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CONCEPTUAL ARTICLE

A Bibliometric Analysis of Publications of Universiti Teknologi Malaysia

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Abstract This study analyses the scholarly publications of Universiti Teknologi Malaysia (UTM) in conjunction with 50 years of UTM establishment. A bibliometric analysis is performed to analyse the UTM's publication and research trends over the 50 years, especially during the post-research university (RU) period, publications impacts, subject area expertise and publications performance in comparison to other RU. Based on the analysis, engineering and computer science are the most prominent fields among the research fields in UTM in terms of a number of publications and citations thus far. Among the top 10 fields in UTM, materials science, chemical engineering, energy and chemistry areas are seen to have a high potential to further excel in citation provided that the publication numbers of these fields are further increased. The publications output for some UTM fields can still be considered low despite having a reasonable number of authors and talents. UTM is the top university in the number of publications from 2015 till 2020 in four fields, namely engineering, computer science, materials science, and chemical engineering, compared to other RU.

Keywords: bibliometric, Scopus publication, Universiti Teknologi Malaysia, research university.

Introduction

Since the proclamation of the formation of Institut Teknologi Kebangsaan (ITK) on March 14, 1972, the ITK, then declared as Universiti Teknologi Malaysia on April 1, 1975, has progressively developed and has undergone a comprehensive institutional transformation towards more impactful functional operations to remain relevant and competitive in an increasingly challenging global environment. Research is one of the criteria that UTM has vigorously prospered, as evidenced by its increasing number of publications every year, especially after its conferment as the research university (RU) in 2010.

Publications could be considered a medium for knowledge discussion and sharing [1] besides providing the latest updates on developing a particular research topic. Publications in Scopus- and ISI-indexed journals have always targeted Malaysia's public universities, particularly the research university (RU). Ministry of Higher Education (MOHE) has prioritized both Scopus- and ISI publications as one of the research performance indicators for Malaysia's public university [2].

Many studies have been published worldwide to analyse scholarly publications of institutions, organizations and certain particular fields using various top tiers publishers and databases such as Web of Science (WOS), Scopus, Elsevier, Science Direct, EBSCO, JSTOR, ProQuest, etc. [3-7]. Several approaches including big data analysis [8], scientometric [9] and bibliometric study [10] have been rousingly performed to thoroughly determine qualitatively and quantitatively the trend of the publications and researches of certain fields and institutions as well. Bibliometric analysis is commonly used to assess a specific field's qualitative and quantitative interest through publications analysis [1].

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The present study uses bibliometric analysis to look in-depth at the UTM's publication and research trends over the 50 years especially the post-RU period, publications impacts, subject area expertise and publications performance compared to other RU. The publication is one of the indicators of research productivity and can be used to rank and analyse the productivity and impacts of researchers, faculties, and academic institutions [1]. Thus, there is a need to review UTM publication outputs to analyse its performance in research in conjunction with UTM's 50-years establishment as a public university in Malaysia.

Methods

Publication record was downloaded from Elsevier's Scopus, arguably the largest scientific indexed abstract and citation database. The dataset preparation stage is relatively straightforward (Figure 1) using the query functions in Scopus. The dataset was separated during the downloading stage due to the system limitation before combining everything into a total of 45,373 records. A total of 3,126 records were discarded, thus restricting the analysis to the range of 1980 (the oldest record affiliated with UTM in Scopus) to 2020.

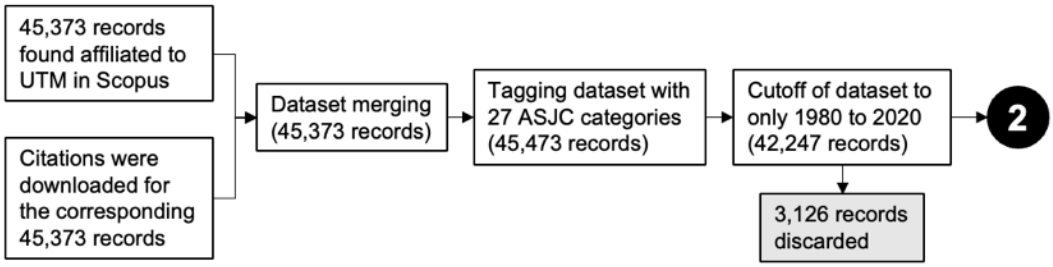

Figure 1. Dataset preparation.

Publications records in Scopus can be tagged to multiple All Science Journal Classification Codes (ASJC) which are divided into two levels of details; the subject areas and the fields. The fields can be grouped into 27 Scopus ASJC categories, as shown in Table 1. Thus, the term 'fields' hereafter used in the present study refers to the Scopus ASJC categories, and it is used interchangeably with the latter throughout this analysis article. During the analysis stage, publications tagged with multiple categories were treated as "contributing" (number of publications, number of citations, etc.) to each category accordingly. The number of authors was determined using the unique identifier (known as Author ID). Authors were grouped, and those with low publication count and not affiliated to UTM were removed (Figure 2).

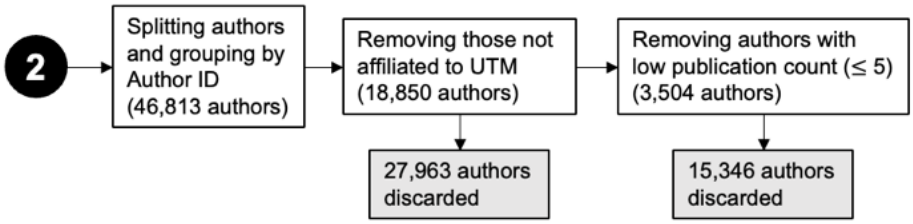

Figure 2. Author(s) identification and screening.

The second dataset used in the analysis comes from UTM's internal database, our integrated research grant management system (known as Research and Development Information System, RADIS, https://radis.utm.my/). RADIS was fully launched in 2013 (the then version 3.0) with continuous updates over the years before being completely refreshed in 2020 as version 4.0. Research grants secured by any researchers in UTM were registered in RADIS and one of the categorizations used is Field of Research (FOR) and Socio-Economic Objective (SEO).

Table 1. Scopus ASJC categories.

Description	Code
Engineering	ENGI
Social Sciences	SOCI
Computer Science	COMP
Agricultural and Biological Sciences	AGRI
Biochemistry, Genetics and Molecular Biology	BIOC
Environmental Science	ENVI
Medicine	MEDI
Earth and Planetary Sciences	EART
Physics and Astronomy	PHYS
Economics, Econometrics and Finance	ECON
Chemistry	CHEM
Arts and Humanities	ARTS
Materials Science	MATE
Business, Management and Accounting	BUSI
Mathematics	MATH
Energy	ENER
Decision Sciences	DECI
Immunology and Microbiology	IMMU
Chemical Engineering	CENG
Psychology	PSYC
Dentistry	DENT
Neuroscience	NEUR
Nursing	NURS
Health Professions	HEAL
Veterinary	VETE
Pharmacology, Toxicology and Pharmaceutics	PHAR
Multidisciplinary	MULT

This classification is based on the Malaysian Research and Development System (MRDS) [11] (only the 6th Edition was implemented in RADIS). A mapping was created between Scopus's ASJC categories and MRDS's FOR, in order for the analysis to be cross-examined between publications records and grants records. Granted, the mapping is not perfect by any means due to the different approaches and categorization used by Scopus and MRDS. MRDS's FOR categorization system employed four levels of detail (Figure 3), and a combination of FOR Group and FOR Area was used to map the research grant to Scopus's ASJC categories.

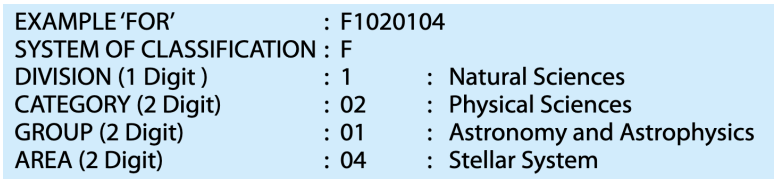

Figure 3. Example of FOR categorization in MRDC 6th Edition

Unlike the publications which used one (publication) to many (ASJC categories) tagging, the research grant only uses one-to-one tagging. Due to the sensitivity of the information, raw values (i.e., funding amount) were not disclosed. However, the values used in the analysis underwent a min-max normalization, resulting in a standard scale of 0 to 1, especially during the analysis in the spider charts (of each ASJC category).

The amount of funding of each research grant was not used in totality but was divided into two groups; the amount allocated for salary pay-out or emolument (denoted as talent) and the amount allocated for equipment purchase (denoted as equipment). The fact that the Government of Malaysia, via the Ministry of Finance, exercise a standard practice of financial coding to differentiate the different source of income and expenditure makes the segregation of talent and equipment more accessible. Assumptions were made that the amount allocated for talent would directly influence supporting staff (research officers, graduate students, etc.) in carrying out the research activities. That equipment would reflect the amount of money spent on the hardware and software directly used in the research.

Results

Publications trend by fields

Table 2 and Table 3 show the number of Scopus-indexed publications of Universiti Teknologi Malaysia (UTM) from the year 1980 till the year 2020 based on different fields (denoted as ASJC categories in Table 1) in the descending order from left to right. It can be seen that there has been a remarkable increase in publications of the majority of the fields from 2010 onwards. The award of research-university status (RU) for UTM in 2010 might lead to this notable increase as the top six of the fields that constantly soar upwards are Engineering (ENGI), Computer Science (COMP), Material Sciences (MATE), Physics and Astronomy (PHYS), Chemical Engineering (CENG) and Environmental Science (ENVI).

In the present study, the number of UTM's Scopus-indexed publications based on the different fields from the year 1980 to 2020 is categorized into four classes, namely primary (>10,000 publications), high potential (between 4,000 and 10,000 publications), potential (between 1,000 and 4,000 publications) and emerging (<1,000 publications). As indicated in Table 4, there are two primary fields with the highest Scopus publications up to 2020; Engineering (ENGI) with 20,043 publications, followed by Computer Science (COMP) with 11,142 publications. Materials Sciences (MATE), Physics and Astronomy (PHYS), Environmental Sciences (ENVI), Chemical Engineering (CENG) and Mathematics (MATH) are the fields constituting the high-potential secondary cohort. Energy (ENER), Chemistry (CHEM) and Social Sciences (SOCI) are the top three for the potential tertiary group. The fourth group, namely the emerging cohort, is led by Decision Sciences (DECI), Economics, Econometrics and Finance (ECON) and Arts and Humanities (ARTS). Nursing (NURS), Dentistry (DENT) and Veterinary (VETE) possess the least number of publications, and this is highly reasonable as these fields have not been a prominent field of UTM thus far. The progression rate of the publication of the areas in UTM from 2010 to 2020 is measured using the compound annual growth rate (CAGR) formula and is summarized in Table 4.

Citation analysis

Table 5 and Table 6 show the number of citations from Scopus-indexed publications of UTM up to the year 2020. Again, Engineering (ENGI) tops the group, followed by Material Sciences (MATE), Computer Sciences (COMP), Chemical Engineering (CENG) and Chemistry (CHEM). Apparently, Physics and Astronomy (PHYS), which ranked 4th in a total number of publications, descends to 8th place in terms of the total number of citations generated. Intriguingly, Chemical Engineering (CENG) and Chemistry (CHEM) have a better rank in the total citation (4th and 5th, respectively) despite being ranked 6th and 9th in total publications, respectively. This finding connotes that a high publication does not necessarily lead to a high citation as the citation highly depends on the quality of the published articles, in general.

The impact of the publication is then assessed as the ratio of total citations to the number of publications for each ASJC category. Table 7 displays the ratio of total citations to the numbers of publications for the top ten ASJC categories selected from 2010 (the conferment of UTM as the RU) up to the year 2020. In general, the ratios of citations to publications show a decreasing trend from 2010 to 2020 for all fields as the ratio remarkably starts to descend in 2016 or 2017. Some ASJC categories such as Energy (ENEG), Chemistry (CHEM), Environmental Sciences (ENVI), Chemical Engineering (CENG) and Material Sciences (MATE) propelled higher in citation/publication ratio particularly in the year 2010 to 2015 period and in fact, surpassing those of Engineering (ENGI) and Computer Sciences (COMP). While a higher number of publications could result in a higher probability of being cited, Table 7 shows a good example that citations can be very field-dependent. This is seen for Engineering (ENGI) and Computer Sciences (COMP), which possess a moderate citation per publication ratio, despite being two of the highest ASJC categories in publication volume.

Table 2. Number of publications by year by ASJC Categories (Part 1) *Colour represents the "intensity" based on the numbers of publication with blue as cold and red as hot.

Year	ENGI	COMP	MATE	PHYS	ENVI	CENG	MATH	ENER	CHEM	SOCI	BIOC	EART	BUSI
1980	0	0	0	0	0	0	0	0	0	0	0	1	0
1982	0	0	0	0	0	0	0	0	0	1	0	0	0
1984	3	0	0	0	0	0	1	0	0	0	0	0	0
1985	3	0	1	1	1	0	0	0	0	1	0	0	0
1986	4	1	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	2	0	0	0	0	0	0	0	0
1988	6	0	3	1	1	0	0	0	0	2	0	1	0
1989	4	0	1	1	1	0	0	0	2	1	0	1	0
1990	8	0	1	0	0	1	0	1	0	0	0	0	0
1991	5	2	1	2	1	0	2	0	0	1	0	3	0
1992	6	4	2	3	0	0	2	0	0	2	0	0	1
1993	9	2	0	1	1	1	1	1	2	2	0	0	0
1994	16	5	7	4	3	5	3	5	6	1	3	0	0
1995	17	6	3	4	0	2	3	1	5	0	1	0	1
1996	13	8	5	5	6	2	4	3	7	1	4	2	1
1997	25	9	11	9	4	5	8	4	14	2	3	4	2
1998	26	14	8	8	4	3	10	6	10	1	3	0	0
1999	23	8	8	3	2	2	4	5	11	0	2	2	0
2000	82	63	25	14	2	5	8	7	14	4	0	2	3
2001	23	28	9	4	4	2	3	6	6	3	1	5	3
2002	73	33	28	9	13	8	14	9	10	17	6	1	0
2003	78	63	15	10	7	14	12	18	15	15	3	3	6
2004	115	41	19	16	17	21	16	9	22	5	9	5	2
2005	164	67	23	20	21	25	18	11	24	6	8	6	5
2006	140	77	45	27	18	45	16	28	42	16	15	14	5
2007	190	117	47	36	36	38	33	27	32	44	16	5	6
2008	376	346	108	82	23	41	83	75	35	51	28	11	14
2009	346	470	145	118	58	48	104	30	60	60	50	41	31
2010	570	457	219	213	77	101	150	81	85	106	86	48	53
2011	840	628	250	289	100	148	285	108	122	78	110	62	92
2012	1128	687	356	370	164	235	297	192	216	125	103	90	82
2013	1693	762	471	362	258	283	361	287	230	234	234	145	67
2014	2321	921	491	454	423	311	315	358	325	229	223	235	151
2015	2265	921	540	489	420	399	345	369	390	384	185	158	226
2016	1803	826	567	588	405	295	276	302	368	350	143	139	226
2017	1937	1197	593	600	490	513	533	530	325	557	141	102	186
2018	1807	1161	701	592	597	599	261	311	353	278	348	245	181
2019	2025	1279	913	711	601	473	384	366	325	400	146	291	321
2020	1882	939	1077	704	616	521	429	388	411	308	329	282	199

Table 3. Number of publications by year by ASJC Categories (Part 2) *Colour represents the "intensity" based on the numbers of publication with blue as cold and red as hot.

Year	AGRI	MULT	MEDI	DECI	ECON	ARTS	PHAR	IMMU	PSYC	HEAL	NEUR	NURS	VETE	DENT
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	1	0	1	0	0	0	0	0	0	0	0	0
1994	1	0	3	0	0	0	1	0	0	0	0	0	0	0
1995	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1997	0	0	2	1	0	0	1	0	0	0	0	0	0	0
1998	0	0	2	0	0	1	1	0	0	0	0	0	0	0
1999	0	0	1	1	0	0	0	1	0	0	0	0	0	0
2000	0	0	0	2	0	0	0	0	0	0	0	0	0	0
2001	0	1	2	2	0	0	0	0	0	0	0	0	0	0
2002	0	0	2	0	0	1	1	0	0	0	0	0	0	0
2003	5	3	1	2	1	0	0	0	0	0	0	0	0	0
2004	3	0	5	3	0	1	1	3	0	0	0	0	0	0
2005	5	2	7	6	0	5	2	2	0	2	0	0	0	0
2006	5	9	5	3	1	2	2	4	0	0	0	1	0	0
2007	3	15	8	22	2	1	4	2	1	0	4	0	0	0
2008	9	17	11	2	2	4	3	5	0	1	1	1	0	0
2009	39	29	20	27	7	1	9	6	0	0	2	1	0	0
2010	38	65	20	31	9	5	16	2	10	2	1	0	0	1
2011	90	116	32	36	13	12	21	27	10	3	8	0	1	0
2012	58	97	30	26	19	26	26	29	5	2	1	3	1	2
2013	100	161	75	37	40	22	36	31	4	8	2	0	1	1
2014	112	123	63	34	57	64	45	41	9	9	8	0	0	3
2015	120	71	133	124	158	113	66	54	9	11	16	4	0	0
2016	132	101	73	80	60	92	59	33	14	14	15	3	1	0
2017	150	53	81	69	59	156	27	19	13	11	8	1	0	1
2018	120	53	132	113	81	30	32	25	12	7	5	1	0	0
2019	130	69	215	106	49	45	44	29	9	11	6	2	2	2
2020	202	122	114	104	70	30	127	39	17	11	5	11	4	0

Table 4. Number of publications, publication growth rate and number of researchers for each field (*Total publication from 1980 to 2020, CAGR is compound annual growth rate, number of authors derived from the corresponding set of publications based on unique Author ID).

ASJC Category	Total Publication	CAGR (%) 2010-2020	No. of Authors
Primary			
Engineering (ENGI)	20,031	14	3,299
Computer sciences (COMP)	11,142	8	2,360
High Potential			
Material sciences (MATE)	6,693	19	2,171
Physics and Astronomy (PHYS)	5,750	14	2,063
Environmental Science (ENVI)	4,376	26	1,964
Chemical Engineering (CENG)	4,146	20	1,693
Mathematics (MATH)	3,981	12	1,812
Potential			
Energy (ENER)	3,538	19	1,668
Chemistry (CHEM)	3,467	19	1,442
Social sciences (SOCI)	3,258	13	1,302
Biochemistry, Genetics and Molecular Biology (BIOC)	2,200	16	1,375
Earth and Planetary Sciences (EART)	1,904	22	884
Business, Management and Accounting (BUSI)	1,864	16	915
Agricultural and Biological Sciences (AGRI)	1,323	20	914
Multidisciplinary (MULT)	1,107	7	917
Medicine (MEDI)	1,039	21	788
Emerging			
Decision Sciences (DECI)	831	14	574
Economics, Econometrics and Finance (ECON)	629	26	384
Arts and Humanities (ARTS)	611	22	355
Pharmacology, Toxicology and Pharmaceutics (PHAR)	525	26	360
Immunology and Microbiology (IMMU)	352	39	262
Psychology (PSYC)	113	6	96
Health Professions (HEAL)	92	21	102
Neuroscience (NEUR)	82	20	94
Nursing (NURS)	28	N/A	36
Dentistry (DENT)	10	-100	11
Veterinary (VETE)	10	N/A	10

Table 5. Citations generated by publications by year by ASJC categories (Part 1) *Colour represents the "intensity" based on the numbers of publication with blue as cold and red as hot. (*Year refers to the year of citation received)

Year	ENGI	MATE	COMP	CENG	CHEM	ENER	ENVI	PHYS	BIOC	MATH	BUSI
<1990	12	12	0	0	0	0	0	16	0	1	0
1990	0	0	0	0	0	0	0	10	0	0	0
1991	1	1	0	0	2	0	2	7	0	0	0
1992	0	1	0	0	3	0	1	9	0	1	0
1993	0	0	0	0	2	0	1	3	0	0	0
1994	5	7	0	0	5	1	2	8	1	3	0
1995	2	4	0	6	8	8	2	8	0	0	0
1996	6	5	1	11	4	9	0	14	1	7	0
1997	14	11	1	15	32	13	13	12	12	7	1
1998	25	8	4	21	29	16	7	15	14	9	0
1999	13	13	5	18	54	14	9	14	12	7	1
2000	21	43	7	17	95	11	8	11	17	9	1
2001	28	43	17	25	74	15	13	12	17	9	3
2002	32	84	15	41	118	16	12	20	18	12	7
2003	59	108	24	46	116	17	12	29	25	15	7
2004	81	157	40	82	171	28	31	39	59	20	7
2005	123	209	59	106	248	36	35	60	63	45	30
2006	274	275	123	229	329	77	85	122	118	54	65
2007	353	327	156	243	333	68	114	130	136	73	94
2008	494	473	233	378	482	101	163	218	201	102	117
2009	819	663	393	522	628	148	304	339	314	157	176
2010	1681	1105	1001	765	862	273	409	614	452	346	183
2011	2549	1502	1591	1129	1286	462	672	860	606	555	235
2012	3924	2313	2240	1638	1716	822	1034	1476	835	790	298
2013	5441	3099	2906	2444	2569	1508	1498	2054	1124	1093	413
2014	8132	4435	3789	3536	3779	2867	2627	2946	1627	1576	627
2015	11045	5878	4740	4759	5133	4065	3870	4044	2065	1825	865
2016	14338	7482	5708	6402	6627	5765	5679	4699	2603	2180	1359
2017	18103	9208	7319	7892	8096	8051	7172	5899	3063	2628	2076
2018	23084	11343	9916	9903	9646	10054	9471	7271	3940	3129	2874
2019	30163	14673	13822	12403	11484	13227	12497	9615	4894	4173	3847
2020	36382	18399	16396	15319	13668	15818	16189	11812	5610	5200	5281

Table 6. Citations generated by publications by year by ASJC categories (Part 2) *Colour represents the "intensity" based on the numbers of publication with blue as cold and red as hot.

Year	EART	SOCI	AGRI	MULT	MEDI	DECI	IMMU	PHAR	ECON	ARTS	PSYC	HEAL	NEUR	NURS	DENT	VETE
<1990	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0
1995	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0
1996	0	5	1	0	0	0	0	0	2	0	0	0	0	0	0	0
1997	0	3	3	0	7	0	0	1	3	0	0	0	0	0	0	0
1998	1	5	3	0	6	0	0	1	2	1	0	0	0	0	0	0
1999	0	1	1	0	7	1	0	2	0	1	0	0	0	0	0	0
2000	1	5	3	0	4	0	0	3	1	0	0	0	0	0	0	0
2001	2	3	3	0	4	2	1	0	0	3	0	0	0	0	0	0
2002	1	3	2	0	6	2	1	2	0	3	0	0	0	0	0	0
2003	0	3	2	0	6	2	1	1	1	0	0	0	0	0	0	0
2004	0	6	3	2	13	11	0	4	0	5	0	0	0	0	0	0
2005	9	8	5	6	9	21	2	5	0	5	0	1	0	0	0	0
2006	11	5	10	31	14	31	8	12	0	4	0	1	0	0	0	0
2007	13	8	8	49	19	31	27	14	0	5	0	2	0	2	0	0
2008	28	10	20	37	24	38	41	13	2	5	2	7	5	3	0	0
2009	34	34	29	36	61	69	40	28	7	9	3	7	7	1	0	0
2010	88	100	68	83	110	105	58	41	12	10	4	14	11	1	0	0
2011	176	156	147	177	135	104	75	72	17	17	10	14	8	1	0	2
2012	306	272	285	228	207	165	153	127	33	19	21	15	11	6	1	3
2013	385	375	386	383	270	172	178	160	74	58	38	34	11	4	12	10
2014	707	674	576	461	330	263	236	225	118	157	51	42	7	13	17	3
2015	1107	883	808	564	469	406	372	269	181	180	63	78	33	16	14	5
2016	1522	1185	1142	711	665	519	578	384	280	237	103	88	69	25	17	8
2017	1794	1637	1539	958	834	687	724	535	415	360	158	142	115	27	20	5
2018	2473	2670	1921	1114	1155	868	824	615	626	594	219	194	170	40	22	5
2019	3919	3731	2609	1380	1447	1177	877	812	849	654	300	242	191	46	17	7
2020	5323	4874	3477	1735	1988	1340	962	1148	1215	704	387	259	192	53	20	13

Table 7. Citations per publications for the UTM's top 10 ASJC categories (based on total publications).

Year	ENGI	COMP	MATE	PHYS	ENVI	CENG	MATH	ENER	CHEM	SOCI
2010	11.8	8.9	18.3	9.5	26.2	31.4	9.2	20.6	38.5	6.3
2011	10.8	8.7	20.5	10.7	34.5	31.6	8.1	42.0	33.8	9.0
2012	13.1	8.1	19.9	14.6	31.6	27.9	9.7	33.6	33.1	7.4
2013	10.6	7.5	18.1	15.8	25.5	24.4	6.0	29.9	29.9	6.1
2014	8.9	7.4	19.1	15.6	19.1	25.5	7.5	25.2	26.0	7.9
2015	8.9	8.7	18.7	11.7	23.1	24.3	6.6	24.4	23.7	5.7
2016	8.3	7.5	13.4	8.7	17.2	16.9	7.9	25.4	16.5	5.4
2017	6.6	5.1	9.0	7.4	8.8	9.3	3.3	12.1	11.5	4.2
2018	5.9	5.2	7.1	5.9	8.8	8.0	4.4	11.7	8.0	6.5
2019	3.0	3.0	4.0	3.8	5.0	5.2	3.0	6.7	6.3	2.7
2020	0.8	1.0	0.8	0.9	1.4	1.5	1.1	1.6	1.5	0.8
2021	0.2	0.3	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.0

Most influential papers

The most influential papers are determined based on the top ten papers with the highest citation number from the best ten fields in UTM (by publication count), i.e., Engineering (ENGI), Computer Science (COMP), Material Sciences (MATE), Physics and Astronomy (PHYS), Environmental Sciences (ENVI), Chemical Engineering (CENG), Mathematics (MATH), Energy (ENER), Chemistry (CHEM) and Social Sciences (SOCI). The most influential papers are listed in Figure S1 (Supplementary information). Apparently, some of the influential papers were ranked top five in more than one field, suggesting that the papers could be constituted as multidisciplinary. In addition, this finding also indicates the importance of multidisciplinary research to produce a more impactful publication. Review papers were excluded from this list regardless of the number of citations generated. Some of the review papers have to be removed manually due to the fact that Scopus did not categorize them as such.

The top ten most influential papers of UTM from top ten fields with the highest citation numbers is analysed in the present study. The most prominent keywords are extracted as Figure 4. There are two main research clusters that represent the most influential papers produced by UTM; (1) photovoltaic-based research which is a renewable energy cluster (the green cluster) and (2) materials science and engineering cluster (the red cluster) which are the constituent of engineering and materials science fields.

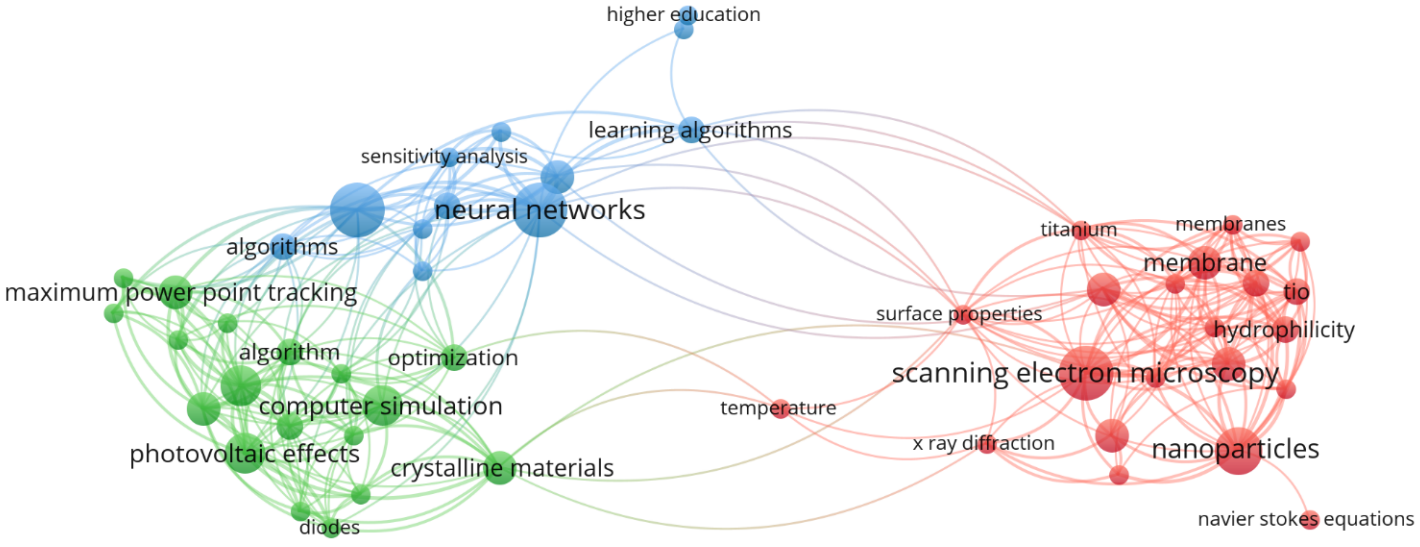

Figure 4. Co-occurrence of keywords from top ten of the most influential papers from top ten fields with the highest citation numbers. The shorter the distance between two nodes, the larger the number of co-occurrences of the two keywords.

Publication maturity

Publications generally need time to generate citations, although the time required for the publication to reach its peak citation varies from publication to publication (evidently in our dataset, Table 8). National Taiwan University (NTU) and Peking University (PKU) reported the highest citations generated sooner than later, at three years and two years, respectively [12]. Taking only the top ten ASJC categories (sorted by the number of publications), further analysis was done to determine the "time of maturity" for publications published by UTM; looking specifically at the changes of the citation generated per paper (Table 8). In order to observe the change of average citation per paper, the "moving" average of the citation per paper was generated using the formula (1). The moving average concept here is a little different from the generalized moving average often seen in stock market analysis where the denominator (number of years) is fixed. On the contrary, the denominator used in the calculation here is dynamic, hence ENGI in 2013 would be:

$$\frac{\sum_{n=start\ year}^{end\ year} citation\ per\ paper_n}{n} \tag{1}$$

$$\frac{11.8 + 10.8 + 13.1 + 10.6}{4} = 11.6$$

All the moving averages for each ASJC category every year were calculated. A buffer of (+/-) 20% was set to observe how far off the citation per paper values (in Table 8) compared to the corresponding moving average in the same year. Publication in Computer sciences (COMP) exhibits significant deviation from the moving average in 2017 (Figure 5 at -34%, more than the buffer set at -20%). Since the cut-off of the study is limited to 2020, the "maturity" (defined as the minimum year needed by the publication to not deviate more than 20% from the moving average citation per paper) for UTM in Computer sciences (COMP) is five years as denoted in Figure 5.

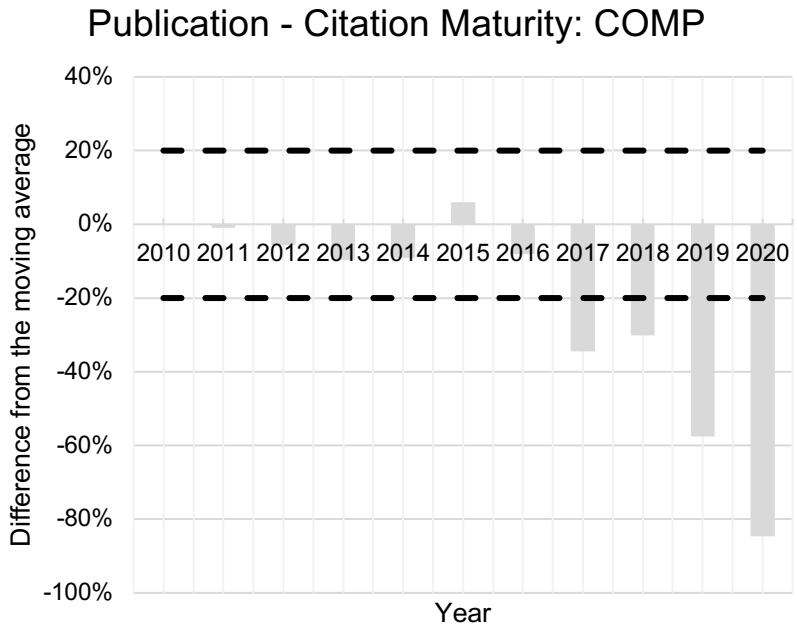

Figure 5. Publication - citation "maturity" analysis for COMP.

Some ASJC categories exhibited anomalies, such as Social Science (SOCI, Figure 6) and Environmental Science (ENVI, Figure 7), where some fluctuation occurred. However, the maturity was determined by consistent "out-of-buffer-zone" behaviour shown by the chart, which resulted in the maturity of five years for SOCI and six years for ENVI. Most of the top ten ASJC categories need at least five to six years, as shown in Table 8, to generate substantial citations so that the citation per paper stays within the buffer zone, except for Chemical Science (CHEM). The maturity analysis could be helpful for the university to set a range years before "revisiting" the impact of the publication published, more importantly recognizing the difference of maturity by field of research.

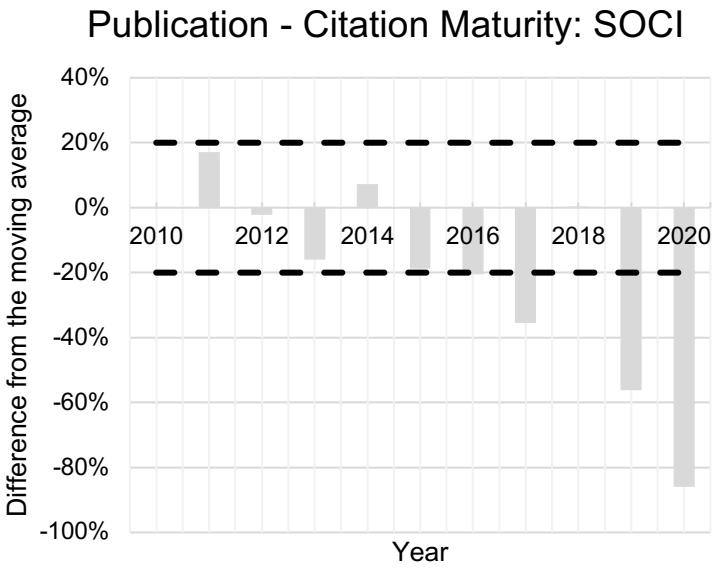

Figure 6. Publication - citation "maturity" analysis for SOCI.

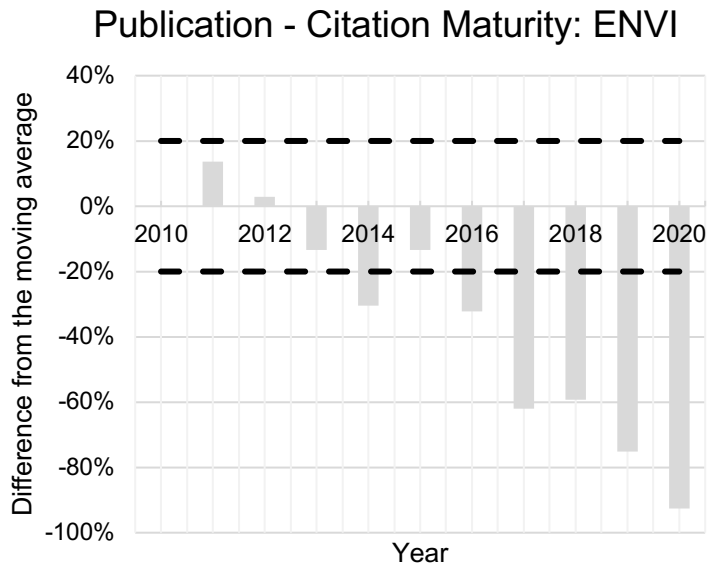

Figure 7. Publication - citation "maturity" analysis for ENVI.

Table 8. Maturity for UTM top ten ASJC category.

ASJC Category	Maturity (Years)
ENGI	5
COMP	5
MATE	6
PHYS	6
ENVI	6
CENG	6
MATH	5
ENER	5
CHEM	7
SOCI	5

Cluster analysis

Cluster analysis was executed on the entire dataset, on the 27 ASJC categories to determine the grouping based on two indicators; the number of citations and the number of publications. While the group in Table 4 is purely based on the preset ranges of publication volume, the clusters here are detected by the k-means algorithm, with a preset of five clusters. This results in five distinct groups (Figures 8, 9, and 10). Both Energy (ENER) and Chemistry (CHEM) were grouped in the first cluster, although ranked lower than Mathematics (MATH) in terms of publication volume due to their high value of citations generated. Mathematics (MATH) was grouped with the second cluster instead, while the rest of the fields were pretty much grouped similarly as in Table 4. The cluster detected could be helpful for UTM to identify different strategies for different clusters in developing the related niche.

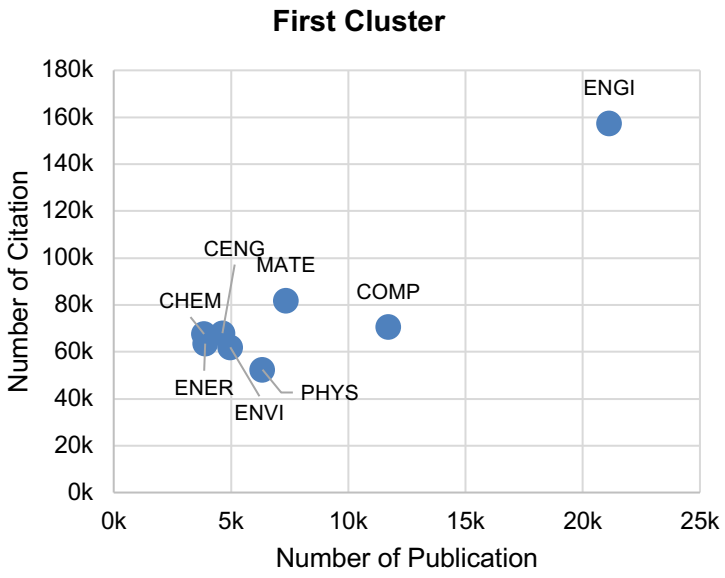

Figure 8. First cluster detected by k-means.

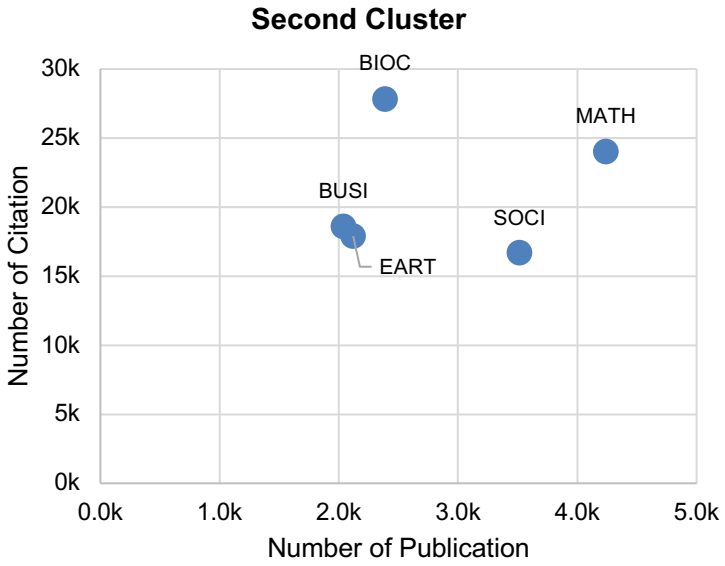

Figure 9. Second cluster detected by k-means.

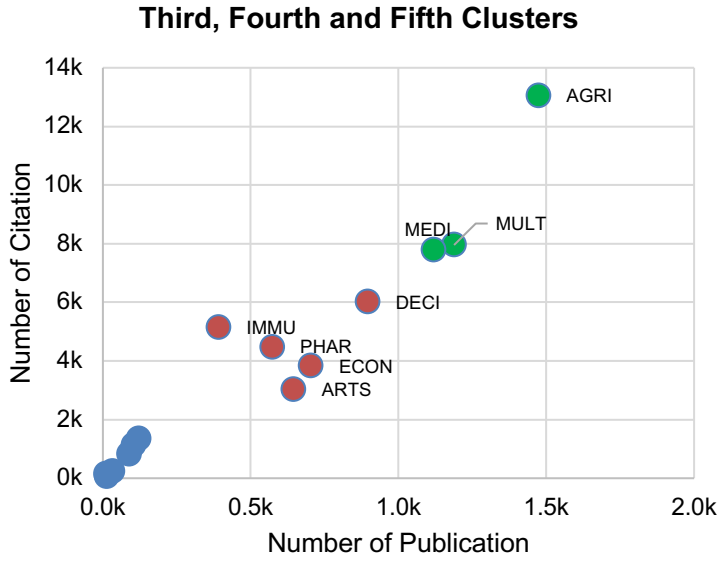

Figure 10. Third (green), fourth (orange) and fifth (blue) clusters detected by k-means

Research factors analysis

Further detailed analysis of the top ten fields in UTM is conducted in five research factors: number of publications, number of citations, number of authors, total equipment allocation, and research talents. The analysis of all the top ten fields in terms of all the five research factors is presented in Figure S3 (Supplementary info). Based on the data obtained as shown in Table 9, some important fields show a favourable citation impact despite having a relatively moderate publication. In addition, Mathematics (MATH) and Social Sciences (SOCI) are the two fields among the top ten fields in UTM that could be further improved in terms of publication outputs (i.e., number of publications and citations) despite having a reasonable number of authors and talents as indicated in Figure 11(a). Another significant finding here is that despite having a lower number of authors and publications, Materials Sciences (MATE) has a higher number of citations in comparison to those of Computer Science (COMP) which has 36% higher

publication volume, as shown in Figure 11(b). In addition, Figure 11(b) also indicates that Material Sciences (MATE), Chemical Engineering (CHEM), Energy (ENER) and Chemistry (CHEM) have favourable citation numbers even though they possess relatively lower talents and publication numbers. This finding suggests the high potential of these four fields to obtain even more citations in the future, provided that the publication numbers of these fields can be further increased. Bear in mind that the number of citations could be increased by increasing the number of publications [13].

Table 9. The five research factors of the top ten ASJC categories in UTM. All values are normalized using the min-max approach.

ASJC Category	Authors	Publications	Citations	Talents	Equipment
ENGI	1.00	1.00	1.00	1.00	1.00
COMP	0.72	0.55	0.45	0.38	0.16
MATE	0.66	0.35	0.52	0.12	0.11
PHYS	0.63	0.30	0.33	0.04	0.04
ENVI	0.60	0.24	0.39	0.24	0.16
CENG	0.51	0.22	0.43	0.31	0.23
MATH	0.55	0.20	0.15	0.07	0.01
ENER	0.51	0.18	0.40	0.03	0.04
CHEM	0.44	0.18	0.43	0.07	0.07
SOCI	0.39	0.17	0.11	0.27	0.10

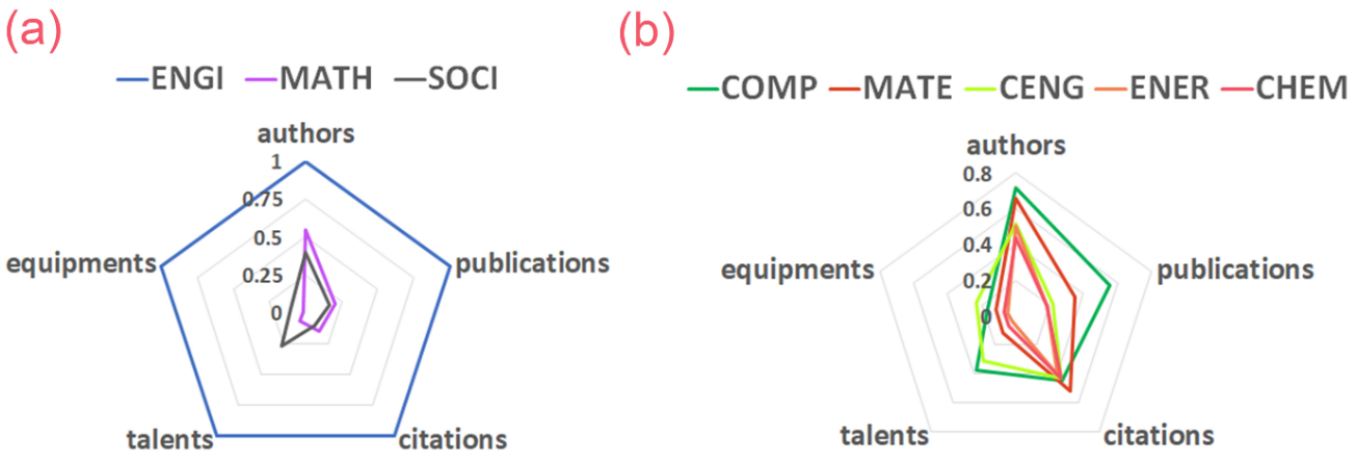

Figure 11. (a) The comparison between the engineering, mathematics and social science fields in terms of five research factors and (b) the analysis of research factors for materials science, chemical engineering, energy and chemistry fields.

UTM's publications in comparison to other Malaysia RU

This study also looks at the publication productivity of UTM in comparison to other Malaysia RU. Figure 12 depicts the total Scopus-indexed publications of all Malaysia RU beginning from the year 1996 to 2020. It can be deduced here that there is a remarkable increase in the publication trend starting the year 2007. This could be due to the research-university conferment to the RU in 2006, except for the UTM conferred its RU status in 2010. Despite all that, UTM publications have started to increase in 2007 and soared upwards more steeply after 2010 till 2015. Specifically, from the trend, it took about 3 years after 2010 (i.e., the conferment of RU status) for the UTM to be on a par with other RU. Then UTM needed another 3 years to surpass other RU except for Universiti Malaya (UM) in terms of publication as the UTM's publications thrived to the maximum from 2014 to 2015. In 2019, UTM was the top university with the highest number of Scopus-index publications surpassing all the RU, including the UM.

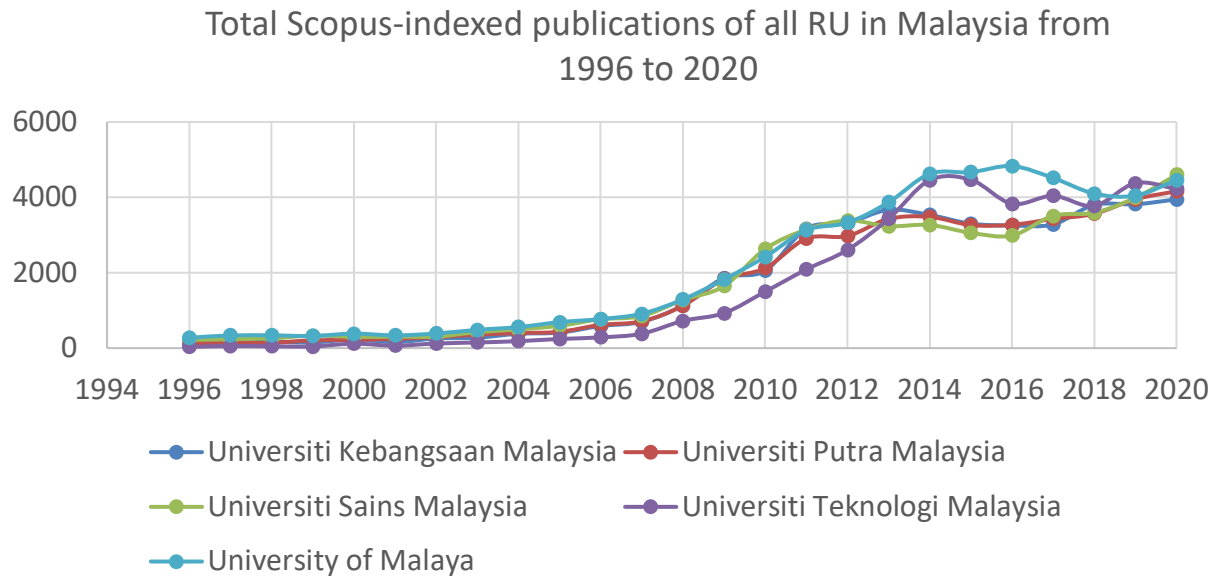

Figure 12. The total Scopus-indexed publications of UTM as compared to other RU in Malaysia from year 1996 to 2020.

In specific, there are four fields in which UTM propelled higher in a number of publications as compared to other RU from the year 2015 to 2020; 1) Computer science, 2) Engineering, 3) Energy, 4) Chemical engineering, as indicated in Figure S2 (Supplementary Info). As computer science and engineering fields are the top two in the number of publications among the fields in UTM, as previously shown in Table 2, this result suggests that both fields are the prominent champion field of UTM over other RU thus far. Table 10 highlights the number of Scopus-indexed publications, highest subject area and top published journals of all Malaysian RU. UM is top of the group with 52,891 publications, followed by USM (45,394) and UKM (47,347). UTM ranks fifth in terms of total publication numbers with 42,170 publications. The highest publication area for all RU is engineering, except for UPM of which the agriculture field is the main subject area in publication. Most of the UM and USM's Scopus publication is in the Acta Crystallographica Section E Structure Reports Online journal, while UPM and UKM are in AIP Conference Proceedings journal. UTM has most of the publications in its journal, Jurnal Teknologi.

Table 10. Number of publications, highest subject area and top journals of all Malaysian RU from year 1996 to 2020.

Research University	No. of publications (1996-2020)	Highest subject area in publications	Second highest subject area in publications	Top Journals
Universiti Malaya	52,891	Engineering (ENG)	Medicine (MEDI)	Acta Crystallographica Section E Structure Reports Online (2,259)
Universiti Teknologi Malaysia	42,170	Engineering (ENG)	Computer science (COMP)	Jurnal Teknologi (1,626)
Universiti Putra Malaysia	43,391	Agriculture (AGRI)	Engineering (ENG)	AIP Conference Proceedings (595)
Universiti Kebangsaan Malaysia	43,747	Engineering (ENG)	Medicine (MEDI)	AIP Conference Proceedings (1,613)
Universiti Sains Malaysia	45,394	Engineering (ENG)	Materials science (MATE)	Acta Crystallographica Section E Structure Reports Online (1,796)

Conclusion

Based on the above discussion, UTM has great strength in several important fields such as engineering, computer sciences, materials science, chemical engineering, energy, environmental science and physics and astronomy in terms of publication outputs (i.e., number of publications and citations). Among the top 10 fields in UTM, materials science, chemical engineering, energy and chemistry areas are seen to have a high potential to further excel in citation provided that the publication numbers of these fields are further increased. The publications outputs (i.e., number of publications and citation) for some UTM fields are still considered low despite showing a promising publication growth in recent years and having a reasonable number of authors and talents. Besides, the top published journals of all the research universities (RU) could describe the impact of the research. On that account, the UTM research can be further enhanced in terms of quality to be published in a more impactful and prestigious journal. There is a need to enhance research quality to obtain a higher publication impact. Based on all the universities' top published journals, there is still plenty of room for research improvement to enhance the RU's publication impact, including UTM.

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