Notes on Intuitionistic Fuzzy Sets
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Quantifying individual scientific output in terms of a new intuitionistic fuzzy sets based author-level metrics (*IFALM*)

Vassia Atanassova

Bioinformatics and Mathematical Modelling Department,
Institute of Biophysics and Biomedical Engineering,
Bulgarian Academy of Sciences
105 Acad. Georgi Bonchev Str., Sofia 1113, Bulgaria
e-mail: vassia.atanassova@gmail.com

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Abstract: The present paper proposes the idea of formulating a new author-level citation metrics, quantifying the individual's scientific output, which uses the concept of intuitionistic fuzzy sets. This new metrics gives more visibility to the proportion of direct self-citations and hidden (co-author or collaborative) self-citations in the form of an intuitionistic fuzzy pair. Examples are given retrieving the necessary information from Scopus, one of the largest databases of peer-reviewed literature, which algorithmically enables retrieval of one's citations including and excluding their own or their co-authors' self-citations, as well as the calculation of three different values of one's h-index with and without these respectively. Linear and triangular graphical representations are given, as well as comparisons with the concept proposed in 2005 by Jorge E. Hirsch, the now famous h-index, and ideas for future elaboration of the concept of the new intuitionistic fuzzy sets based author-level metrics, or shortly *IFALM*.

Keywords: Intuitionistic fuzzy sets, Intuitionistic fuzzy pairs, Bibliometrics, Citations, Self-citation, Scopus, H-index.
2020 Mathematics Subject Classification: 03E72.

1 Introduction

A great number of distinct author-level metrics exist in the scientific literature and practice, measuring the bibliometric impact of individual authors, researchers, academics, and scholars.

Different metrics take into consideration varying numbers of factors, [14] but a central place among these factor traditionally is the researcher's total number of citations.

For instance, the now famous Hirsch-index, or shortly h-index, was defined in 2005 by the physicist Jorge E. Hirsch as an alternative to other bibliometric indicators in attempt to more objectively quantify the research output of scientists. H-index is defined as the maximum value of *h* such that the given author has published at least *h* papers that have each been cited at least *h* times, [8]. It is considered that the h-index is designed to improve upon simpler measures such as the total number of citations or publications. H-index is considered to measure the productivity and impact of published work of scientists, '*combin[ing] productivity with echo*', [11]. Calculating the researcher's h-index has become a standard feature in leading scientific databases like Scopus, Web of Science, Google Scholar (from July 2011). And while of algorithm of determining the h-index is everywhere the same and its robustness stems from its simplicity, each database is likely to produce a different h-index for the same scholar in the same moment of time, because of different coverage of cited and citing publications within that database, [6]. Differences are in the type of indexed publications (e.g. Web of Science has poorer coverage of conference proceedings compared to Scopus), in terms of time (e.g. Scopus has poorer coverage of publications before 1996), etc.

In our considerations in this paper, we will use the information provided by Scopus, which in July 2022 claims to contain over 22,000 titles from more than 5,000 international publishers and thus be '*the world's largest abstract and citation database of peer-reviewed research literature*'. Our choice is dictated not only by that, but also by the fact that its interface allows discrimination between different types of citations and calculation of the authors' h-index under different assumptions. This is a software feature that other comparable databases, like Web of Science, do not offer, at least as of June 2020 per [10], and as of July 2022 per the author's own check.

As a free feature to non-subscribed users, Scopus database allows free author lookup with a simplified metrics overview, containing only limited information: number of Scopus' indexed documents by author, number of citations and a number of citing documents, as well as a calculated author's h-index, accompanied with a trend line of documents and citations, the author's last ten documents and a short list of topics that reflect the author's thematically clustered contributions over the past 5 years. The rest of its multiple other features are disabled for non-subscribed users. We are specifically commenting this for the fact that the so presented h-index metric in the free Scopus Preview is the one calculated on the basis of *all* recorded citations of the author's works including the author's direct self-citations and their co-authors' collaborative (hidden) citations, i.e. it previews an 'inflated' number, as qualified in one of the earliest critical discussions of the h-index metric, [16]. While the 'purified' value of the author's h-index is accessible through for subscribed users, even then retrieving it is not immediate but is a subject of additional efforts for the user to navigate to it through the sophisticate Scopus interface, at least three clicks away from the basic Author Search menu. As other authors have also identified, '*the defaulted definition of "self citations" is not correct here*', [10].

The fact that these different interpretations of the h-index co-exist in Scopus, and the fact that h-index is measured on the basis of citations—part of them 'good' ones to be preserved and part of them 'bad' ones to be avoided—invites for an attempt to interpret this indicator in terms of intuitionistic fuzzy sets.

Intuitionistic fuzzy sets [1, 2] are sets whose elements have a membership and a non-membership functions. They extend the notion of classical fuzzy set in such a way that the constraint in fuzzy sets theory that the non-membership value is one's complement of the membership value of every element is relaxed, so that both functions are independent. The membership of an element x to an intuitionistic fuzzy set A is hence represented as an intuitionistic fuzzy ordered pair $\langle \mu_A(x), \nu_A(x) \rangle$, where the following three conditions simultaneously hold true: $\mu_A(x) \in [0,1]$, $\nu_A(x) \in [0,1]$, $\mu_A(x) + \nu_A(x) \in [0,1]$. In the case when $\mu_A(x) + \nu_A(x) < 1$, the complement to 1 represents the measure of uncertainty whether the element x belongs to the intuitionistic fuzzy set A, or not, and is often named uncertainty index, hesitation margin, etc. Upon this intuitive idea of representing the inherently uncertain real-life objects and scenarios, a robust mathematical theory has been built over the past approximately 40 years, and we will use to support us in constructing our interpretation of the h-index in terms of intuitionistic fuzziness.

The present paper is organized as follows. In Section 2, we start with an example that illustrates the need and advantage of the proposed intuitionistic fuzzy author-level metrics, or shortly *IFALM*, which interprets author's citation metrics in the terms of intuitionistic fuzzy pairs and sets. We give a formal definition of the new metrics in the next Section 3. Section 4 contains some more elaborated examples and comparison with h-index. Finally, Section 5 completes the paper with a short conclusion and directions of future investigation.

2 Starting with an example

Let us motivate the undertaken research efforts with a practical example, and as a case in point the author will discuss her own h-index as calculated by Scopus. In the Scopus' profile page (ID 6603202641), the 'Metrics overview' dashboard features several indicators: the number of documents by the author indexed in Scopus, the number of citations and the number of documents citing works of the author, again indexed in Scopus, the current h-index calculated on this basis, and an illustrative trend line graphic (Figure 1).

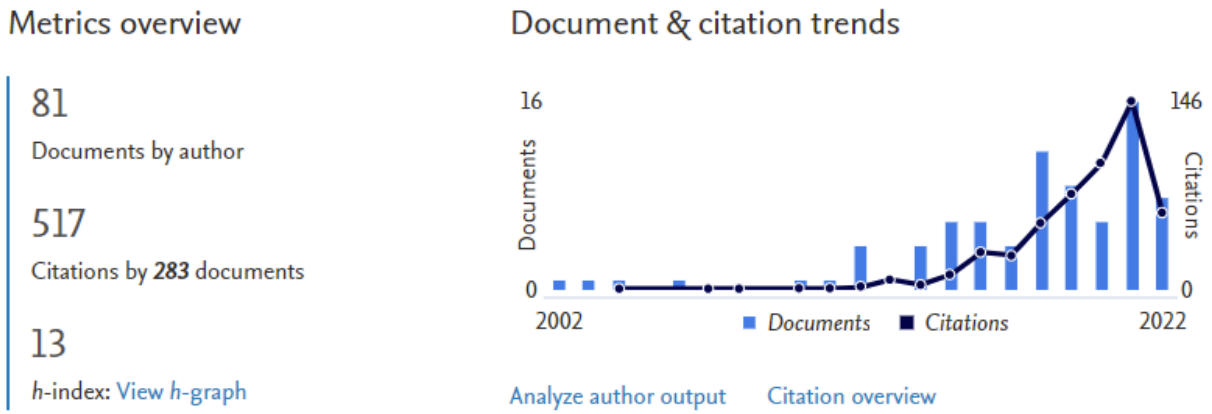


Figure 1. Metrics overview of the author, as of July 2022.

Clicking on the link ‘Citation overview’ under the trend line, a slightly different perspective is provided (Figure 2).

Here, the Scopus interface allows the user to choose from three options in the form of mutually exclusive radio buttons: (1) *Exclude self citations of selected author*, (2) *Exclude self citations of all authors*, and (3) *Exclude citations from books*. Since option (3) is irrelevant to our present discussion, we will not consider it hereafter, but will concentrate on options (1) and (2) as instrumental in the differentiation of the various kinds of citation and self-citation.

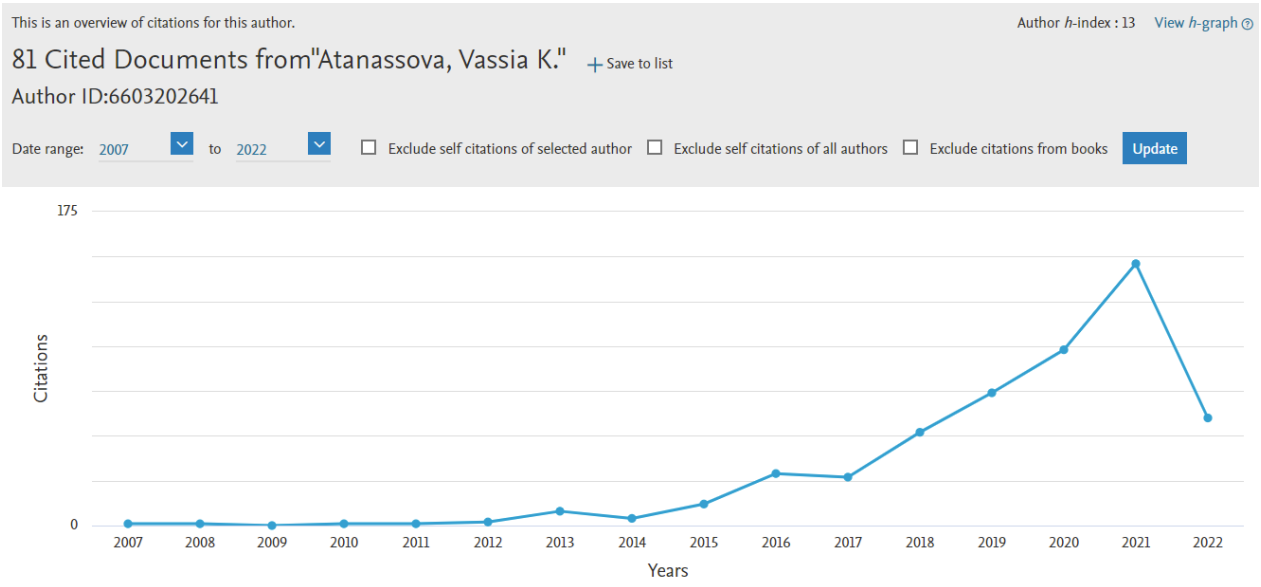


Figure 2. Citations overview in Scopus for the author (July 2022): Graphics

In what follows under this h-graph, selecting the sorting option ‘*Citation count (descending)*’, we obtain the detailed listing of citations per documents, and we notice the 13-th most cited record with 14 citations, with the 14-th one having 12 (Figure 3). We remind the reader, that this is still the statistics of all citations, including direct self-citations (or, in the Scopus’ interface: *self citations of selected author*) as well as the co-author / collaborative (also, ‘hidden’ self-citations, or, in the Scopus’ interface: *self citations of all authors*). The total number of recorded citations, corresponding to the h-index 13, is given as 520.

We have been however aware that this way of retrieving the citation metrics while being the most immediate one is the least precise, as it comprises the author’s self-citations.

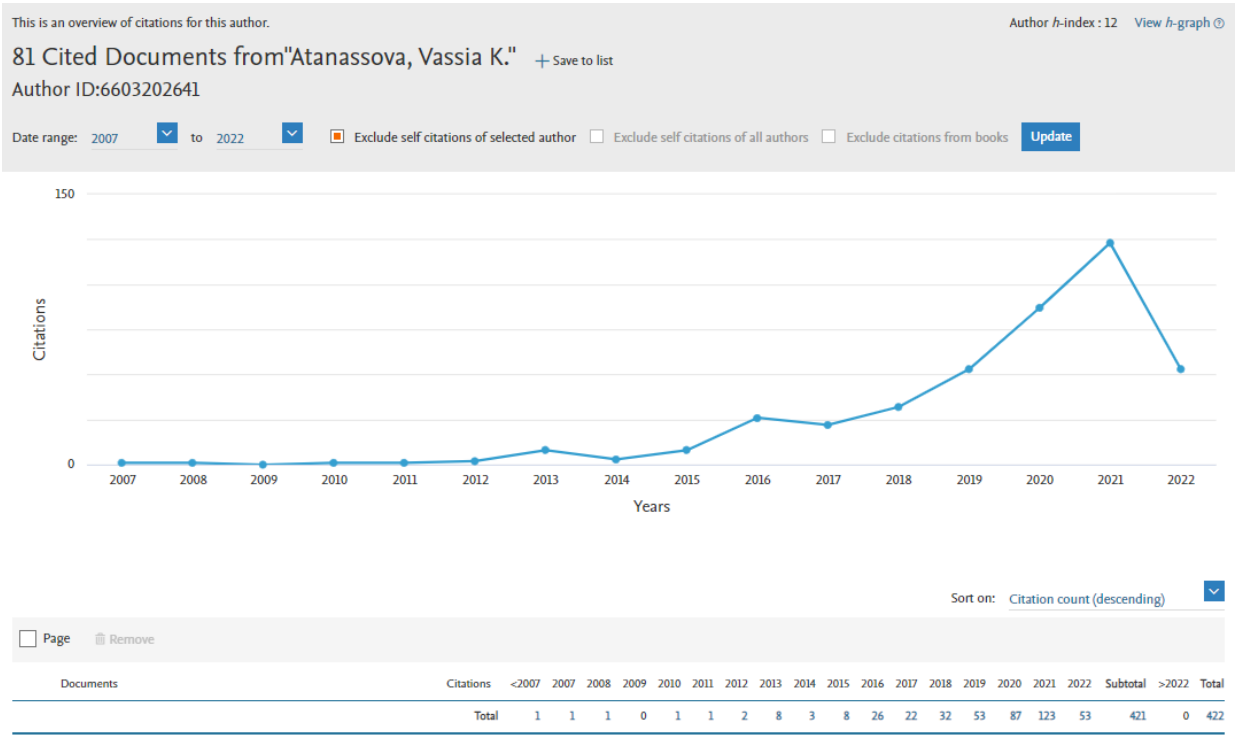
So, the next thing we do is select the option ‘*Exclude self citations of selected author*’. Thus the calculated h-index decreases from 13 to 12 and the total number of citations drops from 520 to 422 (Figure 4).

Sort on: Citation count (descending)

Page Remove

	Documents	Citations	<2018	2018	2019	2020	2021	2022	Subtotal	>2022	Total
		Total	87	52	74	98	146	63	433	0	520
1	Blood plasma thermograms dataset analysis by means of interc...	2016	4	8	10	8	7	4	37		41
2	Intercriteria decision making approach to eu member states c...	2014	18	6	6	1	5	3	21		39
3	A Hybrid Approach for Modular Neural Network Design Using In...	2018		4	2	12	11	5	34		34
4	Investigation of Relationships between Petroleum Properties ...	2015	6	3	4	3	7	4	21		27
5	Investigation of relationships between bulk properties and f...	2016	4	3	7	4	7	1	22		26
6	Dependence of visbroken residue viscosity and vacuum residue...	2015	7	1	3	4	5	3	16		23
7	Cuckoo search algorithm for model parameter identification	2016		4	6	4	3	3	20		20
8	Intercriteria analysis of calorimetric data of blood serum p...	2017	2	2	4	4	5	1	16		18
9	Application of the Intuitionistic Fuzzy InterCriteria Analys...	2017		1	3	5	7	1	17		17
10	Intercriteria decision making approach to EU member states c...	2015	7	4	3	1	2		10		17
11	Commercial Investigation of the Ebullated-Bed Vacuum Residue...	2020					12	4	16		16
12	Multi-person multi-criteria decision making: Intuitionistic ...	2003	13	1		1	1		3		16
13	An approach to a constructive simplification of multiagent m...	2017			3	4	3	4	14		14
14	Cuckoo search and firefly algorithms in terms of generalized...	2020				2	5	5	12		12
15	An intuitionistic fuzzy approach to the hungarian algorithm	2019				6	3	3	12		12
16	Interval valued intuitionistic fuzzy evaluations for analysi...	2018		1	3	4	2	1	11		11
17	InterCriteria decision making approach to EU member states c...	2015	2	5	1		3		9		11

Figure 3. Citations overview in Scopus for the author (July 2022): Table of cited documents



Sort on: Citation count (descending)

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Documents	Citations	<2007	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Subtotal	>2022	Total
	Total	1	1	1	0	1	1	2	8	3	8	26	22	32	53	87	123	53	421	0	422

Figure 4. Citations overview in Scopus for the author with excluded direct self-citations

Finally, we select the option '*Exclude self citations of all authors*', which filters out from the citation overview the indirect (hidden) self-citations made by co-authors. Under this selection, the calculated h-index further reduces to 10, as the total number of citations decreases to 314 (Figure 5). Only after the so performed filtering, we can be safe that these figures reasonably

reflect the output and quality of the research (or at least are the ones that ethical scientists shall present in their curriculum vitae, grant proposals, applications for promotion, etc.).

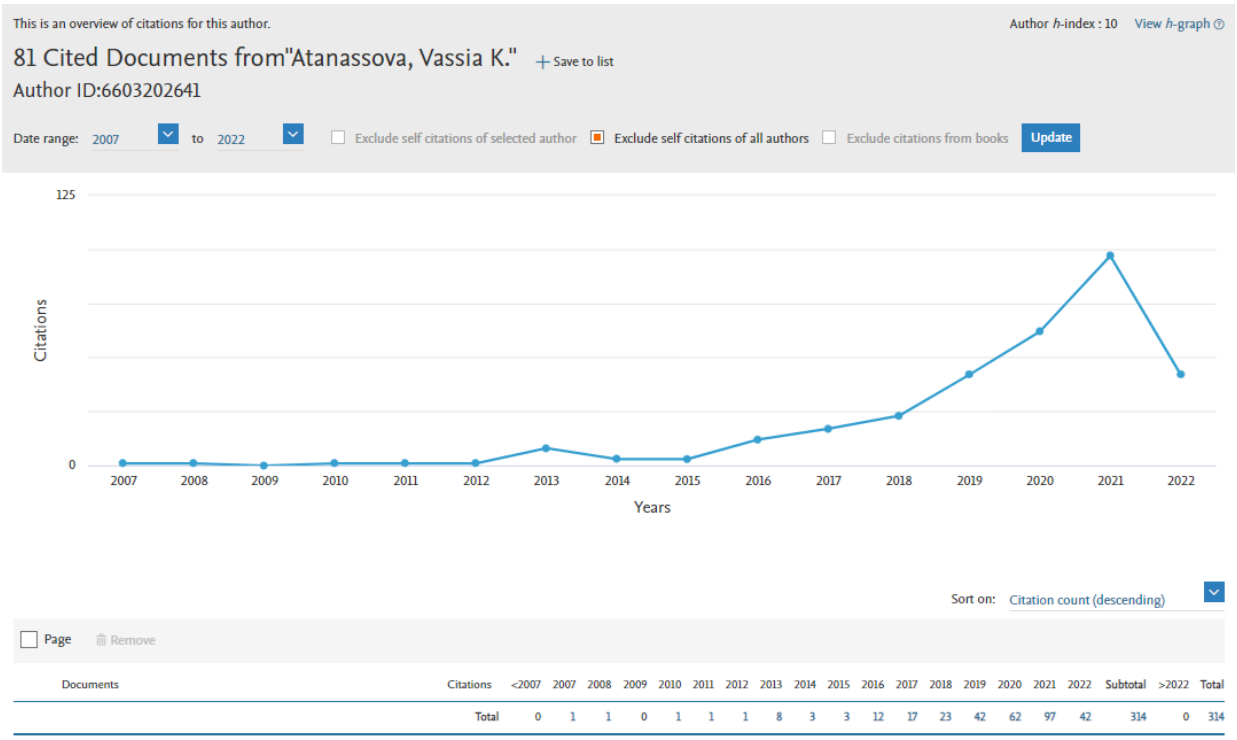

Figure 5. Citations overview in Scopus for the author with excluded self-citations of all authors

We summarize all of the above retrieved information in the following Table 1. Noteworthy, Scopus does not give an easy access to that information about the authors, and while it is usually available on demand, querying and retrieving that requires, first, the user's awareness of the Scopus interface, no less importantly—the motivation and conscience to care to do so, and then it costs certain amounts of time spent in back-and-forth navigation and loading the results. Saying that this information is *usually* available, we explicitly note that for some authors querying their citations with excluded self-citations of all authors may be so computationally heavy task that the results may be directly unavailable, displaying the messages '*The citation overview you requested is too large to calculate and display. The citation overview is available as a comma separated file (.csv) with the first 20,000 documents included, that you can download.* […] *When the file is ready, we will email you a link to download your export.*', as we will illustrate with a real example in Section 4.

Table 1. Comparison between the citations metrics and h-index metrics of the author, as generated in the three possible methods offered by Scopus, with calculated ratios

Method of citations retrieval	**Type of citations** O = by others; C = by co-authors (hidden); S = self	**Citation metrics**		**H-index metrics**	
		Numbers	**Ratio**	**H-index**	**Ratio**
All citations (default, no filtering)	**O + C + S**	**520**	1.00	**13**	1.00
Excluded self-citations of selected author	**O + C**	**422**	0.81	**12**	0.92
Excluded self-citations of all authors	**O**	**314**	0.60	**10**	0.77

From the figures presented in Table 1, we can make the following calculations:

- The 'clean' or 'good' citations, or those that appear when the self-citations of the author and all of her co-authors are excluded, amount to 314, or 0.60 of all author's citations, and the respective h-index based on these citations is 10, instead of the defaultly communicated 13, or given as ratio: 0.77.
- The citations that should be definitely disregarded as 'bad' are those direct self-citations of the author herself. Their number is 98 (= 520 – 422), or 0.19 of all author's citations. Judging from the different h-indexes in Table 1, the 'contribution' of the direct self-citations to the h-index communicated by default seems to be 1 out of 13, or approximately 0.08.
- The rest 108 (= 520 – 314 – 98), or 0.21 of the author's citations appear to have been made by her co-authors citing in their works joint publications with her, i.e. they are attributed as the so called 'hidden self-citations'. Judging from the different h-indexes in Table 1, the 'contribution' of the hidden self-citations to the defaultly communicated h-index seems to be 2 out of 13, or 0.15.

In the next section, we will discuss and formalize the proposal for an intuitionistic fuzzy author-level metrics, based on the presented data and considerations.

3 Intuitionistic Fuzzy Author-Level Metrics (*IFALM*)

From the example given in the previous section, we can make certain generalizations and intuitionistic fuzzification of the problem, in other words to convert the crisp quantities into intuitionistic fuzzy pairs, [4]. We need to make one important clarification here: we are concentrated only on the purely quantitative side of the question of self-citation, avoiding any discussions on the subjective or objective value of the cited works for the understanding of the citing works. We also engage in no discussions on whether the non-self-citations may are organic, perfunctory, coercive, etc., and draw no conclusions regarding the authors' scientific ethics on the basis of their scores. We will just reason here—on the basis of practice and common sense—that it is barely possible for an author to have all of their citations 'clean' of direct or hidden self-citations, or if this is the case, this would only be possible for only a tiny fraction of the researchers and only in the dawn of their scientific careers.

Back to the intuitionistic fuzzy author-level metrics (IFALM), we note first that we are able to attribute one part of the retrieved citations as 'good' ones that is independently obtained citations, where, per the streamlined definition of Kaptay in [9] "there is no single overlap in the lists of authors of the citing and cited papers". In intuitionistic fuzzy terms, these citations take part in forming the IF membership function, μ_A.

On the other hand, we are also able to define part of citations as 'bad' ones, and these are the author's self-citations of own works, which are not only 'the worse of two evils', but also computationally easier, faster and more reliable to filter out. In intuitionistic fuzzy terms these citations take part in forming the IF non-membership function, ν_A.

The rest, hidden self-citations or the citations made by co-authors of joint works with that author, are left to constitute the intuitionistic fuzzy uncertainty index, that is, they complement the sum of μ_A and ν_A to 1, or, formally, $\pi_A = 1 - \mu_A - \nu_A$. Our check has shown that these are computationally much more difficult to filter out, and for some authors the Scopus engine is unable to produce the result in due time, and the result is limited to the first 20 000 results. This additionally justifies framing them as 'uncertainty'.

These two considerations suggest that the ratios of the independent vs. all and the direct self-citations vs. all are two numbers both in the [0,1]-interval, for which it holds that their sum can be maximally equal to 1, which means that they naturally form an intuitionistic fuzzy pair. Therefore, our formal definition of IFALM is the following.

Definition 1. *Intuitionistic Fuzzy Author-Level Metrics (IFALM) is an intuitionistic fuzzy pair of the form* $\langle a, b\rangle$, *where* $a, b \in [0, 1]$ *and* $a + b \leq 1$, *where a is the ratio of the independent vs. all citations of a researcher, and b is the ratio of the direct self-citations vs. all citations of that researcher. Thus the complement to 1 is produced by the ratio of the co-authors' citations, 'hidden self-citations', vs. all citations of that researcher.*

Remark. Here, we immediately have to note that this definition is consciously more liberal than what some readers and researchers on the topic would be willing to see. This definition here does not 'condemn' hidden self-citations as 'bad' like the direct self-citations of the author: it puts them in the 'grey zone' of 'uncertainty'. A more conservative, more rigorous definition here would be one that would define, for instance, *b* as the ratio of both direct and hidden self-citations vs. all citations of the researcher, and *a* as the ratio of the independent vs. all citations of an author, where any sort of connection between that researcher and the citing authors such as same affiliation, past or present collaboration in a funded project, personal friendship or membership to any collaboration networks, etc. is eliminated. Of course, the aim of such drastic limitations would be to evaluate the real, not artificially inflated, potential of a scientific publication, and strip any potential perfunctory, coercive, etc. citations off the researcher's citation record, However, to the best of our knowledge, distinguishing different shades of dependency within the set of so called 'independent' citations is a matter of extensive scientific discussion (e.g. [15]), but there are not yet objectively available tools doing that job algorithmically. Hence, the so constructed definition is rendered in such a (liberal) way in order to reflect the current technological, algorithmic possibilities of databases like Scopus and Web of Science to discriminate between different types of citations, [13].

As we know from the intuitionistic fuzzy sets theory, it is worth considering the three intuitionistic fuzzy boundary values: the IF complete Truth, i.e. ⟨1,0⟩, the IF complete Falsity, i.e. ⟨0,1⟩, and the IF complete Uncertainty, i.e. ⟨0,0⟩:

- In our interpretation, the situation ⟨1,0⟩ holds when all of the author's citations are non-self-citations, neither direct or hidden. Unless we consider some 'one hit wonder scientist' like an amateur mathematician, who only once published a self-authored article, that got the other researches' interest and citations, there is hardly a chance for a scientist to have this score—or probably only in a short period of time in the beginning of one's research career. This is so, as professional researchers tend to pursue a research topic in depth and elaborate upon both others' and their own research, thus hardly being able to avoid citing their previous works (which interprets as raising their citation's IF non-membership ν). Additionally, with the advancement of their research career, scientists tend to enter or form research teams and publish jointly with others, which increases the opportunities of their research being cited by their co-authors, with or without them being informed or being able to encourage or discourage such a behaviour (which all represents as having their citation's IF uncertainty π increased).
- The situation ⟨0,1⟩ takes place when all of the author's citations are direct self-citations. This is possible, and again more probable in the beginning of one's research career (but would sound terribly as a testimony of quality and collaboration, if this remains for the rest of the author's career).
- Finally, the situation ⟨0,0⟩, given that the total number of citations is non-zero, is the case when all of the author's citations come as a result of their co-authors having cited joint works of theirs, with no direct self-citations and no citations from independent third parties. Again not impossible, but more probable at the start of the researcher's career, more of an exception rather than a rule.

After this short and informal analysis, we can generalize that in their pure form the boundary values ⟨0,0⟩, ⟨0,1⟩ and ⟨1,0⟩ could be well explicable in the early days of the author's research path with the inherently low numbers of their citations at this stage (in vein with the statistical law of large numbers), but are generally anomalistic for authors who have a longer publication and citation record, where it is naturally expected to have all the three kinds of citations. Again here, we can note that in case of an author only publishing alone, with no co-authors, the π in their IFALM will always be equal to 0.

Intuitionistic fuzzy pairs and sets are graphically representable in two main ways – first, linear as functions varying in the [0,1]-interval (in a standard and a modified form, see [2], pp. 3, 4) similar to the fuzzy sets visualisation, and second, plotted onto the intuitionistic fuzzy interpretational triangle, which bears no analogue with the visualisation of fuzzy sets but makes sense only for IFS. Both ways are usable and in their diversity they give different, mutually supporting way of the visualization of IF sets and values, although we are intrinsically interested in the triangular interpretation, where the μ-values are plotted along the abscissa, the ν-values are plotted along the ordinate and the hypotenuse forming the IF triangle reflects the condition that $\mu + \nu \leq 1$.

4 Elaborated example and discussions

Continuing the example from Section 2, we are interested to construct the whole set of IF pairs that represent the author's annual IFALM-s as points on the IF interpretational triangle, a series that we already know to finish with the point ⟨0.60, 0.19⟩. Thus, in addition to this momentary snapshot in 2022, the whole author's history of citations per year is traced in the Table 2 below.

These tabular data are graphically represented in three ways, respectively:

- Figure 6, the standard linear IF interpretation, with the plotted μ-values in green and v-values in red, respectively connected with a green and a red line;
- Figure 7, the modified linear IF interpretation (with plotted μ-values in green, and values of $(1 - v)$ in red, i.e. v-values plotted top-down from 1 instead of bottom-up from 0, again connected by lines. Compared to Figure 6, this interpretation allows us to clearly visualize how the IF belt of uncertainty $\pi = 1 - \mu - v$ varies over time.
- Figure 8, interpretation onto the IF interpretational triangle, where the $\langle \mu, v \rangle$ points are plotted on the triangle and the lines connecting them in chronological order are coloured in progressively darkening shades of blue. This connection is an analogue of the chronological ordering of the values that is inherent for the linear interpretation.

Table 2. Author's history of citations per year, and calculated year-wise IF h-indexes

Year	Citations by others (μ)		Citations by co-authors (π)		Self-citations (v)		Total ($\mu + v + \pi$)		IFALM
	Curr Year	All Years	Curr Year	All Years	Curr Year	All Years	Curr Year	All Years	
2004	0	**0**	1	**1**	0	**0**	1	**1**	⟨0.00, 0.00⟩
2005	0	**0**	0	**1**	0	**0**	1	**1**	⟨0.00, 0.00⟩
2006	0	**0**	0	**1**	0	**0**	1	**1**	⟨0.00, 0.00⟩
2007	1	**1**	0	**1**	0	**0**	1	**2**	⟨0.50, 0.00⟩
2009	0	**1**	0	**1**	0	**0**	0	**2**	⟨0.50, 0.00⟩
2008	1	**2**	0	**1**	0	**0**	1	**3**	⟨0.67, 0.00⟩
2010	1	**3**	0	**1**	0	**0**	1	**4**	⟨0.75, 0.00⟩
2011	1	**4**	0	**1**	0	**0**	1	**5**	⟨0.80, 0.00⟩
2012	1	**5**	1	**2**	0	**0**	2	**7**	⟨0.71, 0.00⟩
2013	8	**13**	0	**2**	0	**0**	8	**15**	⟨0.87, 0.00⟩
2014	3	**16**	1	**3**	0	**0**	4	**19**	⟨0.84, 0.00⟩
2015	3	**19**	5	**8**	4	**4**	12	**31**	⟨0.61, 0.13⟩
2016	12	**31**	14	**22**	3	**7**	29	**60**	⟨0.52, 0.12⟩
2017	17	**48**	5	**27**	5	**12**	27	**87**	⟨0.55, 0.14⟩
2018	23	**71**	9	**36**	20	**32**	52	**139**	⟨0.51, 0.23⟩
2019	42	**113**	11	**47**	21	**53**	74	**213**	⟨0.53, 0.25⟩
2020	62	**175**	25	**72**	11	**64**	98	**311**	⟨0.56, 0.21⟩
2021	97	**272**	26	**98**	23	**87**	146	**457**	⟨0.60, 0.19⟩
2022	42	**314**	11	**109**	10	**97**	63	**520**	⟨0.60, 0.19⟩

Notably from both Table 2 and the three Figures 6–8, with the advancement of time and accumulation of publications and citations, the most significant 'jumps' have taken place in the beginning of the researcher's career, and later there is a trend of stabilization. This observation is of course consistent with the Law of large numbers. Any particularly shifted patterns can be explained with significant changes in the publication and citation history of the researcher, like scientific breakthroughs, increase in the culture of collaboration, funded project in the area of research which enables and intensifies the research and publication opportunities for a larger research group, etc.

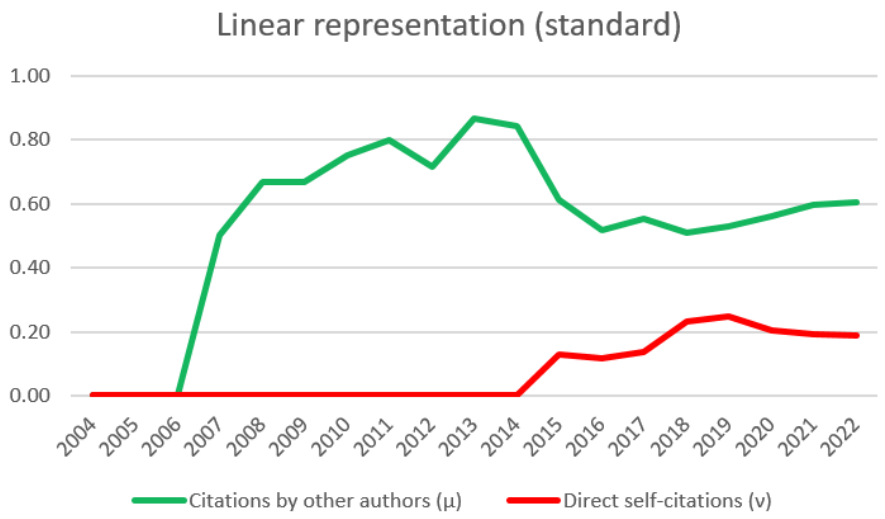

Figure 6. Standard linear IF interpretation of the data from Table 2. It is presented here for completeness, but instead the interpretation from Figure 7 will be utilised.

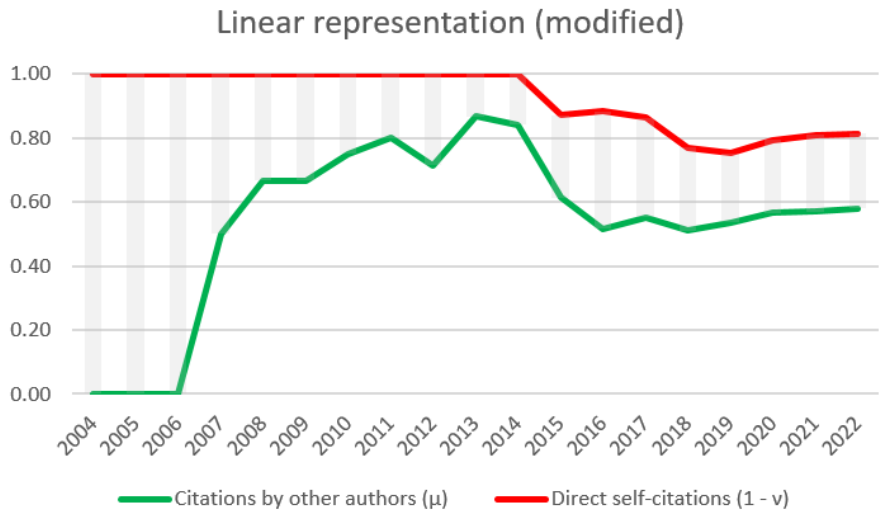

Figure 7. Modified linear IF interpretation of the data from Table 2. Direct self-citations are alternatively visualized as $1 - \nu$ instead of ν (i.e., top-down from 1, instead of bottom-up from 0). A belt of uncertainty standing for the share of hidden self-citations is given with grey stripes.

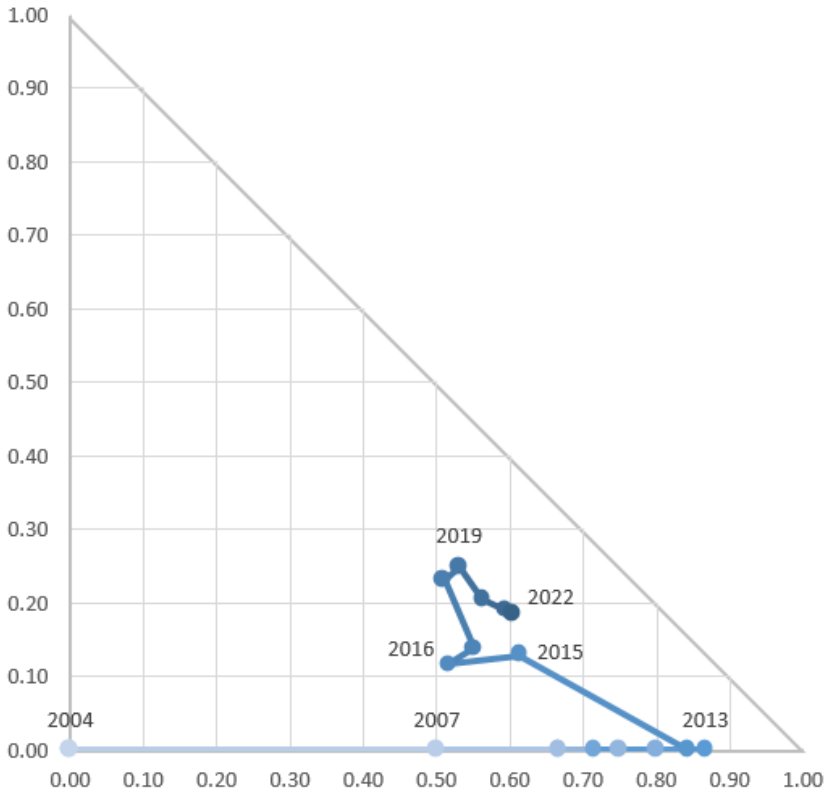

Figure 8. Standard linear IF interpretation of the data from Table 2.
The line chronologically connecting the IF pairs is visualized in a way to change its shade from the lightest blue (2004) to the darkest blue (2022).

It would have brought additional value to our research if we were able to produce data about the yearly development of the h-index, just like the momentary snapshot given in Table 1. Unfortunately, it is a limitation of Scopus that does not allow the retroactive year-wise 'slicing' of one's h-index, and regardless of the selection of years in the 'Citation overview' menu it only gives the h-index values as of the present moment. If such an option was available, we would have been able to show how the h-indexes—as formed in the three ways, including and excluding hidden or direct self-citations—would have changed over the whole period of the author's scientific activity 2004–2022. Comparing such a progress—as graphics, and as tabular data of the ratios between the three h-indexes—with the development of our newly proposed IF interpretation of the h-index would have given additional interesting insights. We can now only remark that the latest reported author's IFALM of ⟨0.60, 0.19⟩ can be compared to the pair ⟨0.77, 0.08⟩ which represents the IF pair of the ratios between the author's h-indexes calculated differently depending on the method of citations retrieval (Table F). Calculating these numbers and making more comparisons of this kind, for example for the researchers in a given field, or from the same affiliation, may give a more informative picture and ideas if the herewith proposed Intuitionistic Fuzzy Author-Level Metrics (IFALM) is usable, adding value to the field of bibliometrics, and worthy of further investigation. Different tools from the arsenal of statistical analysis can be employed here, including the intuitionistic fuzzy sets based method of InterCriteria Analysis, [3].

We will finally note that an additional idea regarding the assessment of the particular IFALM values is given in an earlier author's research [5] about the level operator N_γ over IFS. The operator N_γ works by generating a subset of an intuitionistic fuzzy set A, where the elements of the subset are those elements of A, for which the ratio of their degrees of membership to their degrees of non-membership, respectively, is greater or equal to a given number $\mu / \nu = \gamma > 0$. Taking for granted that IFALM will usually reflect a certain degree of uncertainty (pun not intended!), resulting from many people publishing research works together with co-authors and having these co-authors citing their joint works, we can choose to focus instead on the ratio of the μ / ν parts of the IFALM pair, and may assess that a high 'IFALM' is one that maintains a high γ. In the example given in [5], $\gamma = 5$, as inspired by the book [7] and a study as distant from mathematics as marriage counselling, the "magic ratio" between positive and negative interactions between spouses, which "ensures" stable and happy marriage, is 5 to 1. If we opt for such a proportion for our IFALM example, then that would mean that the author's IFALM 2022 value $\langle 0.60, 0.19 \rangle$ is not high enough, while the ratio $\langle 0.77, 0.08 \rangle$ between the h-indexes is reasonably above the threshold. These observations are visualized on Figure 9, which is the last for the present paper.

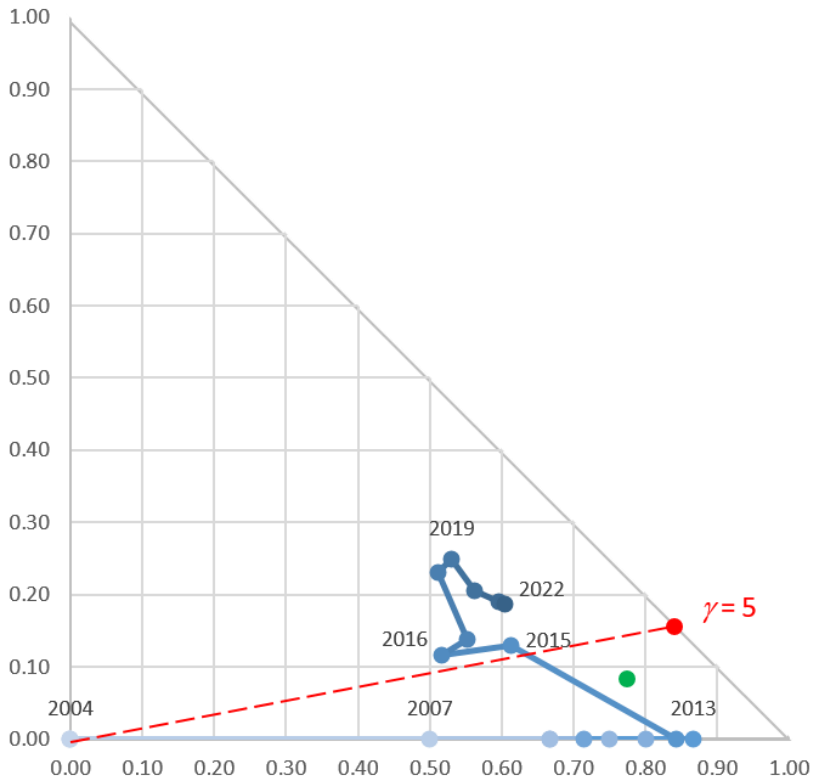

Figure 9. The author's IFALM chronological line is visualized in a way to change its shade from the lightest blue (2004) to the darkest blue (2022). In 2022, the IFALM is $\langle 0.60, 0.19 \rangle$ (in darkest blue), and the ratio $\langle 0.77, 0.08 \rangle$ between the h-indexes (in green), while the red line represents the sample value $\gamma = 5$, and shows well in which years the IFALM values meet the N_γ requirement.

5 Conclusion

In the present paper we propose a new author-level metrics in the form of an intuitionistic fuzzy pair of numbers that incorporates as equally standing criteria the number of author's self-citations (direct self-citations), the number of co-authors' citations (hidden self-citations) and the 'pure' number of citations made by other authors (independent citations). The presented approach is open for further elaboration and improvement, and aims to add a new perspective to the list of existing author-level metrics by employing the intuitionistic fuzziness, which is both ideally designed and theoretically backed up for handling the inherent uncertainty that accompany real-life scenarios. IFALM allows for the data in this format be analysed with decision making methods and tools based on intuitionistic fuzzy sets, one of which is the recently developed InterCriteria Analysis, and this is a future direction of research extending the herewith proposed novel idea.

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