ISSN 1831-9424

European Commission

JRC TECHNICAL REPORTS

Weak signals in Science and Technologies in 2021

Technologies at a very early stage of development that could impact the future

Olivier Eulaerts, Geraldine Joanny, Sotiris Fragkiskos, Marcelina Grabowska, Stefano Brembilla, Davide Rossi, Gabriel Nicula, Sergio Perani

Joint Research Centre

EUR 31171 EN

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information
Email: JRC-TIM-SUPPORT@ec.europa.eu
https://www.timanalytics.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC 129501

EUR 31171 EN

PDF ISBN 978-92-76-55597-1 ISSN 1831-9424 doi:10.2760/700257 KJ-NA-31-171-EN-N

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Eulaerts et al., *Weak signals in Science and Technologies in 2021*, Publications Office of the European Union, Luxembourg, doi:10.2760/700257, JRC129501

Contents

Abstract

Early identification of today's emerging technologies is key for the design of new policies by policymakers, who need to be made aware of potentially disrupting technologies or scientific development as early as possible to develop well-fitted policies that secure both a stable business environment for industrial actors and a safe and secure society for citizens to live in.

This report is the third annual report on weak signals in technology and science published by the Joint Research Centre and presents a list of 93 weak signals in 2021. These early signs of emerging technologies or products were detected using text mining, clustering techniques and scientometric indicators applied on a corpus of peer-reviewed scientific publications (Scopus).

These 93 weak signals have been grouped in seven topics and online thematic dashboards are available to the user to further explore the weak signals.

Some observations can be made on the weak signals detected this year. First, Europe has been found to contribute significantly, in terms of scientific publications, to weak signals related to ICT, Societal issues, Medicine and Biotechnology, Agriculture & Environment.

For weak signals related to Engineering & Physics, the leadership of European organisations is not as strong but the EU is still well positioned when it comes to scientific publications in roughly half of the weak signals (e.g. for atomic scale manufacturing, spectrometry, twistronics or autonomous surface ships).

When it comes to weak signals related to Energy and Materials, Chinese organisations are clearly leading in terms of numbers of scientific publications. Nonetheless, Europe contributes significantly to 8 of the 29 signals (e.g. Calcium batteries, Multi energy grid, Nickelate superconductors or Twisted layer graphene).

Finally, looking at the patenting activity for the weak signals shows that the number of patents applications by European organisations is systematically behind those of China and the US. This is observed even for topics in which Europe has a clear leading role in scientific publications. Although some additional quality indicators could be considered to nuance this observation (differences in the quality of applications in different jurisdictions, extensions to additional territories, number of patents retrieved actually too low to draw a significant conclusion, software not patentable in Europe, etc.), this nevertheless confirms the trend that has been observed in the two previous JRC weak signal reports[1] i.e. that European R&D organisations active in the development of the reported weak signals are less prone to patent early-stage research and technologies than Chinese or US-based organisations.

[1] See references 9,10 and 11.

Acknowledgements

The authors would like to thank Ralf Herold, Ana Cruz, Barbara Zietek and Philip Hines from the Horizon Scanning, Regulatory Science and Innovation Task Force at the European Medicines Agency for their contribution to this report.

1 Introduction

Technology emergence

Considering the societal and market disruption potential related to the emergence of new technologies, their early identification is of strategic importance for the design of new policies at European and national levels[2]. In a time of accelerating technological change and hyperconnectivity, early awareness of potentially disrupting technologies or scientific development gives indeed policy makers more time to design well-fitted policies that secure both a stable business environment for industrial actors and a safe and secure society for citizens to live in[3,4]. In addition, the early design of policies that encourage and frame the development of emerging technologies can lead to new knowledge and new markets[5]. It is therefore not surprising that forward-looking activities have taken a growing role in policy-making processes since the 1990's[6]. Among other methods, technology foresight has gained a lot of momentum, mirroring the increasing pace of technological innovation and its deepening penetration into our daily life. In particular, technology foresight is central to support policy-making mechanisms in areas impacted by the development of these new technologies and innovations, which today is de facto most policy areas

Technology foresight aims at the early identification of emerging scientific and technological issues as its aim is to capture the development trends and frontier areas of future science and technology. Traditionally, technology foresight is performed through qualitative processes involving scientists, technologists, futurologists, and other experts. In the last decade, there has been a staggering interest among academics in the identification of emerging technologies through the use of data[7]. In that context, scientometric techniques are often considered to perform technology foresight[8]. Indeed, while historically scientometric methods have been mainly used in order to trace back academic journal citation, they can also be used nowadays to not only understand the past but also to forecast the future[9]. Scientometrics analyses are often performed using bibliometrics techniques as it allows the measurement of texts and information and enable researchers to explore, organize and analyse large amounts of data to identify 'hidden patterns'[10]. Bibliometrics techniques are based on applying mathematical and statistical methods to scientific publications, books and other media of communication[11] are used extensively in the quest for detecting emerging technologies[12,13].

2 Bakhtin, P., Saritas, O., Chulok, A. et al. Trend monitoring for linking science and strategy Scientometrics 111, 2059–2075 (2017).

3 Martin, B.R., Technology Analysis & Strategic Management, Volume 7, Issue 2, 1 January 1995, Pages 139-168, Foresight in Science and Technology.

4 Henry Small, Kevin W. Boyack, Richard Klavans, Identifying emerging topics in science and technology, Research Policy, Volume 43, Issue 8, 2014, Pages 1450-1467.

5 Martin, B. R. (1995). Foresight in science and technology. Technology Analysis and Strategic Management, 7(2), 139–168.

6 I. Miles, The development of technology foresight: a review, Technol. Forecast. Soc. Change, 77 (9) (2010), pp. 1448-1456.

7 Rotolo, D., Hicks, D., & Martin, B. R. (2015). What is an emerging technology?. Research policy, 44(10), 1827-1843.

8 Daim, T. U., Rueda, G., Martin, H., & Gerdsri, P. (2006). Forecasting emerging technologies: Use of bibliometrics and patent analysis. Technological forecasting and social change, 73(8), 981-1012.

9 Morris, S., DeYong, C., Wu, Z., Salman, S., & Yemenu, D. (2002). DIVA: a visualization system for exploring document databases for technology forecasting, Computers & industrial engineering, 43(4), 841-862.

10 M.J. Norton, Introductory concepts in information science ; Information Today Inc., for the American Society for Information Science, Medford, NJ: 2000, v, 127, [3] pp.

11 Pritchard A., Statistical bibliography or bibliometrics?, Journal of Documentation, 25 (4) (1969), pp. 348-349

12 John Mingers, Loet Leydesdorff; A review of theory and practice in scientometrics, European Journal of Operational Research,Volume 246, Issue 1, 2015, Pages 1-19.

Other scientometric approaches use for example patent databases to detect the emergence and maturation of technologies[14,15], text mining of online news articles from the Web[16], network analysis[17,18], the use of information extracted from internet[19], other alternative data sources like social media[20], or mixed approaches e.g. combining citations indicators and count of online clicks on scientific publications platforms to determine the prominence of scientific topics[21]. The recent contest organised by the Georgia Institute of Technology, where contestants applied more than 19 different scientometric techniques to predict highly active research topics using 10 years of scientific publications, shows how dynamic the field of data-driven technology foresight is today[22].

Technological foresight at JRC

Within the European Commission, the Joint Research Centre, acting at the interface between science and policy making, is the main provider of technological foresight studies to policy makers. At JRC, technological foresight is a multidisciplinary activity and combines a “qualitative” approach, involving expert’s opinions, and a data-driven “quantitative” approach involving hard data analysis.

Through its “qualitative” foresight activities, the JRC brings together relevant experts and stakeholders to develop anticipatory knowledge and collect insights on possible alternative futures. As many policy fields have a technological component, these scenarios for the future are used to support policy-makers with long-term implications and opportunities on technological development[23].

Broad and granular scanning of technology development are usually performed through qualitative foresight. In the spirit of Foresight 2.0 which foster complementary approaches to foresight studies[24], JRC started to develop in 2018 an in-house quantitative process for technology foresight. This data-oriented approach aims at detecting early signs of emerging technologies or of scientific developments (weak signals[25]) using a mix of text mining

13 Abercrombie, R.K., Udoeyop, A.W. & Schlicher, B.G. A study of scientometric methods to identify emerging technologies via modeling of milestones. Scientometrics 91, 327–342 (2012).

14 Changyong Lee, Ohjin Kwon, Myeongjung Kim, Daeil Kwon, Early identification of emerging technologies: A machine learning approach using multiple patent indicators, Technological Forecasting and Social Change, Volume 127, 2018, Pages 291-303.

15 Liu, S. J., & Shyu, J. (1997). Strategic planning for technology development with patent analysis. International journal of technology management, 13(5-6), 661-680.

16 Janghyeok Yoon, Detecting weak signals for long-term business opportunities using text mining of Web news, Expert Systems with Applications, Volume 39, Issue 16, 2012, p. 12543-12550.

17 Huang, L., Chen, X., Ni, X., Liu, J., Cao, X., & Wang, C. (2021). Tracking the dynamics of co-word networks for emerging topic identification. Technological Forecasting and Social Change, 170, 120944.

18 Fefie Dotsika, Andrew Watkins, Identifying potentially disruptive trends by means of keyword network analysis, Technological Forecasting and Social Change, Volume 119, 2017, p.114-127, ISSN 0040-1625,

19 Dirk Thorleuchter, Dirk Van den Poel, Weak signal identification with semantic web mining, Expert Systems with Applications, Volume 40, Issue 12, 2013, Pages 4978-4985, SSN 0957-4174.

20 X. Zhou et al., "Identifying and Assessing Innovation Pathways for Emerging Technologies: A Hybrid Approach Based on Text Mining and Altmetrics," in IEEE Transactions on Engineering Management, vol. 68, no. 5, pp. 1360-1371, Oct. 2021.

21 https://joint-research-centre.ec.europa.eu/system/files/2018-06/fta2018-paper-b3-rota.pdf

22 Alan L. Porter, Denise Chiavetta, Nils C. Newman, Measuring tech emergence: A contest, Technological Forecasting and Social Change, Volume 159, 2020.

23 See for example the 2022 Strategic Foresight Report “Twinning the green and digital transitions in the new geopolitical context” at https://ec.europa.eu/info/strategy/strategic-planning/strategic-foresight/2022-strategic-foresight-report_en#documents

24 Schatzmann, J., Schäfer, R. & Eichelbaum, F. Foresight 2.0 - Definition, overview & evaluation. Eur J Futures Res 1, 15 (2013).

25 Mari Holopainen, Marja Toivonen, Weak signals: Ansoff today, Futures, Volume 44, Issue 3, 2012, Pages 198-205,

techniques and scientometric indicators applied on a corpus of peer-reviewed scientific publications or patents[26,27,28]. More information about the process can be find in Chapter 3 of the present report.

In addition to the weak signals reports published in 2019 and 2020[29,30,31], weak signals of technology emergence detected through this data driven process have also been used to feed various foresight processes in the Commission and related institutions (see for example the two public reports on border control technologies[32] and horizon scanning for nuclear safety and security[33]).

Tool and data

The 93 weak signals presented in this report are the result of a detection process ran by the JRC during the first quarter of 2022 on a corpus of peer-reviewed scientific publications using TIM Trends[34]. This software combines text mining techniques with computational and data visualisation means and has been specifically designed by JRC to detect weak signals of emerging technologies or new scientific topics.

The weak signals were detected by analysing data from the Scopus collection of scientific publications (from 1996 to 2020), following a methodology combining text mining, scientometrics and domain knowledge (read more about the methodology in section 3). Domain knowledge for the weak signals related to biotechnologies, medicine and health was provided by the European Medicine Agency. It is important to note that the list of weak signals is not exhaustive and may also contain signals that will never lead to new technologies or innovations.

Dashboards

Thematic dashboards are available online for deeper exploration of the weak signals, through visualisations based on the collection of documents (peer-reviewed scientific publications, patents and EU funded research projects) associated to each of them. The dashboards offer many features to quickly grasp the main characteristics of each signal: what the signal is about, which organisations are active in the field, what countries are involved, what is the dynamics and the trajectory of the research, etc. The dashboard have been set up in the TIM Technology system[35] and can be accessed here:

---

26 G. Joanny, S. Perani, O. Eulaerts, Detection of disruptive technologies by automated identification of weak signals in technology development. Proceedings of the ISSI, International Society for Scientometrics and Informetrics (2019), pp. 2644-2645.

27 A. Moro, E. Boelman, G. Joanny, J.L. Garcia, A bibliometric-based technique to identify emerging photovoltaic technologies in a comparative assessment with expert review, Renewable Energy, 123 (2018), pp. 407-416

28 A. Moro, G. Joanny, C. Moretti, Emerging technologies in the renewable energy sector: a comparison of expert review with a text mining software, Futures, 117 (2020), Article 102511

29 Eulaerts O., Joanny G., Giraldi J., Fragkiskos S., Perani S., Weak signals in Science and Technologies - 2019 Report, EUR 29900 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12386-6.

30 Eulaerts O., Joanny G., Perani S., Weak signals in Science and Technologies 2019 - Analysis and recommendations, EUR 30061 EN, Publications Office of the European Union, Luxembourg.

31 Eulaerts et al, Weak signals in Science and Technologies –Weak signals in 2020, EUR 30714 EN, Publications Office of the European Union, Luxembourg.

32 Eulaerts, O. and Joanny, G., Weak Signals in Border Management and Surveillance Technologies, EUR 31126 EN, Publications Office of the European Union, Luxembourg, 2022.

33 Tanarro Colodron, J., Simola, K., Simic, Z., Cihlar, M., Gerbelova, H., Liessens, A. and Joanny, G., Horizon Scanning for Nuclear Safety, Security and Safeguards Yearly Report - 2020, EUR 30607 EN, Publications Office of the European Union, Luxembourg, 2021.

34 TIM Trends is a tool of the TIM analytics suite developed by JRC. Link to TIM analytics website: https://knowledge4policy.ec.europa.eu/text-mining/topic/tim_analytics_en

35 https://www.timanalytics.eu/TimTechPublic/main.jsp?dataset=s_1507

Engineering & Physics:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1857

Information and Communication technologies:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1853

Materials: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1856

Agriculture & Environment:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1852

Medicine & Biotechnology:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1858

Societal issues:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1854

Energy:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1855

Analysis & Visualisations

Scientific publications, patents and EU projects are retrieved for each weak signal and key data and indicators are calculated. Visualisations are provided for each individual signal and for all the signals belonging to the same topic.

- At weak signal level

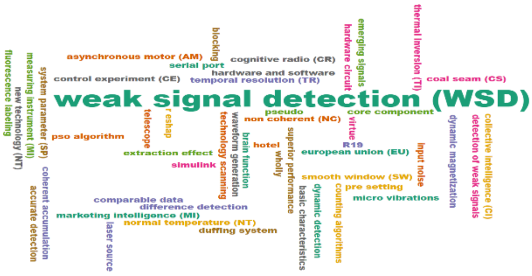
Three visualisations are presented for each weak signals (see figure 1):

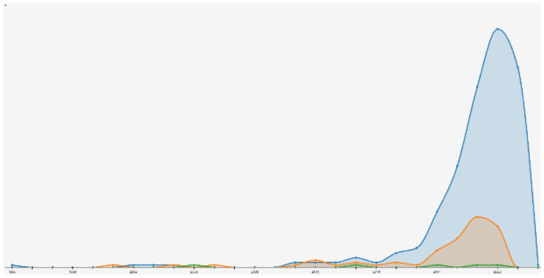
The Word cloud of relevant keywords allows to quickly grasp the important concepts related to the weak signal. Fifty keywords are generated by TIM's language processing algorithms to represent the set of documents as a whole. The size of the keywords in the cloud measures the "relevance" of the term in the set (see annex for the calculation of the relevance).

The Distribution of documents shows the distribution of documents retrieved for the weak signal with (X,Y)=(years,#documents). The sharper and higher the peak in the last 3 years, the most intense the weak signal is. The same colour code is used for all the weak signals: Blue = Scientific publications; Orange = Patents; Green = EU projects.

The List of main organisation provides the most active organisations for each weak signal. The number next to the organisation name is the number of documents in which the organisation was the entity of the author of a scientific publication, applicant of a patent or beneficiary of an EU project. The country in which the entity is located is also shown.

Figure 1: Visualisations at Weak Signal level





ERIDE INC	1.0	[United States of America]
U-BLOX AG	1.0	[Switzerland]
GMV	1.0	[Spain]
Universidad Autónoma	1.0	[Spain]
Korea Energy Economics Institute	1.0	[South Korea]
Korea Institute of Science and Technology Information	1.0	[South Korea]
European Space Agency	1.0	[Netherlands]
Joint Research Centre	1.0	[Italy]
Amirkabir University of Technology	1.0	[Iran]
Fraunhofer Institute for Production Technology IPT	1.0	[Germany]
RWTH Aachen University	1.0	[Germany]
EFS Pyrénées Méditerranée	1.0	[France]

- At topic level

Three visualisations are shown at topic level: two radar charts that allow to compare the signals together, and a double histogram comparing publishing and patenting between territories.

The first visualisation (figure 2 left) is a radar chart that shows four dimensions related to the characteristics of each signal: activeness; number of articles; number of patents and persistence.

Activeness is considered as a proxy for signal novelty. This indicator is defined as the ratio between the number of documents retrieved for a certain period and the total number of documents retrieved for the total period 1996-2021. The indicator displayed here is activeness[2019-2021] and corresponds to the ratio [#documents published during the period 2019-2021] / [#documents published during the period 1996-2021]. A high activeness score means that a high percentage of documents have been published during the recent selected period, and are therefore new and active.

Number of articles and *number of patents* indicate the intensity of research and market closeness respectively. They simply correspond to the number of documents for each type retrieved in the period 1996-2022.

Persistence indicates for how long the signal has being studied or researched. This indicator is calculated by counting the number of years for which documents relating to the signal were retrieved.

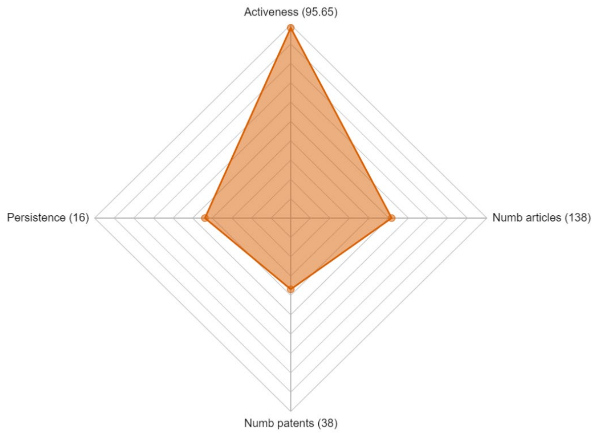
The maximum value for each of the axis of the first visualisation is the absolute maximum for said axis among all the signals for the topic considered. Figure 2 (left) shows a typical shape for a weak signal.

The second visualisation (figure 2 right) shows the contribution of various territories (contribution of organisations located in these territories). 7 axis are used to show the contributions from: EU, US, China, South Korea, UK, Japan, and the rest of the world (ROW).

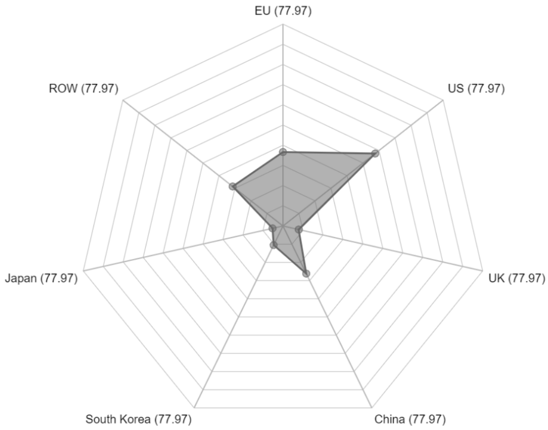
For example, a contribution of 45% from Japan means that there is at least one organisation from Japan in 45% of the documents related to the signal.

A different choice has been made for the maximum value of each axis in the territories radar: the maximum value for each axis is the absolute maximum value for any of the countries considered. In the example used here, the maximum value for each of the axis is 77.97%, which is the value for US for one of the weak signal in this topic. It is also important to note that because of documents with international collaboration, the sum of the contributions from each country might exceed 100% (as there might be several organisations from various territories involved in one publication or patent).

Figure 2: Visualisations at topic level



Radar visualisation of weak signal characteristics



Radar visualisation of WS territorial contributions

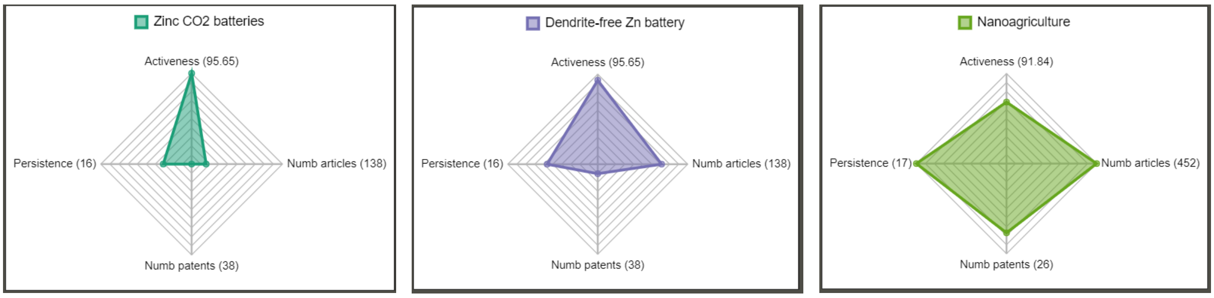
The use of radar visualisations introduces a geometrical element in the analysis of weak signals, which might be the first step towards automated graph analysis where variations of shapes with time would be monitored and trigger alarms when significant changes is observed. In particular, the visualisation using four indicators characteristic of a weak signal (figure 2 left) might be used in that perspective. Although all shapes and forms are observed, three main types of shapes can be distinguished (see figure 3):

- *narrow flat triangles* (high activeness, relatively low persistence, relatively low number of scientific publications and patents), that could be associated to very early weak signals;

- *broad flat triangles* (high activeness, average persistence and number of articles, low number of patents), which describes weak signals in development for some time:

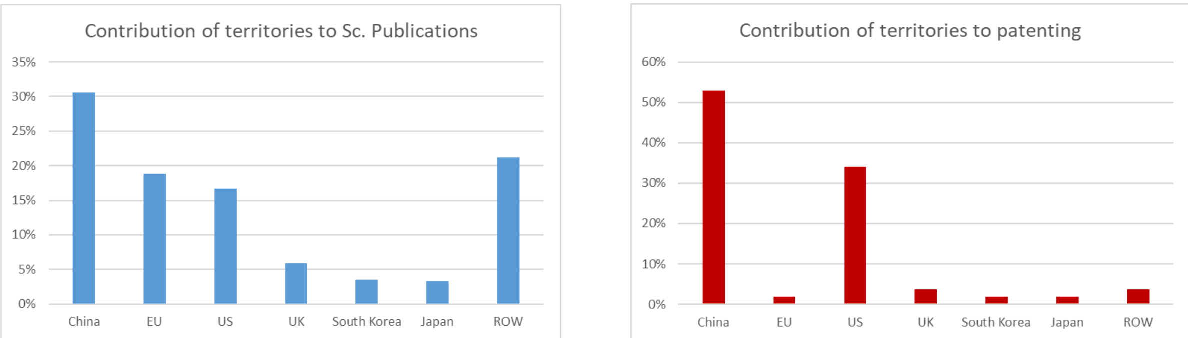
- *diamonds* (a high or relatively lower activeness, high persistence, number of articles and number of patents), mainly associated with “older” weak signals with intense R&D over the last years, typical of very promising technologies where patenting goes in parallel with publishing, or even precedes publishing.

Figure 3: Typical shapes for radar visualisation Weak Signal



A **third visualisation** (figure 4) at topic level completes the picture by showing the contributions of the same territories separately to publishing scientific articles and to patenting. Because patents from both individuals and organisations have been taken into account, and because the overall number of patents is usually small for weak signals, any conclusion made on patenting numbers should be made with caution and should at most be considered as indicating a mere emerging trend.

Figure 4: Visualisations at topic level "From publishing to Patenting"



2 Weak Signals

93 weak signals have been detected and grouped in 7 topics: Engineering & Physics, Information and Communication Technologies (ICT), Materials, Agriculture & Environment, Medicine and Biotechnology, Societal issues, and Energy. This grouping has been made by looking at most populated journal categories for each weak signal.

Numerous weak signals related to neural networks and SARS-coV-2 have also been detected but have not been considered for the purpose of this report. The following pages briefly present the weak signals for each topic.

Figure 5: List of the weak signals by topic

Medicine & Biotechnology
BiSCaO antiseptics
CELMoDs for cancer
Chemodynamic therapy
CRISPR based diagnostics
Direct RNA sequencing
DIY artificial pancreas
eCIRP
Facial genotyping
FAPI PET/CT
Firibastat
Flash radiotherapy
Flualprazolam
Heritable human genome editing
Inebilizumab
Intravascular Lithotripsy
Mavacamten
Molnupiravir
Nanocatalyst cancer therapy
Soluble immune checkpoints
Spatial and temporal omics
Urobiome

Engineering & Physics
Atomic scale manufacturing
Autonomous surface ship
Gas chromatography-ion mobilit
Nanoparticle exsolution
Optoelectronic synapses
Passive radiative cooling
Rotating detonation rocket engine
Space-air-ground integrated networks
Spintronic terahertz emitter
Twistronics

Materials
Eutectogel
High entropy carbides
Hybrid nanofluid
Ionic skin
Kagome superconductors
Martian concrete
Monolayer MA2Z4
Monolayer tellurene
Mxenes aerogels
Mycelium-based materials
Nb2CTx mxene
Nickelate superconductor
Organohydrogel
Quantum metasurfaces
twin graphene
Twisted bilayer graphene
ultrawide bandgap semiconductor
V2CTx Mxene

Energy
Aqueous Al ion batteries
Calcium batteries
Dendrite-free Zn battery
Hydrovoltaics
Mg metal batteries
Multi-energy microgrids
Potassium metal batteries
Sodium CO2 batteries
Zinc CO2 batteries
Zinc-organic batteries
Zinc ion capacitor

ICT
3D multi-object tracking
Cognitive digital twin
Directed Acyclic Graph blockchain
DNS-over-HTTPS
Dual blockchain
Earable computing
Edge artificial intelligence
External Human-Machine Interfaces
Few-shot object detection
Fog robotics
Health chatbot
Human digital twin
Internet of space things
Programmable wireless environments
Unpaired image translation
Versatile video coding
Wireless time sensitive network

Agriculture & Environment
Agrophotovoltaics
Biomass chemical looping gasification
Interfacial solar evaporators
Microplastics removal
Nanoagriculture
Nanofertilisers
Plasma agriculture
Plastic chemical upcycling

Societal issues
AI ethics
Fake news detection
Green AI
Misinfodemics
Peer-to-peer energy trading
Real world clinical outcome

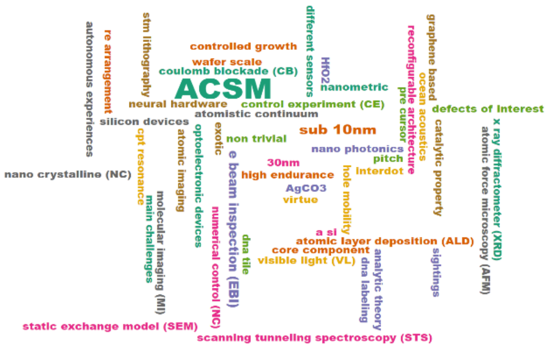
2.1 Engineering & Physics

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1857

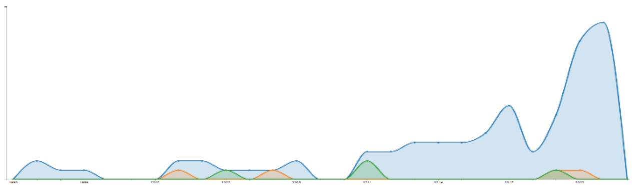
Atomic scale manufacturing

This concept has a large potential to disrupt technical field where the performance of materials are important. In atomic scale manufacturing, single atoms and molecules are precisely positioned to form flawless products

Figure 6: Visualisations for Atomic scale manufacturing



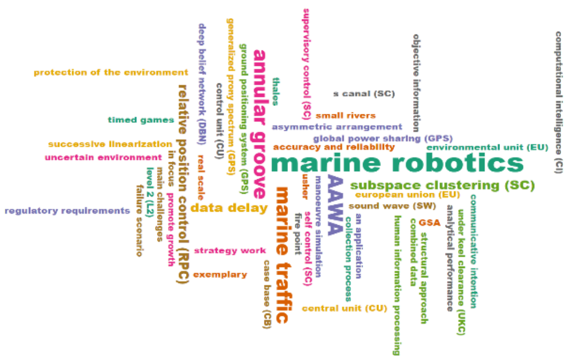
Osaka University	12	[Japan]
Tianjin University	11	[China]
University of New South Wales	9	[Australia]
University College Dublin	9	[Ireland]
Hunan University	5	[China]
EUVL Infrastructure Development ...	5	[Japan]
Chinese Academy Of Sciences	5	[China]
University of Science and Technology	4	[China]
TOKYO OHKA KOGYO CO LTD	3	[Japan]
St. Petersburg State Electrical Engi...	3	[Russian Federation]



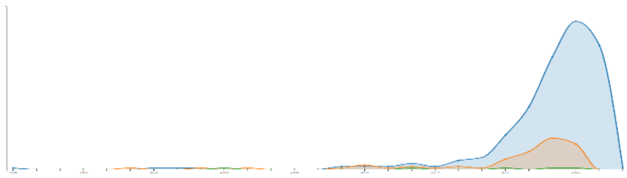
Autonomous surface ships

Autonomous ships are the future of the maritime transport industry, promising to overcome conventional vessels in terms of performance, safety and environmental impact. Many challenges remain for researchers before they become a reality, e.g. collision avoidance, GPS tracking reliability, or safe docking mechanism.

Figure 7: Visualisations for Autonomous surface ships



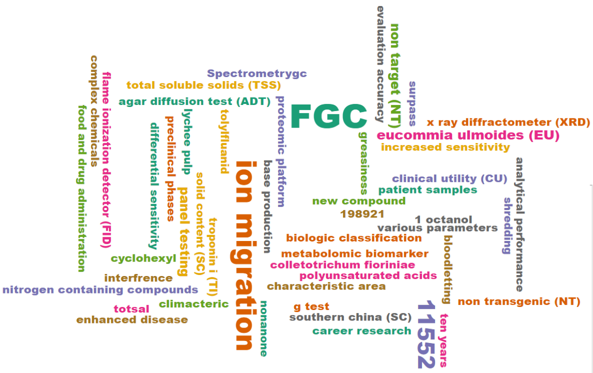
Norwegian University of Science and Technology	29	[Norway]
Delft University of Technology	25	[Netherlands]
Wuhan University of Technology	24	[China]
Gdynia Maritime University	19	[Poland]
Dalian Maritime University	19	[China]
Aalto University	15	[Finland]
STIFTELSEN SINTEF	8	[Norway]
Massachusetts Institute of Technology	8	[United States of America]
Korea Maritime and Ocean University	8	[South Korea]
Kongsberg Group	7	[Norway]



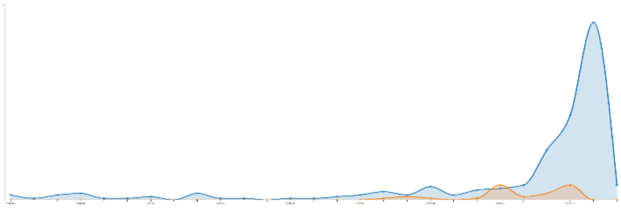
Gas chromatography-ion mobility spectrometry

GC–IMS is an emerging technique which seems particularly adapted to detect volatile organic components down to parts per billion (ppb) or even parts per trillion (ppt).

Figure 8: Visualisations for Gas chromatography-ion mobility spectrometry



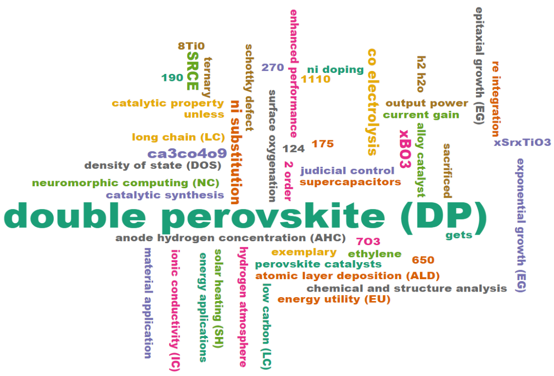
Universidad de Córdoba		15	[Spain]
Chinese Academy of Agricultural Sciences		13	[China]
China Agricultural University		13	[China]
Zhejiang University		12	[China]
University of Warwick		11	[United Kingdom]
Dalian Polytechnic University		11	[China]
Jiangsu University		10	[China]
Beijing Technology and Business University		10	[China]
Isfahan University of Technology		8	[Iran]
Air Force Research Laboratory		8	[United States of America]



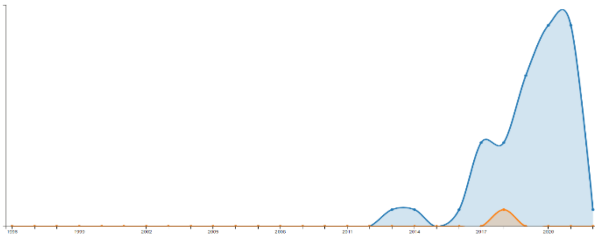
Nanoparticles exsolution

is a promising novel and time efficient method to build catalyst surface with a high degree of precision. It is emerging in recent years in the field of surface catalysis, in particular for applications in fuel cells.

Figure 9: Visualisations for Nanoparticles exsolution



Pohang University of Science and Technology		5.0	[South Korea]
TU Wien		4.0	[Austria]
Shenzhen University		4.0	[China]
School of Materials Science and Engineering		3.0	[China]
Massachusetts Institute of Technology		3.0	[United States of America]
Hong Kong University of Science and Technology		3.0	[Hong Kong]
Chinese Academy Of Sciences		3.0	[China]
Chemical Engineering		3.0	[United States of America]
University of St. Andrews		2.0	[United Kingdom]
University of Science and Technology		2.0	[China]

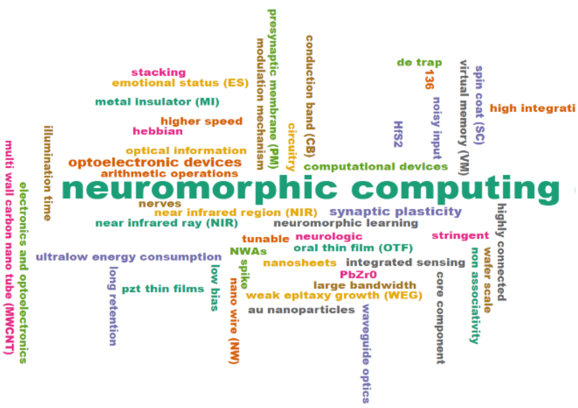


Optoelectronic synapses

These devices aim at mimicking biological synapses for applications in neuromorphic engineering, a new interdisciplinary subject that takes inspiration from biology, physics, mathematics, computer science, and electronic engineering to design artificial neural systems. Research in optoelectronic synapses is paving the way to disrupting technologies (e.g. vision systems, head-eye systems, auditory processors, autonomous robots).

Chinese Academy Of Sciences		8.0	[China]
Sungkyunkwan University		4.0	[South Korea]
Zhengzhou University		3.0	[China]
Tianjin University of Technology		3.0	[China]
Shanghai University		3.0	[China]
Peking University		3.0	[China]
Hong Kong Polytechnic University		3.0	[Hong Kong]
Central South University		3.0	[China]
Yonsei University		2.0	[South Korea]
University of Rochester		2.0	[United States of America]

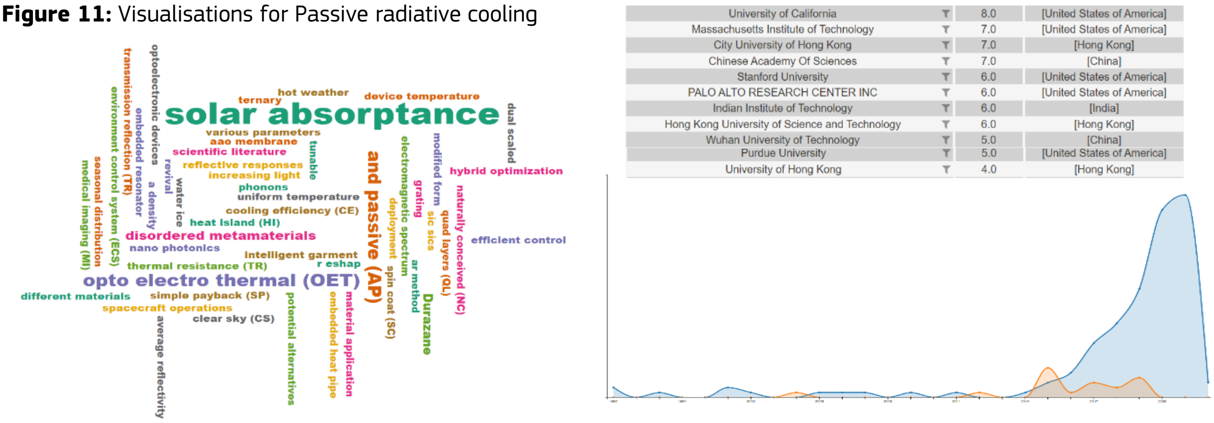
Figure 10: Visualisations for Optoelectronic synapses



Passive radiative cooling

is a promising strategy for saving energy that enables the cooling of the ambient temperature by synchronously reflecting sunlight and dissipating heat to the ultracold outer space through the atmospheric transparency window.

Figure 11: Visualisations for Passive radiative cooling

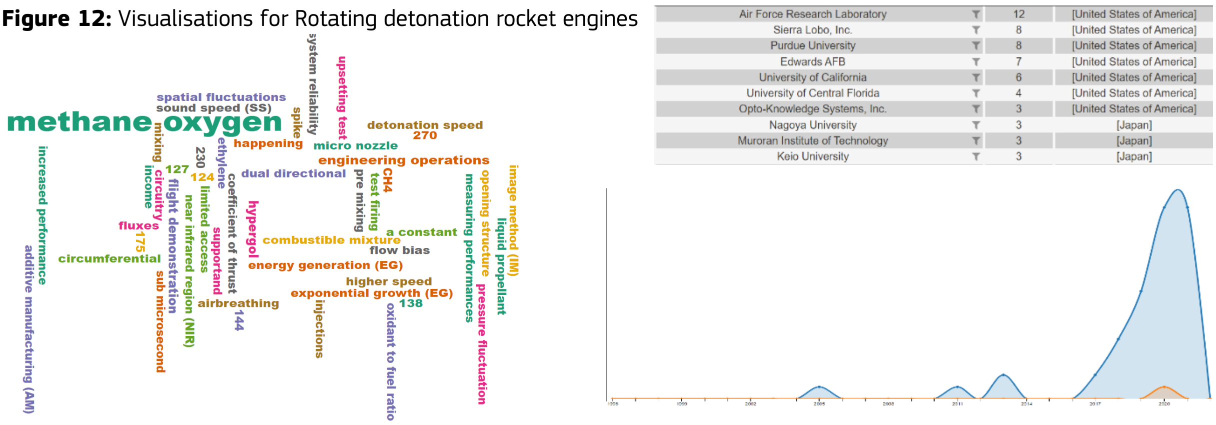


University of California	8.0	[United States of America]
Massachusetts Institute of Technology	7.0	[United States of America]
City University of Hong Kong	7.0	[Hong Kong]
Chinese Academy Of Sciences	7.0	[China]
Stanford University	6.0	[United States of America]
PALO ALTO RESEARCH CENTER INC	6.0	[United States of America]
Indian Institute of Technology	6.0	[India]
Hong Kong University of Science and Technology	6.0	[Hong Kong]
Wuhan University of Technology	5.0	[China]
Purdue University	5.0	[United States of America]
University of Hong Kong	4.0	[Hong Kong]

Rotating detonation rocket engines

Conventional propulsion systems for rockets have reached a plateau in performance. Rotating detonation engines technology is emerging as one of the most promising alternative, with increased thermodynamic performances that may significantly enhance current capabilities of existing rocket platforms.

Figure 12: Visualisations for Rotating detonation rocket engines

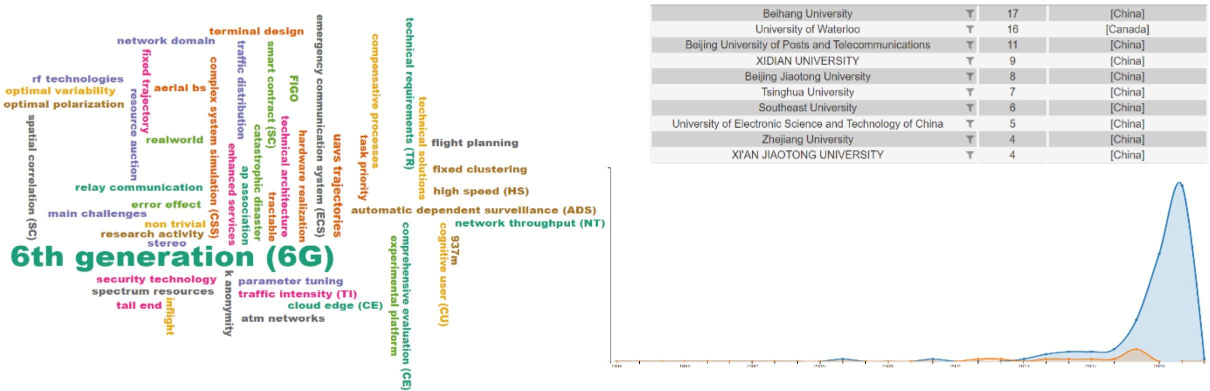


Air Force Research Laboratory	12	[United States of America]
Sierra Lobo, Inc.	8	[United States of America]
Purdue University	8	[United States of America]
Edwards AFB	7	[United States of America]
University of California	6	[United States of America]
University of Central Florida	4	[United States of America]
Opto-Knowledge Systems, Inc.	3	[United States of America]
Nagoya University	3	[Japan]
Muroran Institute of Technology	3	[Japan]
Keio University	3	[Japan]

Space-air-ground integrated network

These networks integrate satellite systems, aerial networks, and terrestrial communications in a promising architecture that will provide ubiquitous and ultra-reliable network connectivity.

Figure 13: Visualisations for Space-air-ground integrated network

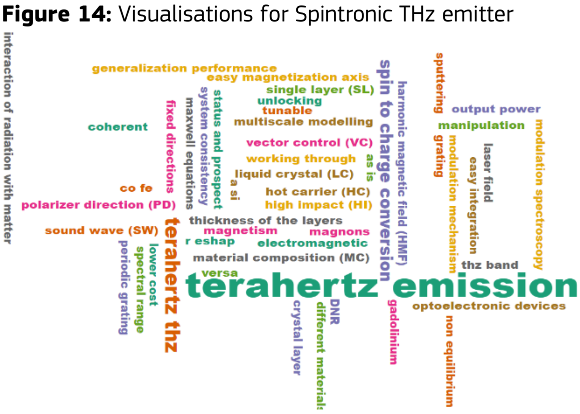


Beihang University	17	[China]
University of Waterloo	16	[Canada]
Beijing University of Posts and Telecommunications	11	[China]
XIDIAN UNIVERSITY	9	[China]
Beijing Jiaotong University	8	[China]
Tsinghua University	7	[China]
Southeast University	6	[China]
University of Electronic Science and Technology of China	5	[China]
Zhejiang University	4	[China]
XI'AN JIAOTONG UNIVERSITY	4	[China]

Spintronic terahertz emitter

Terahertz emission technology, i.e. the ability to generate and manipulate broadband chiral terahertz waves, shows great potential applications in e.g. material imaging, terahertz sensing, non-linear spectroscopy, diagnosis and security. The existing methods, however, often suffer from low efficiency, narrow bandwidth, or poor flexibility, and research on spintronic THz emitters is picking up in the recent years.

Figure 14: Visualisations for Spintronic THz emitter

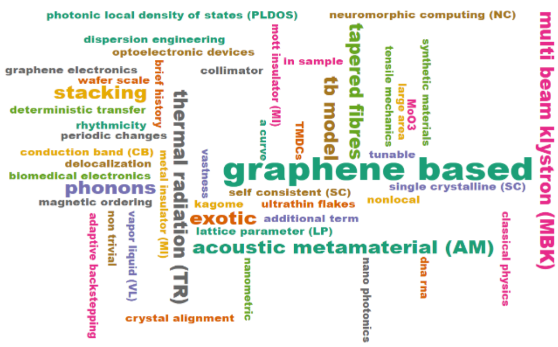


Beihang University		7.0	[China]
Chinese Academy Of Sciences		5.0	[China]
Nanjing University		4.0	[China]
University of Münster		3.0	[Germany]
University of Augsburg		3.0	[Germany]
Freie Universität Berlin		3.0	[Germany]
University of Victoria		2.0	[Canada]
University of Tokyo		2.0	[Japan]
University of Manchester		2.0	[United Kingdom]
University of Kansas		2.0	[United States of America]

Twistronics

is a contraction of the words twist and electronics and is a new area of research studying how angle modifications (the twist) between layers of two-dimensional materials change their electrical properties and electronic behavior.

Figure 15: Visualisations for Twistronics

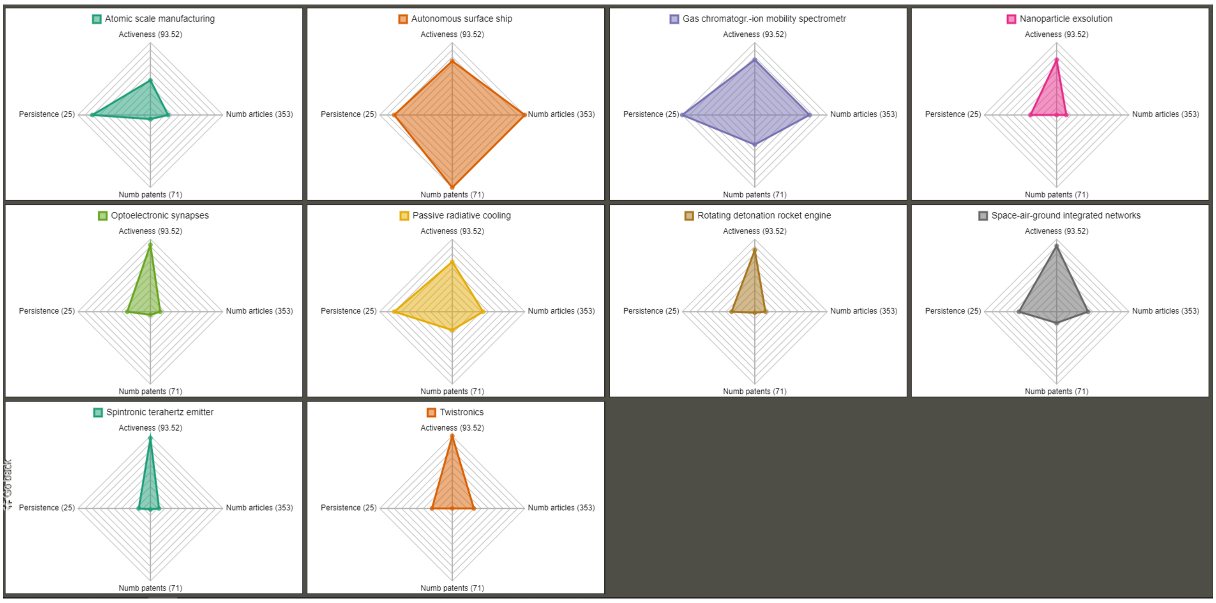


University of Manchester		12	[United Kingdom]
National Institute for Materials Science		11	[Japan]
Russian Academy of Sciences		10	[Russian Federation]
Chinese Academy Of Sciences		9	[China]
Harvard University		7	[United States of America]
National University of Singapore		6	[Singapore]
Barcelona Institute of Science and Technology		5	[Spain]
University of California		4	[United States of America]
New York University		4	[United States of America]
University of Texas at Dallas		3	[United States of America]

Radar Weak Signal

9 out of the ten weak signal in Engineering & Physics have a very high activeness. This is the case even for the three diamond-shaped signals: Autonomous Surface Ships, Gas Chromatography Ion Mobility Spectrometry, and Passive Radiative Cooling. We also observe a high persistence for these three signals, meaning that there is being research on these topics for many years but there is also a clear peak of R&D activity in the last years, reflecting a renewed interest for the technique or the technology leading to an acceleration of R&D. One of the weak signals, Atomic scale manufacturing, has an relatively low activeness (44), but still exhibits some characteristics of a weak signal, and was considered for this report due to the possible future impact of this manufacturing technique.

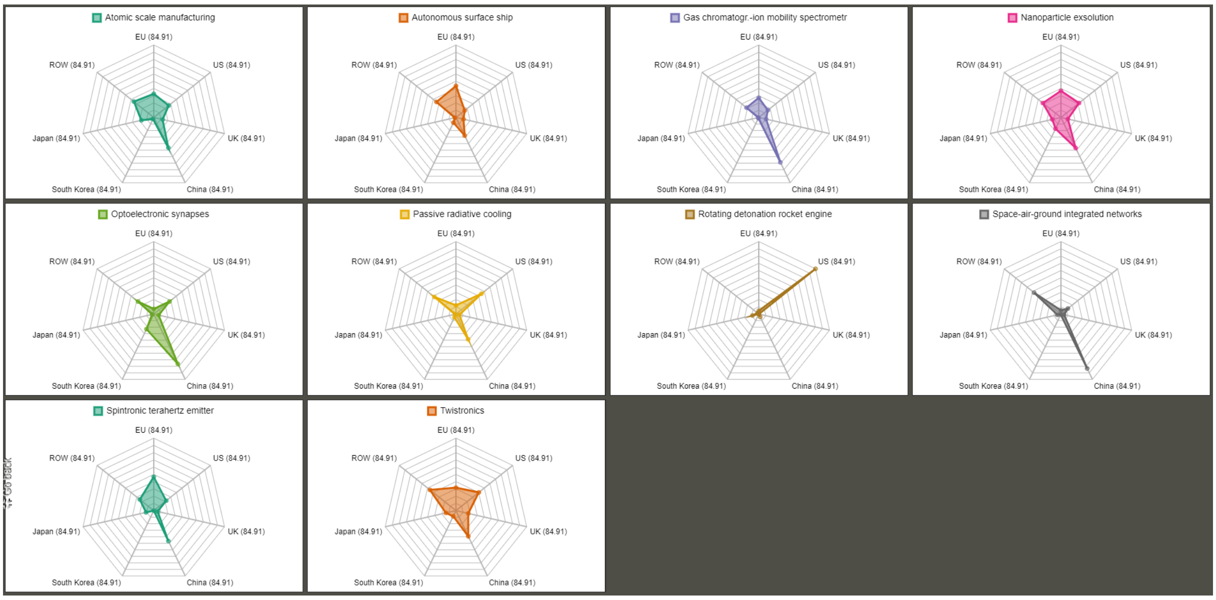
Figure 16: Radar Weak Signal for Engineering and Physics



Radar Territories

The EU is relatively well positioned in five of the weak signals (atomic scale manufacturing, gas chromatography ion mobility spectrometry, nanoparticles exsolution, spintronic terahertz emitters, twistronics) and leading in autonomous surface ships, with China or US leading in the development of all the other weak signals.

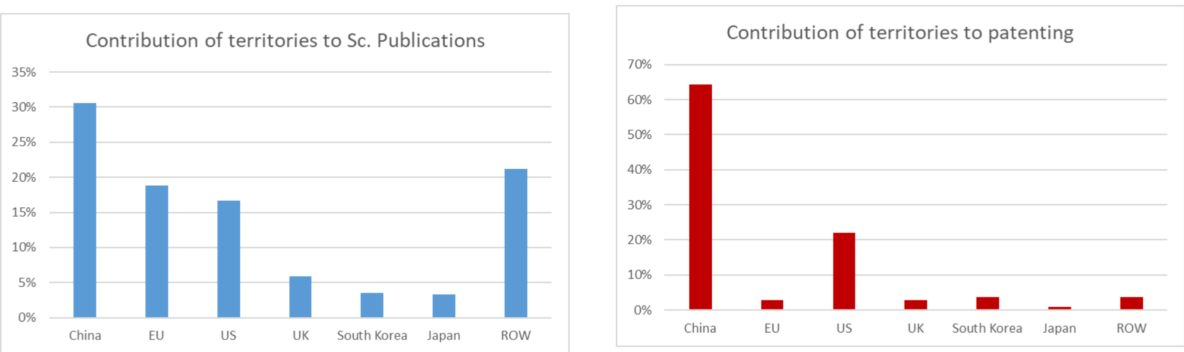
Figure 17: Radar territories for Engineering and Physics



From publishing to patenting

It appears clearly that the while Europe contributes strongly to scientific publications, of which 20% involve at least one R&D organisation from EU, the situation for patenting is very different, with China and the US strong leading in filing patents.

Figure 18: From publishing to Patenting for Engineering and Physics



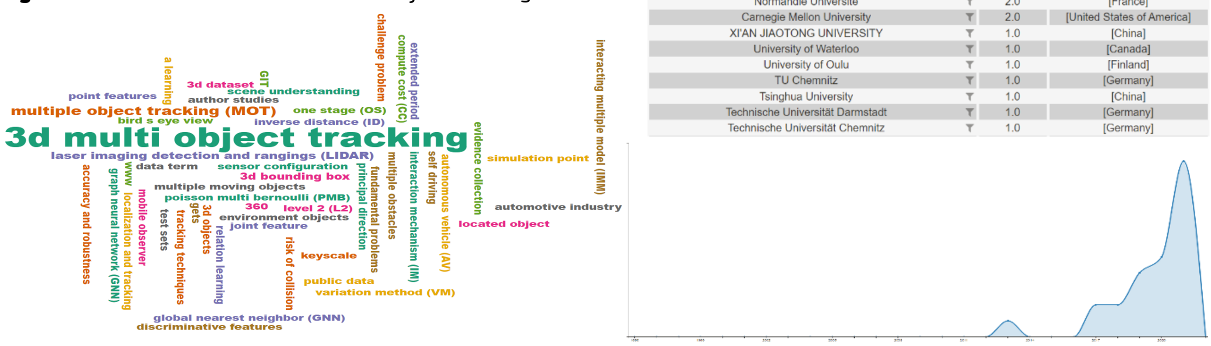
2.2 Information & Communication technologies

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1853

3D multi-object tracking

Robust and reliable 3D multi-object detection and tracking is an essential technological component for many applications in today's world like in autonomous driving, surveillance technologies, person tracking, autonomous robots, etc.

Figure 19: Visualisations for 3D multi-object tracking

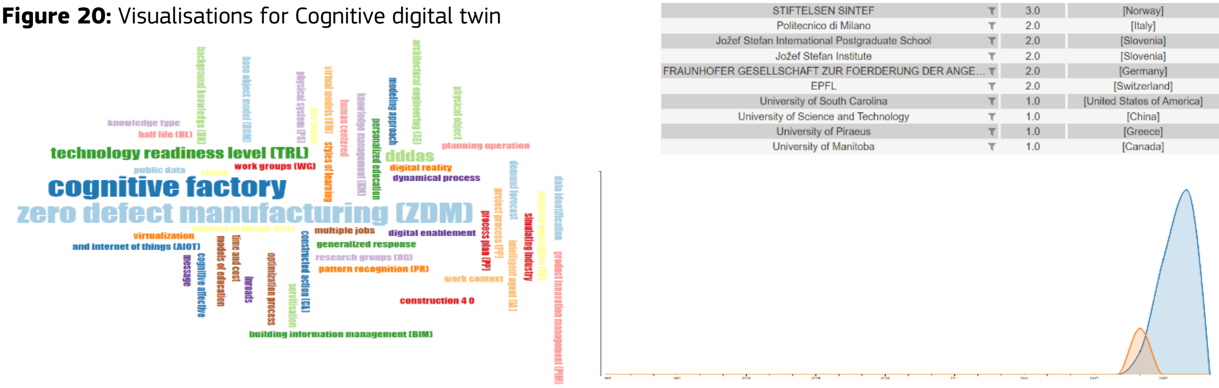


Universidad de Alcalá		2.0	[Spain]
Normandie Université		2.0	[France]
Carnegie Mellon University		2.0	[United States of America]
XI'AN JIAOTONG UNIVERSITY		1.0	[China]
University of Waterloo		1.0	[Canada]
University of Oulu		1.0	[Finland]
TU Chemnitz		1.0	[Germany]
Tsinghua University		1.0	[China]
Technische Universität Darmstadt		1.0	[Germany]
Technische Universität Chemnitz		1.0	[Germany]

Cognitive digital twin

This technology is the next stage of advancement of the concept of digital twin which aim at producing virtual replica of physical systems. Digital twins provide models and data for design, production, operation, diagnostics, and autonomy of machines and products. Cognitive digital twins will transform traditional digital twins into smart and intelligent agents that can access, analyze, understand, interpret and react to particular situations or physical states.

Figure 20: Visualisations for Cognitive digital twin

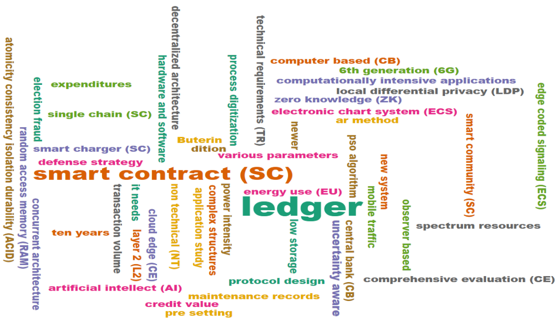


STIFTELSEN SINTEF		3.0	[Norway]
Politecnico di Milano		2.0	[Italy]
Jožef Stefan International Postgraduate School		2.0	[Slovenia]
Jožef Stefan Institute		2.0	[Slovenia]
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGE...		2.0	[Germany]
EPFL		2.0	[Switzerland]
University of South Carolina		1.0	[United States of America]
University of Science and Technology		1.0	[China]
University of Piraeus		1.0	[Greece]
University of Manitoba		1.0	[Canada]

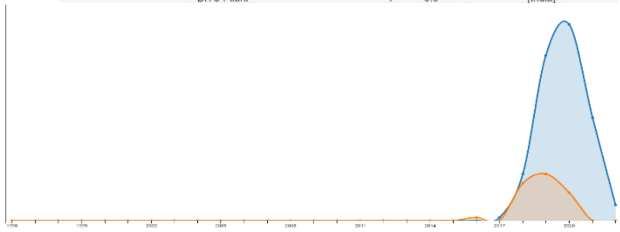
Directed Acyclic Graph

is an emerging distributed ledger technology. While some see it as an alternative to blockchain, others see it more as an enabler. The two technologies differ in both the ledger structures and consensus mechanisms.

Figure 21: Visualisations for Directed acyclic graph



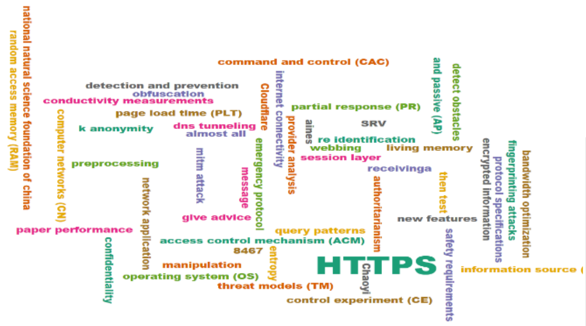
Shenzhen University	7.0	[China]
Beijing University of Posts and Telecommunications	7.0	[China]
Chinese Academy Of Sciences	6.0	[China]
University of Electronic Science and Technology of China	5.0	[China]
Shanghai Jiao Tong University	5.0	[China]
Shandong University	5.0	[China]
Northeastern University	5.0	[China]
Imperial College London	5.0	[United Kingdom]
Chinese University of Hong Kong	5.0	[Hong Kong]
BITS Pilani	5.0	[India]



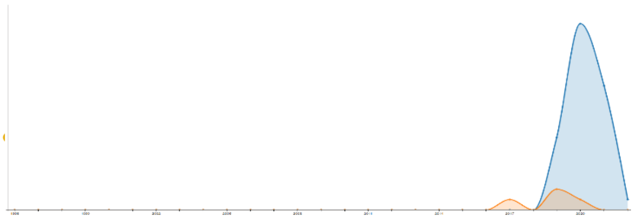
DNS over HTTPS

Is a protocol recently introduced to address the privacy concerns of exchanging plain text DNS messages over potentially malicious transit network. HTTPS is used to encrypt DNS messages, making the traffic indistinguishable from regular encrypted Web traffic, rendering active disruption by transit networks difficult.

Figure 22: Visualisations for DNS over HTTPS



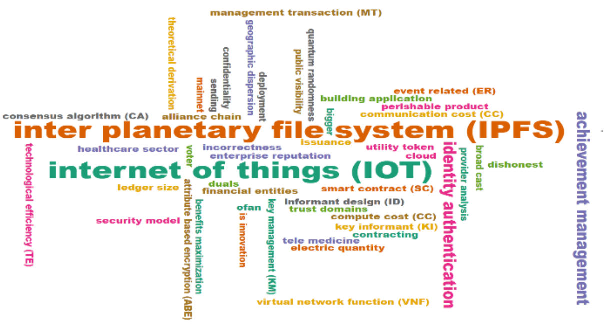
University of Chicago	3.0	[United States of America]
University of California	3.0	[United States of America]
Tsinghua University	3.0	[China]
Princeton University	3.0	[United States of America]
University of Illinois at Urbana-Champaign	2.0	[United States of America]
Ruhr-University Bochum	2.0	[Germany]
CTU in Prague	2.0	[Czech Republic]
China University of Mining and Technology	2.0	[China]
CESNET, ZAJMOVE SDRUZENI PRAVNICKYCH OSOB	2.0	[Czech Republic]
Virginia Tech	1.0	[United States of America]



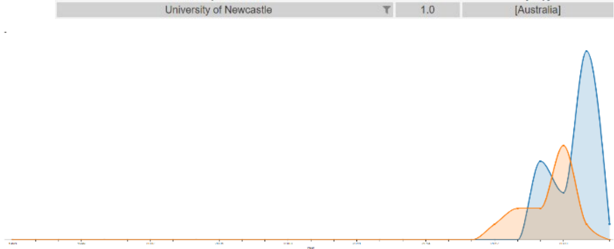
Dual blockchain

Blockchain technologies support the evolution of the Internet of Things by providing a secure way for communication between IoT devices. Dual blockchain architectures are explored to improve IoT security e.g. the safety of communication and transactions or the compression methods for storing data.

Figure 23: Visualisations for Dual blockchain



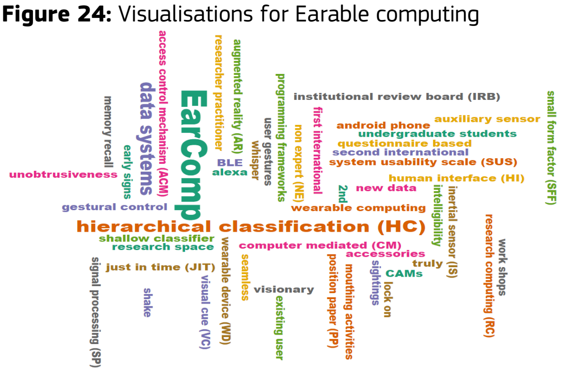
Zhejiang Province	1.0	[China]
Yangzhou University	1.0	[China]
Wuhan University of Technology	1.0	[China]
WIPRO LTD	1.0	[India]
VIT University	1.0	[India]
University of Technology Sydney	1.0	[Australia]
University of Sydney	1.0	[Australia]
University of Science and Technology	1.0	[China]
University of Salerno	1.0	[Italy]
University of Newcastle	1.0	[Australia]



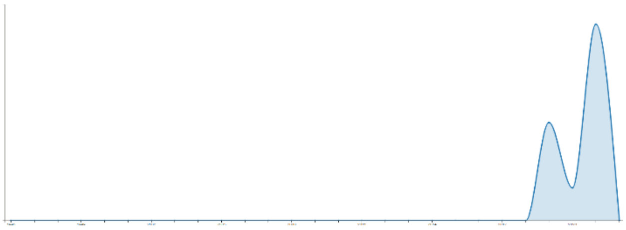
Earable computing

This new research field looks into the future of wearable devices, and is developing new hardware, software, and apps that will run on earable platform (earphones). The capabilities of such devices would include sensing human behaviour, acoustic augmented reality, digital assistants whispering of just-in-time information, tracking user motion and health.

Figure 24: Visualisations for Earable computing



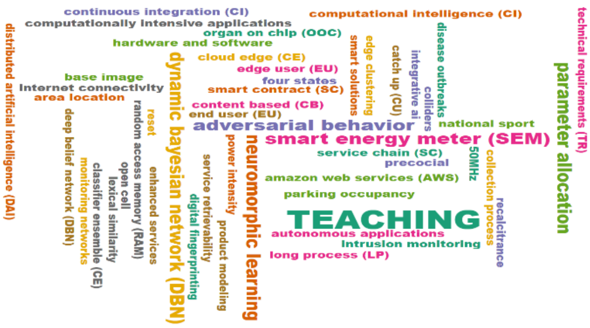
Università della Svizzera Italiana		2.0	[Switzerland]
NOKIA CORP		2.0	[Finland]
University of Science and Technology of China		1.0	[China]
University of Massachusetts Amherst		1.0	[United States of America]
University of Illinois at Urbana-Champaign		1.0	[United States of America]
University of Cambridge		1.0	[United Kingdom]
Technical University of Denmark		1.0	[Denmark]
Samsung Corp		1.0	[South Korea]
Rutgers University		1.0	[United States of America]
Ritsumeikan University		1.0	[Japan]
Microsoft Corp		1.0	[United States of America]



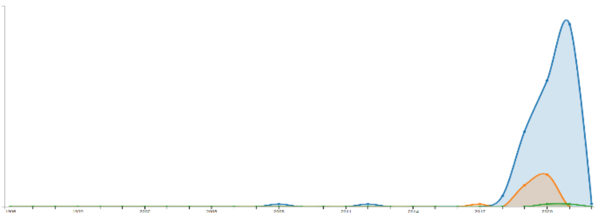
Edge artificial intelligence

Edge AI brings the decentralization of data and computing to a new level, providing for the functioning of AI on edge devices. Intelligence at the edge alleviates privacy concerns related to the streaming and storing of data to the cloud, it enables real-time fast operations on devices at the edge, and it brings AI services to remote areas, using edge devices to compensate poor networking infrastructures.

Figure 25: Visualisations for Edge artificial intelligence



University of Electronic Science and Technology of China		5.0	[China]
Université de Mons		4.0	[Belgium]
University of Liège		4.0	[Belgium]
STMicroelectronics Inc		3.0	[Italy, France]
Shanghai Jiao Tong University		3.0	[China]
King Saud University		3.0	[Saudi Arabia]
Zhejiang University		2.0	[China]
XIDIAN UNIVERSITY		2.0	[China]
XI'AN JIAOTONG UNIVERSITY		2.0	[China]
University of Thessaly		2.0	[Greece]

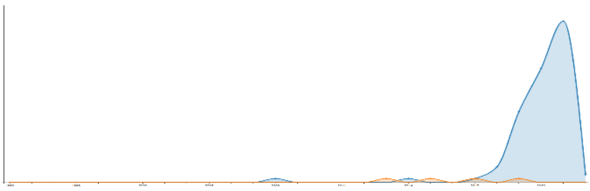


External Human-Machine Interfaces

One challenge to make autonomous driving a reality is the interaction between autonomous vehicles and other users of road infrastructures (pedestrians, bikers, skateboarders, etc.). External Human-Machine interfaces (eHMIs) are currently investigated to compensate for the communication problems that may arise between autonomous vehicles and other users.

Figure 26: Visualisations for External human-machine interfaces

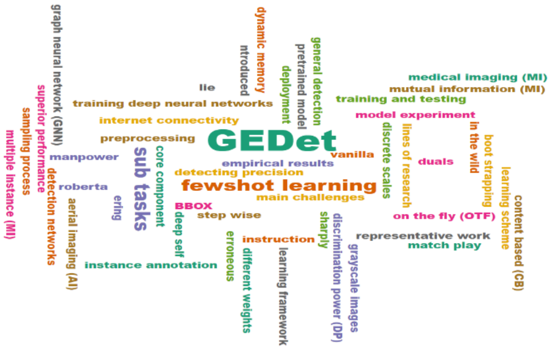
Delft University of Technology		13	[Netherlands]
Eindhoven University of Technology		12	[Netherlands]
Technical University of Munich		9	[Germany]
Ulm University		8	[Germany]
German Aerospace Center DLR		7	[Germany]
University of Leeds		6	[United Kingdom]
Technische Hochschule Ingolstadt		5	[Germany]
Stanford University		4	[United States of America]
Mercedes-Benz AG		4	[Germany]
Chemnitz University of Technology		4	[Germany]



Few-shots object detection

Localizing objects is a key step in object detection tasks in autonomous systems (vehicles, robots, etc.). High accuracy in localisation requires object-level annotations and are unable to detect objects of unknown categories. Few-shot object detection is a new method that aims at developing detectors that can detect and adapt to previously unseen objects with scarce or indirect annotated examples.

Figure 27: Visualisations for Few-shots object detection

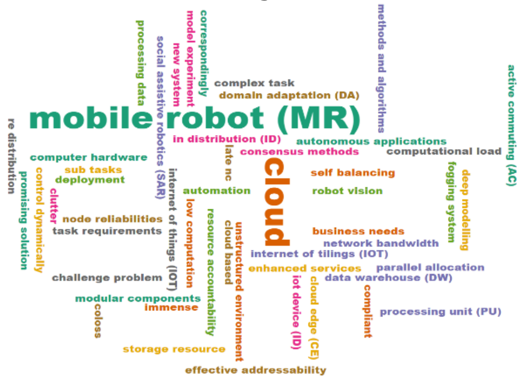


National University of Defense Technology	5.0	[China]
University of Illinois at Chicago	4.0	[United States of America]
Chinese Academy Of Sciences	4.0	[China]
Beijing University of Posts and Telecommunications	3.0	[China]
Beihang University	3.0	[China]
Zhejiang University	2.0	[China]
Xiamen University	2.0	[China]
Tencent	2.0	[China]
Korea University	2.0	[South Korea]
IBM Corp	2.0	[United States of America, Chi...
Huawei Noah's Ark Lab	2.0	[Hong Kong]

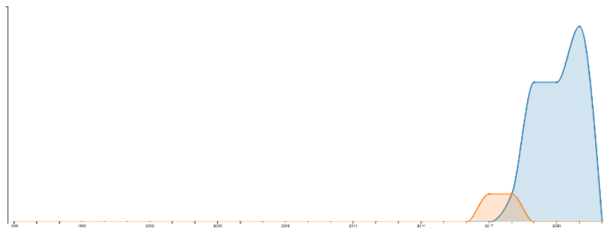
Fog robotics

is an emerging research area in the field of robotics that applies the concept of fog computing to robots. In addition to using computation capacities through cloud services, which can be costly in terms of network communication usage, robots are connected to each other and to devices at the edge, pushing part of the computation and memory needs on them.

Figure 28: Visualisations for Fog robotics



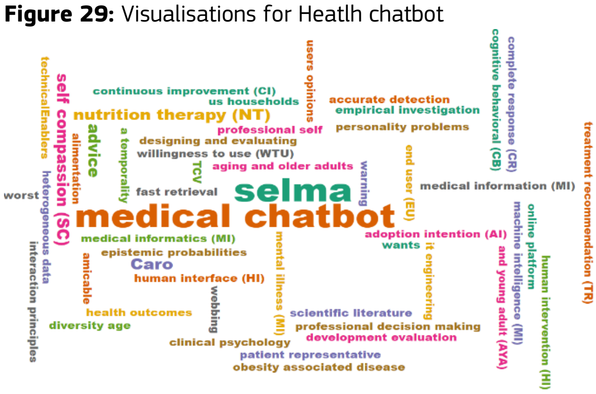
Southern Federal University	5.0	[Russian Federation]
University of California	4.0	[United States of America]
Vienna University of Technology	1.0	[Austria]
University of Turku	1.0	[Finland]
University of Technology	1.0	[Australia]
University of North Carolina at Chapel Hill	1.0	[United States of America]
University of Dhaka	1.0	[Bangladesh]
Tongmyong University	1.0	[South Korea]
Tata Consultancy Services	1.0	[India]
Shanghai Jiao Tong University	1.0	[China]



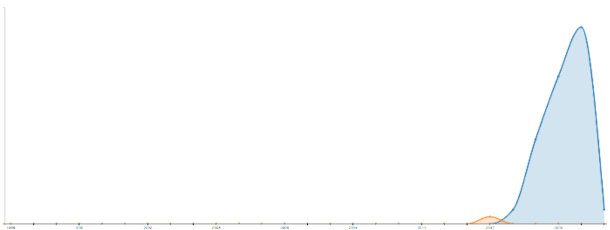
Health chatbots

are increasingly used in the field of Health and trigger research on various aspects: health data security and health data privacy, patients perception and acceptance, metrics for chatbot evaluation, health ethics, automation of diagnosis, etc.

Figure 29: Visualisations for Heatlh chatbot



Hamad Bin Khalifa University	5.0	[Qatar]
Bern University of Applied Sciences	5.0	[Switzerland]
University of Auckland	4.0	[New Zealand]
Jazan University	4.0	[Saudi Arabia]
University of Warwick	3.0	[United Kingdom]
University of Leeds	2.0	[United Kingdom]
University of Bergen	2.0	[Norway]
University of Applied Sciences	2.0	[Germany]
School of Engineering	2.0	[United States of America]
National Tsinghua University	2.0	[Taiwan]

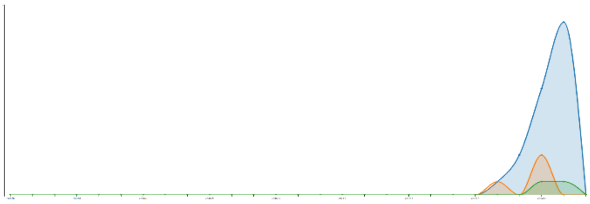


Human digital twin

Digital twins are virtual representations that serve as real-time digital equivalent of physical objects or processes, with the aim to support decision making. When applied to humans, digital twins are representations of individuals and dynamically reflect their properties (physiological status, life style, health status, etc.). Human digital twin technology is driving a radical transformation in the fields of medicine and public health, bringing highly personalised treatments and interventions in the future.

Figure 30: Visualisations for Human digital twin

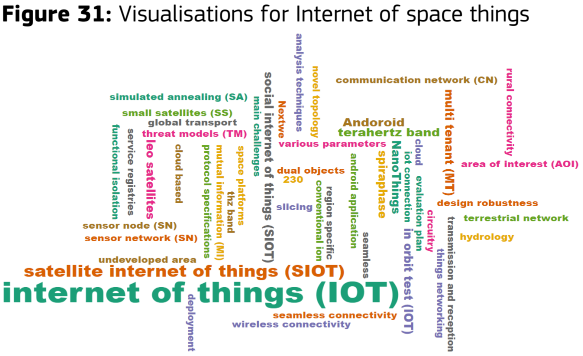
Shenzhen University	3.0	[China]
University of Stuttgart	2.0	[Germany]
Fraunhofer IAO	2.0	[Germany]
Delft University of Technology	2.0	[Netherlands]



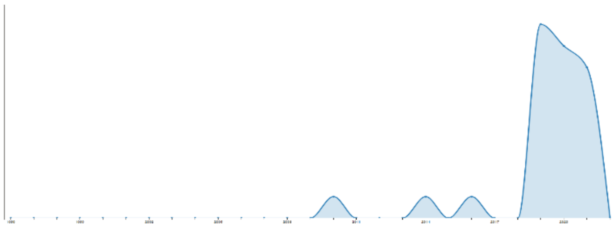
Internet of space things

is an extension of the “traditional” Internet of Things concept which is based on using satellites to serve terrestrial devices and aims at integrating the space segment into the global Internet of Things (IoT) infrastructure.

Figure 31: Visualisations for Internet of space things



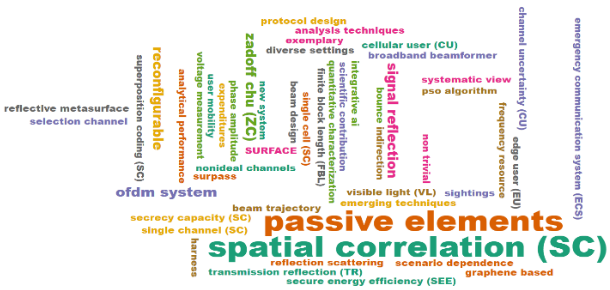
Georgia Institute of Technology	7	[United States of America]
Universidad de Chile	3.0	[Chile]
University of Warwick	2.0	[United Kingdom]
Universidad Tecnológica Metropolitana	2.0	[Chile]
Universidad Autónoma	2.0	[Spain]
Politecnico di Torino	2.0	[Italy]
Federal University of Santa Catarina	2.0	[Brazil]



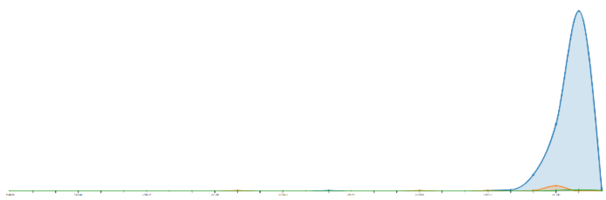
Programmable wireless environment

Programmable intelligent surfaces have triggered a lot of research interest over the last years. They hold the promise of green(er) wireless communication. They will have real-time reconfigurable properties to beamform wireless signals to desired destinations.

Figure 32: Visualisations for Programmable wireless environment



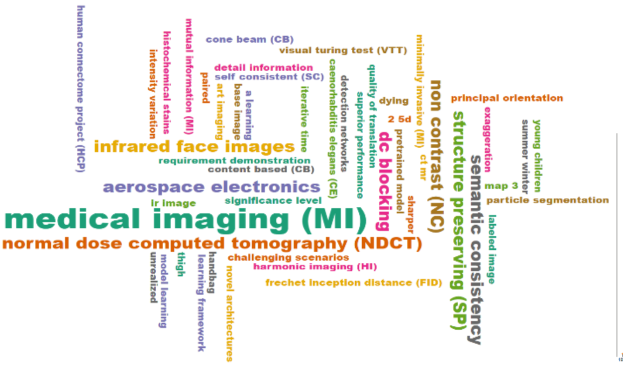
Southeast University	33	[China]
Université Paris-Saclay	32	[France]
University of Electronic Science and Technology of China	29	[China]
Singapore University of Technology and Design	17	[Singapore]
Zhejiang University	15	[China]
National and Kapodistrian University of Athens	15	[Greece]
King Abdullah University of Science and Technology	14	[Saudi Arabia]
University of Houston	12	[United States of America]
Princeton University	12	[United States of America]
Tsinghua University	11	[China]



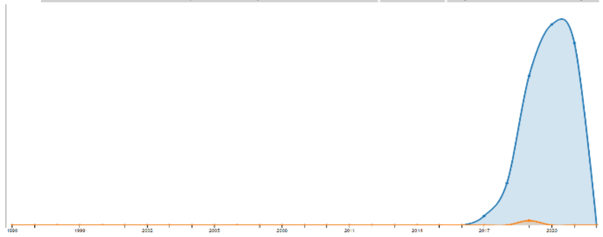
Unpaired image-to-image translation

is a class of vision and graphics problems where the goal is to translate an image from a source domain to a target domain in the absence of paired examples. It is a promising technique to e.g. accelerate and reduce the cost of medical imaging interpretation.

Figure 33: Visualisations for Unpaired image-to-image translation



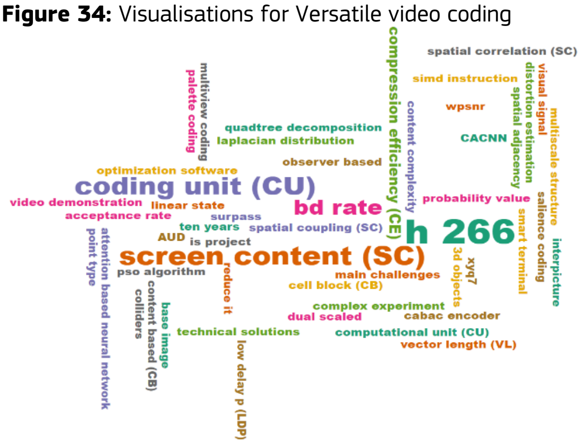
Chinese Academy Of Sciences	5.0	[China]
Mannheim University of Applied Sciences	4.0	[Germany]
Chinese University of Hong Kong	4.0	[Hong Kong]
University of Electronic Science and Technology of China	3.0	[China]
University of California	3.0	[United States of America]
Universitat Autònoma de Barcelona	3.0	[Spain]
Tel Aviv University	3.0	[Israel]
Peking University	3.0	[China]
Microsoft Corp	3.0	[United States of America]
KAIST	3.0	[South Korea]
Johns Hopkins University	3.0	[United States of America]



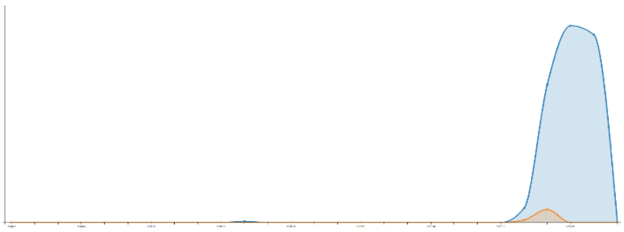
Versatile video coding

is the most recent international video coding standard that brings significant bit-rate reductions (around 50%) for the same subjective video quality, compared to its predecessor HEVC. Finalised in July 2020, VVC is now being implemented in devices and chipsets, explaining the peak of research papers on this technology.

Figure 34: Visualisations for Versatile video coding



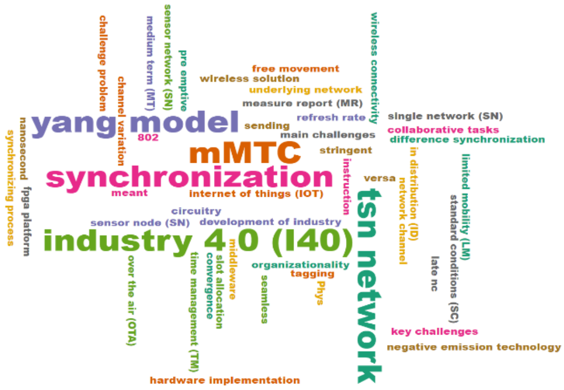
Peking University	22	[China]
CNRS	21	[France]
Fraunhofer Institute for Telecommunications	19	[Germany]
Fraunhofer HHI	15	[Germany]
City University of Hong Kong	15	[Hong Kong]
Chinese Academy Of Sciences	13	[China]
Nokia Technologies	12	[Finland]
University of Sfax	11	[Tunisia]
Tencent	11	[China]
QUALCOMM TECH INC	11	[United States of America]



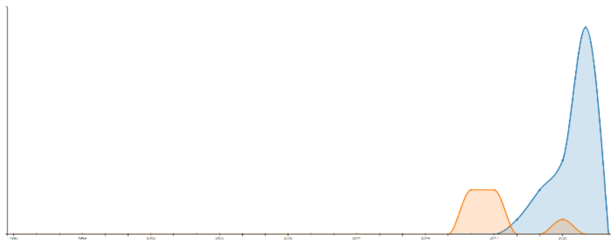
Wireless time sensitive network

In industrial environments, multiple devices need to exchange data with latency down to 1ms. Time-sensitive networking over wireless networks are being developed to allow such low latency communication.

Figure 35: Visualisations for Wireless time sensitive network



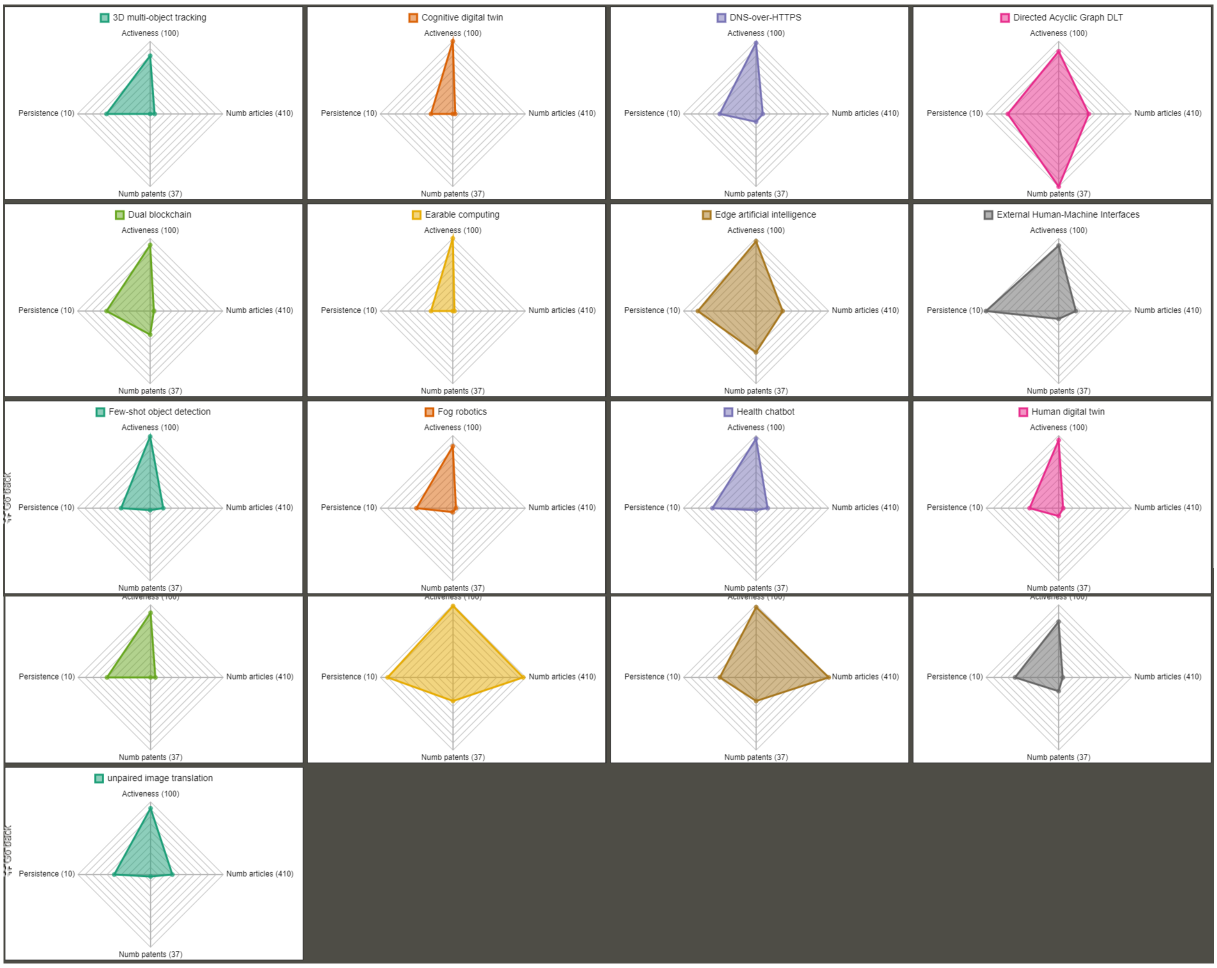
IBM Corp	7.0	[United States of America]
Research Centre	4.0	[Saudi Arabia]
Bosch Corp	4.0	[Germany]
Universidad de Oviedo	3.0	[Spain]
Technische Universität Kaiserslautern	2.0	[Germany]
Offenburg University of Applied Sciences	2.0	[Germany]
Darmstadt University of Applied Sciences	2.0	[Germany]



Radar Weak Signal

All of the weak signals have a very high activeness. 9 of the weak signals in ICT have very similar shapes: small number of articles and patents, low or average persistence, and very high activeness. Those are typical characteristics of technologies in a very early stage of development. 5 weak signals stand out: Directed acyclic graphs (with a relatively high number of patents (37)); Edge artificial intelligence (some patents ad high persistence); External human-machine interface (high persistence); Programmable wireless environment (High number of patents, high persistence); Versatile video coding (very high number of articles).

Figure 36: Radar Weak Signal for ICT



Radar Territories

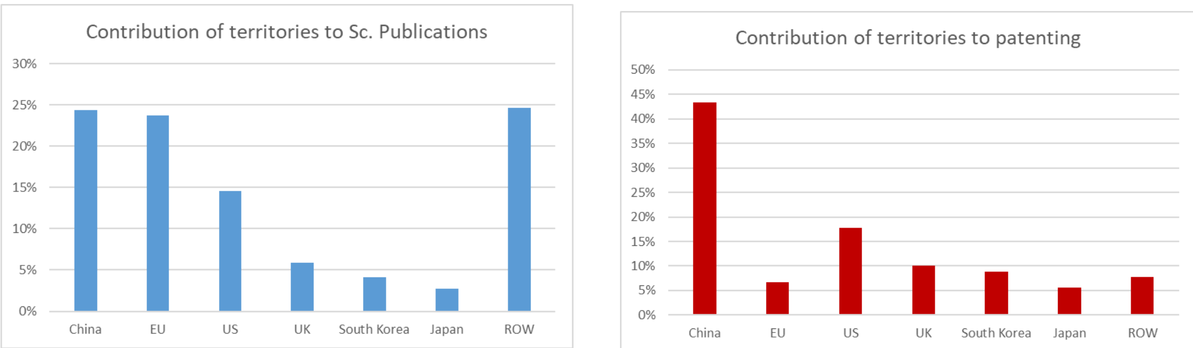
Europe is well-positioned or even leading in many of the weak signals relate to ICT. The US and China are often prominent players in the ICT weak signals.

Figure 37: Radar Territories for ICT

From publishing to patenting

Looking into the contributions of the main territories to scientific publication on the one hand, and patenting on the other hand, shows that Europe is indeed strong when it comes to publishing but is lagging behind in patenting. The fact that software inventions cannot be protected by patents at the European patent office might explain partially the low patenting of Europe in the ICT domain.

Figure 38: From publishing to Patenting for ICT



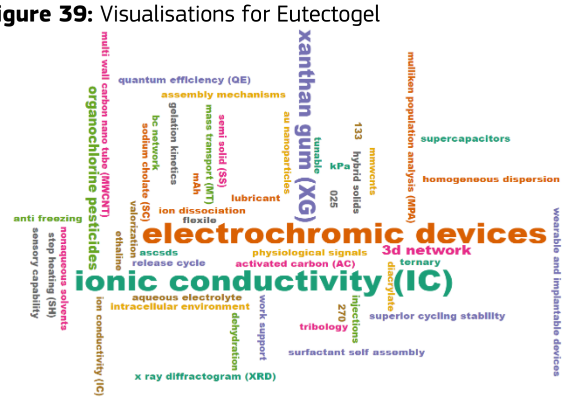
2.3 Materials

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1856

Eutectogel

Made of deep eutectic solvent, eutectogels are promising self-adhesive, stretchable, nonvolatile, and biocompatible materials meant to surpass traditional gels (hydrogels, ionogels). They have applications in flexible electronic devices such as wearable sensors or biopotential electrodes for precise health monitoring.

Figure 39: Visualisations for Eutectogel

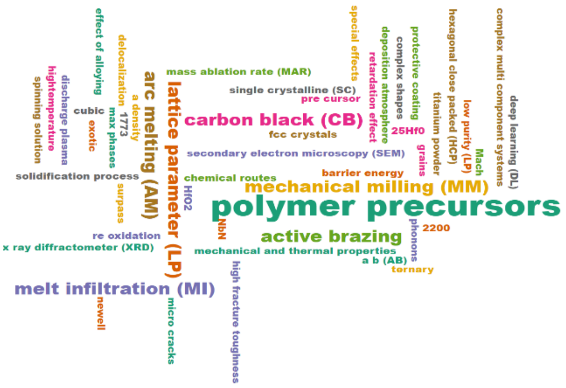


University of Science and Technology of China	4.0	[China]
Tufts University	4.0	[United States of America]
Zhengzhou University of Light Industry	3.0	[China]
Henan University of Technology	3.0	[China]
Zhejiang University	2.0	[China]
Università degli Studi di Palermo	2.0	[Italy]
National Yunlin University of Science and Technology	2.0	[Taiwan]
National Taiwan University of Science and Technology	2.0	[Taiwan]
National Synchrotron Radiation Research Center	2.0	[Taiwan]
Hunan Agricultural University	2.0	[China]
Hasselt University	2.0	[Belgium]

High-entropy carbide ceramics

have recently attracted significant attention due to their interesting surface and electronic properties which allow for various structural and functional applications like for example in batteries, capacitors, magnetic resonance imaging, targeted drug delivery, microelectronics, biocompatible coatings, etc.

Figure 40: Visualisations for High-entropy carbide ceramics

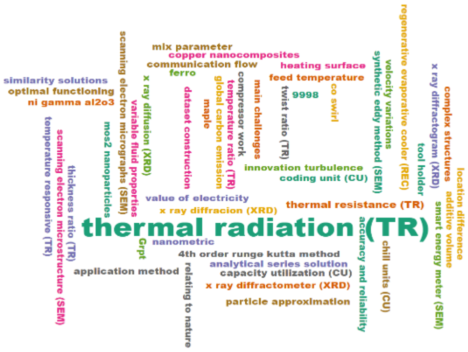


South China University of Technology	8.0	[China]
Chinese Academy Of Sciences	7.0	[China]
NORTHWESTERN POLYTECHNICAL UNIVERSITY	6.0	[China]
University of California	5.0	[United States of America]
Donghua University	5.0	[China]
University of Virginia	4.0	[United States of America]
University of Science and Technology Beijing	4.0	[China]
Slovak Academy of Sciences	4.0	[Slovakia]
School of Materials Science and Engineering	4.0	[China]
Queen Mary University of London	4.0	[United Kingdom]
Missouri University of Science and Technology	4.0	[United States of America]

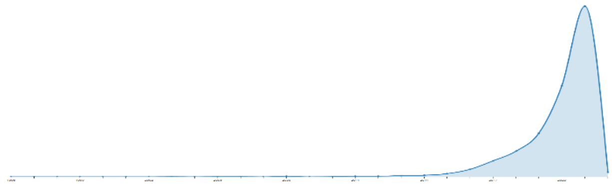
Hybrid nanofluids

With the advent of nanotechnologies came the necessity to develop fluids with high-performance thermal transport properties for heat transfer and lubrication. Hybrid nanofluids, which are composites mixture of metallic, polymeric or non-metallic nano-sized powder with a base fluid, have higher heat transfer and better lubrication power than pure fluids.

Figure 41: Visualisations for Hybrid nanofluids



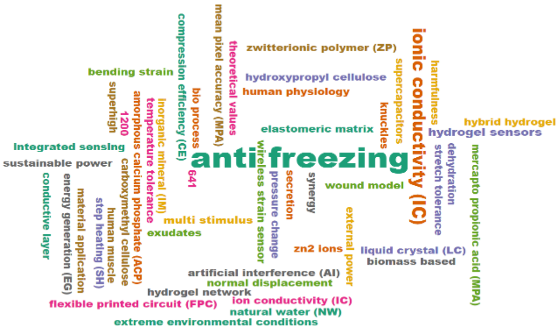
Islamic Azad University	180	[Iran]
Ton Duc Thang University	134	[Viet Nam]
King Abdulaziz University	96	[Saudi Arabia]
King Khalid University	87	[Saudi Arabia]
Universiti Kebangsaan Malaysia	86	[Malaysia]
Babeș-Bolyai University	85	[Romania]
Universiti Teknikal Malaysia Melaka	76	[Malaysia]
Duy Tan University	68	[Viet Nam]
Indian Institute of Technology	62	[India]
China Medical University Hospital	60	[Taiwan]



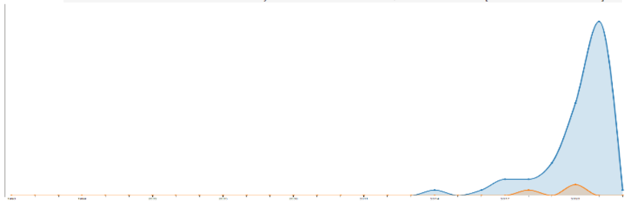
Ionic skin

is being developed to overcome the limitations of hydrogels used for example in stretchable wearable electronics and soft robots (freezing, dehydration, weak adhesion). Ionic skins are meant to have high toughness, high stretchability, excellent stability, superior anti-freezing capability, and strong surface adhesion, thus opening the way for new developments in advanced electronics.

Figure 42: Visualisations for Ionic skin



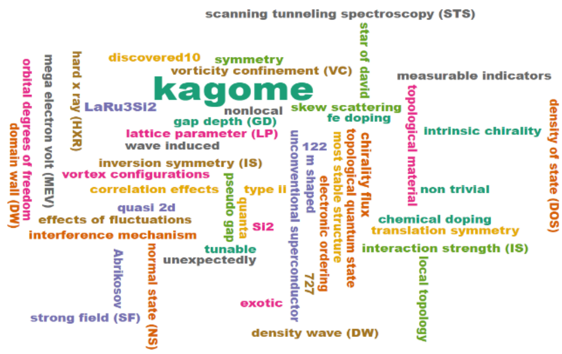
Chinese Academy Of Sciences	9.0	[China]
Donghua University	8.0	[China]
Tianjin University	4.0	[China]
Huazhong University of Science and Technology	4.0	[China]
Fudan University	4.0	[China]
Zhengzhou University	3.0	[China]
Zhejiang University	3.0	[China]
XI'AN UNIVERSITY OF ARCHITECTURE AND TECHNOLOGY	3.0	[China]
XI'AN JIAOTONG UNIVERSITY	3.0	[China]
South China University of Technology	3.0	[China]
Shanghai Jiao Tong University	3.0	[China]
Harvard University	3.0	[United States of America]



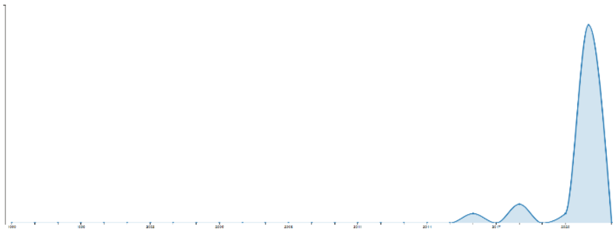
Kagome superconductors

Superconductors with kagome lattices are known for over 40 years. Recently though, certain kagome superconductors have been found to exhibit an unusual behaviour that has relaunched some interest for these materials.

Figure 43: Visualisations for Kagome superconductors



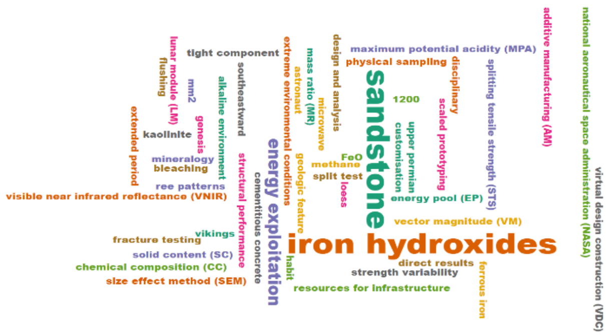
Chinese Academy Of Sciences	10	[China]
University of Science and Technology of China	6	[China]
University of California	6	[United States of America]
Renmin University of China	6	[China]
QUANTUM CORP	5	[United States of America]
Collaborative Innovation Center of Advanced Microstructures	5	[China]
Boston College	5	[United States of America]
Science Center	4	[United States of America]
Princeton University	4	[United States of America]
Nanyang Technological University	4	[Singapore]
Lawrence Berkeley National Laboratory	4	[United States of America]

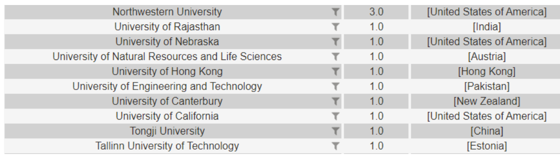


Martian concrete

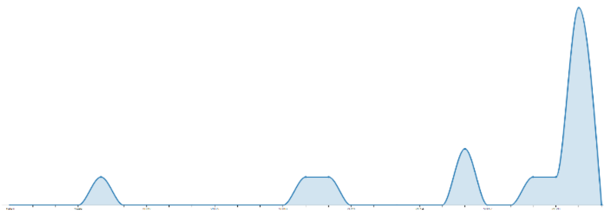
As the perspective for Humanity to install long-term living infrastructures on planet Mars becomes a possibility, research on building materials for Martian applications has discretely started. Among possible materials, concrete made with Martian components is being investigated.

Figure 44: Visualisations for Martian concrete





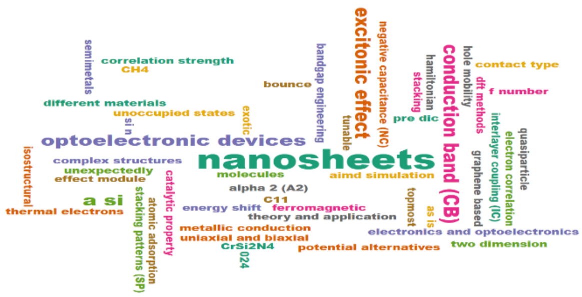
Northwestern University	3.0	[United States of America]
University of Rajasthan	1.0	[India]
University of Nebraska	1.0	[United States of America]
University of Natural Resources and Life Sciences	1.0	[Austria]
University of Hong Kong	1.0	[Hong Kong]
University of Engineering and Technology	1.0	[Pakistan]
University of Canterbury	1.0	[New Zealand]
University of California	1.0	[United States of America]
Tongji University	1.0	[China]
Tallinn University of Technology	1.0	[Estonia]



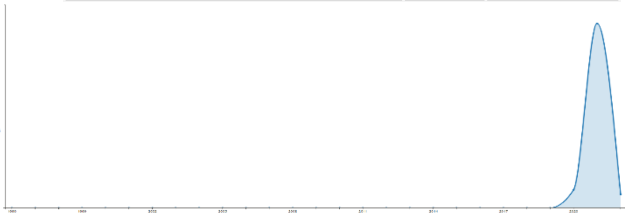
Monolayer MA2Z4

The recent synthesis of 2D MoSi2N4, with remarkable mechanical, thermal, optical, and electronic properties, has triggered a surge of interest for the new family of two-dimensional materials MA2Z4 (e.g. MoSi2N4, WSi2N4, NbSi2N4, VSi2N4, VSi2P4).

Figure 45: Visualisations for Monolayer MA2Z4



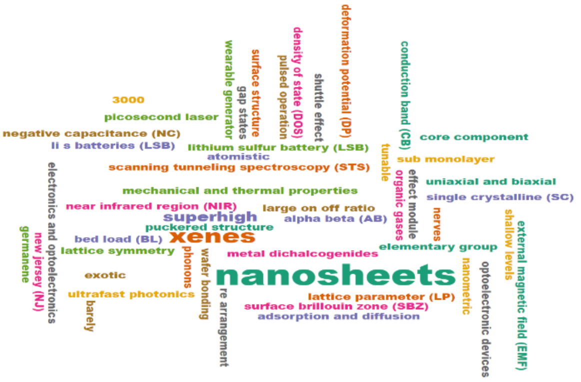
Chinese Academy Of Sciences	9.0	[China]
University of Science and Technology of China	6.0	[China]
TOBB University of Economics and Technology	5.0	[Turkey]
Singapore University of Technology and Design	5.0	[Singapore]
Shahid Beheshti University	5.0	[Iran]
Islamic Azad University	5.0	[Iran]
Xi'an University of Posts and Telecommunications	4.0	[China]
University of Antwerp	4.0	[Belgium]
Sungkyunkwan University	4.0	[South Korea]
Duy Tan University	4.0	[Viet Nam]
Benha University	4.0	[Egypt]



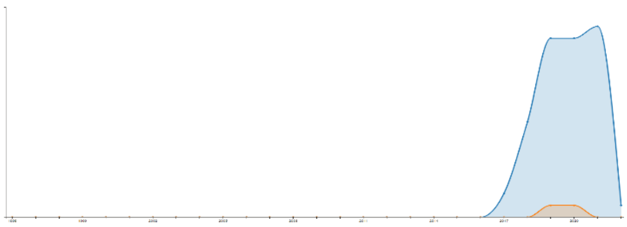
Monolayer Tellurene

Is a new emerging two-dimensional material whose unique optoelectronic properties and behaviour holds promises for applications in e.g. photoelectronic devices or energy harvesting devices.

Figure 46: Visualisations for Monolayer Tellurene



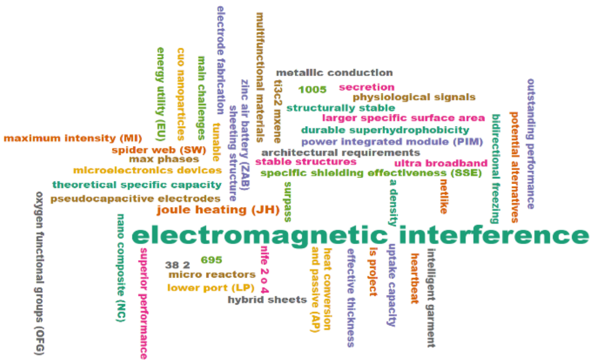
Shenzhen University	6.0	[China]
Shandong University of Technology	4.0	[China]
Purdue University	4.0	[United States of America]
Peking University	4.0	[China]
Collaborative Innovation Center of Quantum Matter	4.0	[China]
Chongqing University	4.0	[China]
Zhengzhou University	3.0	[China]
University of Science and Technology of China	3.0	[China]
Henan University	3.0	[China]
Henan Polytechnic University	3.0	[China]
Beijing University of Posts and Telecommunications	3.0	[China]
Beijing Key Laboratory	3.0	[China]



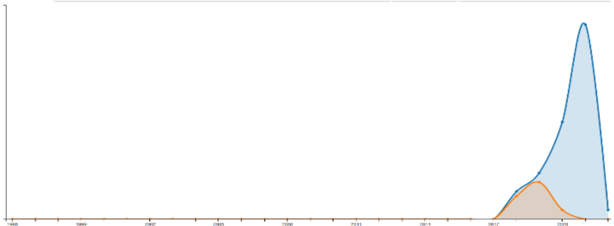
Mxenes aerogels

are ultralight 3D structures with applications in many fields like catalysis, stretchable electronics, supercapacitors, hydrogen storage.

Figure 47: Visualisations for Mxenes aerogels



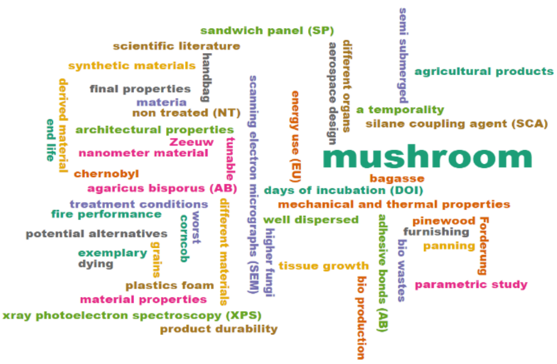
Chinese Academy Of Sciences	13	[China]
Beijing University of Chemical Technology	9	[China]
University of Science and Technology of China	4	[China]
Sichuan University	4	[China]
Qingdao University	4	[China]
Zhejiang University	3	[China]
Tianjin University	3	[China]
SHAANXI UNIVERSITY OF SCIENCE&TECHNOLOGY	3	[China]
NORTHWESTERN POLYTECHNICAL UNIVERSITY	3	[China]
Guangdong University of Technology	3	[China]
Drexel University	3	[United States of America]
University of Manchester	2	[United Kingdom]



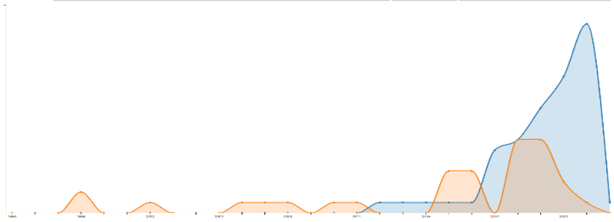
Mycelium-based materials

are new composite materials based on the mycelium of fungus. These are novel green materials that could replace plastic films and sheets, synthetic foams and plastics, and semi-structural materials (e.g., paneling, flooring, furniture, decking). Some clinical trials have also explored their use for wound healing, showing the potential for biomedical applications.

Figure 48: Visualisations for Mycelium-based materials



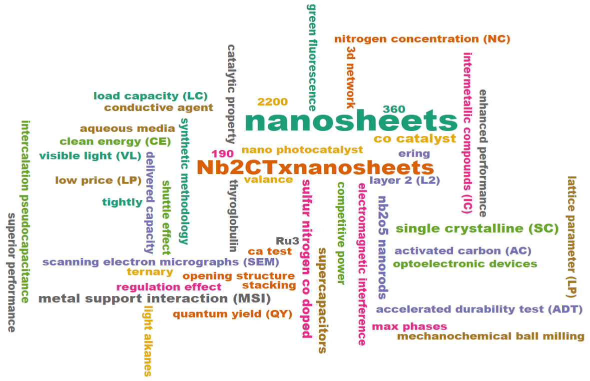
RMIT University	7.0	[Australia]
University of Vienna	5.0	[Austria]
Utrecht University	4.0	[Netherlands]
University of California	4.0	[United States of America]
Vrije Universiteit Brussel	3.0	[Belgium]
University of New South Wales	3.0	[Australia]
University of Genoa	3.0	[Italy]
Institute of Science and Technology	3.0	[United Kingdom]
University of Pavia	2.0	[Italy]
University of Helsinki	2.0	[Finland]



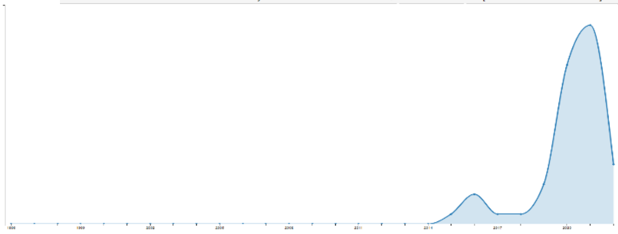
Nb2CTx MXene

are new types of MXenes based on Niobium carbides. Mxenes are two-dimensional nanostructured inorganic compounds with unique properties and potential applications in the design of batteries, supercapacitors, new composites, antennas, optoelectronics, chemical sensing, catalysis etc.

Figure 49: Visualisations for Nb2CTx MXene



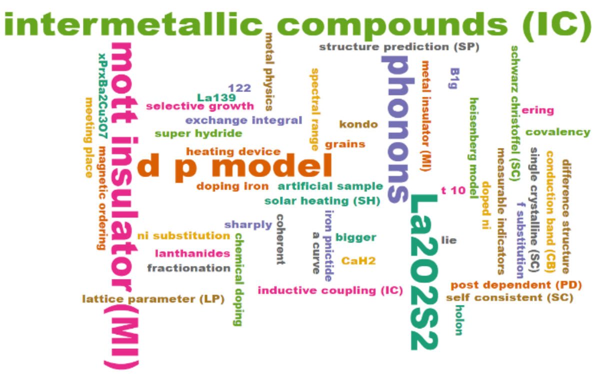
Chinese Academy Of Sciences	8.0	[China]
University of Electronic Science and Technology of China	4.0	[China]
South China University of Technology	4.0	[China]
Qingdao University	4.0	[China]
Harbin Normal University	4.0	[China]
Drexel University	4.0	[United States of America]
Shandong University	3.0	[China]
Zhengzhou University	2.0	[China]
Wuyi University	2.0	[China]
University of Jinan	2.0	[China]
University of Alberta	2.0	[Canada]
Tulane University	2.0	[United States of America]



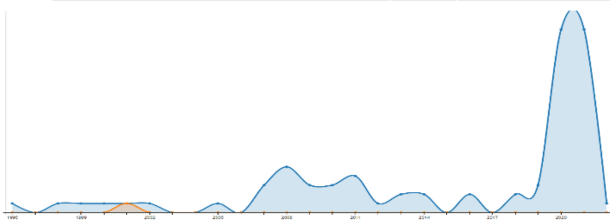
Nickelates superconductors

is a novel class of superconductors discovered in 2019. Because of their similarities with Cuprates semiconductors, they provide a great opportunity to finally reveal the mechanisms of High-Tc superconductivity, which remain unclear for more than 30 years now. This class of superconductors also open new roads for research on nickel-based superconductivity.

Figure 50: Visualisations for Nickelates superconductors



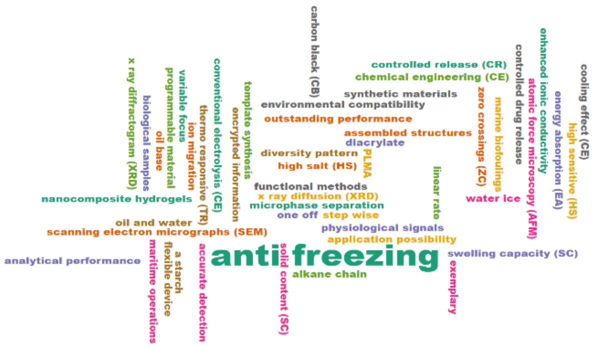
Chinese Academy Of Sciences	10	[China]
Zhejiang University	5	[China]
University of Tokyo	5	[Japan]
University of Science and Technology of China	5	[China]
Nanjing University	5	[China]
Hangzhou Normal University	5	[China]
University of California	4	[United States of America]
Tokyo Institute of Technology	4	[Japan]
Stanford University	3	[United States of America]
RIKEN	3	[Japan]
Princeton University	3	[United States of America]
Harvard University	3	[United States of America]
Arizona State University	3	[United States of America]



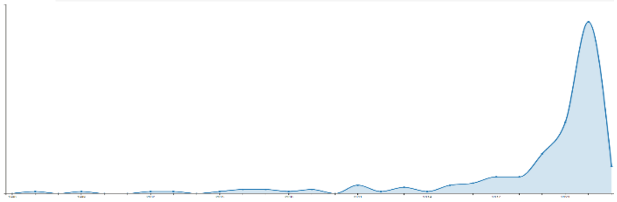
Organohydrogels

Hydrogels have many applications but lose moisture or solvent in open environment, which induces a decrease in volume and an increase in hardness. They also lose flexibility at lower temperature due to water freezing. Organic materials are introduced into hydrogels to form organohydrogels that could maintain their properties at high and low temperatures with the view to use them in stretchable electronics, biosensors, as intelligent coating materials, etc.

Figure 51: Visualisations for Organohydrogels



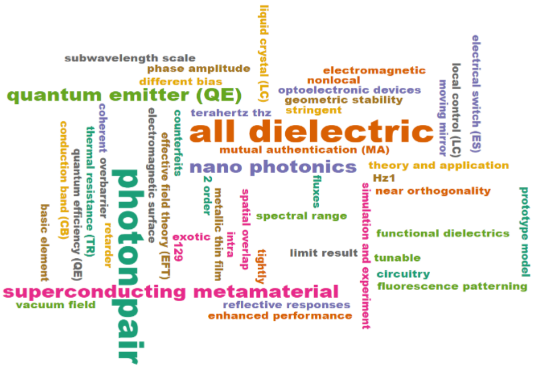
Chinese Academy Of Sciences		28	[China]
Beihang University		14	[China]
Shenzhen University		12	[China]
Sun Yat-Sen University		11	[China]
NORTHWESTERN POLYTECHNICAL UNIVERSITY		10	[China]
Fuzhou University		8	[China]
Tianjin University		7	[China]
Yuzuncu Yil University		6	[Turkey]
University of Science and Technology of China		6	[China]
Sichuan University		6	[China]



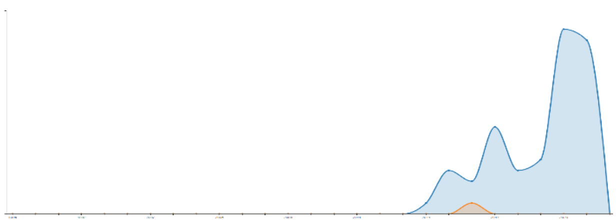
Quantum metasurfaces

Metasurfaces have been widely investigated in the past decade for creating the next-generation multifunctional flat-optics devices, and they have now reached a mature stage where applications are now flourishing (e.g. light bending, EM wave modifications, metalenses, etc.). Some of the research efforts looks into how metasurfaces can be used for quantum applications i.e. the manipulation of matter at a quantum level.

Figure 52: Visualisations Quantum metasurfaces



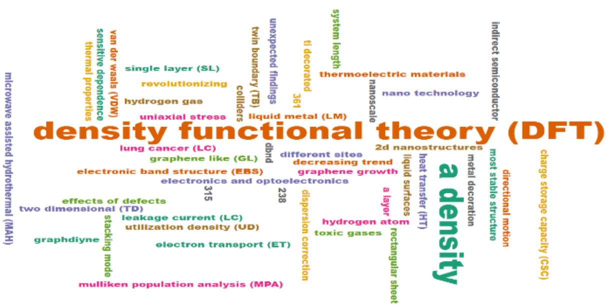
University of California		20	[United States of America]
Center for Integrated Nanotechnologies		14	[United States of America]
California Institute of Technology		4	[United States of America]
University of Tsukuba		3	[Japan]
University of Texas at Austin		3	[United States of America]
Samsung Corp		3	[South Korea]
National Institute for Materials Science		3	[Japan]
Université Montpellier II		2	[France]
University of Victoria		2	[Canada]
University of New South Wales		2	[Australia]



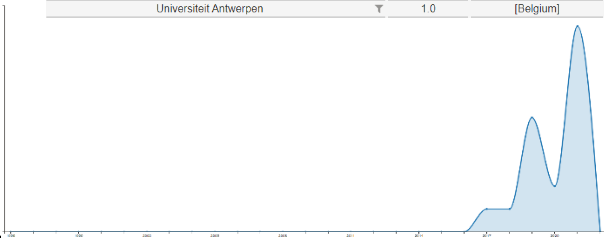
Twin graphene

is a novel two-dimensional semiconducting allotrope carbon material that has a modified energy band, giving to the material unique electron transport properties, which will lead to potential applications in the fields of energy storage, spin transport or photoluminescence.

Figure 53: Visualisations for Twin graphene



Shanghai University		3.0	[China]
Shahid Rajaee Teacher Training University		3.0	[Iran]
Assam University		3.0	[India]
University of Zanjan		2.0	[Iran]
School of Materials Science and Engineering		2.0	[China]
Institute for Basic Science		2.0	[South Korea]
XI'AN UNIVERSITY OF SCIENCE AND TECHNOLOGY		1.0	[China]
Wuhan University of Science and Technology		1.0	[China]
University of Calgary		1.0	[Canada]
Universiteit Antwerpen		1.0	[Belgium]

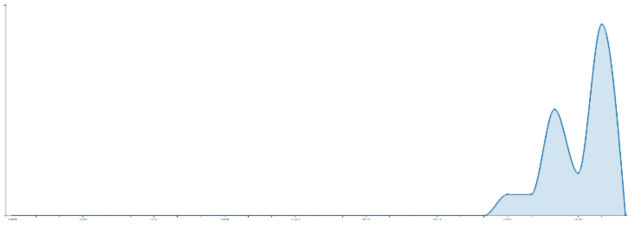


Twisted bilayer graphene

is a new material that differs from plain bilayer graphene by having an angle between the two layers. Surprisingly, the angle between the two layers modifies the electronic behaviour of the material e.g. making the material superconducting.

Figure 54: Visualisations for Twisted bilayer graphene

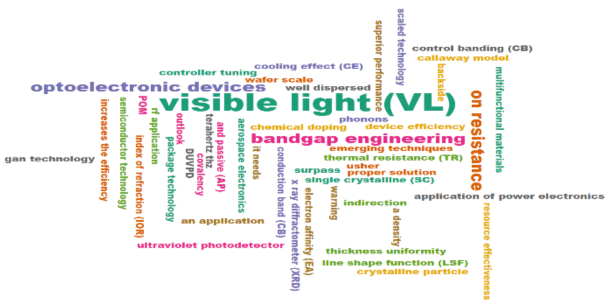
National Institute for Materials Science		87	[Japan]
University of California		53	[United States of America]
Massachusetts Institute of Technology		53	[United States of America]
Harvard University		44	[United States of America]
Chinese Academy Of Sciences		43	[China]
University of Texas at Austin		25	[United States of America]
Princeton University		24	[United States of America]
University of Manchester		21	[United Kingdom]
Beijing Normal University		21	[China]
University of Minnesota		20	[United States of America]
University of Maryland		20	[United States of America]
Universidade Federal de Minas Gerais		20	[Brazil]
CNRS		20	[France]



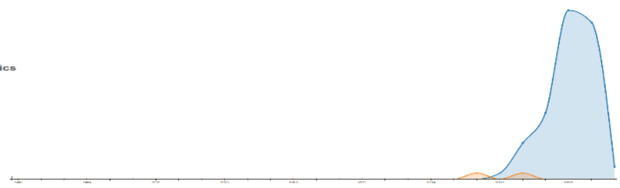
Ultrawide bandgap semiconductors

have wider bandgap than traditional semiconductors and have promising potential applications in radio frequency and high-power electronics, optoelectronics, quantum electronics, and for electronics submitted to harsh environmental conditions.

Figure 55: Visualisations for Ultrawide bandgap semiconductors



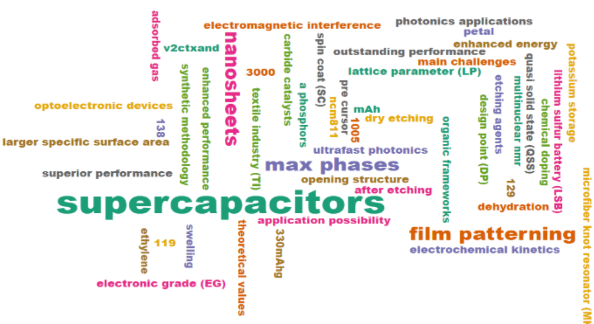
University of Michigan		8.0	[United States of America]
Ohio State University		7.0	[United States of America]
Cornell University		6.0	[United States of America]
Nanjing University		5.0	[China]
University of California		5.0	[United States of America]
Chinese Academy Of Sciences		4.0	[China]
George W. Woodruff School of Mechanical Engineering		4.0	[United States of America]
Sandia National Laboratories		4.0	[United States of America]
Zhengzhou University		4.0	[China]



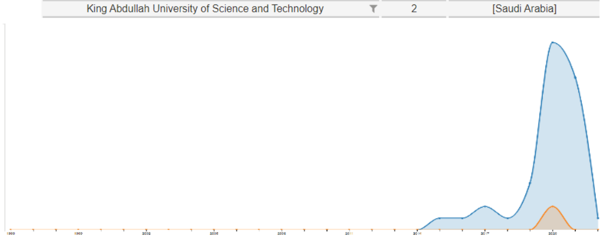
V2CTx MXene

are new types of MXenes based on Vanadium carbides. Mxenes are two-dimensional nanostructured inorganic compounds with unique properties and potential applications in the design of batteries, supercapacitors, new composites, antennas, optoelectronics, chemical sensing, catalysis etc.

Figure 56: Visualisations for V2CTx MXene



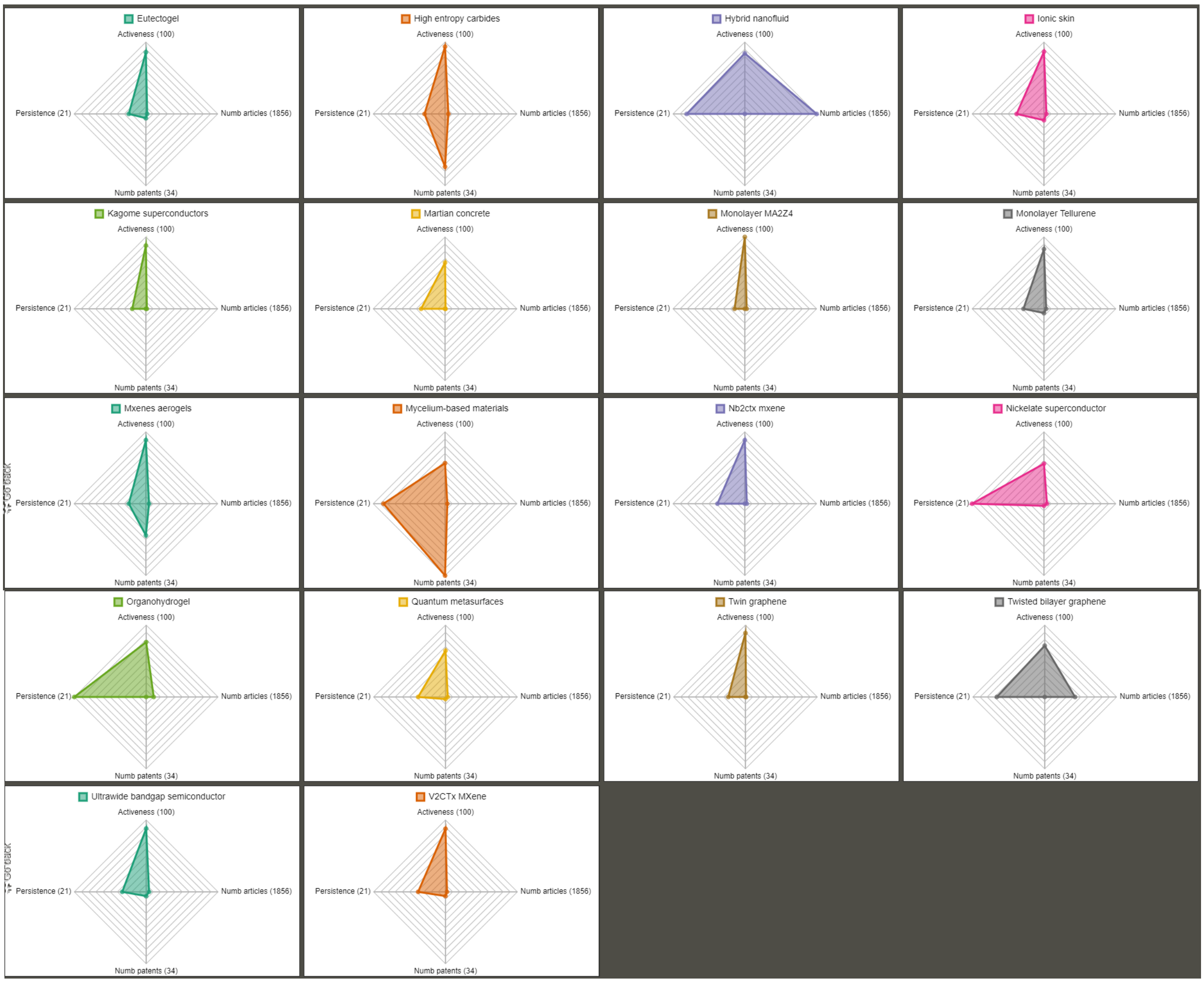
Chinese Academy Of Sciences		10	[China]
Drexel University		6	[United States of America]
Auburn University		5	[United States of America]
Shenzhen University		4	[China]
University of Electronic Science and Technology of China		3	[China]
Henan Polytechnic University		3	[China]
Zhengzhou University		2	[China]
University of Science and Technology of China		2	[China]
Nantong University		2	[China]
King Abdullah University of Science and Technology		2	[Saudi Arabia]



Radar WS

12 of the weak signals share the similar shape of a very sharp triangle pointing to the left, characteristic of high activeness, low number of patents and articles, and low persistence. The weak signal about “Hybrid nanofluid” and, to a lesser extent, the one on “Twisted layer graphene”, have a high number of articles, high activeness, and high persistence, leading to a broad flat triangle. Two other signals have a slightly different shape (left triangle) with a relatively low number of articles and high persistence: nickelate superconductors and organohydrogel. Finally, two weak signals have a relatively high number of patents: mycelium-based materials and High entropy carbides.

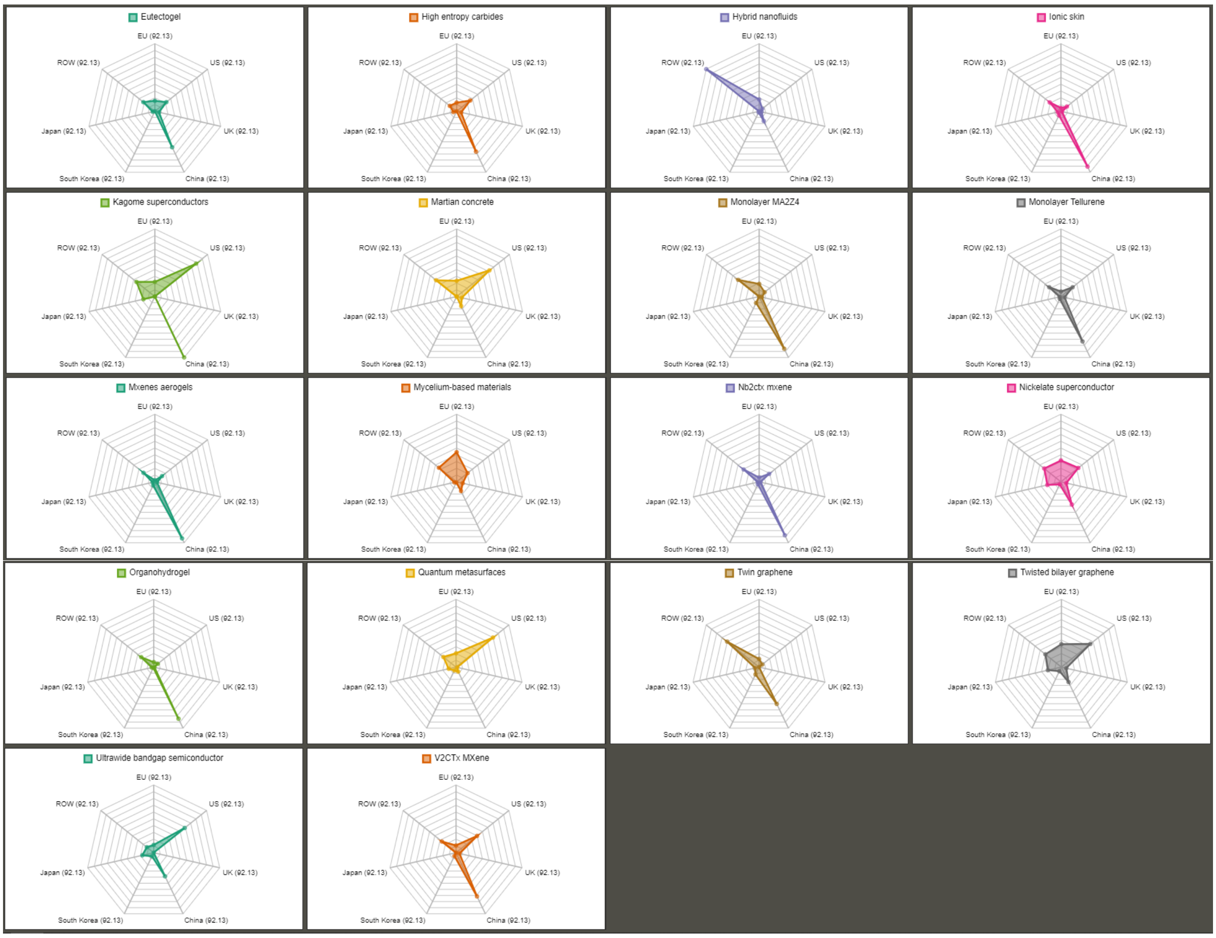
Figure 57: Radar Weak Signal for Materials



Radar Territories

The leadership of China in emerging materials cannot be contested, with a massive contribution in 10 of 17 weak signals and co-leadership with the US in two weak. Europe is well-positioned in 4 of the WS: Martian concrete, Mycelium-based materials, Nickelate superconductors and Twisted layer graphene.

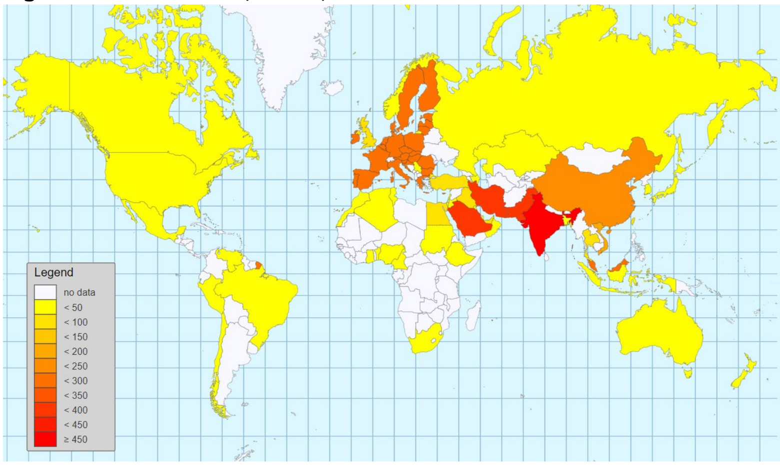
Figure 58: Radar Territories for Materials



From publishing to patenting

Looking at all the weak signals together, one can see that China, EU, and the US contribute to 10-15% of the scientific publications and patents, with the rest of the territories contributing up to 50%. This is not what is usually observed for weak signals and is actually caused by one particular weak signal: “hybrid nanofluid” which has a high activeness but also a very high number of articles (~1850 articles). As the views are relative to the topic (so to the 16 weak signals), and as many of the weak signals have a low number of articles, “hybrid nanofluids” is skewing the visualisations. Countries like Saudi Arabia, India, Malaysia are very active on this topic and are pushing up the proportion for “ROW”.

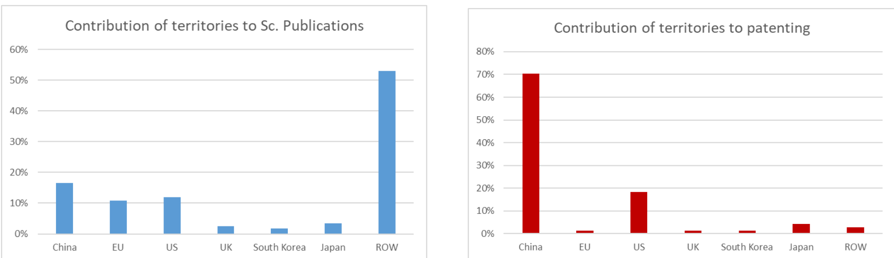
Figure 60: EU/world map for “hybrid nanofluids”



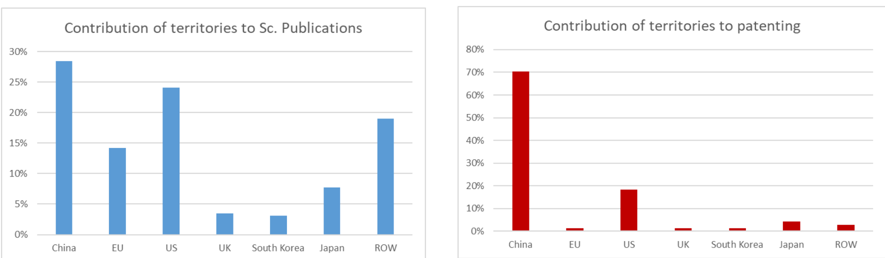
Looking at the contribution of territories for all the weak signals except for “hybrid nanofluids”, one can observe that China and the US are indeed leading in terms of number of scientific publications for weaks signals in materials, with respective contributions up to 30% and 25%. Europe contributes in 15% of the scientific publications, but when it comes to patents, is far behind China and the US.

Figure 61: From publishing to Patenting for Materials

For all weak signals



For all weak signals except “hybrid nanofluids”



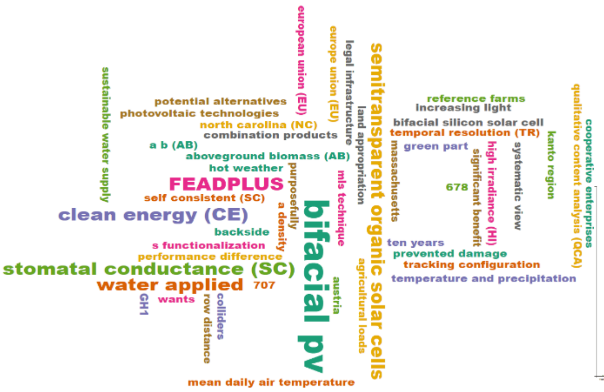
2.4 Agriculture & Environment

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1852

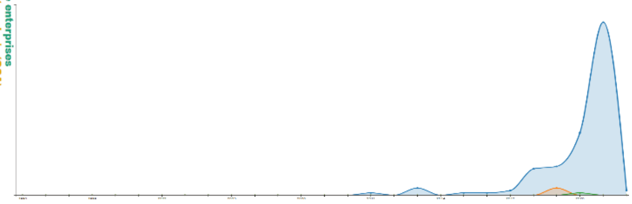
Agrivoltaics

Is the symbiotic spatial combination of photovoltaics installations and agriculture. The challenge is to optimise the energy harvest by crops and photovoltaic cells, which are competing for energy from the sun.

Figure 62: Visualisations for Agrivoltaics



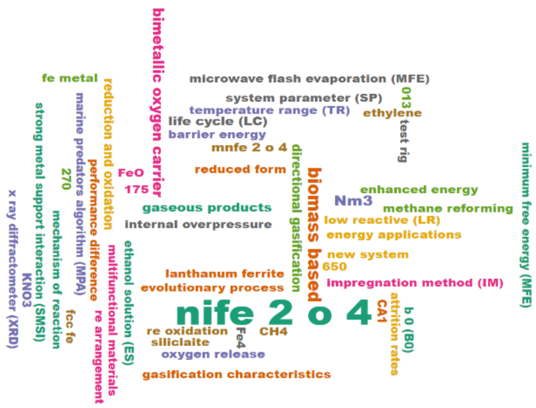
Oregon State University	9.0	[United States of America]
University of Hohenheim	6.0	[Germany]
Universiti Putra Malaysia	6.0	[Malaysia]
Michigan Technological University	6.0	[United States of America]
Lahore University of Management Sciences	5.0	[Pakistan]
University of Arizona	4.0	[United States of America]
UMR SYSTEM	4.0	[France]
Purdue University	4.0	[United States of America]
Fraunhofer Institute for Solar Energy Systems ISE	4.0	[Germany]
Università Cattolica del Sacro Cuore	3.0	[Italy]
Kyoto University	3.0	[Japan]
Fudan University	3.0	[China]
Arizona State University	3.0	[United States of America]
Aalto University	3.0	[Finland]



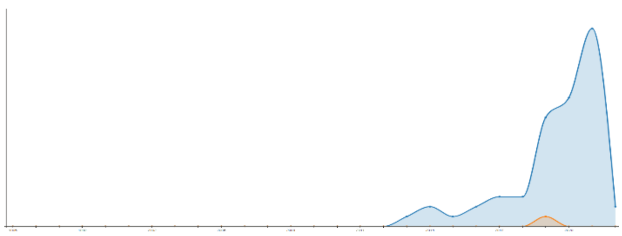
Biomass chemical looping gasification

Biomass is one of the most promising renewable energy sources. Chemical looping gasification of biomass is a novel approach that allows to use biomass in various applications. It is considered a suitable pathway to produce valuable products from biomass among biomass conversion processes.

Figure 63: Visualisations for Biomass chemical looping gasification



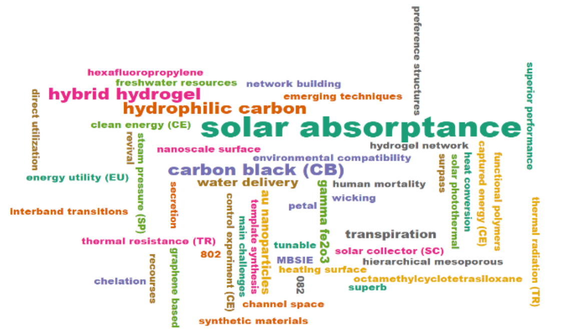
Chinese Academy Of Sciences	15	[China]
Southeast University	7	[China]
South China University of Technology	5	[China]
Instituto de Carboquímica ICB-CSIC	5	[Spain]
Guilin University of Technology	4	[China]
North China Electric Power University	3	[China]
Ningxia University	3	[China]
Nanjing Normal University	3	[China]
XI'AN JIAOTONG UNIVERSITY	2	[China]
University of Sheffield	2	[United Kingdom]



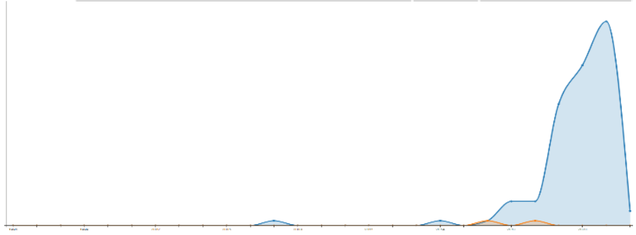
Interfacial solar-driven evaporators

are efficient, sustainable, and low-cost devices for producing clean water. Research is ongoing to enhance overall performance by using new materials or new system architecture, but also to solve some issues related to scaling up such as the stability of evaporation performances or the reliability for long-term operations.

Figure 64: Visualisations for Interfacial solar-driven evaporators



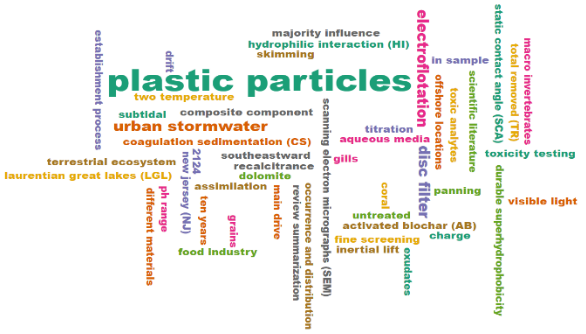
Nanjing University	12	[China]
University of Texas at Austin	7	[United States of America]
Chinese Academy Of Sciences	7	[China]
Zhejiang University	6	[China]
Tianjin University	5	[China]
Southeast University	5	[China]
Hubei University	5	[China]
Huazhong University of Science and Technology	5	[China]
National University of Singapore	4	[Singapore]
Donghua University	4	[China]



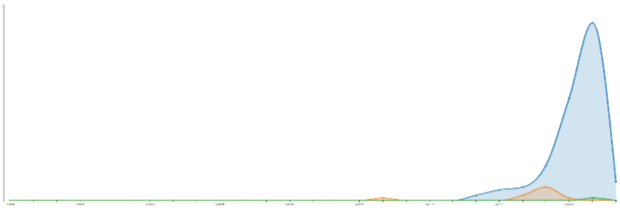
Microplastics removal

Microplastics are a threat for the environment and a big challenge for the future. Researchers are investigating possible physical, chemical or biological removal options. Good results have been achieved in laboratory but many of these options still lack efficiency in real environmental conditions.

Figure 65: Visualisations for Microplastics removal



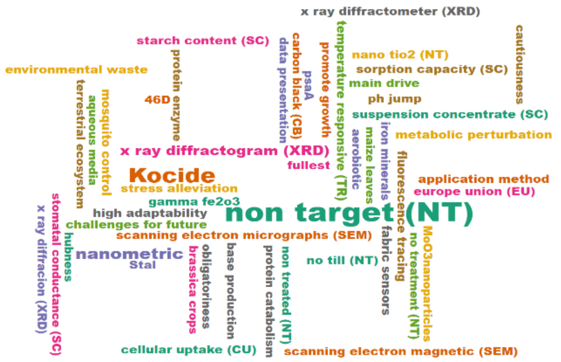
Universitat de Barcelona	4.0	[Spain]
Hunan University	4.0	[China]
Chinese Academy Of Sciences	4.0	[China]
Wageningen University and Research	3.0	[Netherlands]
University of Alberta	3.0	[Canada]
Tongji University	3.0	[China]
Silesian University of Technology	3.0	[Poland]
Ocean University of China	3.0	[China]
Harbin Institute of Technology	3.0	[China]
Czestochowa University of Technology	3.0	[Poland]



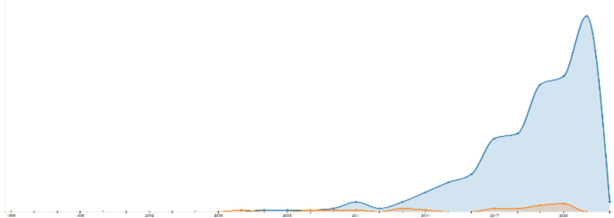
Nanoagriculture

is a relatively new approach that aims at addressing current issues in agriculture and to meet future challenges. It includes the use of nano-biotechnology and nanomaterials in agriculture, nanofertilisers, nanopesticides, nanosensors, etc. Researchers are developing new products and processes, and are also studying the effect of using nanomaterials on human and animal health and the environment.

Figure 66: Visualisations for Nanoagriculture



Universidade Estadual Paulista	17	[Brazil]
University of California	15	[United States of America]
University of Pisa	11	[Italy]
University of Massachusetts	10	[United States of America]
China Agricultural University	10	[China]
University of Vienna	9	[Austria]
Nanjing University	9	[China]
King Saud University	9	[Saudi Arabia]
Connecticut Agricultural Experiment Station	9	[United States of America]
Zhejiang University	8	[China]

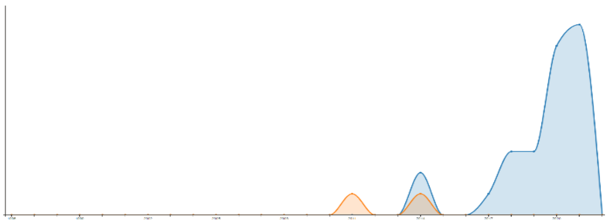


Nanofertilisers

is a weak signal associated to nanoagriculture. Scientists are converting fertilizers into their nano-size version, which improves their efficacy. Research is needed to achieve reliable industrial processes and to evaluate the impact of nanofertilisers on the food chain and the environment.

Figure 67: Visualisations for Nanofertilisers

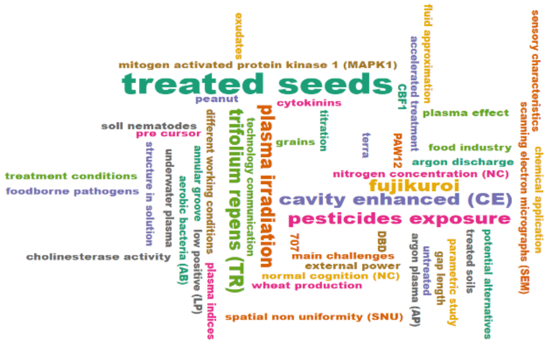
Quaid-i-Azam University		3.0	[Pakistan]
University of South Australia		2.0	[Australia]
University of Nottingham		2.0	[United Kingdom]
University of Adelaide		2.0	[Australia]
Institute of Crystallography		2.0	[Russian Federation]
Australian Nuclear Science and Technology Organisation		2.0	[Australia]



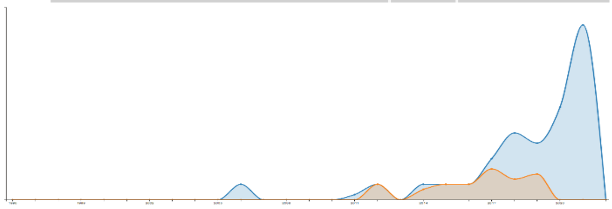
Plasma agriculture

describes the use of plasma treatments in seed processing for agricultural purposes. In this type of treatments, seeds are subjected to pre-sowing treatments to improve the timeliness and uniformity of the germination. Various plasma treatments have proven to be efficient at laboratory scale, reporting enhanced plant growth, improved stress tolerance, and improved antimicrobial resistance, but scaling-up in real conditions as yet to be achieved.

Figure 68: Visualisations for Plasma agriculture



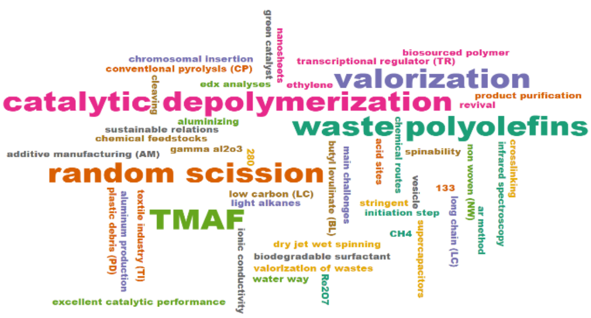
Nagoya University		7.0	[Japan]
Meijo University		6.0	[Japan]
Kyushu University		6.0	[Japan]
Chinese Academy Of Sciences		6.0	[China]
China Agricultural University		6.0	[China]
University of Rajshahi		5.0	[Bangladesh]
Leibniz Institute for Plasma Science and Technology		5.0	[Germany]
Tohoku University		4.0	[Japan]
Comenius University		4.0	[Slovakia]
University of Agricultural Sciences and Veterinary Medicine		3.0	[Romania]



Plastic chemical upcycling

Upcycling of plastics is meant to complement plastics recycling by offering a way to transform plastic waste into higher-value products and contribute to reduce the environmental burden of plastic on the environment. Various conversion methods (e.g. pyrolysis, gasification, photoreforming) are currently under development and scaling up.

Figure 69: Visualisations for Plastic chemical upcycling

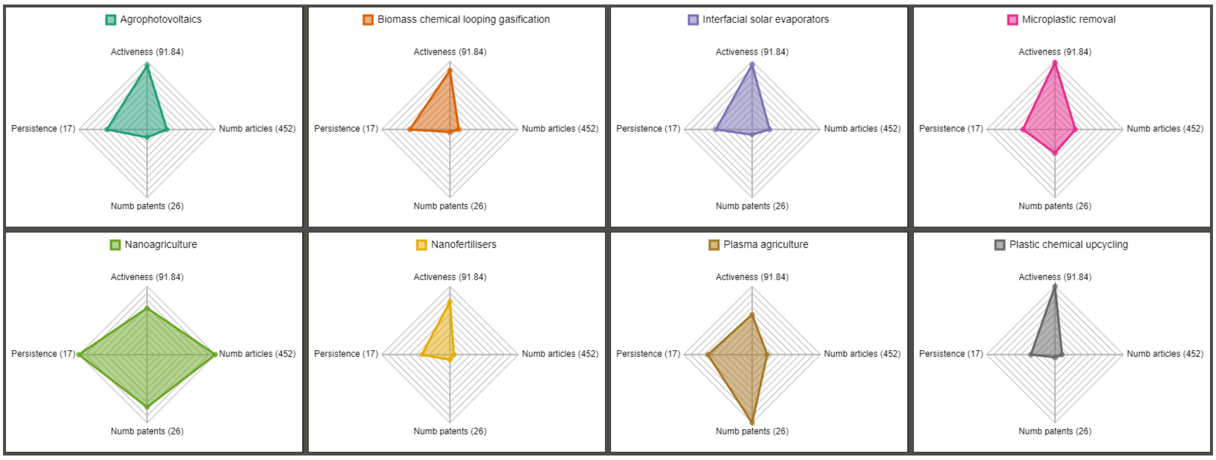


University of the Basque Country UPV/EHU		4.0	[Spain]
RWTH Aachen University		4.0	[Germany]
Nanyang Technological University		4.0	[Singapore]
Kumaun University		3.0	[India]
Washington State University		2.0	[United States of America]
University of Sydney		2.0	[Australia]
University of Minnesota		2.0	[United States of America]
University of Birmingham		2.0	[United Kingdom]
University College Dublin		2.0	[Ireland]
South China University of Technology		2.0	[China]

Radar WS

Six of the 8 weak signals have a similar shape, with a high activeness, a relatively low number of articles and patents, and average persistence (Agriphotovoltaics, Biomass chemical looping gasification, interfacial solar evaporation, microplastics removal, nanofertilisers, plastic chemical upcycling). For the weak signal on plasma agriculture, we can observe that there are already some patents registered. Although the distribution of documents corresponds to a weak signal, activeness is clearly lower than for the other six (activeness 19-22 of 53) because of higher persistence (so more documents published before 2019). The same analysis is valid for the weak signal on nanoagriculture (activeness 19-22 of 62) which has a diamond shape due to its longer persistence, relatively high number of patents and scientific publications, and a high activeness, making it the strongest of the weak signals for this topic.

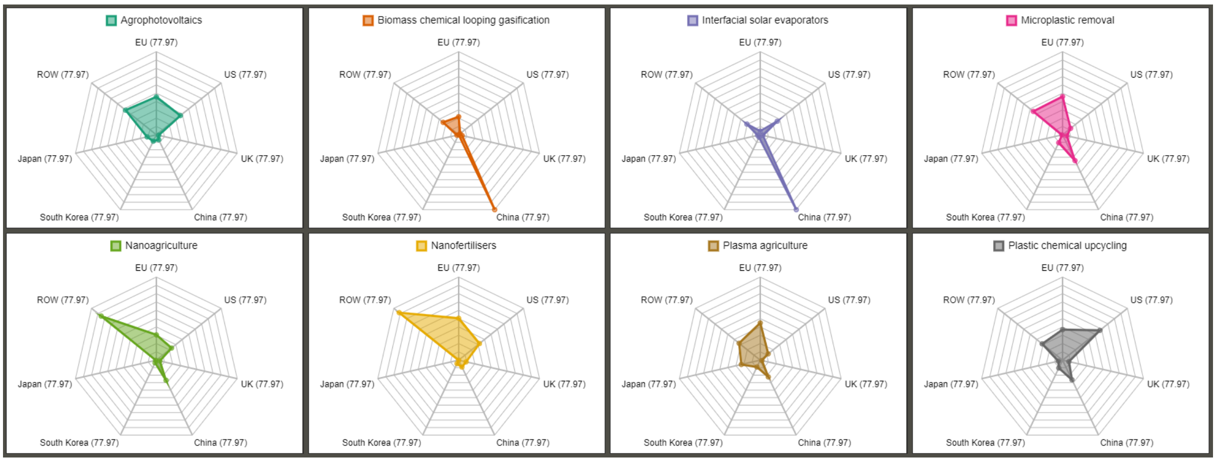
Figure 70: Radar Weak Signal for Agriculture & Environment



Radar Territories

One can observe that Europe is strong in the weak signals on agrophotovoltaics, microplastics removal, nanofertilisers, plasma agriculture. The only WS for which Europe is clearly lagging behind is the one related to interfacial solar evaporators. The US seems to have, on average, a lower interest in this category of topics.

Figure 71: Radar Territories for Agriculture & Environment

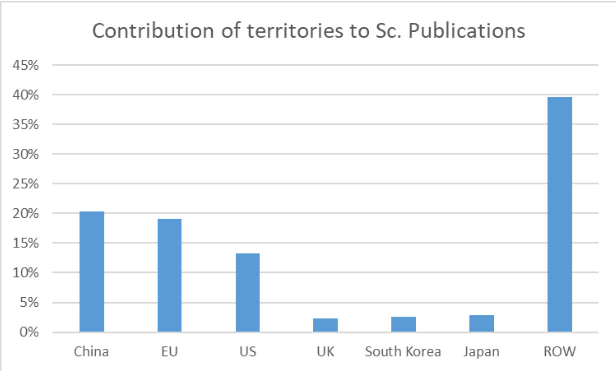


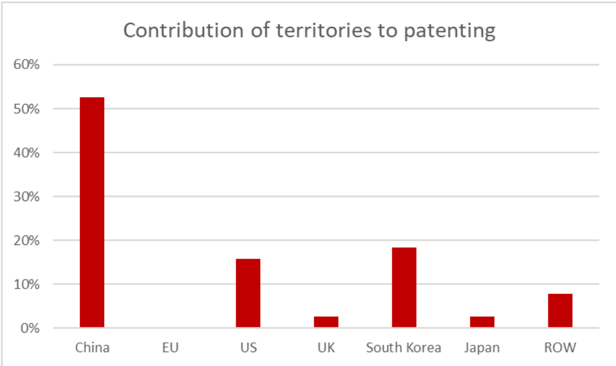
From publishing to patenting

While European organisations lead with Chinese organisations in scientific publications for weak signals in agriculture and environment, they are clearly not translating this research into patents. Similarly to what is observed for WS in materials, one weak signal (nanoagriculture) pushes up the contribution of the ROW, mainly because of the massive contribution from India to this WS.

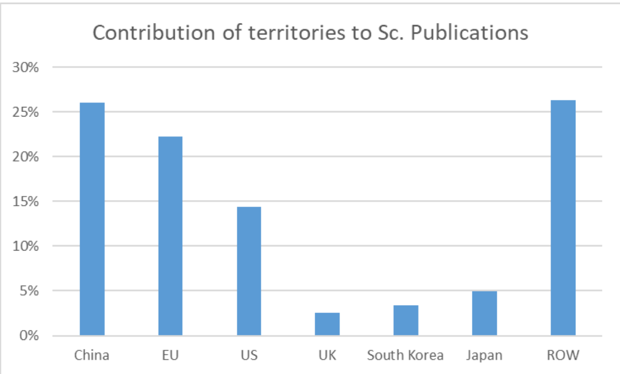
Figure 72: From publishing to Patenting for Agriculture & Biotechnology

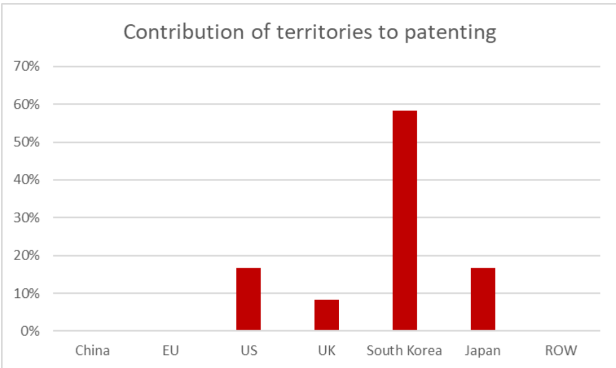
For all weak signals





For all weak signals except "nanoagriculture"





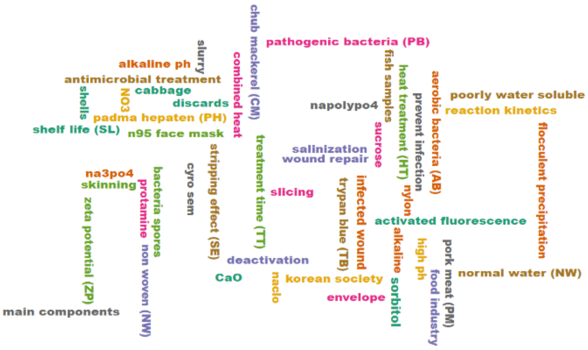
2.5 Medicine and Biotechnology

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1858

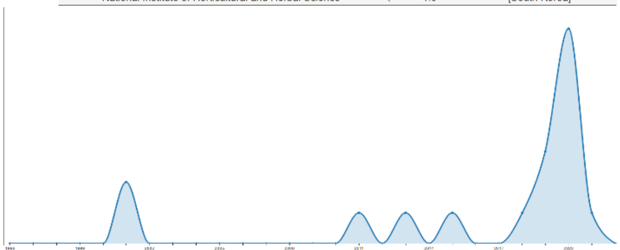
BiSCaO antiseptics

are new antiseptics obtained by heating scallop shells. They exhibit a wide microbicide activity and their production is potentially cheap and environmentally-friendly.

Figure 73: Visualisations for BiSCaO antiseptics



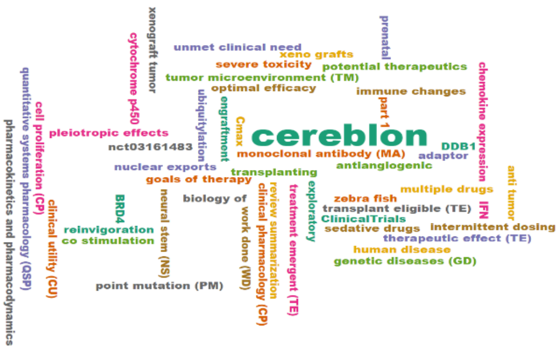
National Defense Medical College	8.0	[Japan]
Kanagawa Institute of Technology	6.0	[Japan]
Shizuoka General Hospital	5.0	[Japan]
National Defense Medical College Hospital	3.0	[Japan]
National Defense Medical College Research Institute	2.0	[Japan]
National Institute of Horticultural and Herbal Science	1.0	[South Korea]



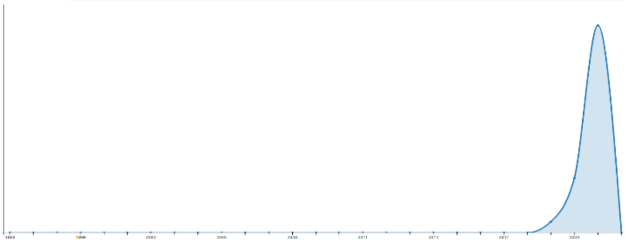
CELMoDs for cancer

Cereblon E3 ligase modulation (CELMoD) drugs are a new generation of compounds with antitumor activity that are being tested in the treatment of cancers, in particular in multiple myeloma therapy.

Figure 74: Visualisations for aphantasia



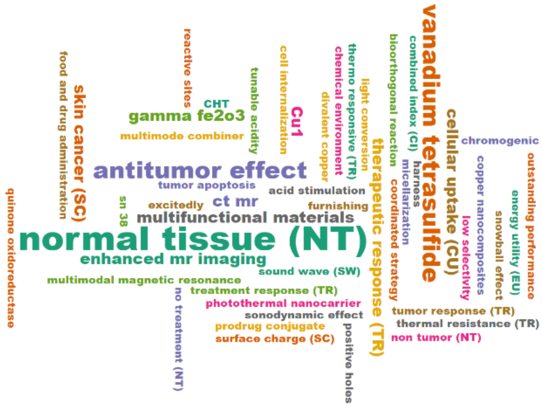
Bristol-Myers Squibb	6.0	[United States of America]
Celgene Corporation	5.0	[United States of America]
Bristol-Myers Squibb Company	3.0	[United States of America]
School of Medicine	2.0	[United States of America]
King's College London	2.0	[United Kingdom]



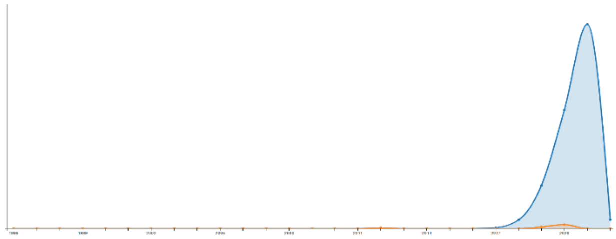
Chemodynamic therapy

is a new cancer therapy that relies on a Fenton-type chemical reaction that convert endogenous hydrogen peroxide into cytotoxic hydroxyl radical (•OH) to destroy tumor cells.

Figure 75: Visualisations for Chemodynamic therapy



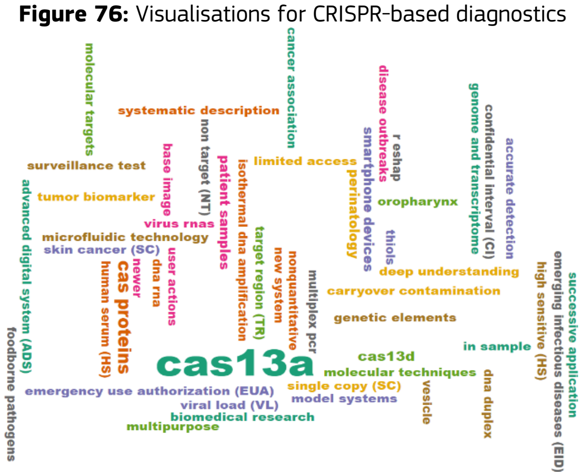
Chinese Academy Of Sciences	99	[China]
University of Science and Technology of China	43	[China]
Soochow University	22	[China]
Fudan University	22	[China]
Huazhong University of Science and Technology	18	[China]
Southeast University	17	[China]
Shanghai Jiao Tong University School of Medicine	16	[China]
Harbin Engineering University	16	[China]
Zhejiang University	15	[China]
Sun Yat-Sen University	15	[China]



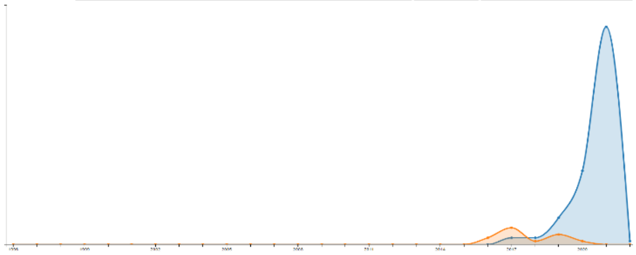
CRISPR-based diagnostics

Because of the capability of the CRISPR-CAS system to target specific gene, applications as rapid, highly-sensitive, and very specific diagnostic tools is being explored.

Figure 76: Visualisations for CRISPR-based diagnostics



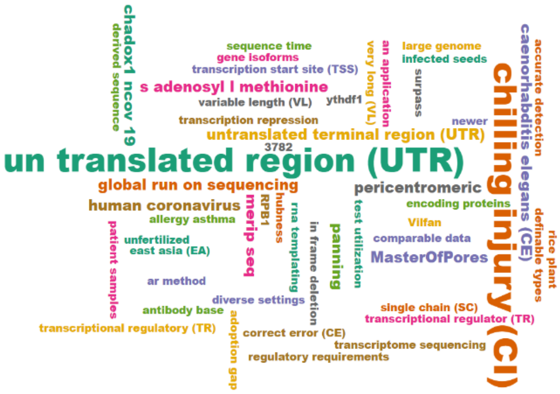
Harvard University	17	[United States of America]
Massachusetts Institute of Technology	14	[United States of America]
MIT-Harvard	7	[United States of America]
Chinese Academy Of Sciences	6	[China]
University of California	5	[United States of America]
Stanford University	4	[United States of America]
Hacettepe University	4	[Turkey]
Shanghai Normal University	3	[China]
Near East University	3	[Cyprus]
Howard Hughes Medical Institute	3	[United States of America]



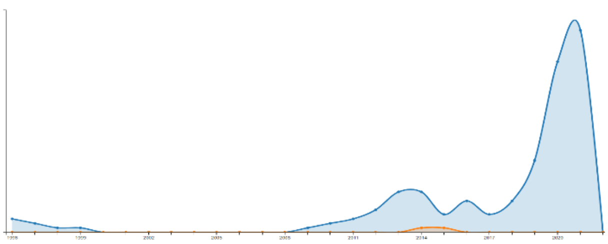
Direct RNA sequencing

is a promising technology that, when combined with protein nanopore sensing, can provide precise mapping of pre-translational mature RNA, single-molecule resolution maps of RNA modifications and a better understanding of the RNA cycle.

Figure 77: Visualisations for Direct RNA sequencing



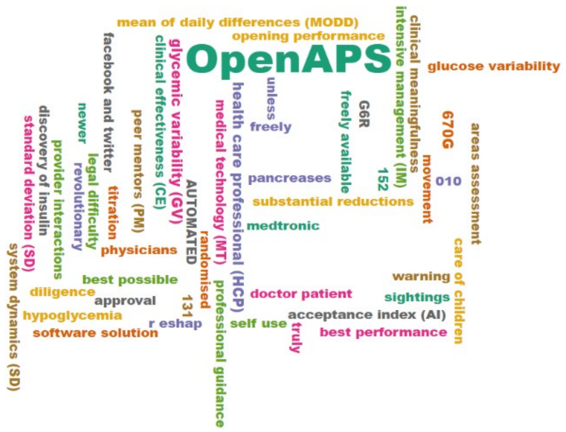
University of Szeged	11	[Hungary]
University of California	8	[United States of America]
Stanford University	8	[United States of America]
HELICOS BIOSCIENCES CORP	8	[United States of America]
University of Dundee	7	[United Kingdom]
Chinese Academy Of Sciences	7	[China]
Hong Kong Baptist University	6	[Hong Kong]
Harvard University	6	[United States of America]
Garvan Institute of Medical Research	6	[Australia]
University of Warsaw	5	[Poland]
Universitat Pompeu Fabra	5	[Spain]



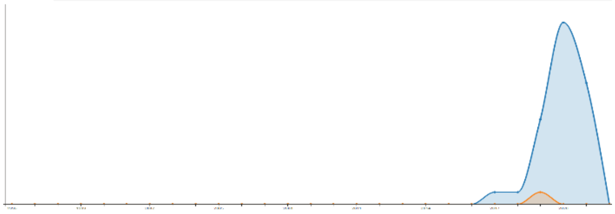
Do-it-yourself artificial pancreas

To compensate for the slow pace of development of diabetes management technologies, a growing number of patients with this disease are building their own DIY systems to dose and deliver insulin.

Figure 78: Visualisations for Do-it-yourself artificial pancreas



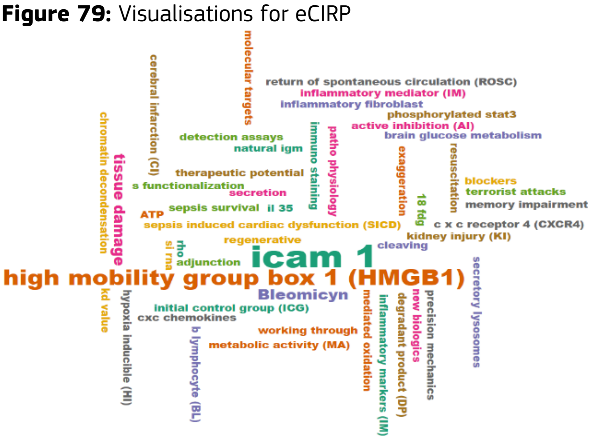
Diabetes Research Centre	3.0	[India]
Charité-Universitätsmedizin Berlin	3.0	[Germany]
University of Waikato	2.0	[New Zealand]
University of Utah	2.0	[United States of America]
University of Otago	2.0	[New Zealand]
University of Chicago	2.0	[United States of America]
University of Birmingham	2.0	[United Kingdom]
University Hospitals	2.0	[Belgium]
University College Dublin	2.0	[Ireland]
Steno Diabetes Center	2.0	[Denmark]
King's College London	2.0	[United Kingdom]



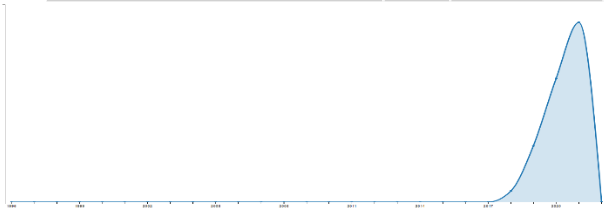
eCIRP

or Extracellular Cold-Inducible RNA-binding Protein, is a protein that has a role in the inflammation mechanism and therefore in diseases such as Alzheimer. Its role has been discovered recently and the protein is therefore a promising target for new drugs.

Figure 79: Visualisations for eCIRP



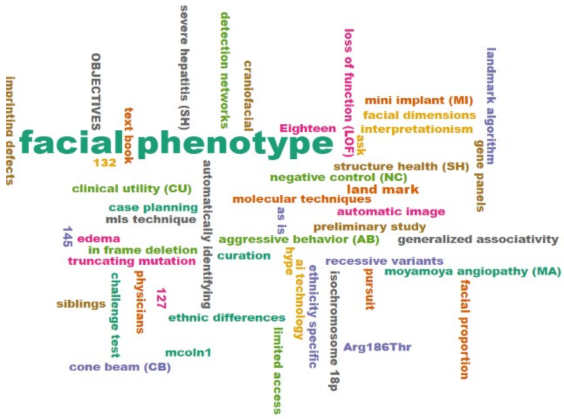
Donald and Barbara Zucker School of Medicine at Hofstra/Northwell	25	[United States of America]
Elmezzi Graduate School of Molecular Medicine	11	[United States of America]
Feinstein Institute for Medical Research	5	[United States of America]
First Affiliated Hospital of Xi'an Jiaotong University	2	[China]
Cohen Children's Medical Center	2	[United States of America]



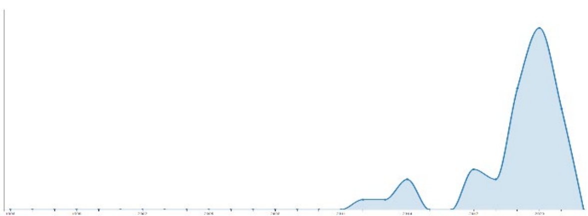
Facial genotyping

aims at using modern machine learning algorithms on facial photographs to evaluate the probably of the subject to have a genetic syndrome.

Figure 80: Visualisations for Facial genotyping



University of California	4.0	[United States of America]
National Hospital	4.0	[Norway]
George Washington University	4.0	[United States of America]
University of Kinshasa	3.0	[Congo]
University of Colorado Anschutz Medical Campus	3.0	[United States of America]
University Hospital Bonn	3.0	[Germany]
Tel Aviv University	3.0	[Israel]
Sapienza University	3.0	[Italy]
Institut National de Recherche Biomédicale	3.0	[Congo]
University of Southern California	2.0	[United States of America]

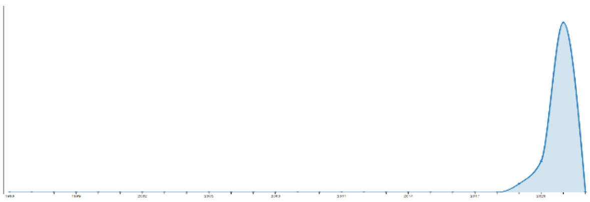


FAPI PET/CT

Fibroblast activation protein (FAP) is overexpressed in the case of epithelial tumors. Using radiolabelled FAP inhibitors allows for better imagery than what can be obtained by using more traditional markers like FDG, and therefore allow for better diagnostic and more precise treatment.

Figure 81: Visualisations for FAPI PET/CT

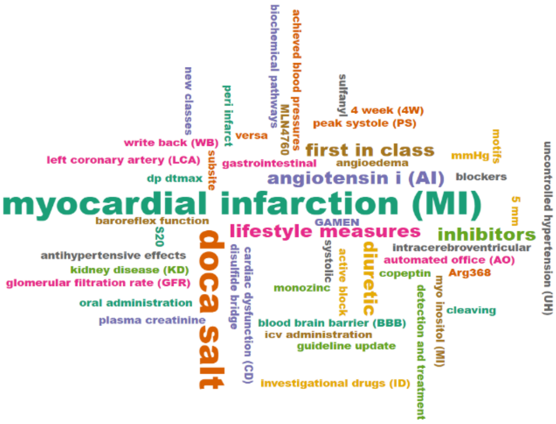
The Affiliated Hospital of Southwest Medical University	13	[China, United States of ...
Heidelberg Institute of Radiation Oncology	12	[Germany]
German Center for Lung Research	12	[Germany]
Heidelberg University Hospital	10	[Germany]
University Hospital Heidelberg	9	[Germany]
Teaching Hospital of Fujian Medical University	9	[China]
National Center for Tumor Diseases	8	[Germany]
National Institutes of Health	5	[United States of America]
First Affiliated Hospital of Xiamen University	5	[China]
University Hospital Düsseldorf	4	[Germany]



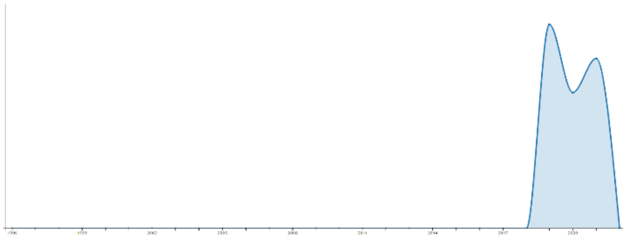
Firibastat

a brain aminopeptidase A inhibitor, is a promising new compound that may be efficient in achieving blood pressure control in patients with resistant hypertension.

Figure 82: Visualisations for Firibastat



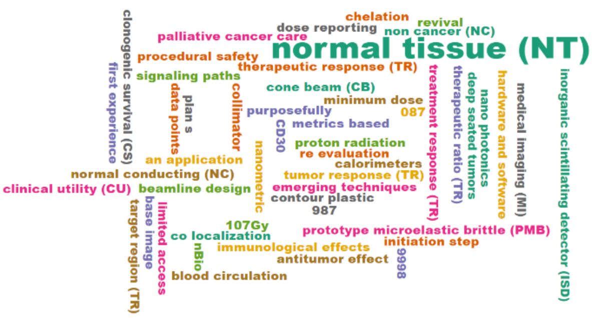
QUANTUM CORP	8.0	[United States of America]
Interdisciplinary Research	5.0	[Japan]
INSERM	4.0	[France]
Westchester Medical Center	2.0	[United States of America]
Université Paris Descartes	2.0	[France]
College de France	2.0	[France]
Université René Descartes	1.0	[France]
Université de Perpignan Via Domitia	1.0	[France]
Université de Lyon	1.0	[France]
University of Texas Southwestern Medical Center	1.0	[United States of America]



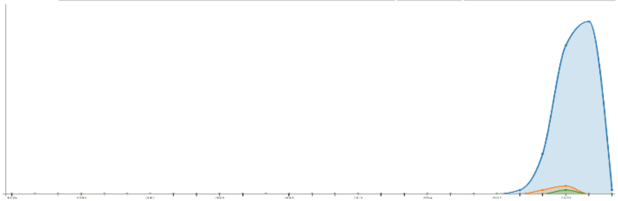
Flash radiotherapy

is a new potentially breakthrough technology in the treatment of cancer. It uses ultra-high doses radiation for a shorter irradiation time, which seeks to minimize the toxicity for healthy tissues while still inducing apoptosis on malignant tissues.

Figure 83: Visualisations for Flash radiotherapy



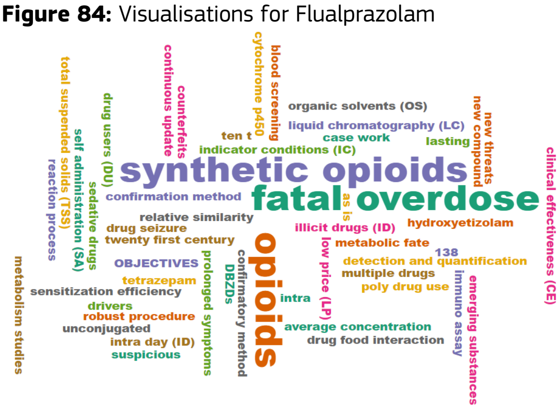
University of California	8.0	[United States of America]
Lausanne University Hospital	7.0	[Switzerland]
Université de Sherbrooke	5.0	[Canada]
University of Oxford	4.0	[United Kingdom]
University Hospital and University of Lausanne	4.0	[Switzerland]
University College London	4.0	[United Kingdom]
Queen's University Belfast	4.0	[United Kingdom]
New York	4.0	[United States of America]
Chinese Academy Of Sciences	4.0	[China]
University of Victoria	3.0	[Canada]
University of Michigan	3.0	[United States of America]
University of Manchester	3.0	[United Kingdom]
Skåne University Hospital	3.0	[Sweden]
Istituto Nazionale di Fisica Nucleare	3.0	[Italy]



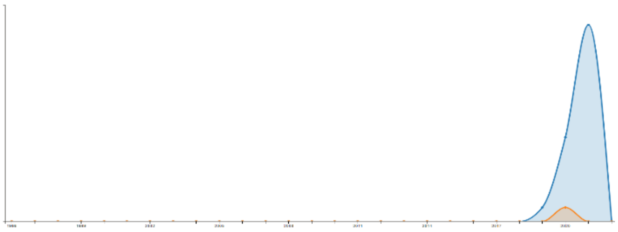
Flualprazolam

is a novel designer benzodiazepine, a class of chemical compounds characterised by a constant emergence of new slightly modified compounds. These novel psychoactive substances pose health challenges to legislators and the public health system. Flualprazolam has quickly gained attention as a new sedative drug with severe adverse effects.

Figure 84: Visualisations for Flualprazolam



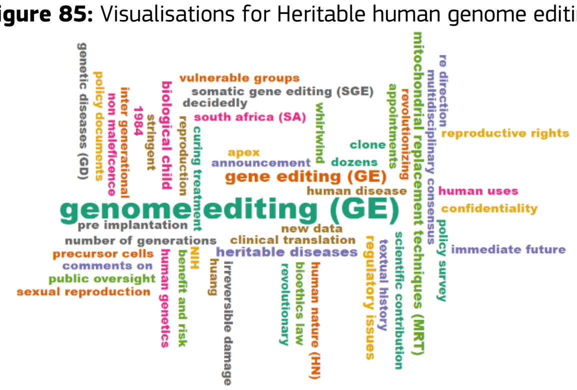
NMS Labs		4.0	[United States of America]
Thomas Jefferson University		2.0	[United States of America]
New York University		2.0	[United States of America]
Institute of Forensic Science		2.0	[China]
Wuhan Polytechnic		1.0	[China]
Vancouver Coastal Health Authority		1.0	[Canada]
Université du Québec à Trois-Rivières		1.0	[Canada]
University of Helsinki		1.0	[Finland]
University of Freiburg		1.0	[Germany]
University of Florida		1.0	[United States of America]
University of California		1.0	[United States of America]



Heritable human genome editing

With the advent of modern genome editing techniques like CRISPR-Cas, interventions on the genome of gametes and embryos are now possible and could contribute to eradicate deadly genetic diseases and genetic orphan diseases. Heritable human genome editing raises a vast number of social, ethical and political issues.

Figure 85: Visualisations for Heritable human genome editing

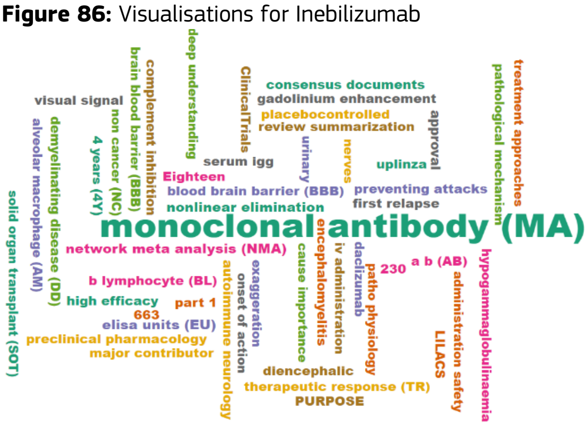


Brown University		3.0	[United States of America]
Dalhousie University		2.0	[Canada]
University of Zurich		1.0	[Switzerland]
University of Wisconsin		1.0	[United States of America]
University of South Florida		1.0	[United States of America]
University of Pennsylvania		1.0	[United States of America]
University of Otago		1.0	[New Zealand]
University of Oregon		1.0	[United States of America]
University of Malta		1.0	[Malta]
University of London		1.0	[United Kingdom]

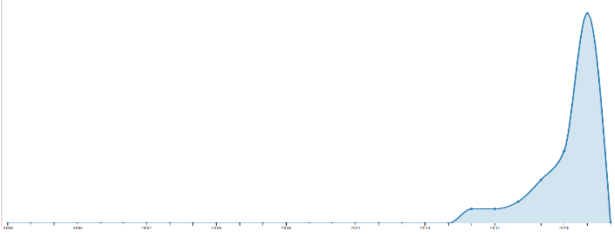
Inebilizumab

is a new drug that brings new promising perspectives in the treatment of neuromyelitis optica spectrum disorder, a rare inflammatory central nervous disease.

Figure 86: Visualisations for Inebilizumab



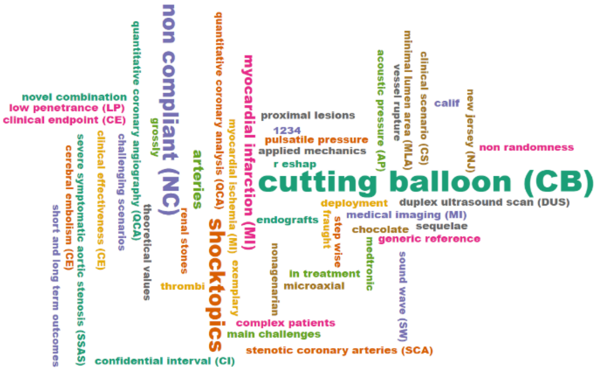
Mayo Clinic		6.0	[United States of America]
University of California		5.0	[United States of America]
MedImmune		4.0	[United States of America]
Max Delbrück Center for Molecular Medicine		4.0	[Germany]
Fukushima Medical University		4.0	[Japan]
Charité-Universitätsmedizin Berlin		4.0	[Germany]
Southern TOHOKU Research Institute for Neuroscience		3.0	[Japan]
Heinrich-Heine-University		3.0	[Germany]
Harvard University		3.0	[United States of America]



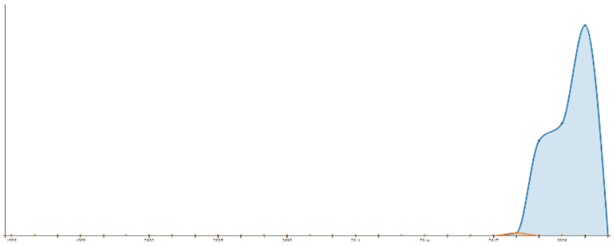
Intravascular Lithotripsy

is a new technique for treating severely calcified lesions that uses acoustic shockwaves to fracture the calcific plaques, improving luminal dimension gain and vessel expansion.

Figure 87: Visualisations for Intravascular Lithotripsy



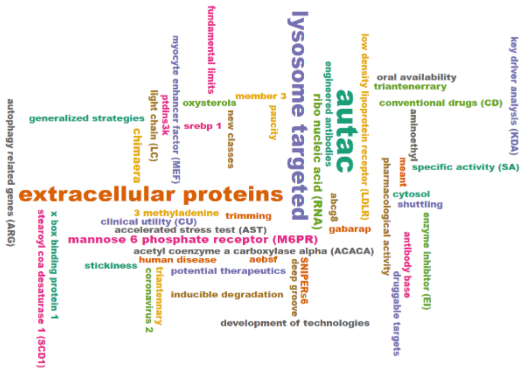
Icahn School of Medicine at Mount Sinai	11	[United States of America]
Careggi University Hospital	10	[Italy]
MedStar Washington Hospital Center	9	[United States of America]
St. Francis Hospital	8	[United States of America]
Royal Brompton Hospital	7	[United Kingdom]
Cardiovascular Research Foundation	7	[United States of America]
Wroclaw Medical University	5	[Poland]
King's College Hospital NHS Foundation Trust	5	[United Kingdom]
Golden Jubilee National Hospital	5	[United Kingdom]
Clinique Pasteur	5	[France]
Belfast Health and Social Care Trust	5	[United Kingdom]
Auckland City Hospital	5	[New Zealand]



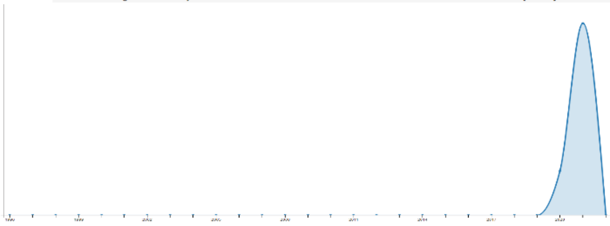
Lysosome TArgeting Chimaeras (LYTACs)

Targeted protein degradation is a relatively new technique to eliminate disease-causing undruggable proteins. LYTACs is the latest tool for targeted protein degradation that makes use of the lysosome degradation pathway. In particular, it targets extracellular proteins and proteins attached to the membrane.

Figure 88: Visualisations for LYTACs



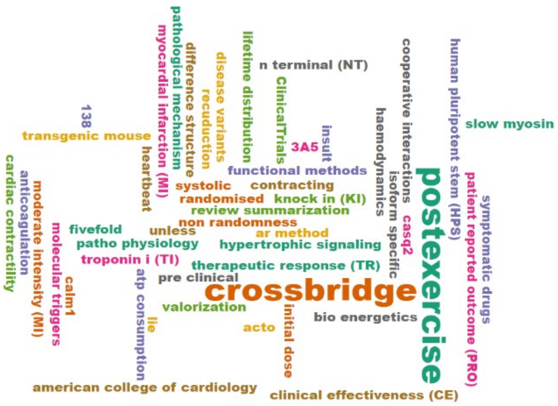
Stanford University	3.0	[United States of America]
Howard Hughes Medical Institute	3.0	[United States of America]
Yale University	1.0	[United States of America]
University of Wisconsin-Madison	1.0	[United States of America]
University of Queensland	1.0	[Australia]
University of Mississippi	1.0	[United States of America]
Texas A and M University	1.0	[United States of America]
Sorbonne University	1.0	[France]
Sichuan University	1.0	[China]
Shanghai University of Traditional Chinese Medicine	1.0	[China]



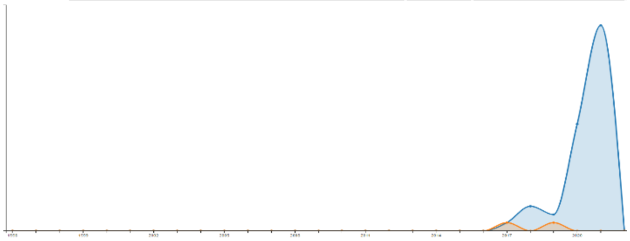
Mavacamten

is an inhibitor of cardiac myosin ATPase that is currently under development and testing as an oral medicine under development to treat symptomatic obstructive hypertrophic cardiomyopathy, for which there are no efficient treatment options.

Figure 89: Visualisations for Mavacamten



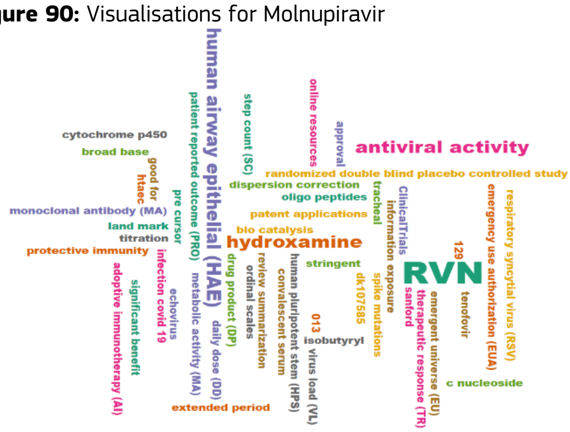
Yale University	5.0	[United States of America]
University of Pennsylvania	5.0	[United States of America]
University of Florence	5.0	[Italy]
Careggi University Hospital	5.0	[Italy]
Brigham and Women's Hospital	4.0	[United States of America]
Yale School of Medicine	3.0	[United States of America]
University of Michigan	3.0	[United States of America]
University of California	3.0	[United States of America]
Oregon Health and Science University	3.0	[United States of America]
Mayo Clinic Arizona	3.0	[United States of America]
Mayo Clinic	3.0	[United States of America]
Azienda Ospedaliero-Universitaria Careggi	3.0	[Italy]



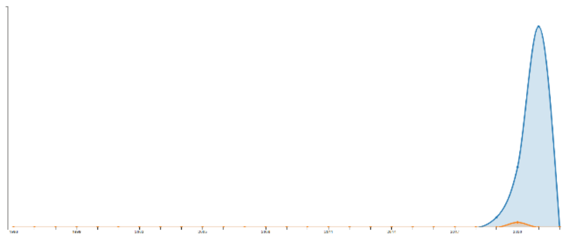
Molnupiravir

is a prodrug metabolised in the body as a mutagenic ribonucloside (active ribonucleoside triphosphate) and concentrates in genomes of RNA viruses during replication. The action mechanism is known as viral error catastrophe: the ribonucloside is incorporated into the RNA, leading to the accumulation of errors in the viral genome and the inhibition of replication. In the EU, it is being used to treat COVID-19 after EMA issued a pre-authorization for emergency use last year.

Figure 90: Visualisations for Molnupiravir



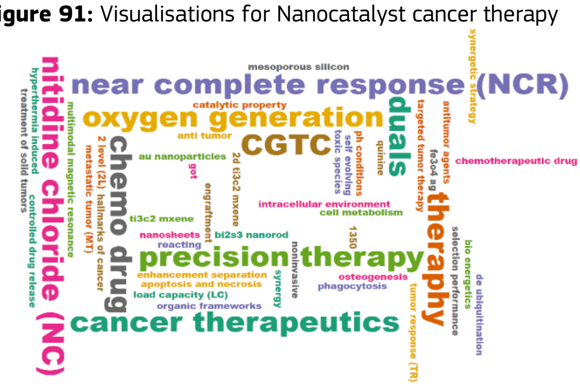
Emory University	5.0	[United States of America]
University of North Carolina at Chapel Hill	3.0	[United States of America]
Rega Institute for Medical Research	3.0	[Belgium]
Massachusetts Institute of Technology	3.0	[United States of America]
Georgia State University	3.0	[United States of America]
Emory University School of Medicine	3.0	[United States of America]
University of Tartu	2.0	[Estonia]
University of California	2.0	[United States of America]
Scripps Research Institute	2.0	[United States of America]
National Institutes of Health	2.0	[United States of America]
Clinical Research Unit	2.0	[Italy]



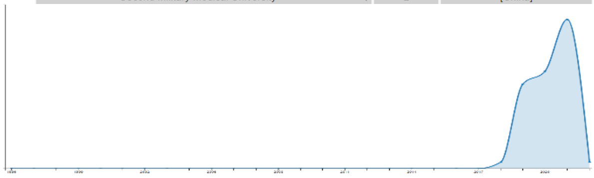
Nanocatalysts cancer therapy

Nanocatalytic medicine is emerging as a highly promising strategy for cancer therapeutics. It enables the suppression of tumors by generating toxic agents within tumors through catalytic reactions, without using traditional highly toxic and nonselective chemical drugs.

Figure 91: Visualisations for Nanocatalyst cancer therapy



Chinese Academy Of Sciences	26	[China]
Tongji University School of Medicine	10	[China]
Tongji University	6	[China]
Shanghai Jiao Tong University School of Medicine	6	[China]
Shanghai University	5	[China]
Fudan University	5	[China]
Wenzhou Medical University	2	[China]
University of New South Wales	2	[Australia]
University of Macau	2	[Macao]
Southeast University	2	[China]
Second Military Medical University	2	[China]

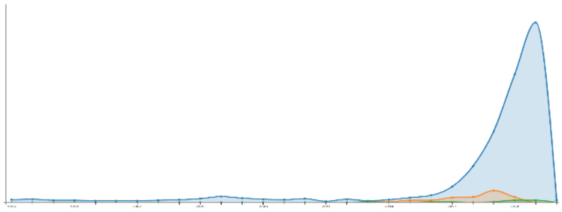


PROteolysis TArgeting Chimaeras (PROTACs)

are bifunctional molecules combining a ligand targeting a protein of interest and a ligand for binding to an E3 ubiquitin ligase. They are one of the tools used in targeted protein degradation, which is a relatively new technique to eliminate disease-causing undruggable proteins.

Figure 92: Visualisations for PROTACs

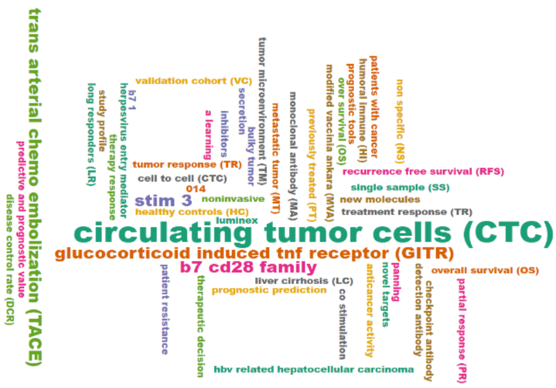
Yale University	56	[United States of America]
University of Dundee	40	[United Kingdom]
Harvard University	40	[United States of America]
China Pharmaceutical University	29	[China]
University of Michigan	28	[United States of America]
Chinese Academy Of Sciences	25	[China]
Tsinghua University	24	[China]
Dana-Farber Cancer Institute	22	[United States of America]
Zhengzhou University	20	[China]
University of California	19	[United States of America]
ASTRAZENECA AB	19	[Sweden]



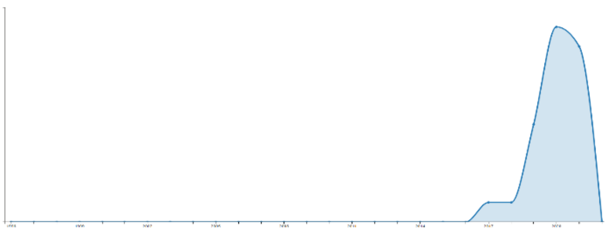
Soluble immune checkpoints

Immune checkpoints are cell membrane-bound systems of receptors and ligands able to switch on or off immune cell functions. A new form of soluble immune checkpoints has been discovered. They consist in biologically active molecules that participate to the regulation of immune responses. Applications in prognosis and prediction of response to therapy and in immunotherapy to fight cancer are being explored.

Figure 93: Visualisations for Soluble immune checkpoints



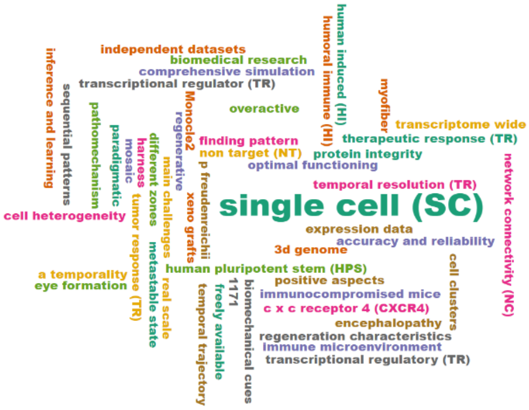
CNRS	3.0	[France]
University of Queensland	2.0	[Australia]
University of Palermo	2.0	[Italy]
Osaka City University	2.0	[Japan]
Chinese PLA General Hospital	2.0	[China]



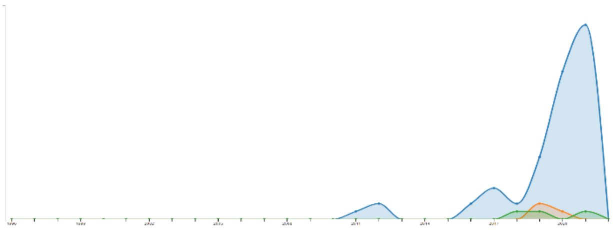
Spatial and temporal Omics

These new methods, also called pseudo time single cell analysis, are useful to detect inter and intra cellular differences in omics across distances or time. It allows for example to map the differences in proteins or RNA respectively produced in different parts of a tumour or produced across time as cells differentiate. These new methods are important for measuring and understanding the variations of different types of molecules during the course of a disease.

Figure 94: Visualisations for Spatial and temporal Omics



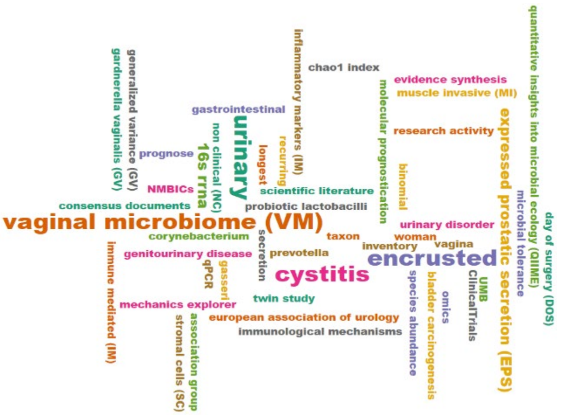
University of California		6.0	[United States of America]
Yale University		5.0	[United States of America]
Yale School of Medicine		3.0	[United States of America]
Harvard University		3.0	[United States of America]
Cornell University		3.0	[United States of America]
Chinese Academy Of Sciences		3.0	[China]
Zhongnan University of Economics and Law		2.0	[China]
Tsinghua University		2.0	[China]
Sun Yat-Sen University		2.0	[China]
Stanford University		2.0	[United States of America]



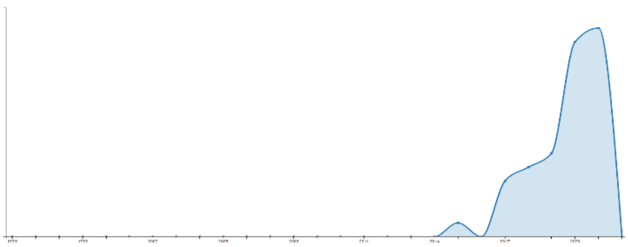
Urobiome

Studying the microbiome living in human urinary tract could potentially help understanding better a wide range of diseases like kidney or lower urinary tract diseases. Research is ongoing to understand the role of the microbes constituting the core urobiome of an individual.

Figure 95: Visualisations for Urobiome



Loyola University Chicago		13	[United States of America]
University of California		11	[United States of America]
Duke University		4	[United States of America]
University of California Los Angeles		3	[United States of America]
Stanford University School of Medicine		3	[United States of America]
Stanford University		2	[United States of America]
Oregon Health and Science University		2	[United States of America]
Loyola University Medical Center		2	[United States of America]



Radar WS

Most of the radar visualisations for weak signals in Medicine and Biotechnology look alike: a sharp and flat triangle characteristic of high activeness, relatively low number of publications, and low persistence. 3 signals have different characteristics: Direct RNA sequencing, which is a technique that is explored for many years (the signal nevertheless has a relatively high activeness); CRISPR based diagnostic, which has a relatively more patents than the other signals; and Chemodynamic therapy which has a relatively high number of scientific publications and patents, compared to the other weak signals.

Figure 96: Radar Weak Signal for Medicine & Biotechnology

Radar Territories

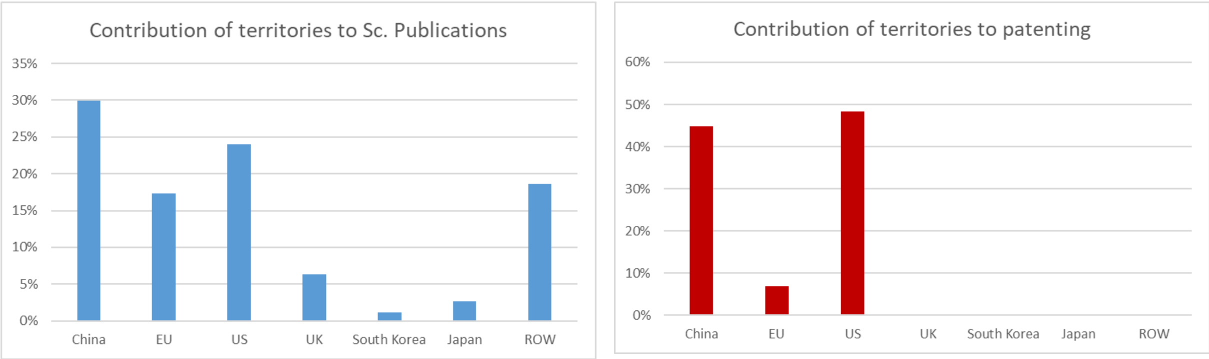
European organisations contribute significantly to most of the weak signals in Medicine and Biotechnology Moreover, in most of those, the contribution is very balanced with the relative contribution of the US. In general, those are also topics in which China doesn't seem to have much interest. Some extreme country distributions are observed for BisCaO antiseptic, Chemodynamic Therapy, Nanocatalyst Cancer Therapy and eCIRP, for which one of the territories produced almost all of the documents retrieved (Japan, China, China and US respectively), with the other territories (including EU) contributing anecdotally.

Figure 97: Radar Territories for Medicine & Biotechnology

From publishing to patenting

Again, while contributing to 17% of the scientific publications for the weak signals in Medicine and Biotechnology (China and US respectively at 30% and 24%), European organisations contribute to only 7% of the patents, leaving most of the patents to Chinese and US based organisations.

Figure 98: From publishing to Patenting for Medicine & Biotechnology



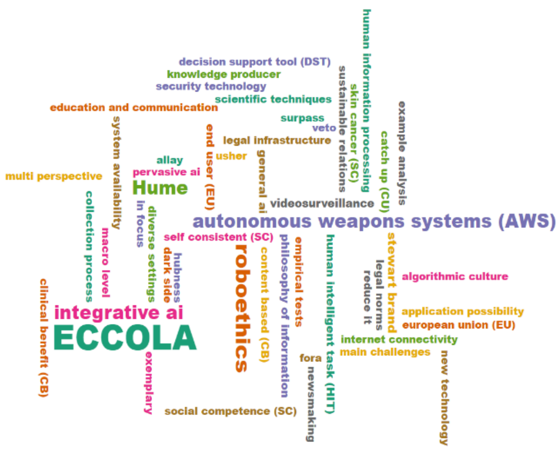
2.6 Societal issues

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1854

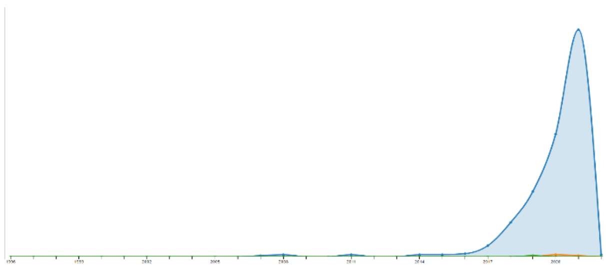
AI ethics

Fast advances in Artificial Intelligence (AI), coupled to advances in robotics, will bring major disruptions in our Society. All the processes, systems, supply chains that underlie the functioning of our Society are increasingly dependent on digital technologies that integrate AI to various levels. The spreading of AI to digital systems raises ethical questions that the research community is currently addressing.

Figure 99: Visualisations for AI ethics



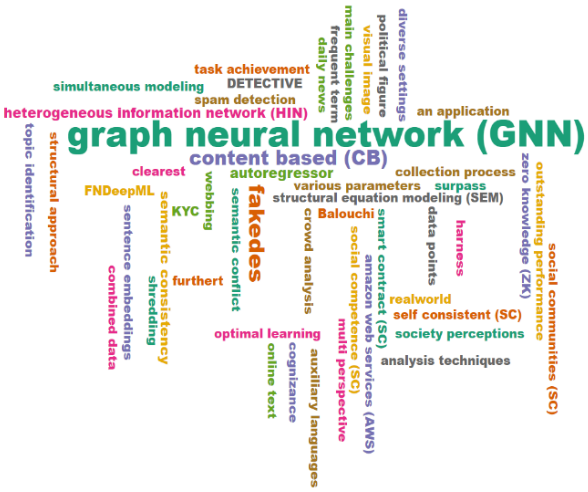
University of Oxford		17	[United Kingdom]
University of Jyväskylä		17	[Finland]
IBM Corp		11	[United States of America, I...
University of Cambridge		9	[United Kingdom]
University of California		9	[United States of America]
McGill University		8	[Canada]
Carnegie Mellon University		8	[United States of America]
University College Dublin		7	[Ireland]
Delft University of Technology		7	[Netherlands]
University of Toronto		6	[Canada]
Harvard University		6	[United States of America]



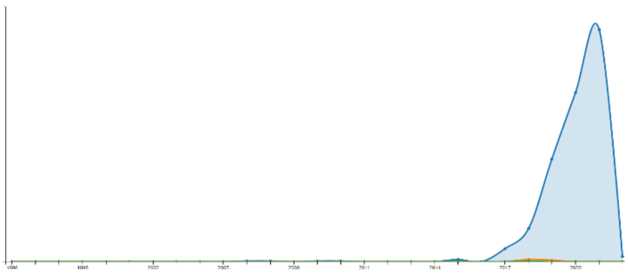
Fake news detection

Not surprising considering some recent events, research related to fake news and misinformation has rapidly increased in the last few years. Scientists from various fields are looking at means to detect fake news and track their propagation on social media.

Figure 100: Visualisations for Fake news detection



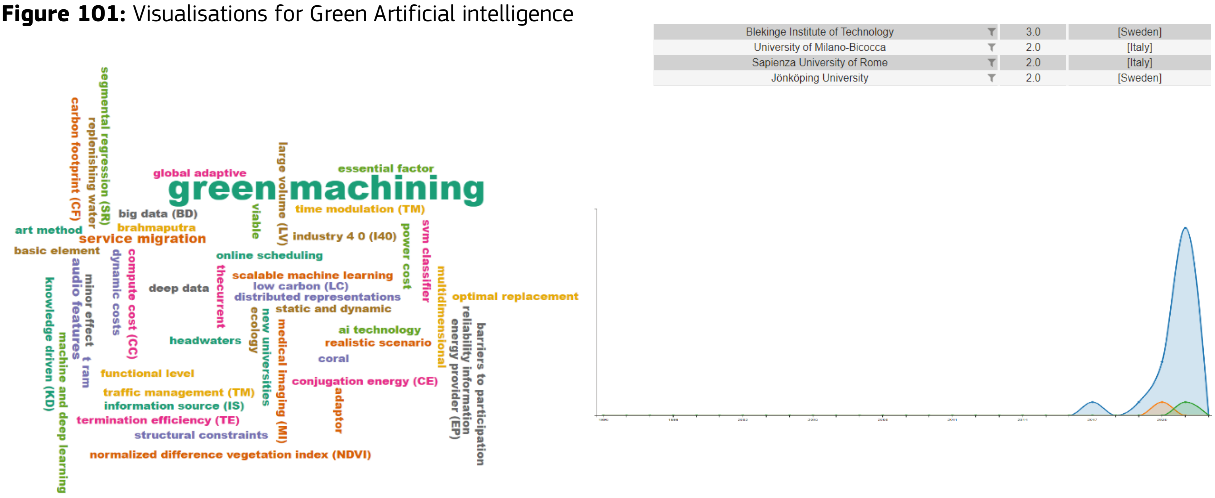
Delhi Technological University		23	[India]
Arizona State University		21	[United States of America]
Chinese Academy Of Sciences		19	[China]
Nanyang Technological University		11	[Singapore]
UTP University of Science and Technology		10	[Poland]
Universidad Politécnica de Valencia		10	[Spain]
University of Science and Technology		9	[China]
Queen's University Belfast		9	[United Kingdom]
Pennsylvania State University		9	[United States of America]
Indraprastha Institute of Information Technology		9	[India]



Green Artificial Intelligence

is a new research topic covering two dimensions: reduce the resource consumption of systems using artificial intelligence and explore how artificial intelligence can be used in processes and systems to decrease resources consumptions overall.

Figure 101: Visualisations for Green Artificial intelligence

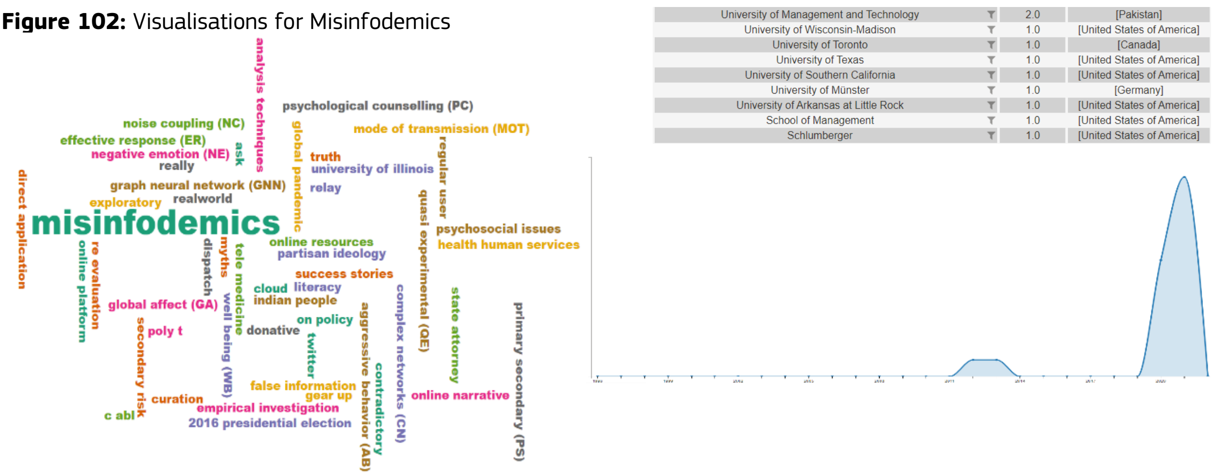


Blekinge Institute of Technology	3.0	[Sweden]
University of Milano-Bicocca	2.0	[Italy]
Sapienza University of Rome	2.0	[Italy]
Jönköping University	2.0	[Sweden]

Misinfodemics

Since the onset of Sars-Cov2 in 2019, fake news and disinformation about the virus and the pandemic have been flourishing on social and sometimes more traditional media. But disinformation on epidemics was also observed for other events (e.g. measles cases US 2016 or Ebola in 2014-16). Research on the impact of such disinformation campaigns on health and society and on how to mitigate this impact is picking up.

Figure 102: Visualisations for Misinfodemics

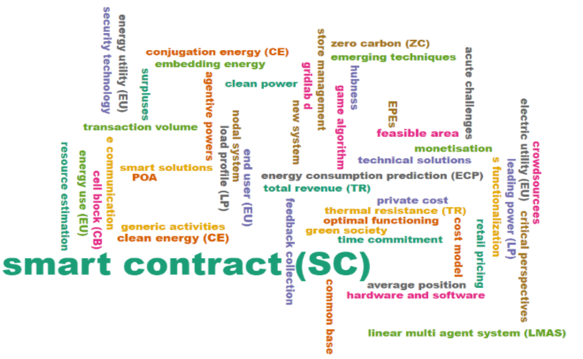


University of Management and Technology	2.0	[Pakistan]
University of Wisconsin-Madison	1.0	[United States of America]
University of Toronto	1.0	[Canada]
University of Texas	1.0	[United States of America]
University of Southern California	1.0	[United States of America]
University of Münster	1.0	[Germany]
University of Arkansas at Little Rock	1.0	[United States of America]
School of Management	1.0	[United States of America]
Schlumberger	1.0	[United States of America]

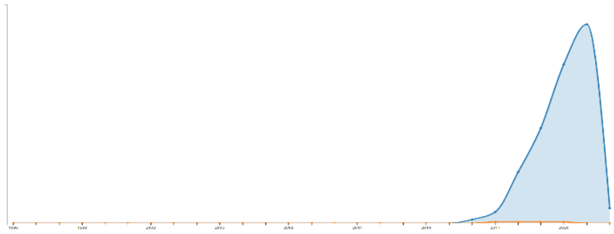
Peer-to-Peer energy trading

The current shift towards distributed energy resources implies that electricity generation and intermediary storage elements (like batteries) are distributed as well. This call for a new business model in which consumers have also become prosumers, generating and consuming energy. A peer-to-peer energy trading mechanism where prosumers interact (and transact) directly is being investigated.

Figure 103: Visualisations for Peer-to-peer energy trading



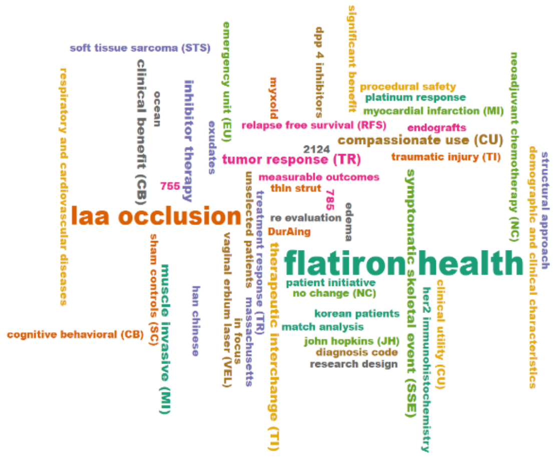
Cardiff University	▼	14	[United Kingdom]
Nanyang Technological University	▼	13	[Singapore]
University of Queensland	▼	12	[Australia]
University of Oxford	▼	11	[United Kingdom]
Manchester Metropolitan University	▼	9	[United Kingdom]
University of Electronic Science and Technology of China	▼	8	[China]
National University of Ireland Galway	▼	8	[Ireland]



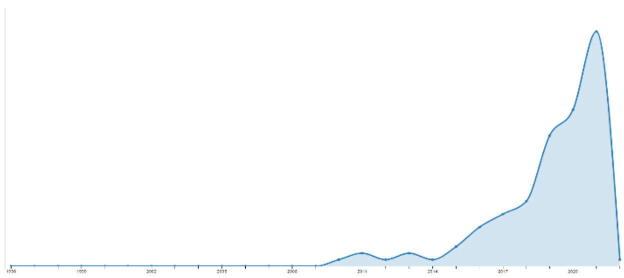
Real world clinical outcome

This signal is actually strong, but it was evaluated as very important by the European Medicine Agency during their review. Real world clinical outcomes are safety and effectiveness data on medicines obtained from patient data collected outside random clinical trials, such as data provided by electronic health records. This data is of increasing importance for the development of medicines but also for their regulation, pricing and reimbursement as it can give insights into the effectiveness in a variety of clinical and patient populations an context.

Figure 104: Visualisations for Real world clinical outcome



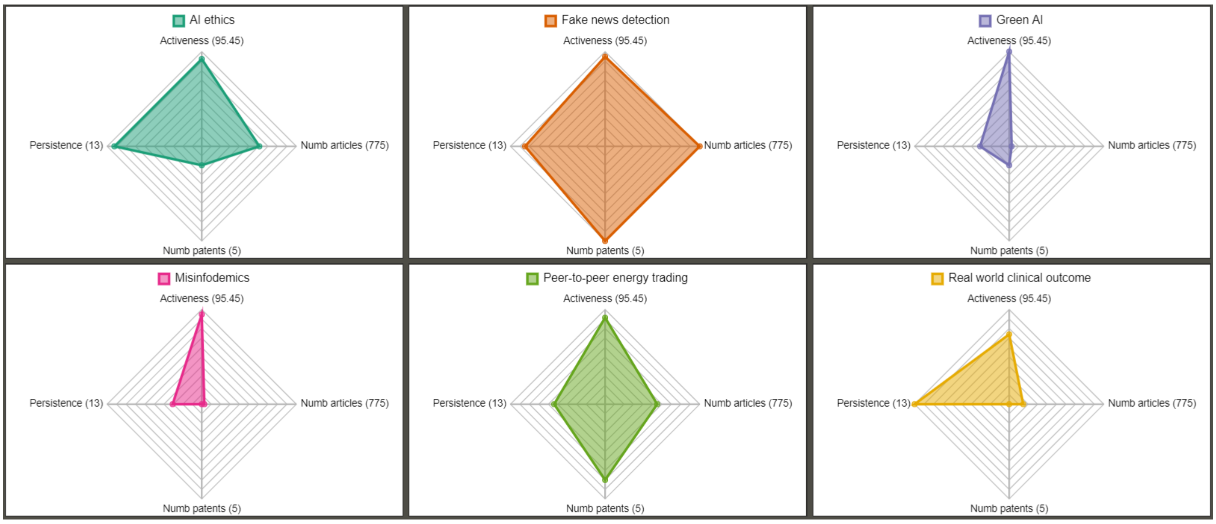
Pfizer Inc.	▼	6.0	[United States of America]
University of Pennsylvania	▼	5.0	[United States of America]
Eli Lilly and Company	▼	5.0	[United States of America]
Harvard University	▼	4.0	[United States of America]
University of California	▼	3.0	[United States of America]
Seoul National University Hospital	▼	3.0	[South Korea]
Mayo Clinic	▼	3.0	[United States of America]
Janssen Scientific Affairs, LLC	▼	3.0	[United States of America]
Dana-Farber Cancer Institute	▼	3.0	[United States of America]
Cancer Center	▼	3.0	[United States of America]
Bristol-Myers Squibb	▼	3.0	[United States of America]
Brighton and Sussex University Hospitals	▼	3.0	[United Kingdom]



Radar WS

All six of the weak signals have high activeness and very few patents. AI ethics, Fake news detection, Real world clinical outcome have a high persistence. Combined with high activeness, this means that these topic are being discussed for a long time in scientific publications but that there is a recent surge in the number of publications. Green AI and Misinfodemics have similar shapes: very new topics with a small number of publications. The weak signal on Real world clinical outcome has a particular shape, with very high persistence, high activeness, and a relatively low number of articles (115).

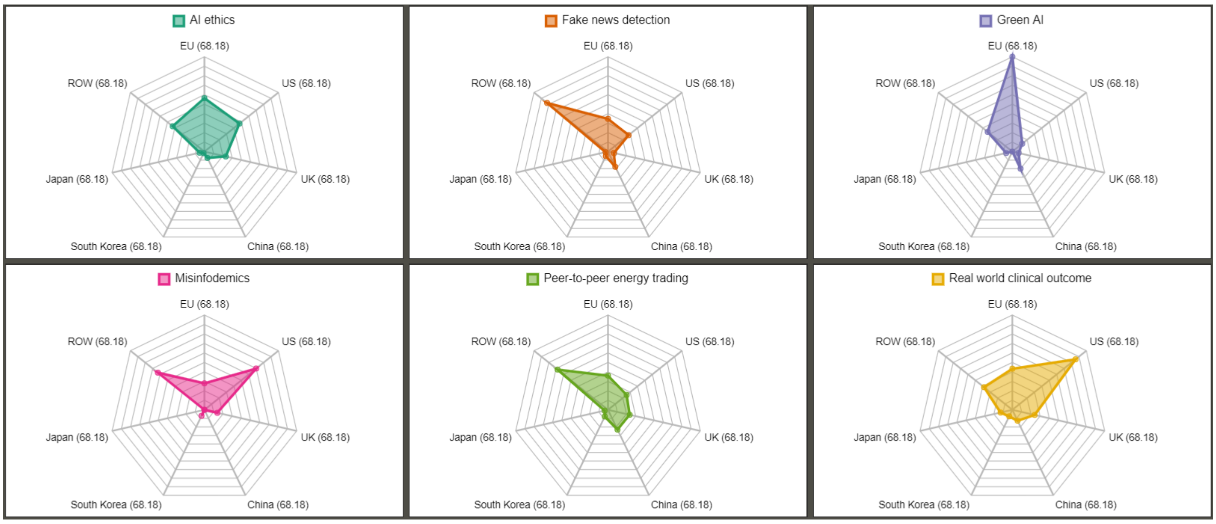
Figure 105: Radar Weak Signal for Societal issues



Radar Territories

Europe is well-positioned in weak signals related to societal issues, leading in a few of them. China, as observed in previous reports, is not very active in weak signal related to social sciences.

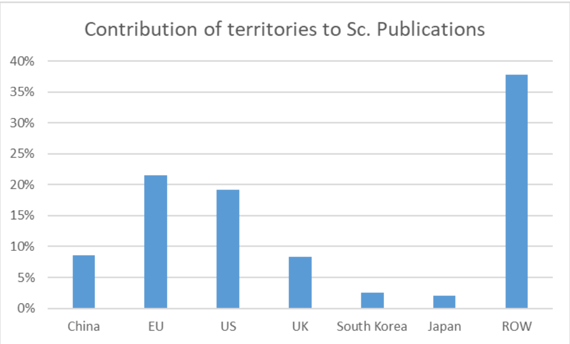
Figure 106: Radar Territories for Societal issues

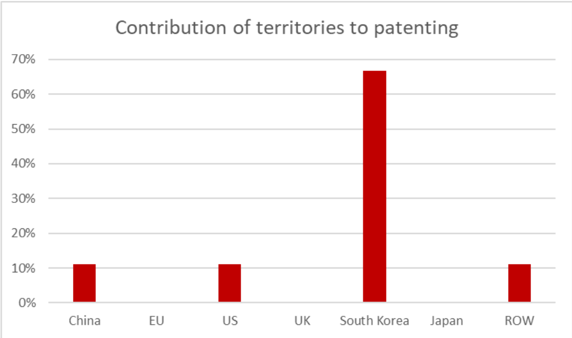


From publishing to patenting

The dominance of European, Chinese, and US based organisations is less marked for weak signals on societal issues, with organisations from the rest of the world (mainly from India and Australia) contributing significantly to scientific publications. While Europe is not involved in patenting for the 6 weak signals, it must be noted that only 8 patents have been retrieved for all of the signals and the contribution to patenting should not be taken here has a concrete indication. Also, the particular nature of the topics makes it natural that very few patents were found.

Figure 107: From publishing to patenting for Societal issues





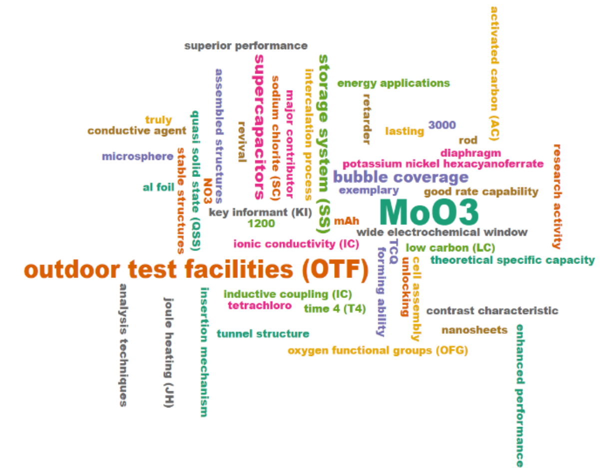
2.7 Energy

Dashboard:
https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_1855

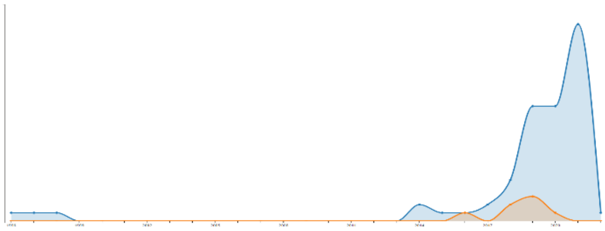
Aqueous Aluminium ion batteries

Because of their low manufacturing costs, superior safety, and flexibility, aqueous energy storage systems have attracted a lot of attention in the recent years and are the key to the widespread usage of wearable electronics. Among these aqueous energy storage systems, the aqueous Al ion battery is a promising candidate.

Figure 108: Visualisations for Aqueous Aluminium ion batteries



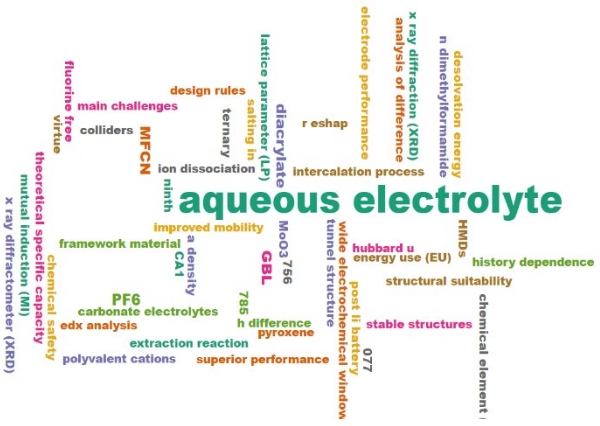
Tezpur University	9.0	[India]
Chinese Academy Of Sciences	6.0	[China]
Nankai University	5.0	[China]
City University of Hong Kong	5.0	[Hong Kong]
Zhengzhou University	4.0	[China]
University of Hong Kong	4.0	[Hong Kong]
School of Materials Science and Engineering	4.0	[China]
Harbin Institute of Technology	4.0	[China]
Queensland University of Technology	3.0	[Australia]
Nanyang Technological University	3.0	[Singapore]



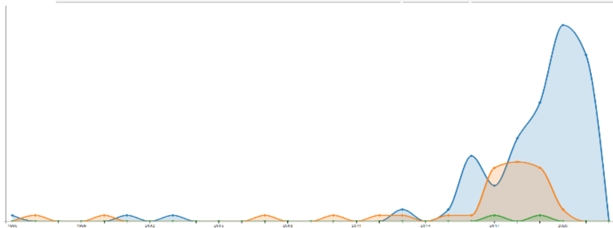
Calcium batteries

is considered as one of the most promising post-lithium era ion battery, mainly because of abundance of Calcium on Earth, the high volumetric capacity of multivalent ion batteries compared to monovalent metal batteries, and the low reduction potential of the couple Ca^{2+}/Ca. Some recent advances related to the Calcium anode have triggered an increase in research on Calcium rechargeable batteries.

Figure 109: Visualisations for Calcium batteries



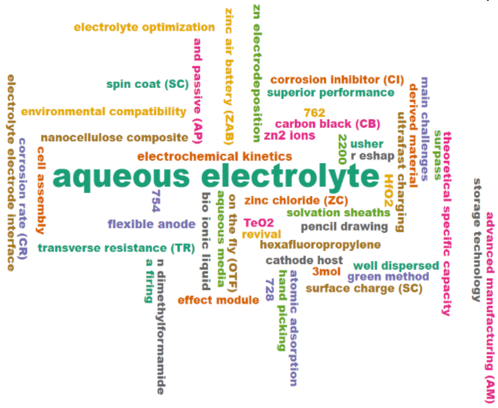
CNRS	11	[France]
Daegu	9	[South Korea]
Universidad Complutense de Madrid	8	[Spain]
Institut de Ciència de Materials de Barcelona	8	[Spain]
Syracuse University	7	[United States of America]
Soonchunhyang University	7	[South Korea]
University of California	6	[United States of America]
Joint Center for Energy Storage Research	6	[United States of America]
DAEGU GYEONGBUK INSTITUTE OF SCIENCE&TECH	6	[South Korea]
Toyota Motor Corp	4	[Japan]

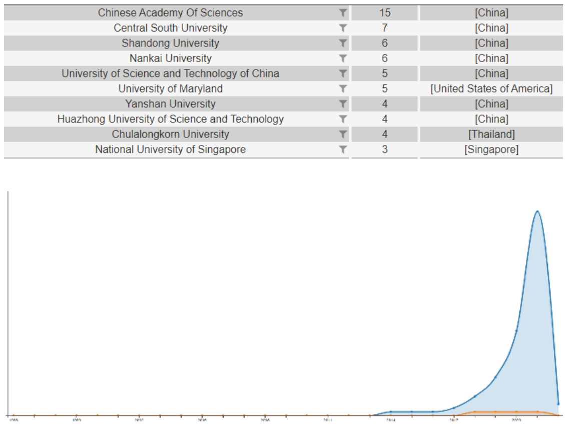


Dendrite-free Zinc battery

Rechargeable aqueous Zinc batteries are promising for portable electronic equipment and large-scale energy storage due to their high energy density and low manufacturing costs. However, their practical application has been put to a halt by the poor reversibility of Zinc anodes, mainly due to the growth of dendrites and other interfacial interfering reactions. Researchers are exploring how to produce dendrite-free Zinc batteries.

Figure 110: Visualisations for Dendrite-free Zinc battery



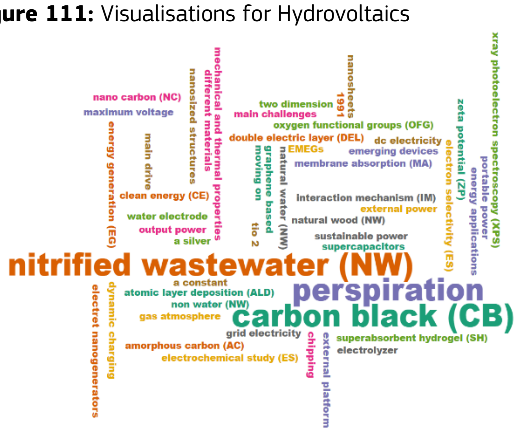


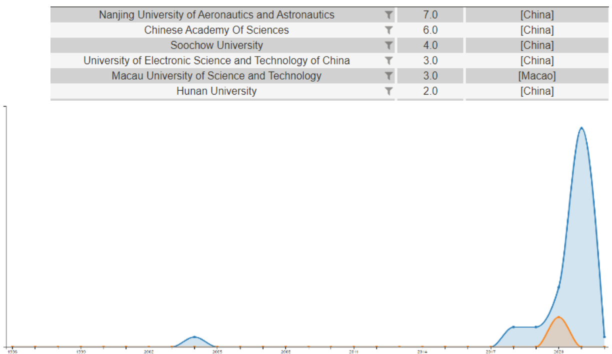
Chinese Academy Of Sciences		15	[China]
Central South University		7	[China]
Shandong University		6	[China]
Nankai University		6	[China]
University of Science and Technology of China		5	[China]
University of Maryland		5	[United States of America]
Yanshan University		4	[China]
Huazhong University of Science and Technology		4	[China]
Chulalongkorn University		4	[Thailand]
National University of Singapore		3	[Singapore]

Hydrovoltaics

is the word coining a recently discovered phenomenon i.e. the generation of electricity induced by the evaporation of water that was interacting with nanostructured materials like graphene. Research to transform this effect observed in laboratory into a renewable source of electricity is still in its infancy, but could potentially lead to some disrupting innovations.

Figure 111: Visualisations for Hydrovoltaics



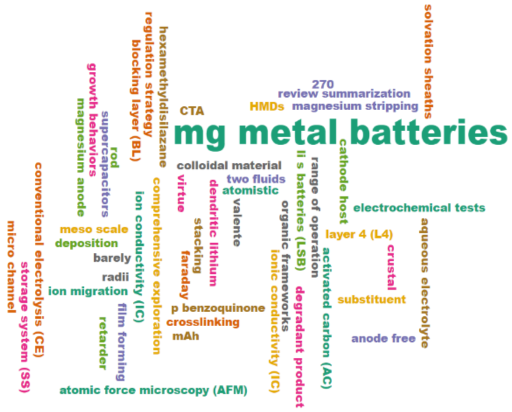


Nanjing University of Aeronautics and Astronautics		7.0	[China]
Chinese Academy Of Sciences		6.0	[China]
Soochow University		4.0	[China]
University of Electronic Science and Technology of China		3.0	[China]
Macau University of Science and Technology		3.0	[Macao]
Hunan University		2.0	[China]

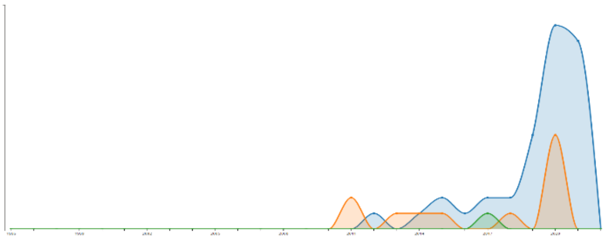
Magnesium metal batteries

are regarded as another promising alternative to lithium-ion batteries due to their high theoretical capacity, relatively high potential, and also due to the natural abundance of magnesium. Research is ongoing to bring Mg battery closer to commercial applications, notably on the corrosive nature of magnesium electrolytes, the irreversibility of the passivation of surfaces, and the lack of suitable cathode materials.

Figure 112: Visualisations for Magnesium metal batteries



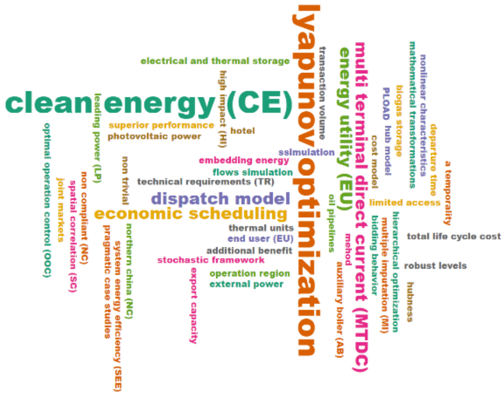
Chinese Academy Of Sciences	11	[China]
Qingdao University of Science and Technology	5	[China]
MAT CO LTD	5	[South Korea]
Bosch Corp	5	[China]
National Institute of Chemistry	4	[Slovenia]
University of Ljubljana	3	[Slovenia]
Wuhan University of Technology	2	[China]
Université Paris-Saclay	2	[France]
University of Maryland	2	[United States of America]
Shangqiu Normal University	2	[China]



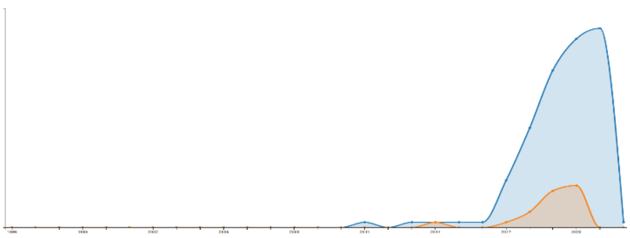
Multi-energy microgrids

In the recent years, multi-energy microgrids have emerged as platform for connecting multiple terminal resources and multiple distributed components for energy production, conversion, and storage. Using this type of grids allows to form a network of connected and optimized multiple energy sources, with the goal to minimize energy waste.

Figure 113: Visualisations for Multi-energy microgrids



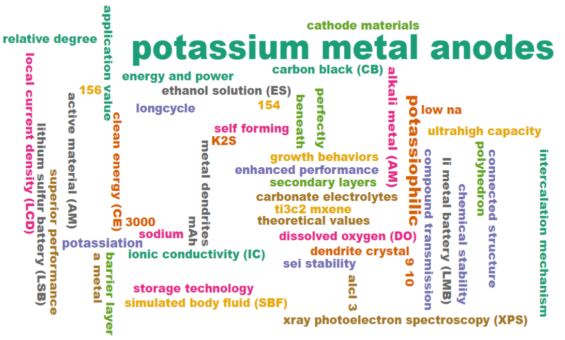
Nanyang Technological University	15	[Singapore]
STATE GRID	11	[China]
Tsinghua University	10	[China]
Zhejiang University	9	[China]
Tianjin University	9	[China]
XI'AN JIAOTONG UNIVERSITY	7	[China]
STATE GRID CORPORATION OF CHINA	7	[China]
Aalborg University	7	[Denmark]
Shenyang University of Technology	6	[China]
Guangdong Power Grid Corporation	6	[China]



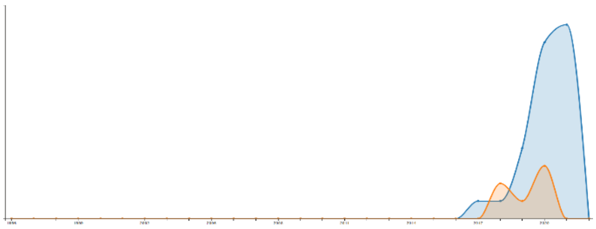
Potassium metal batteries

are promising energy storage devices with a theoretical high energy density and low manufacturing cost. Research is ongoing to tackle the two main challenges preventing this type of batteries to become a reliable technology: eliminating the dendrites growth issue and achieving a stable electrode/electrolyte interface.

Figure 114: Visualisations for Potassium metal batteries



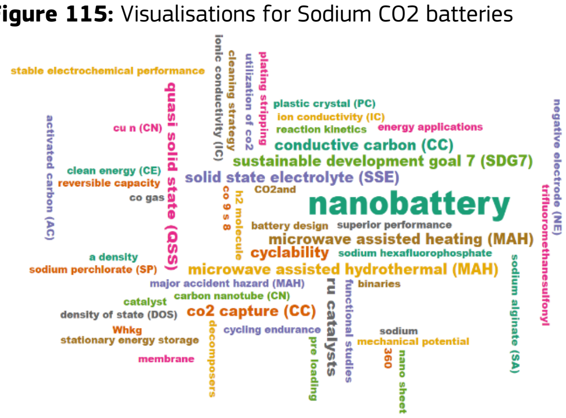
University of Texas at Austin		7.0	[United States of America]
Tsinghua University		4.0	[China]
Ohio State University		3.0	[United States of America]
University of Technology Sydney		2.0	[Australia]
Sichuan University		2.0	[China]
Ocean University of China		2.0	[China]



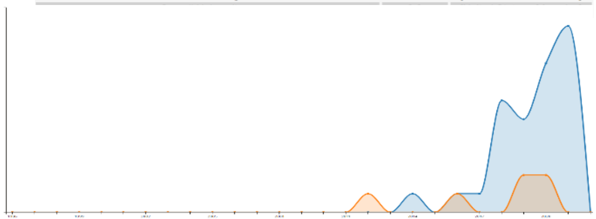
Sodium CO2 batteries

Rechargeable Na-CO2 batteries are promising energy storage devices with high theoretical energy density that use earth-abundant Sodium and CO2. Solutions are currently being explored for solving poor electrochemical performance and short durability. Batteries with cathode made of CO2 are also of potential interest for the exploration of Mars, where CO2 makes 96% of the atmosphere.

Figure 115: Visualisations for Sodium CO2 batteries



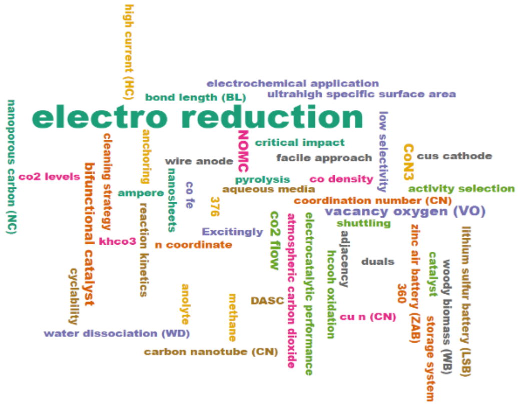
Nankai University		6.0	[China]
Zhengzhou University		4.0	[China]
National Taiwan University		4.0	[Taiwan]
National Taiwan Normal University		4.0	[Taiwan]
Kunming University of Science and Technology		4.0	[China]
Chinese Academy Of Sciences		4.0	[China]
University of Wollongong		3.0	[Australia]
National Taipei University of Technology		3.0	[Taiwan]
Central South University		3.0	[China]
Zhejiang University of Technology		2.0	[China]
University of Western Ontario		2.0	[Canada]
National Taiwan University of Science and Technology		2.0	[Taiwan]
National Engineering Laboratory		2.0	[United Kingdom]
Dartmouth College		2.0	[United States of America]



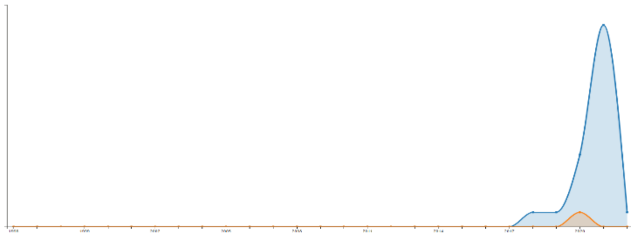
Zinc CO2 batteries

Rechargeable Zinc CO2 batteries are promising energy storage devices with high theoretical energy density that uses earth-abundant Zinc and CO2. Providing they become commercial viable, this type of batteries will allow to deal with greenhouse gas effect while providing alternative to lithium ion batteries.

Figure 116: Visualisations for Zinc CO2 batteries



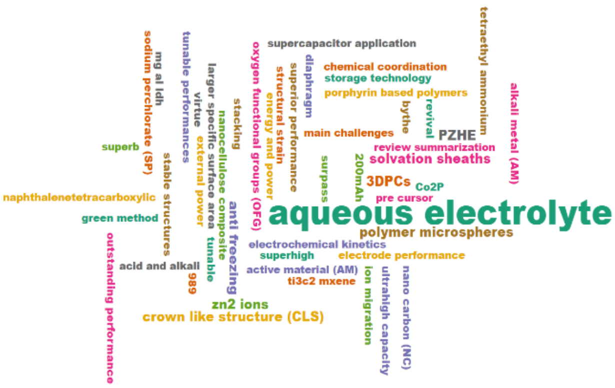
Chinese Academy Of Sciences		8.0	[China]
Zhejiang University		6.0	[China]
Zhejiang University of Technology		3.0	[China]
University of Western Ontario		2.0	[Canada]
Technische Universität Dresden		2.0	[Germany]
State University of New York		2.0	[United States of America]
Jiaxing University		2.0	[China]
Hunan University		2.0	[China]
CHANGZHOU UNIVERSITY		2.0	[China]
Central China Normal University		2.0	[China]
Case Western Reserve University		2.0	[United States of America]



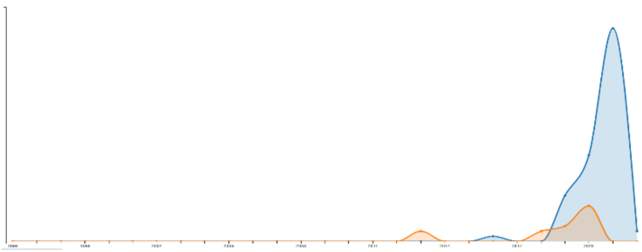
Zinc ion capacitors

are emerging high-performance hybrid capacitors that have great advantages: high-energy-power density, abundance of zinc, low production costs and high safety.

Figure 117: Visualisations for Zinc ion capacitors



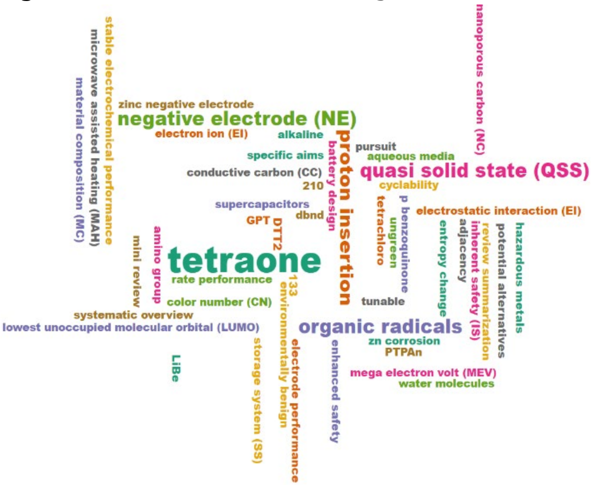
Chinese Academy Of Sciences		12	[China]
Tsinghua University		8	[China]
University of Technology Sydney		4	[Australia]
Lanzhou University of Technology		4	[China]
King Abdullah University of Science and Technology		4	[Saudi Arabia]
Guangdong University of Technology		4	[China]
City University of Hong Kong		4	[Hong Kong]
Central South University		4	[China]
University of Sydney		3	[Australia]
University of New South Wales		3	[Australia]
University of Cambridge		3	[United Kingdom]



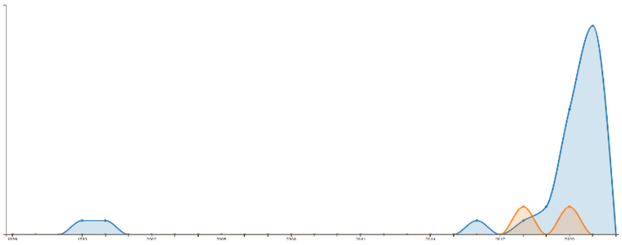
Zinc organic batteries

Zn-organic batteries are recently attracting attention of researchers, which are trying to alleviate their low energy density and corrosion and dendrites formation problems. Here too, the abundance of Zinc on the planet and their safety makes them good candidates for the next generation of batteries.

Figure 118: Visualisations for Zinc organic batteries



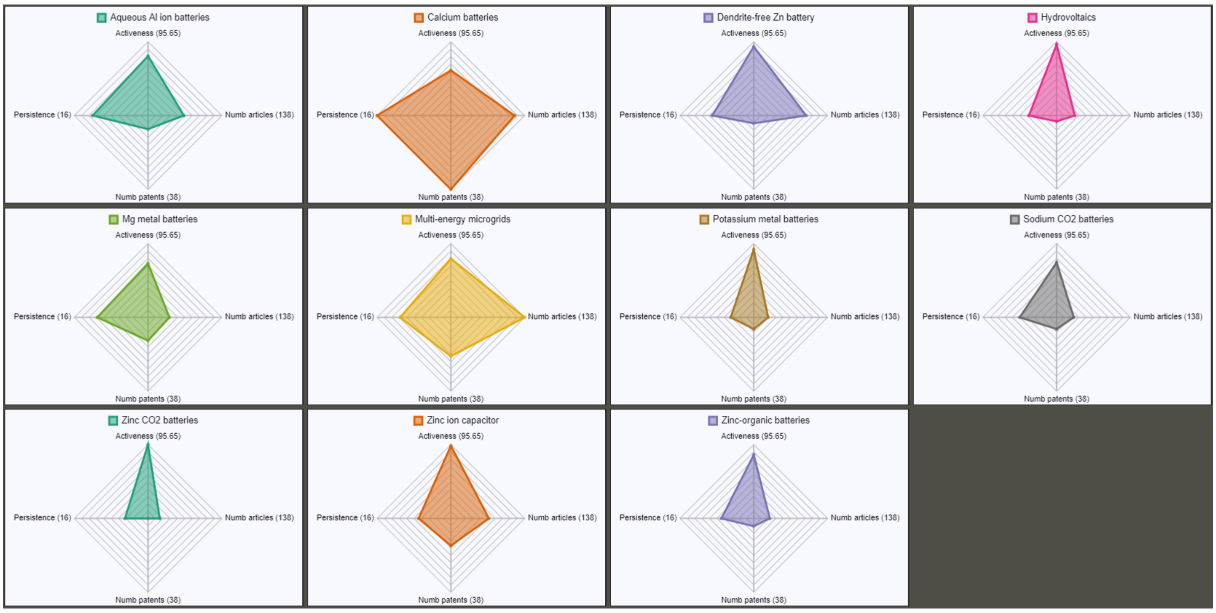
Fudan University	⊤	6.0	[China]
Nankai University	⊤	5.0	[China]
Chinese Academy Of Sciences	⊤	5.0	[China]
Nanyang Technological University	⊤	4.0	[Singapore]
Zhengzhou University	⊤	2.0	[China]
Shanghai University	⊤	2.0	[China]
Nanjing University	⊤	2.0	[China]
Ctrl. Electrochemical Res. Institute	⊤	2.0	[India]
City University of Hong Kong	⊤	2.0	[Hong Kong]



Radar WS

Three types of weak signals in Energy can be distinguished: narrow triangles (high activeness, relatively low persistence, relatively low number of scientific publications and patents), broad triangles (high activeness, average persistence and number of articles, low number of patents), and diamonds (which have a lower activeness and many more patents).

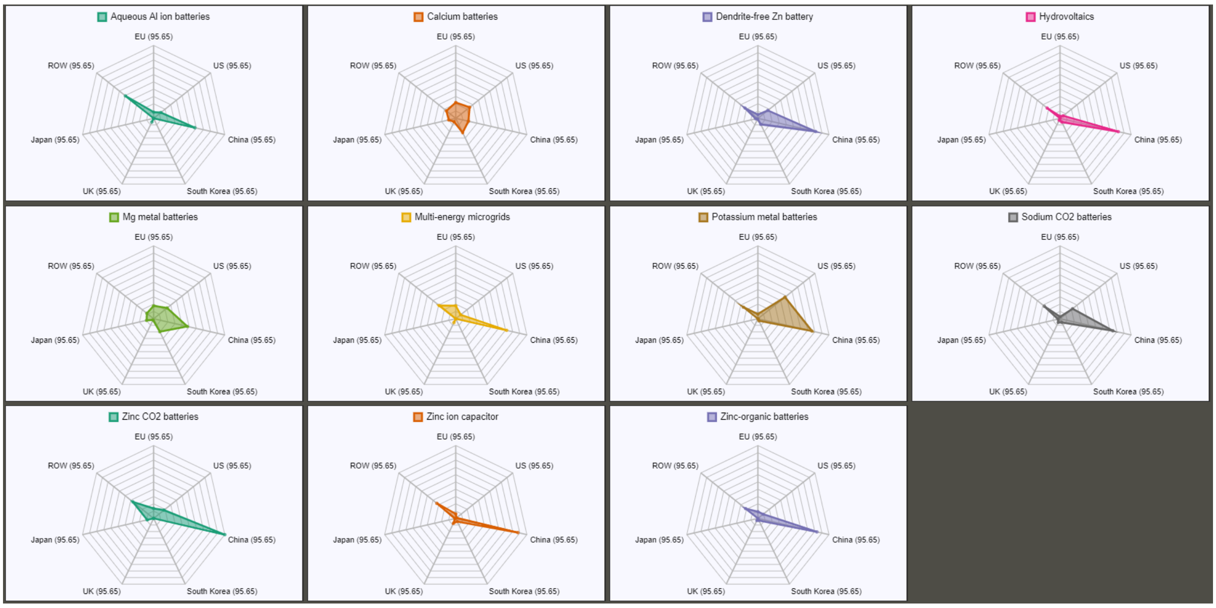
Figure 119: Radar Weak Signal for Energy



Radar Territories

Europe is well-positioned for Calcium batteries, Magnesium metal batteries, multi energy grid, and to a lesser extend in Zinc CO2 batteries. However, China is leading in most of the weak signals.

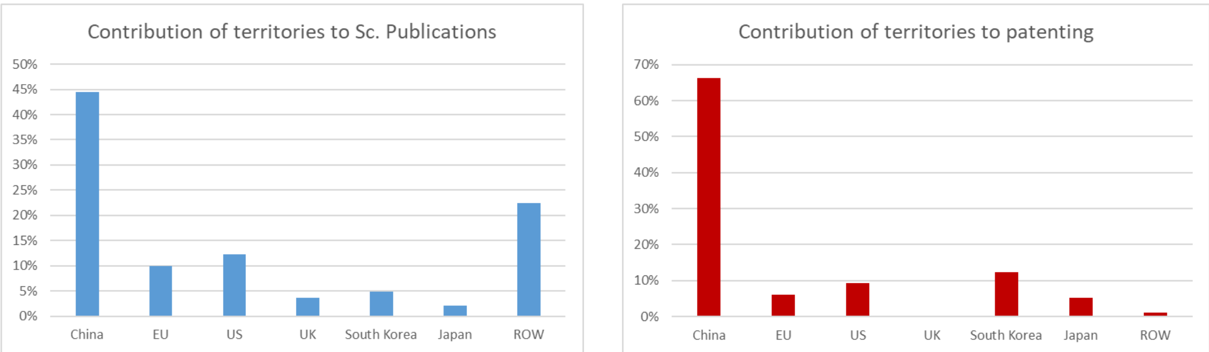
Figure 120: Radar Territories for Energy



From publishing to patenting

Chinese organisations contribute massively to scientific publications for the weak signals in Energy, which reflects in patenting where also most of the patents originate from China.

Figure 121: From publishing to Patenting for Energy



3 Methodology

3.1 Data

For the purpose of this report, scientific publications are considered as a proxy of early technological development. The assumption is that a weak signal of technological development in a certain domain will see a sudden increase in the number of publications (see figure 122).

The Scopus database of scientific publications from Elsevier (covering 01/1996 to 12/2021) was used for the detection of weak signals. Scopus is Elsevier's abstract and citation database and covers nearly 36,377 scientific journals from approximately 11,678 publishers, of which 34,346 are peer-reviewed journals in top-level subject fields such as life sciences, social sciences, physical sciences and health sciences. The methodology applied for this exercise combines text mining, scientometrics and domain/topic knowledge.

3.2 Detection of raw weak signals

The approach is to automatically build sets of documents that represent as many concepts included in the data as possible. Indicators are then calculated on those sets to filter for the most emerging ones.

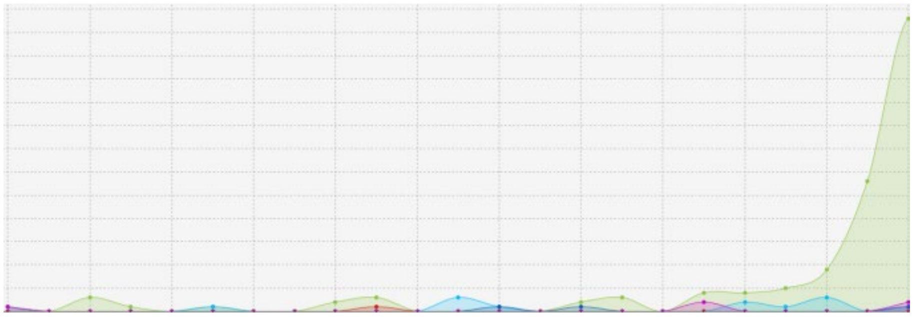
Building the sets of documents
The sets are built by automatically querying the Scopus database for concepts from a text-mining generated dictionary. The creation of the dictionary is a crucial step in this process. The dictionary of multi-words concepts is generated from a corpus of documents using text mining techniques. Single and compound words as well as acronyms are extracted from titles, abstracts and keyword fields in the reference corpus. To capture the recent vocabulary used in scientific publications, documents from the last seven years (2015-2021) of the Scopus database are used as corpus (~11 million scientific publications). The extracted words are then processed to group instances of the same concept, remove inconsistencies in e.g. spelling or word choice, rank the concepts by relevance and store them in a dictionary. For the 2021 round of weak signal detection, the resulting dictionary was composed of 7.884.935 concepts, each of them subsequently used in an automated query process that builds an equivalent number of sets containing scientific publications ranging from 1996 to 2021[36].

Detection of raw weak signals
After the creation of the sets of documents – each of them representing a “concept” – a custom-built indicator called "activeness" is used to sort these sets. This indicator is defined as the ratio between the number of documents retrieved for a certain period and the total number of documents retrieved for the period 1996-2021. For example, activeness[2019-2021] corresponds to the ratio [#documents published during the period 2019-2021] / [#documents published during the period 1996-2021]. A high activeness score means that a high percentage of documents has been published during the selected period. The following activeness indicators have been used to detect the weak signals from the list of sets: activeness[2017-2021], activeness[2019-2021] and activeness[2020-2021]. The sets are ordered by decreasing activeness for further evaluation.

[36] Detecting weak signals implies looking into the past to verify novelty.

The sets containing scientific articles with a high activeness are considered as raw weak signals i.e. they might be related to emerging topics in science or emerging technologies.

Figure 122: Typical shape of a weak signal on a graph #documents (Y-axis) Vs years (X-axis).



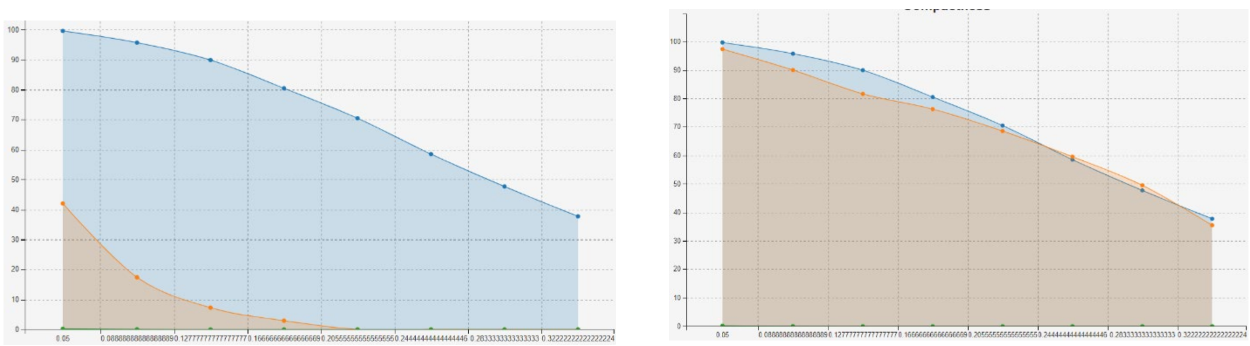
3.3 Selection of relevant weak signals

Filtering before reconstruction

Various filters are used to refine the list of raw weak signals, which inevitably also contains false positives. These filters are based on size of the sets of documents, manual detection or semantic proximity.

First, a simple filter is applied to reject sets that do not reach a certain minimum number of documents (the trigger was put on 5 documents for the present exercise). Manual filtering is also used to reject sets resulting from errors in the original corpus (e.g. spelling mistakes). A more elaborated filtering relying on "semantic compactness" is used to reject weak signals containing documents that are not similar from a semantic perspective. Weak signals pertaining to different conceptual areas but with one or two semantic concepts in common are not considered (e.g. documents related to a conference where the only common term between the documents is the name of said conference). As shown in figure 123, “compactness” in TIM shows the percentage of documents (y axis, from 0 to 100%) that have at least 10 documents within the similarity threshold on the x-axis. In the figure below, one can see the compactness graph for two sets of documents (orange curves): “Metallic nanoparticles in food” on the left, “Tenebrio Molitor” (an insect) on the right. The orange curve is always compared to two other curves, for reference: a blue curve based on a very compact set, and a green curve based on randomly collected scientific publications.

Figure 123: Typical shapes for a non-compact (left) and a compact set of documents (right)



Compactness helps to understand how similar the documents within the sets are. For some f the sets, a higher variability of topics is expected in the documents (resulting in articles less similar and therefore a lower compactness, as exemplified on the left for “Metallic nanoparticles in food”) and for some others the similarity among documents is expected to be higher (when the topic is narrower, like for “Tenebrio Molitor” on the right, resulting in a higher compactness). One can observe that the compactness (orange curve) is very different for the two sets. The graph are to be interpreted as follow. For “Metallic nanoparticles in food” (left), 40% of the documents in the set have at least ten documents with whom semantic distance is smaller than 0,05 (which is a very low semantic similarity). For Tenebrio Molitor (right), 95% of the documents are within that similarity range. The second points on the left graph is located at (0.15,16): only 16% of the documents have at least 10 documents similar when the threshold is increased to 0.15 of semantic similarity. For the graph on the right, the second point is at (0.15, 90): 90% of the documents have at least 10 documents that are similar with a threshold at 0.15. the same for the other points on the graphs.

In other words, the higher and more horizontal the orange curve is, the more compact the set of documents is i.e. the more it is composed by semantically similar documents. The faster the orange curve goes to zero, the less compact the set of documents is i.e. the more diverse the documents are. To compute these compactness curves, each document in the set is first compared to the other documents using cosine similarity. A minimum value of cosine distance under which two documents are not considered similar is then fixed:
- If cosine similarity > threshold, the two documents are similar
- If cosine similarity < threshold, the two documents are not similar
This threshold was fixed at 0.35 for the present exercise.

A document that is not similar to at least 10 other documents is considered as an outlier relatively to the other documents in the set. See annex below for more information on semantic similarity in TIM.

Reconstruction in TIM Technology
To finalise the selection, new sets of articles are created for the promising raw weak signals in the TIM Technology system, which, in addition to scientific publications, also contains patents and EU R&D grants.
This “reconstruction” consists in optimising the search queries to increase the recall of documents and to further validate the list of signals. Because of the semantic nature of the process, it may be that what was considered as a weak signal appears to be a strong signal i.e. a trend or an issue known for long. A typical example is a technology for which a new word, or new semantic concept appears after a few years: although the technology is not new, the concept is new and it might be detected in the weak signal process. Other examples of such false positive include typos or specific conference names. This reconstruction in TIM Technology may appear as a tedious process, but it is the unfortunate price to pay for a highly sensitive process. Various features support the optimisation of the search queries: relevant keywords, clustering of articles, documents gram, compactness, document list and online access.

The full list of search queries can be found in figure 129 at the end of this report.

Relevant keywords
The relevant keywords function in TIM is used to rapidly spot keywords that although relevant to the set of documents considered are not related to the weak signals. In other words, scanning through the list of relevant keywords allows to spot the keywords related to outliers i.e. articles recalled by the search query but not related to the topic of the weak signal.

The relevance of the keywords are calculated as follow. First a bag of concepts is built, containing concepts with a rank associated to each of them. The bag of concepts can be calculated at the level of individual documents or for a group of documents. In the case of relevant keywords, it is the bag of concepts for the set of documents. For each of these concepts, the Inverse Document Frequency (IDF) is calculated, where

$$\text{IDF} = \log \frac{\text{number of docs with concept}}{\text{total number of docs}}$$

The idea behind the IDF calculation is that more weight is given to the terms that are rarer. To calculate the rank:

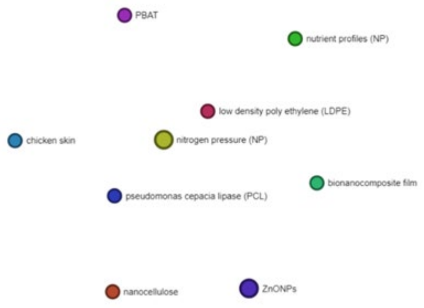
$$\text{Rank} = \text{frequency} \times \text{IDF} \times \text{mod\_field}$$

where frequency is the number of times the concept appears in set of documents and mod_field is a modifier that gives more or less weight to the terms depending on where they are found (title, abstract or keyword). In the specific case of relevant keywords, the modifier is calculated as follows: Title: 1 Abstract: 0.5 Keyword: 2. This is made so that the “important” words are attributed a higher rank.

Clustering
This functionality is useful to rapidly spot the composition of a collection of documents. Outliers can be quickly identified; the search query is then modified accordingly. The clustering is the grouping of a set of documents in such a way that documents in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters).

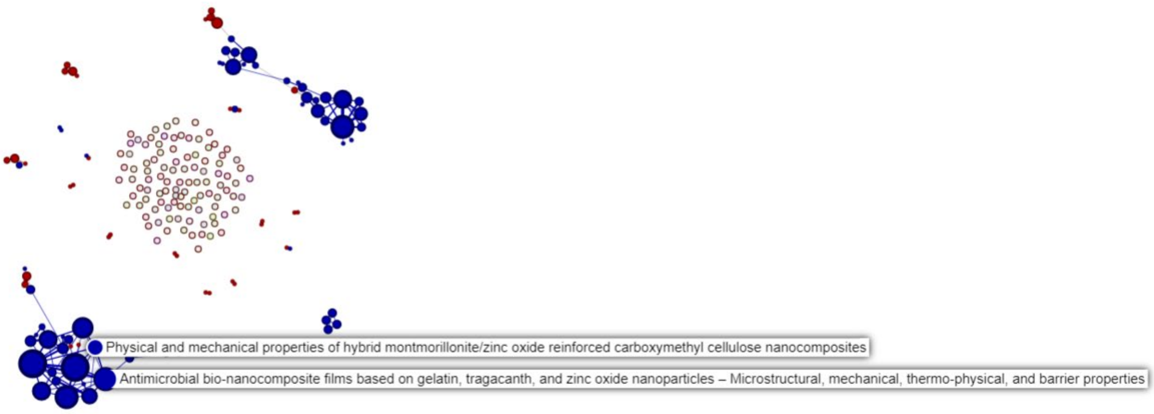
In figure 124, each node represents a cluster of documents. The documents that are inside a cluster are considered to be similar to each other, i.e. they have a cosine similarity higher than the threshold (set here at 0.35). The name of the cluster – or label of the node - is the keyword that is the most relevant in the cluster of documents.

Figure 124: Clusters for the set “Zinc oxide nanoparticles”.



Document gram: is a graphic representation of the semantic distance (or similarity) between documents in a set of documents. It is another way of taking a quick glance at the composition of a document collection. It allows to spot easily outlier articles and detect the keywords that should be used to exclude them.

Figure 125: example of document gram for the set of documents on the weak signal "Zinc oxyde nanoparticles".

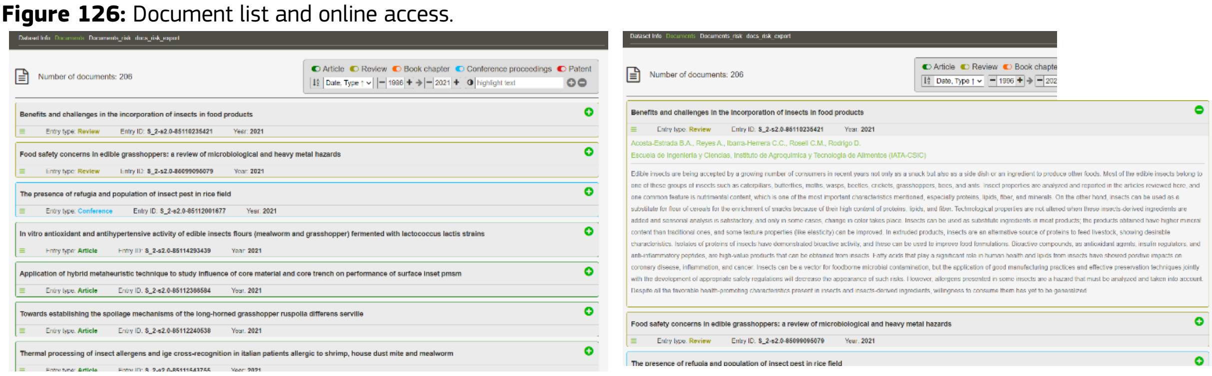


Each node represents a document in the set. An edge between two nodes is present if the cosine similarity between the two document vectors is higher than the threshold (the threshold is set by default at 0.35). The size of the edge is proportional to the cosine similarity between the pair of documents. The size of the node represents the number of documents that are similar (over a specific threshold).

Document list and online access

In some cases, access to the articles composing the set of documents for a weak signal is needed to fine tune the search queries used to reconstruct the signals in TIM Technology. TIM's document list presents the main information about each document in a set and offers, whenever possible, to access directly to the articles online. Final access to the full version of the articles will of course depend on the access right of the user.

Figure 126: Document list and online access.



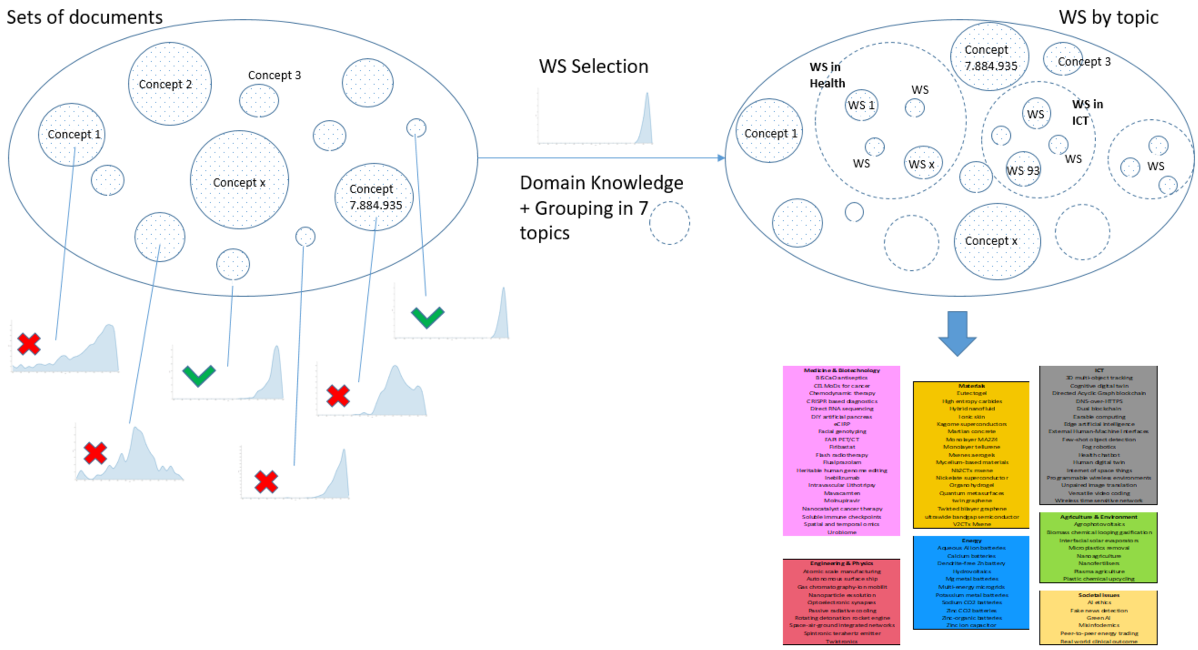
Domain knowledge

Domain knowledge can be used to further select the weak signals of relevance for a particular scientific area or policy field. For the present round of detection, domain knowledge related to biotechnologies, medicine and health was provided by the European Medicine Agency, whose experts highlighted which weak signals were the most relevant relative to their technical knowledge and policy remit.

Grouping in 7 topics

Using the main journal categories to which the documents of each weak signals belong, a grouping of the 93 weak signals has been made to facilitate the readability of the report. Many of the weak signals are of course cross topics.

Figure 127: Selection of the weak signals



Few words on the semantic distance in TIM

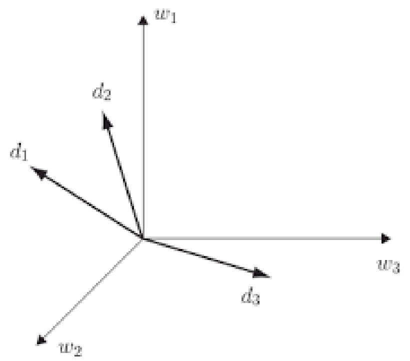
Several features in TIM are using the semantic similarity between documents e.g. clustering, document gram or compactness. This similarity that is measured is similarity in the meaning (semantic, beyond lexicographical): similarity is defined over a set of documents and the distance between documents is based on the likeness of their meaning or semantic content. Computationally speaking, semantic similarity can be estimated using statistical means such as a vector space model to correlate words and concepts. For each document a vector in a semantic space is computed. Vector operations can then be used to compare the vector-documents with one another. Cosine similarity measures the similarity between two vectors of an inner product space. It is measured by the cosine of the angle between two vectors and determines whether two vectors are pointing in roughly the same direction. It is often used to measure document similarity in text analysis and is expressed as follow:

$$similarity = \cos(\theta) = \frac{A \cdot B}{\|A\| \|B\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \sqrt{\sum_{i=1}^{n} B_i^2}}$$

with A and B two vectors of terms and cos(θ) the similarity between them. A cosine value of zero means that the two document vectors are orthogonal (90 degrees) and have no similarity at all. A cosine value of 1 would mean that the angle between the two vectors is 0 degrees and the document vectors are identical. The similarity metric between two documents calculated in TIM is therefore a value between 0 and 1.

Figure 128: Vectorial representation of a cosine distance measurement.

cosΘ(d1-d2)= semantic distance between d1 and d2



List of search queries used to reconstruct the weak signals in TIM

Figure 129: List of search queries.

Weak signals	Query
PROteolysis TArgeting Chimeras (PROTACs)	topic:("PROteolysis TArgeting Chimeras" OR PROTAC)
mxenes aerogels	topic:("mxene aerogel"~2)
hydrovoltaics	topic:(hydrovoltaics)
Dendrite-free zn battery	topic:("dendrite free"~2 AND "zinc battery"~2)
organohydrogel	topic:("organohydrogel" OR "organo hydrogel"~2)
microplastic removal	topic:("microplastic removal"~2)
nanocatalyst cancer therapy	topic:(nanocatalytic AND (cancer OR tumor) AND therapy)
Zinc CO2 batteries	topic:("ZN CO2 batteries"~2 OR "zinc CO2 batteries"~2)
hybrid nanofluid	topic:"hybrid nanofluid"
Zinc ion capacitor	topic:("zinc ion capacitor"~2)
Zinc-organic batteries	topic:("zinc organic batteries"~2 OR "zn organic batteries"~2)
agrivoltaics	topic:(agrophotovoltaic OR agrivoltaic)
Flualprazolam	topic:Flualprazolam
plastic chemical upcycling	topic:(("chemical upcycling" AND (plastics OR polymer OR waste)) OR "plastic upcycling"~1 OR "polymer upcycling"~1)
Gas chromatogr.-ion mobility spectrometr	topic:("gas chromatography-ion mobility spectrometry"~2)
rotating detonation rocket engine	topic:("rotating detonation rocket engine"~2)
eutectogel	topic:(eutectogel OR "deep eutectic solvent gel"~2)
interfacial solar evaporators	topic:(("interfacial solar evaporation"~2 OR "solar vapor generation"~2 OR "interfacial solar vapor generation"~2) AND (desalination OR "water purification"~2))
aqueous Al ion batteries	topic:("aqueous al batteries"~2 OR "aqueous aluminum batteries"~2) NOT ti:"non aqueous"
plasma agriculture	topic:("plasma agriculture"~2 OR "plasma seed treatment"~2)
V2CTx MXene	topic:("V2CTx MXene"~2)
Mg metal batteries	topic:("MG metal batteries"~2 OR "magnesium metal batteries"~2)
nb2ctx mxene	topic:("nb2ctx mxene"~3)
calcium batteries	topic:("calcium battery" OR "calcium ion battery" OR "calcium rechargeable batteries"~2 OR "CA rechargeable batteries"~2)
wireless time sensitive network	topic:("wireless TSN" OR "wireless time sensitive network"~2)
human digital twin	topic:("human digital twin"~2)
health chatbots	topic:("health chatbot"~2)
Earable computing	topic:("earable computing"~2)
Biomass chemical looping gasification	topic:("Biomass chemical looping gasification"~2)
cognitive digital twin	topic:("cognitive digital twin"~2)
programmable wireless environments	topic:("programmable wireless environments" OR (("intelligent surface" OR "programmable surface" OR "reconfigurable surface") AND wireless))
Internet of space things	topic:("Direct-to-Satellite IoT"~2 OR "DtS IoT" OR "Internet of Space Things" OR "internet of space IOS"~2)
DNS-over-HTTPS	topic:("DNS-over-HTTPS"~2)
unpaired image-to-image translation	topic:("unpaired image image translation"~2 OR "unpaired image translation"~2)
Directed Acyclic Graph DLT	topic:(("Directed Acyclic Graph" AND (blockchain OR "distributed ledger")) OR "DAG blockchain"~2 OR "DAG DLT"~2)
green ai	topic:("green ai" OR "green artificial intelligence"~1 OR "green machine learning" OR "artificial intelligence resource efficiency"~2) NOT ti:quantum
Few-shot object detection	topic:("Few-shot detection"~1 OR (FSOD AND object AND detection))
dual blockchain	topic:("dual blockchain" OR "double blockchain") NOT topic:("double spending")
edge artificial intelligence	topic:("edge artificial intelligence"~2) NOT topic:cutting
Sodium CO2 batteries	topic:("NA CO2 batteries"~2 OR "sodium CO2 batteries"~2 OR "sodium carbon dioxide batteries"~2 OR "NA carbon dioxide batteries"~2)
AI ethics	topic:("AI ethics"~2)
Peer-to-peer energy trading	topic:("peer to peer energy trading"~2 OR "peer to peer energy market"~2)
misinfodemics	topic:(misinfodemics OR "misinformation epidemics"~2 OR "disinformation epidemics"~2)
space-air-ground integrated networks	topic:("space-air-ground integrated networks"~2)
fog robotics	topic:("fog robotics")
potassium metal batteries	topic:("potassium metal batteries"~2)
twisted bilayer graphene	topic:("twisted bilayer graphene")
ionic skin	topic:("ionic skin")
nanoparticle exsolution	topic:("nanoparticle exsolution"~2)
optoelectronic synapses	topic:("optoelectronic synapses"~2)
3D multi-object tracking	topic:("3D multi-object tracking"~2 OR "3D multi-object detection"~2)
autonomous surface ship	topic:(("autonomous surface ship"~2 OR "unmanned surface ship"~2 OR "autonomous vessels"))
Atomic scale manufacturing	topic:("atomic scale manufacturing"~2 OR "close to atomic scale manufacturing"~2 OR "sub 10nm manufacturing"~2 "atomic scale fabrication"~2 OR "close to atomic scale fabrication"~2 OR "sub 10nm fabrication"~2)
mycelium-based materials	topic:(("mycelium materials"~1 AND based) OR "mycelium material" OR ("mycelium composite"~1 AND based) OR "mycelium composite") NOT topic:(biochemistry OR camemberti OR pasteurized OR accumulation OR flammulina OR Larch OR Paracoccidioidomycosis OR "white rot")
versatile video coding	topic:("versatile video coding")

Weak signals	Query
Fake news detection	topic:("fake news detection"~2)
Inebilizumab	topic:("inebilizumab")
kagome superconductors	topic:("superconductors kagome"~3)
nanofertilisers	topic:(nanofertiliser OR "nano fertiliser" OR "fertiliser nanoparticle"~2)
Passive radiative cooling	topic:("passive radiative cooling")
martian concrete	topic:("martian concrete"~2 OR marscrete)
multi-energy microgrids	topic:("multi energy microgrid" OR "multi energy micro grid" OR "combined energy microgrid" OR "combined energy micro grid" "mixed energy microgrid" OR "mixed energy micro grid")
spintronic terahertz emitter	topic:("spintronic terahertz emitter"~2)
quantum metasurfaces	topic:("quantum metasurfaces"~2)
nickelate superconductor	topic:((superconductor AND (NdNiO2 OR LaNiO2 OR SrNIO2 OR xSRxNIO2)) OR "nickelate superconductor"~2)
external Human-Machine Interfaces	topic:("external Human-Machine Interfaces"~2 OR (eHMI AND human AND machine))
high entropy carbides	topic:(("high-entropy carbide"~2 AND ceramics) OR ("high entropy ceramics"~2 AND carbides))
nanoagriculture	topic:("nano* agriculture"~2 OR nanoagriculture OR nanofertiliser OR nanopesticides OR "nanobiosensor agriculture"~2)
Soluble immune checkpoints	topic:"soluble immune checkpoint"
CRISPR based diagnostics	topic:("CRISPR diagnostic"~2)
Facial genotyping	topic:(DeepGestalt OR "face2gene" OR "facial genotyping" OR "Computer aided facial analysis" OR (("dysmorphic recognition"~2 OR "dysmorphology analysis"~2 OR "facial analysis" OR "facial dysmorphology") AND ("computer aided" OR "machine learning" OR "algorithm") AND (phenotype OR genotype OR disease OR syndrome OR diagnosis)))
Flash radiotherapy	topic:"Flash radiotherapy"
Do-it-yourself artificial pancreas	topic:("DIY APS" OR "do-it-yourself artificial pancreas" OR "DIY artificial pancreas" OR "OpenAPS" OR "do-it-yourself APS")
Firibastat	topic:firibastat
eCIRP	topic:("extracellular cold inducible RNA binding protein" OR eCIRP)
FAPI PET/CT	topic:("fapi pet ct" OR ("isotope labelled fibroblast activation protein inhibitor" AND pet AND ct))
Urobiome	topic:("urinary tract microbiome" OR urobiome)
CELMoDs for cancer	topic:(CELMoDs OR "Cereblon E3 ligase modulator")
Direct RNA sequencing	topic:"direct RNA sequencing"
Chemodynamic Therapy	topic:(("chemodynamic therapy" OR "CDT therapy") AND (cancer OR tumor))
LYsosome-TArgeting Chimaeras (LYTACs)	topic:("lysosome targeting chimaera" OR lytac OR "lysosome targeting chimera")
BiSCaO antiseptic	topic:(("bioshell calcium oxide" OR biscao OR "bio shell calcium oxide" OR "heated Scallop Shell Powder") AND (antiseptic OR disinfectant OR sanitizer OR pathogen OR disinfection OR microbicidal OR bactericidal))
Mavacamten	topic:mavacamten
Molnupiravir	topic:(Molnupiravir OR "EIDD 2801" OR "MK 4482")
Intravascular Lithotripsy	topic:"intravascular lithotripsy"
Real world clinical outcome	topic:("real world progression free survival" OR "real world clinical outcome")
Spatial and temporal omics	topic:("spatial omics" OR "temporal omics" OR "pseudo time single cell"~3 OR "pseudotime cell"~2)
Heritable human genome editing	topic:("heritable human genome editing" OR (HHGE AND genome AND editing))
Twistronics	topic:twistronics
Ultrawide bandgap semiconductor	topic:("ultrawide bandgap semiconductor"~2)
Monolayer Tellurene	topic:("monolayer tellurene"~2 OR "two dimensional tellurene"~2 OR "nanosheet tellurene"~2 OR "nanoplate tellurene"~2 OR "mono layer tellurene"~2 OR "layered tellurene"~2)
Monolayer MA2Z4	topic:((monolayer OR nanosheet OR "layered MoSi2N4"~2 OR "layered WSi2N4" OR "two dimensional" OR nanoplate OR "mono layer") AND (MoSi2N4 OR WSi2N4)) OR topic:(MA2Z4)
Twin graphene	topic:("twin graphene")

List of figures and tables

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office of the European Union