the cryptographic - protected information, in particular, to the RSA (Rivest-Shamir-Adleman) algorithm based on factoring large numbers into their prime components. In 1994 the Shor’s algorithm ([https://en.wikipedia.org/wiki/Shor%27s\\_algorithm](https://en.wikipedia.org/wiki/Shor%27s_algorithm)) was published, and attempts followed to exploit Quantum Computers in this frame. The attempts supplied the following results: (i) in 2003, 15 was factorized into 3 and 5; (ii) in 2011, 21 was factorized (with some external hint) into 3 and 7; (iii) after 2011, no more progress was noticed on running Shor’s algorithm with QC.

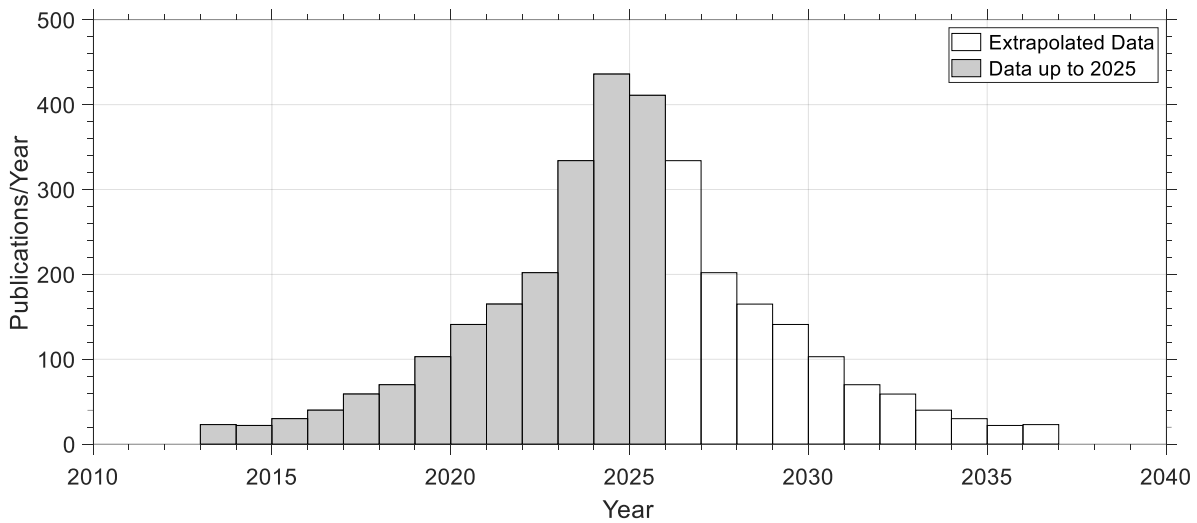
**Figure 2a** shows (in red) the QC publications (2013 – 2025) whose titles contain the words “quantum computer(s)” OR “quantum computing” OR “quantum computation” as referenced in IEEEXplore.



**Figure 2a.** Red: publications whose titles contain the words “quantum computer(s)” OR “quantum computing” OR “quantum computation” referenced in IEEEXplore. Blue: quantum radar publications.

A peak in 2024 is followed by a decreasing trend in 2025. For comparison, the quantum radar publications are shown in blue. It appears that QC publications are thirty times more numerous than QR and their peak is about four years later than QR.

The QC publications have been extrapolated for pictorial purposes and the result is depicted in **Figure 2b**.



**Figure 2b.** Extrapolation of QC publications.

### 3.3 Advertising and investments in quantum technologies

A wide list of quantum-related Companies is available in:

[https://en.wikipedia.org/wiki/List\\_of\\_companies\\_involved\\_in\\_quantum\\_computing\\_or\\_communication](https://en.wikipedia.org/wiki/List_of_companies_involved_in_quantum_computing_or_communication) (accessed on 09/01/2026).

Despite some decay in the funding and the number of patents and of spin-offs, *quantum fever* and *quantum hype* continue to be well alive. The quantum-related investments arrived at significant values on both sides of the Atlantic. In Europe, the Quantum Flagship initiative is funded for 1 B€ (one billion Euro) in the period 2018 – 2028.

In (Soller et al., 2025) we find an exemplary case of hype: “... for each of the three pillars of QT, we found that by 2035, quantum computing could be worth \$28 billion to \$72 billion, quantum communication could be worth \$11 billion to \$15 billion, and quantum sensing could be worth \$7 billion to \$10 billion—for a total of as much as \$97 billion. This growth shows no signs of slowing. We predict that by 2040, the total QT market could reach \$198 billion”.

**Table 1** resumes some private investment by region (\$ million).

	Americas	EMEA	APAC	Total
<b>2022</b>	1369	762	260	2391
<b>2023</b>	240	781	217	1238

**Table 1.** Total private investment in quantum technologies by region (\$ million). EMEA: Europe, Middle East, and Africa; APAC: Asia-Pacific. Source: The Quantum Insider, updated at the end of December 2023, (Galda, 2024).

A comprehensive analysis of the year-by-year number of new QC spin-offs is shown in **Figure 3**.

In the USA it is noticeable the competitive effort by Google, Microsoft, IBM (the year-by-year number of patents granted to three top companies on Quantum Computer is shown in

Figure 4) accompanied by a large and ubiquitous effort for their worldwide advertising of some results (showing the operation of a kind of *Academia of Hype*).

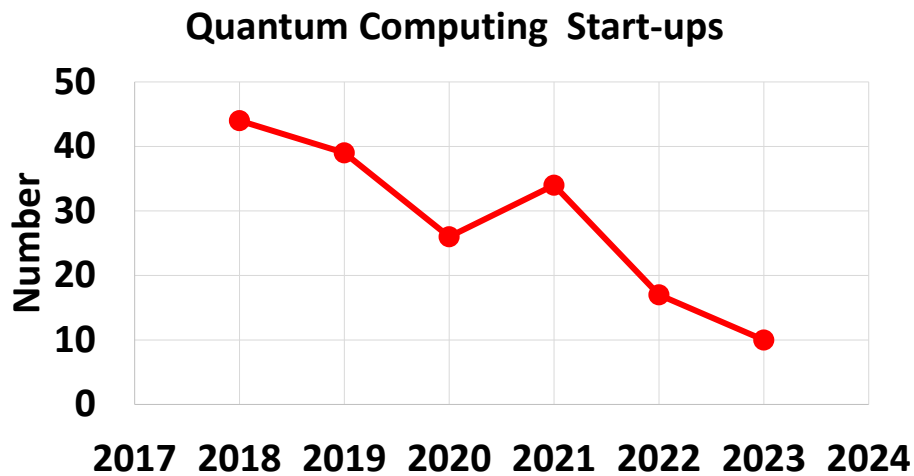


Figure 3. The year-by-year number of new QC spin-offs (Data sources: Capital IQ; Crunchbase; PitchBook; Quantum Computing Report; McKinsey analysis).

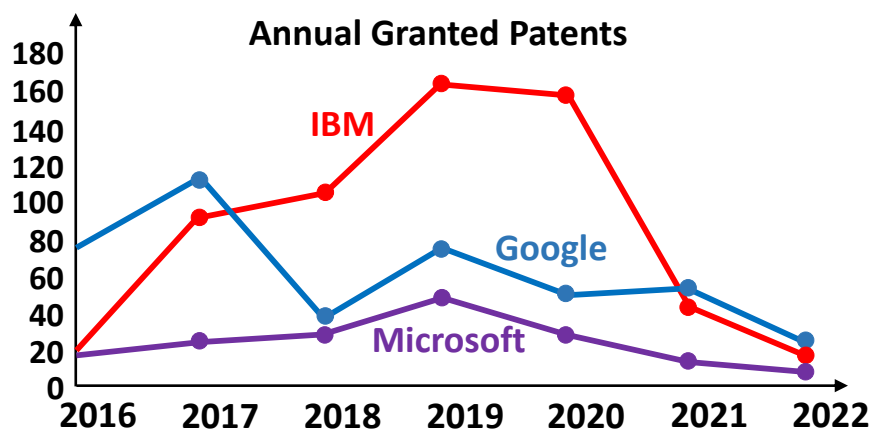


Figure 4. The year-by-year number of patents on Quantum Computer granted to three top companies (IBM, Google and Microsoft). (Data source: Capital IQ; Crunchbase; PitchBook; Quantum Computing Report; McKinsey).

According to (Ezratty, 2024) the investments on quantum technologies, evaluated on a five-year basis, are geographically divided as shown in **Table 2** (in billion Dollars, B\$). Overall, from **Table 2** the global expense is of the order of over five billion Euro (B€) per year.

	Private (B\$)	Public (B\$)	Total (B\$)
USA	4.6	6.4	11.0
EU including members States	6.6	2.0	8.6
China	2.3	1.0	3.3
Canada	0.8	1.3	2.1
United Kingdom	1.0	0.6	1.6

Table 2. Five-years investments (B\$) in quantum technologies. From (Ezratty, 2024).

Clearly, the suggestions to invest (which show more and more in the Internet, including some professional social networks such as LinkedIn) call for some care. According to (Dargan, 2024) not one of the quantum computing companies or start-ups earns revenue from selling their products unless we count D-Wave Systems' quantum annealers drip in sales since about 2011. The main critical elements of QC programs and proposals are resumed in (Supplementary Information, 2025).

In (Ezratty, 2022) some interesting proposals are described to mitigate the potentially damaging effects of the current quantum hype. In (Coenen et al., 2022), it is proposed to make quantum technologies understandable by the public with key criteria: it should be *comprehensible, specific and practical, open, accessible, responsible, culturally embedded and meaningful*.

Summing up, the evident today's *quantum fever and hype* deserve a critical reflection, but it is clear that predatory commercial forces and hype only drive a part of the worldwide quantum-mechanical research, with little effect on the *truth-searching* researchers honestly working in quantum-related fields. However, important problems remain.

#### **4. Research assessment problems**

##### **4.1 Ethics of research**

Ethical problems arise when advertising some (real or alleged) research results.

An excerpt from (Feynman, 1982) deserves valuable reflections even today.

*"For example, I was a little surprised when I was talking to a friend who was going to go on the radio. He does work on cosmology and astronomy, and he wondered how he would explain what the applications of this work were. "Well," I said, "there aren't any." He said, "Yes, but then we won't get support for more research of this kind." I think that is somewhat dishonest. If you are representing yourself as a scientist, then you should explain to the layman what you're doing – and if they don't want to support you under those circumstances, then that's their decision. One example of the principle is this: If you have made up your mind to test a theory, or you want to explain some idea, you should always decide to publish it whichever way it comes out. If we only publish results of a certain kind, we can make the argument look good. We must publish both kinds of result"*.

A general teaching is the urgent need to restore what Feynman (Feynman, 1974) calls the *culture of doubt* necessary for science to operate a self-correcting, truth-seeking process.

Dedicated considerations and proposals follow.

##### **4.2 Avoiding further accidents after the QR one**

Within the today's *quantitative* increase of technical and scientific information, it is more and more difficult to separate meaningful and promising results of research from "*wrong way*" documents. This old problem was treated, among others, in (Haven, Van Woudenberg, 2021) and in (Margolis, 1967) where we read "*Publication of results ... puts a premium on quantity at the expense of quality...: the more papers are written, the less they count for and the greater is the pressure to publish more... the sheer volume of the "literature" makes it increasingly difficult to separate what is worthwhile from the rest. Critical reviews have become somewhat of a rarity, and editorial judgment is usually relegated to referees, who are contemporaries and, perhaps, competitors of the authors—a situation which has its own undesirable implications. It requires little imagination to discover other vicious circles...*".

A recent, increasing threat is the one of Generative Artificial Intelligence, shortly treated in Section 7.

From the social point of view, discovering and cutting away the *dry branches* in research and development is more and more urgent, especially in situations of limited or reduced resources and of an increasing level of widespread hype.

Experience from the “*Quantum Radar saga*” shows that “*wrong way*” plans may be promoted by research groups *closed in a bubble* (Grimstrup, 2025) and keeping outside (in practice, ignoring) any realistic and documented criticism, or even fighting it with all the available means, including the review process for submitted papers. Sections H and K of (Supplementary Information, 2025) show, *inter alia*, the blameworthy use of these *means*.

As explained in the Introduction, we exploited our internationally recognized radar expertise in order to analyze in detail the Quantum Radar research. This “*financially small*” case undoubtedly showed an insufficient, not to say, absent, evaluation within the critical arena of research publication and funding. Such a single “*failure*” in given area (as evidenced in the Quantum Radar saga (Galati et al., 2025), (Pavan, Galati, 2024), (Supplementary Information, 2025)) induces to reconsider the whole evaluation process.

From one “*side of the coin*” the generous activity by reviewers, editors, and existing evaluation panels for research products (papers, reports) and programs deserves a maximum respect and has produced significant benefits to the research system. From the other side, it is a fact that our specific background allowed us to notice the presence of a significant number of scientifically wrong and/or misleading publications about Quantum Radar even in well-known Reviews, Journals, and Magazines. Following Karl Popper, the claim: “*Editors and Reviewers always prevent the publication of false, fabricated and biased matter*” is “*falsified*” with no blame at all to Editors and Reviewers worldwide.

Summing up, we are convinced that the well-documented case of QR has clearly shown the need to improve the whole research assessment and evaluation, not to mention older, better-known examples as the one of the *Sokal hoax*, (Sokal, Bricmont, 1998).

Therefore, the intrinsic limitations of this paper shall not prevent us to discuss and draw some general conclusions. For instance, it is a fact that since decades the managers of the programs of Quantum Computer and of Controlled Nuclear Fusion (to name two popular ones) continuously shift ahead, year by year or by five (or ten) years, the time horizon to arrive at practical and/or significant and/or valuable results.

Generalizing, we do believe that researchers and proposers of (real or prospective) unsuccessful (or “*never concluding*”) activities sometimes misuse the widely accepted paradigm of “*freedom of research*”, (Torsten, 2010), (Santosuosso et al., 2007).

Hence, avoidance of such a misusement when applied to “*non-research*” should be seriously considered, at the expense of some *freedom of research*, in order to improve the unsatisfactory situation about research evaluation and funding.

A comparison with the Air Traffic may clarify this concept.

During the years between World Wars the technical improvements of aircraft and the increase of their traffic made it impossible to maintain the previous system in that the collision avoidance was responsibility of pilots only and based on the “*see and be seen*” rule. The need arose for common regulations, new airways systems, modern control centres and so on. The full freedom for each flight ended and some, first national, then international coordination of regulations, procedures and systems was necessary to avoid incidents and accidents, giving birth to the ICAO (International Civil Aviation Organization) as explained in the ensuing Section.

#### 4.3 The need for discriminating research from “non-research”

The “*mission impossible*” of separating – in a publicly recognized way – *research* from *non-research* seems necessary for the health of the scientific research itself and for a correct use of the money from the taxpayer and/or from the investor. Some definitions of *research* and of *non-research* are in (Charlton, 2012). As a basic criterion, following Karl Popper, research results shall be “*falsifiable*”. For example, the more and often found claim (see for instance (Moreira-Almeida, et al., 2022)) that “*consciousness is not an epiphenomenon of the brain activity and continues after death*” is not falsifiable (and not demonstrable) for the obvious lack of witness by dead people. Hence, it is non-scientific.

Second, research shall not be based on grounds that have been demonstrated to be false (e.g. the possibility of building a long-range quantum radar (Pavan, Galati, 2024), (Galati, Pavan, 2024)), nor on personal thoughts and feelings, such as in the books by Federico Faggin (Faggin, 2024).

A vast literature exists on the evaluation of research, including (Gingras, 2016) which contains motivated critics to the widely used bibliometric indexes (H-Index, G-Index, i10-Index, ...), see also (Poder, 2022). More books on this debated topic are (Pagell, 2014) and (Roemer, 2015). The book (Gingras, 2016), in addition to proposing criteria for valuable bibliometric indicators, considers problems such as the misuse and misinterpretation of the impact factor as well as bibliometric manipulations (*ranking boosting, dummy affiliations, and intellectual fraud*).

Concerning the search for potential improvements, let us consider some examples from the afore mentioned Air Traffic, being *criticality* a common feature of Scientific/Technological Research and Air Traffic. The latter is *safety critical* and calls for the Air Traffic Management (ATM) system in order to avoid incidents and accidents, while the former is a critical item of the *cultural, economic and social development*.

The Air Traffic Control and Management needs strict regulations to guarantee, according to the definition by the International Civil Aviation Organization (ICAO – OACI – ИКАО) “*a safe and expedite traffic of aircraft*” where, not by chance, the term “*safe*” is the leading one. Air traffic safety is guaranteed by the worldwide respect of the International Standards and Recommended Practices (SARPs) contained in the ICAO’s Technical Annexes to the Convention on International Civil Aviation (originally, the *Chicago Convention*, 1944).

The related legal frame is conceptually simple. The assembly of ICAO, with its 193 Member States, sets and adjourns the SARPs based on the work of ICAO’s working groups. The SARPs become valid within each member States which enforces them by suited national laws.

The ICAO Annex 13, *Aircraft Accident and Incident Investigation* (see also: <https://unitingaviation.com/news/safety/accident-investigation-provisions-of-icao-annex-13/>, accessed on 09/01/2026) clearly states its aim: “*The sole objective of the investigation of an accident or incident shall be the **prevention of accidents and incidents**. It is not the purpose of this activity to apportion blame or liability*”.

As the Research System is a critical one (although for different reasons than ATM), we may state that a prevention of its “*incidents and accidents*” is definitely and urgently needed, while respecting the universal principles of “*freedom of research*” and “*freedom of expression*”.

The related starting point is, of course, from scientific publications.

#### 4.4 Reviews, publications and bibliometric indexes

The bibliometric indexes are widely used for competing evaluations and for career advancements. The source data for bibliometric indexes come from the approval of manuscripts for publication. Unfortunately, paper's reviews do not help to manage the overwhelming quantity of scientific and technical information (sometimes even in the academic channels) generated to attract investments.

Hence, review procedures and their implementation deserve a close attention as a key element for the evaluation of researchers, of research plans and of results.

Most Journals, Proceedings, Transactions, ... (for short, *Journals* in the following) use "peer review" to accept/correct/reject the submitted manuscripts. The peer review is often preceded (in a few cases, substituted) by an *Editor review* aiming to check whether the manuscript is worth of peer review or, instead, it does not fit the Journal.

Different Journals use various types of peer review: double blind (Authors and Reviewers remain anonymous), blind Reviewers and known Authors, open Reviewers who publish and sign their reviews, and so on.

Examples are found in <https://libraryguides.mcgill.ca/journalpublishing/typesofreview> (accessed on 09/01/2026) where the different types (with advantages and drawbacks) are listed in a table.

The Reviews situation may change with time: from February 2020 the Original Research Articles of Nature, <https://www.nature.com/nature/for-authors/editorial-criteria-and-processes> (accessed on 09/01/2026) adopts a *transparent peer review system*, showing, for a published paper, the Reviewer's comments to the Authors and the Authors' rebuttals.

Reviewers are voluntary, i.e. they only receive formal appreciations for their time and effort. Moreover, these qualified experts in a given scientific area are generally very busy (and sometimes are asked to suggest an alternative reviewer). The drawback, of course, is that a voluntary activity, (often *unsupervised* or *poorly supervised* for workload reasons) does not guarantee "per se" an appropriate level of quality, as noticed long time ago (Margolis, 1967).

For example, the publication experience by the authors of this paper shows a wide range for the quality of reviews. They go from very detailed and constructive reviews to *quick and dirty* ones clearly showing that the manuscript was barely read, see also Section L of (supplementary Information, 2025).

According to (Charlton, 2007; 2012), the truly definitive scientific evaluation is not by peer review but, rather, by "peer usage", meaning that facts and theories are tested not by opinion but in actual practice. That is, new scientific findings should be *retrospectively validated by their use* in further relevant research by competent *peers*.

The bibliometric indexes (prone to fraud and misuse) have a significant, increasing effect on the academic system, being more and more used for enrolling new researchers and for the advancements of careers. Warning symptoms include the damaging effects named *overproduction* and *over signatures*. The former is the *multiplication of papers* by splitting a single, significant content into two or more papers. The latter is the *multiplication of signatures*, i.e. ad addition of one or (often) more signatures to a document that is clearly the product of a single person (or of a few persons).

According to the USA National Science Foundation, <https://nces.nsf.gov/> (accessed on 09/01/2026), the number of papers worldwide (including reviews, conference proceedings, and short surveys) in the areas of Science and Engineering (S&E) reaches 5.14 million (about 1400 daily!) in 2023 with an exponential growth of about 5.6% per year. These figures shall be compared with the overall production of academic papers (not only S&E) arriving to the amount of 90 to 100 million per year.

The scientific community seems to accept the multiplications of papers and of signatures, despite exemplary cases such as that of a professor at the Universidad de Cordoba (here anonymized, Ph.D. in 2005) showing in *Google Scholar* a list of 1263 publications and declaring to have published 58 papers from January 2023 to April 2023, i.e. 3.6 papers per week. For comparison, the much older Anton Zeilinger, Nobel Prize for Physics in 2022, has 643 publications overall.

Summing up, in spite of the generous effort by Reviewers and Editors, the present peer review system and the subsequent system of bibliometric indexes present significant and increasing problems (Ross-Hellauer, et al. 2025), (Kalim Akhtar, 2024). Peer review does not always block the publication of wrong, deceptive or fabricated results (Sokal, Bricmont, 1998) and has been criticized (Peh, 2022) as “*slow, expensive, easily abused, prone to bias, unable to detect fraud*”. Possible improvements are proposed in the following.

## 5. (Impossible) policy proposals - Establishing evaluation teams and an Agency

### 5.1 Research evaluation teams – Scientific and technical advisory References

Research assessments require the analysis of technical and scientific papers, whose publication depends on Referees and on Editors. As explained before, the papers’ evaluation has caused an exceeding number of published papers, sometimes of low, or very low, quality. Hence, a new approach is required, not to endanger but, rather to increase the value of the technical/scientific research. It shall be based on the *quality control of every scientific/technical document* (book, paper...) by a *permanent committee of experts* (called STARS - Scientific and Technical Advisory Reviewers in the following) based in each Nation participating to the Organization described in Section 5.3.

The STARS shall be made up by *independent, competent, blackmail-free, full-time* experts, covering the active and all potential research areas and operating like a jury. These scholars and researchers, dedicating their full-time to assessments for, say, five years, shall be civil servants for the whole duration of their charge, with a status similar to the one of a *juror* or *lay judge* (called *juré d’assises* in France and *juez leguano* in Spain).

The national body responsible for University and Research, e.g. the Department of Research and Education, will nominate them. Of course, getting them in a sufficient number remains an open question – similar to the one to find enough young persons for the military service. It should be relatively easy in a monocratic State, as in China or in Russia, but more difficult in contexts such as the European one. The preferred enrolment shall be just after the retirement date.

The operation and procedures of the STARS worldwide need to be harmonized and regulated by an ad-hoc International Research Evaluation Organization (IREO), proposed and shortly described in Section 5.3.

The STARS’ assessments, including both “*predictive*” and “*retrospective*” aspects, evolve with time, along with the development of each research under exam. The pertaining time span should follow the whole duration of the well-known Gartner hype cycle as drawn in **Figure 5** (see also [https://en.wikipedia.org/wiki/Gartner\\_hype\\_cycle](https://en.wikipedia.org/wiki/Gartner_hype_cycle), accessed on 09/01/2026).

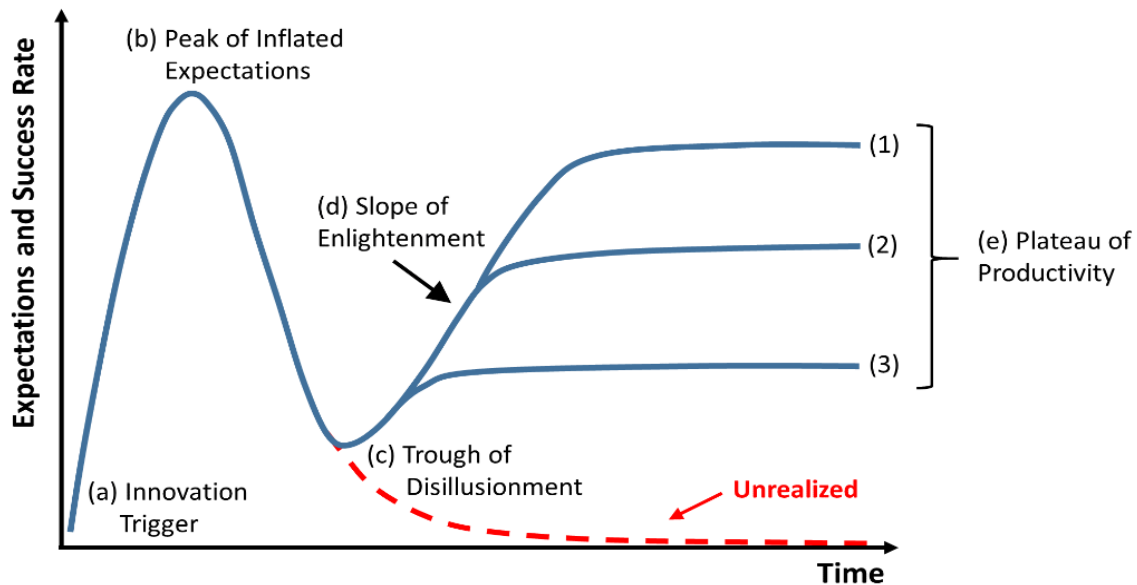
Considering the time scale in **Figure 5**, it is worth noticing that the recognition of a failure of a very big project (such as the multi-billion Controlled Nuclear Fusion, for example) is politically hard and tends to be delayed as much as possible.

In other cases, the recognition can be quicker, as is the case of the Quantum Radar project, whose cost is of the order of “*only*” one million € (please compare **Figure 5** with **Figure 1**).

The STARS committee, following the general IREO’s regulations (Sections 5.2 and 5.3), evaluates each document according – in one or more meeting(s) – to criteria such as, for

example: (i) originality/novelty, (ii) clarity and completeness, (iii) verifiability of results, (iv) scientific/technical value, (v) relevance and interest for the scientific and users' community.

A score accompanies each criterion: (1) unacceptable, (2) barely acceptable, (3) good, (4) very good, (5) excellent.



**Figure 5.** Hype Gartner model for (1) very successful, (2) average, (3) slightly successful realizations (continuous line) and unrealized, such as the exemplary Quantum Radar – (red dashed line).

The STARs approve the work when: (a) all scores are above one, and (b) the sum of scores is equal or greater than a threshold, e.g. Thirteen.

Scores and pertaining motivations are published online and appear on the cover of all published documents.

These national regulations are not intended at all to forbid the publication of any paper either approved or not approved by a STAR (Section 5.2). They only intend to correctly inform the user (the reader).

The research projects and the research advancement reports undergo a similar scoring process to be repeated every year, following the research advancements.

## 5.2 Bibliometric regulations

A theoretically simple solution to the problem of overproduction of the paper's signatures is twofold: (i) to weight the signatures and (ii) to limit the number of signatures per unit time. Exemplary numerical values follow.

Item (i) consist in asking each author of a technical/scientific document (article, paper, report, ...) to add, to his/her signature, the own percentage contribution, as agreed within the author's team for that paper. Each contribution shall show as an integer figure from 1% to 99% (100% applies, of course, to the trivial case of a single author). Contributions less than 1%, if any will appear only in a final "thanks" section. Hopefully, the present situation showing, in some cases, a number of signatures of the order of hundred, shall disappear.

Item (ii) consists in limiting an author's contribution to all bibliometric indexes to an upper "physically possible" limit. This voluntary limit could be set to his/her best ten papers per year (in terms of number of weighted signatures: ten for a single author paper, twenty for two-

authors, fifty for a 20% contribution paper and so on) with an upper limit of one hundred papers per year in every case.

In practice, “*Author side*” regulations, today “*impossible*” for the lack of a proper Authority (the equivalent of ICAO for Research and Technology is proposed in the ensuing Section), should be complemented by the companion “*Editor-side*” ones.

Suited laws from the legislature by the Nation of the author and the editor, respectively, will enforce both types of regulation.

Of course, these regulations shall not limit the freedom of Authors and of Editors and Publishers; simply, publications not complaining with them will clearly, show a *non-complain mark* both online and on the main cover, to make aware readers (and users).

The related recommendations and the “*modi of operandi*” can only be developed and adjoined by an ad-hoc international body: like air traffic, scientific research is international in nature.

### 5.3 The IREO– an International Organization aimed to research evaluation

Reforming research assessment is a priority to ensure quality, performance and impact of research. Reforms, however, requires cultural and systemic changes, which prove to be very complex and slow to implement.

The last decades have seen attempts to establish international bodies for research assessment. One of them is CoARA – Coalition for Advancing Research Assessment, <https://coara.eu/> (accessed on 07/01/2026) which is aimed at shifting research evaluation from purely *quantitative* metrics (like Impact Factors) to *qualitative*, researcher-centric assessments.

Its key strategic points include: (a) Quality over Quantity: a move toward evaluating research based on its own merits rather than the metrics of the venue where it is published. (b) Broadening the “*Outputs*”: recognition of data, software, patents, and other research outputs, not just journal publications. (c) Responsible Metric Usage: a commitment to using quantitative indicators as support, not as the primary driver of evaluation.

CoARA has made some progress since its launch in December 2022, and as of late 2024, more than 700 research organizations, funders, and academic associations worldwide have joined it as members or signed the Agreement on Reforming Research Assessment (RRA).

RRA is generally referring to *the ethical and equitable evaluation of research outputs, and involves assessing the quality, impact, and significance of research in a fair and transparent manner, while also considering the societal implications and ethical considerations. RRA shall be more inclusive, less focused on publication-based metrics, rewarding more-qualitative factors and open science, including data sharing and collaboration, recognizing and valuing contributions from diverse perspectives, disciplines, and methodologies.*

Overall, our feeling is that RRA remains a weakly defined concept: *bright formulation, undefined implementation.*

Another relevant initiative is the *Declaration on Research Assessment (DORA)* that recognizes the need to improve the assessment of scholarly research beyond the bibliometric indexes, (<https://sfdora.org/> accessed on 09/01/2026), see (Thelwall et al. 2022) and (Orduna-Malea, Bautista-Pui 2023). In March-November 2021, the European Commission consulted European stakeholders on how to facilitate and speed up changes, see (European Union Commission, 2021).

Apart from praiseworthy declarations and mostly formal agreements, the research assessment/evaluation system is not really changing. Among the resistance factors to any real change, one can include (perhaps, maliciously) the aforementioned (Section 4.2) concept of *non-research* and *research groups closed in a bubble* where, in this case, a bubble is that of

bibliometrics. For instance, in (Abramo, 2024) the President of the International Society for Scientometrics and Informetrics (ISSI) declares the supremacy of *quantitative* over *qualitative* methods in research assessment concerning robustness, accuracy, validity, functionality, time and cost convenience in the areas of Mathematics, Physics, Chemistry, Earth Sciences, Biology, Medicine, Agricultural Sciences, and Engineering. Difficult not to see a “*scientific group bias*” in those declarations.

Summing up, we believe that voluntary agreements and coalitions do not suffice to solve the aforementioned problems concerning publishing and research evaluation. These problems are exacerbated by the digital revolution, the explosion of open-access publishing, and the competitiveness in securing research funding and career advancement.

Hence, a crucial question remains about establishing and approving the international regulations for their uniform and transparent use by the STARs. A subsequent *dream* is an Agency of the United Nations, similar to the aforementioned ICAO: the *International Research Evaluation Organization (IREO) - a United Nations (UN) Agency*.

Like ICAO, the main *product* by IREO is a series of *recommended practices and standards* for the assessment and evaluation of research and of research products, including – of course – scientific and technical papers. These *Evaluation Practices and Standards*, or EPaS, have to be produced by IREO’s working groups and approved by periodic meetings of the General Assembly. Following that, Member States are expected to include them in their own legislation.

## 6. Discussion

The present criteria of research quality or impact, based on bibliometric indicators, have been criticized in different instances, see for instance (Qutaiba, 2025), (Neale et al. 2010) and (Curry et al. 2010). A detailed critics of the widely used Journal Impact Factor (JIF) is found in (Abambres et al. 2018) where we read: “*Deans, sponsors, government agencies and employment panels use the JIF as a convenient, yet flawed, performance measure*” with several examples of countries and institutions supporting these types of (*mis*)evaluation.

The present way of research funding is also critical. In (Philipps, 2022) and (Kjær et al., 2023) it is suggested that it could be improved by adding a suited degree of random choices (a kind of “*lottery*”) to the imperfect judgements and suggestions by experts. The limits of the Performance-Based Research Evaluation are evidenced in (Duncan, 2020).

Shortly said, the criteria based on bibliometric indicators show three types of drawback: (i) reduction of the *diversity of research purposes*, leading researchers and institutions to focus on lower-risk, easy-to-publish *incremental work*, (ii) *biases* against those who do not prioritise the standardized criteria and indicators of quality or impact, and - last not least - (iii) *distortion of incentives* (because of the celebrated *Goodhart's law*: “*When a measure becomes a target, it ceases to be a good measure*”) damaging research integrity and reproducibility.

Overall, the misuse of these criteria is impairing the diversity, the creativeness and the legitimacy of the research community.

In the frame of the above proposals, one has to consider that the present situation will likely exacerbate the problems described in the significant book (Charlton, 2012) <https://scispace.com/authors/bruce-g-charlton-360e0gt7rc> (accessed on 09/01/2026), which contains the aforementioned concepts of “*predictive and fast*” peer review and “*retrospective and slow*” peer usage.

Some quotes from this book include the following: “*It is entirely normal and unremarkable for ordinary scientists to spend their entire professional life doing work they know in their hearts to be trivial or bogus*”, and “*The consequences? Research literature must be assumed to be worthless or misleading and should almost always be ignored*”.

No one will negate that freedom shall be granted to every Author to submit a work to Journals, Reviews, Conference Proceedings or similar, as well as to any Editor (or Conference Chair) to accept (or reject) it. However, it seems reasonable to state that any user, before accessing or buying a publication, should choose (use or discard) it in an informed way; hence, each publication shall clearly show the compliance and the STARS' score with the pertaining motivation.

Finally, it appears that the present situation cannot stand anymore: a “hard” regulation by law of the assessment of manuscripts submitted for publication can prevent the well-known distortions while fully respecting the freedom of expression and of research.

Such a situation seems preferable to any uncertain attempt of voluntary international coordination.

## 7. Conclusions and perspectives

The abundance of data in the present Internet era makes researchers, analysts and decision-makers more and more prone to fake news, hype and lobbying actions. The increasing flood of publications as well as some very “resources intensive” programs such as the aforementioned “never concluding” Controlled Nuclear Fusion and Quantum Computer (but more “unfair” research programs could be mentioned, such as in (Grimstrup, 2025)) “desperately” call for a critical, deep and timely analysis by independent “honest” experts, accompanied by new procedures and regulations for scientific publications.

Summing up, the present situation advantages quantity over quality: the more papers appear, the greater is the pressure to publish more. The huge volume of scientific literature makes it more and more difficult to distinguish what is worthwhile from the rest. Paper's review is delegated to Referees, who are contemporaries and, maybe, either competitors or – even worse – “scientific opponents” of the Authors (Supplementary Information, 2025).

This paper outlines some (im) possible, and preliminary, proposals. Of course, an extensive analysis of the limitations and of the possible drawbacks of the proposals related to STARS and to IREO is beyond the normal space limits.

Hence, future investigations in this field should include:

- analysis of existing bodies and of their limitations and drawbacks
- technical, economic and legal feasibility
- operational structure and governance
- cost/benefit analysis
- analysis of internal risks (biases, bureaucratization, ...) and related mitigation means
- analysis of external risks (lobbying, political control, capture, ...) and related mitigation means.

As an example of preliminary cost analysis, the rough order of magnitude of the costs of STARS is quickly analysed in the following, selecting Italy as a typical European State.

The Italian research system is made up by 14 Areas, from Area 01 - Mathematics to Area 14 - Political and Social Science. Each Area has a variable (between 6 and 20) number of Groups, and there are 181 Groups overall.

Hence, in the exemplary case of Italy, the minimum theoretical requirement is for 181 STAR committees, each including at least three members for majority voting. Considering the workload and the presence of Sub-Groups, this figure shall be multiplied by, say, five. The resulting number of experts working full-time in these committees is slightly above 2700.

Let us assume 70% of the competent people to be enrolled for of 5 years (e.g. aged from 65 to 70). Five years is one seventh of the typical 35 years of research activity in a scientific

career. Hence, in a “*steady state condition*” (constant number of researchers) the evaluation teams shall be able to develop a number of working hours theoretically equal to 10% of the whole hours spent in research. In a worst-case analysis with constant financial resources, a 10% reduction of the overall research budget for working hours would permit to afford the STARS’ cost. When considering the research equipment and consumables costs and the overheads, the reduction shall be significantly less than 10% (a reasonable estimate is 5%). In the case of Italy, where - in the universities and in the national research bodies - there are roughly 70,000 public researchers, the above rough evaluation of cost for the estimated 2700 members of Italian STARS is less than 4%.

On another side, the analysis – with a reasonable level of detail – of some significant and very costly “*Big Science*” projects (such as, for example, the so much advertised Controlled Nuclear Fusion) is beyond the specific field of knowledge and experience of the authors of this paper and outside its – necessarily, limited – scope and size.

Finally, it is worth mentioning that the above discussion on bibliometry and evaluation of submitted manuscripts does not consider the potentially disruptive effects of the Generative Artificial Intelligence, which should require further studies and *ad hoc* publications.

In fact, the Large Language Models (LLMs), such as ChatGPT, Gemini, Grok, Claude and more, may automatically generate papers hardly distinguishable from human production. It appears that more and more persons – especially non-native English speaking – use them.

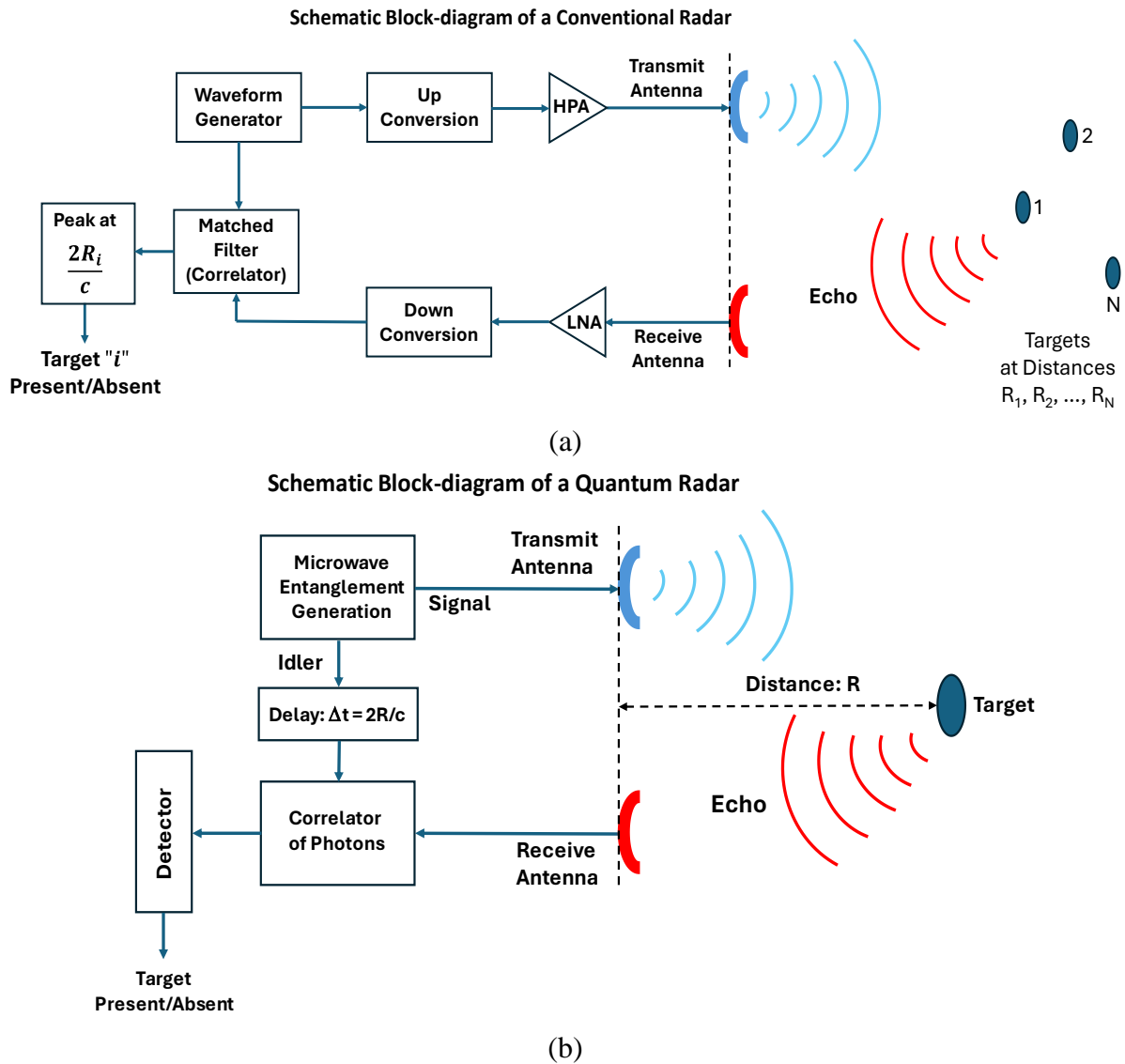
Quantitative data are hard to find, for qualitative data please see (Kusumegi, 2025) and <https://www.euronews.com/next/2025/12/31/scientists-are-publishing-more-than-ever-with-ai-but-not-all-papers-measure-up-study-finds> (accessed on 09/01/2026).

LLMs create a problem of overproduction and, more important, of quality. In fact, *linguistic and generative models don't produce knowledge*. They produce *plausible language*. Each output is the result of a *probabilistic process* that selects what sounds most consistent with the training data, not what is true, verified, or well founded. There is no reality check, no distinction between correct and incorrect statements: only *statistical continuity*. The risk arises when this *plausibility* is mistaken for *knowledge*, arriving to the replacement of *knowledge* with *its simulation*.

The fraud in research has generated reactions such as the recent establishment of the society “Clear Skies” (<https://clear-skies.co.uk>) aimed to supply Research Integrity Services. Their Papermill Alarm (<https://clearskiesadam.medium.com/the-papermill-alarm-90b10fb8a6cc>) is an AI-based (Artificial Intelligence) tool to detect fraud in publications. According to (Van Noorden, 2023) the percentage of scientific papers produced by papermills increased by 1.5% in seven years i.e. from about 0.16% in 2015 to 1.66% in 2022. This is a small percentage, but the absolute values are huge. In fact, considering that the annual average number of published papers in 2022 is about three million, the pertaining fake papers is about a remarkable figure of fifty thousand. In fact, (Van Noorden, 2023) suggests that there are hundreds of thousands of “*paper-mill*” articles in the literature.

### Appendix A. Classical Radar vs. Quantum Radar

A conventional, or Classical, Radar (CR) (Skolnik, 2000) sends radio signals toward objects of interest, or “*targets*”, and listen to their echoes. The measured two-way propagation delay is proportional to the distance of a target. The optimal reception of the radar echo is performed by its correlation with a replica of the transmitted signal (Turin, 1960). The operating principle of a “*classical*”, or *conventional* radar (CR) is shown in **Figure A.1(a)**, while that of a Quantum Radar (QR) is shown in **Figure A.1(b)**.



**Figure A.1** - Schematic Block-diagrams: (a) Conventional (or classical) Radar - HPA: High Power Amplifier, LNA: Low Noise Amplifier - (b) Quantum Radar.

It is straightforward to bear in mind that the maximum Range of a radar depends on the echo energy, which is proportional to the transmitted energy. The energy of a single microwave photon – at the most used wavelength  $\lambda = 3 \text{ cm}$ , ( $f_0 = 10 \text{ GHz}$ , X-band) – is of the very low order of  $6 \cdot 10^{-24} \text{ J}$ . For a 200 MHz band the corresponding power is of the order of  $10^{-15} \text{ W}$ ,

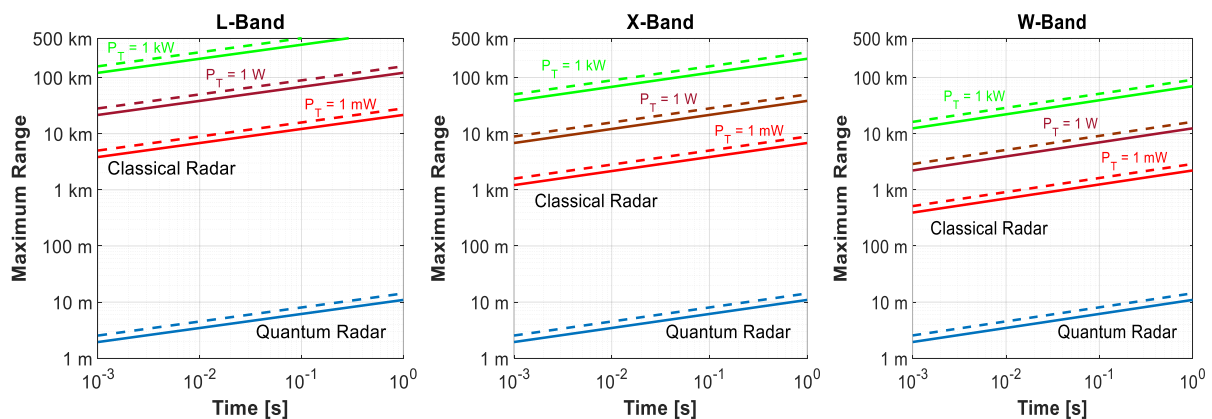
i.e. *one femtowatt*, calling for an exceedingly large correlation time, not compatible with target's motion (Pavan, Galati, 2024).

For an updated review on Quantum Radar, one may see (Karsa et al., 2024).

The inherent limitations of Quantum Radar are also found in Wikipedia ([https://en.wikipedia.org/wiki/Quantum\\_radar](https://en.wikipedia.org/wiki/Quantum_radar), accessed on 09/01/2026).

A set of curves (see Figure A.2), operating in L-band ( $f_0 = 1 \text{ GHz}$ ), X-band ( $f_0 = 10 \text{ GHz}$ ) and W-band ( $f_0 = 95 \text{ GHz}$ ), show the limited Range of a QR for reasonable values of the illumination time  $T$ , as compared to a Classical (Continuous Wave) Radar. The pertaining computations (Pavan, Galati, 2024) use the well-known Radar Equation, (Skolnik, 2000).

Other relevant considerations such as technical feasibility, operational problems and, last but not least, cost are found in (Daum, 2020b) and (Sorelli et al., 2022). Regarding the cost, QRs require costly cryogenic generators (in the *micro Kelvin* range) using Helium-4 and in some cases the hardly available Helium-3. A synthesis on the operational problems of QR and its readiness is presented in (Brandsema, 2018).



**Figure A.2** Comparison between the Maximum Range for Continuous Wave Classical Radar and for Quantum Radar, at L, X, W-band ( $f_0 = 1, 10, 95 \text{ GHz}$ ) vs the time-duration  $T$ . System noise temperature equal to 290 K (solid line) and 100 K (dashed line). The Classical Radar transmitted power is 1 mW, 1 W, 1 kW, with antenna gain of  $G = 30 \text{ dB}$ . Target's RCS is  $1 \text{ m}^2$ , the overall losses are  $L = -4 \text{ dB}$ , the bandwidth is the 10% of  $f_0$ , the minimum signal-to-noise ratio is  $SNR_{min} = 13.2 \text{ dB}$ . The quantum advantage is assumed equal to the reciprocal of the average number of photons per mode (less than the unity). Ideal propagation, no horizon, no atmospheric attenuation, no clutter, no radiofrequency interference.

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